IN SITU RAIN WATER HARVEST, CONSERVATION AND UTILIZATION FOR ESTABLISHMENT AND EARLY GROWTH OF SAPPAN WOOD (*Caesalpinia sappan* L.)

BEENA, J.S.

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Department of Agronomy
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM 695522

DECLARATION

I hereby declare that this thesis entitled "***In situ* rain water harvest, conservation and utilization for establishment and early growth of sappan wood (*Caesalpinia sappan* L.)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
20-09-2005.

BEENA, J.S.
(2003-11-04)

CERTIFICATE

Certified that this thesis entitled "***In situ* rain water harvest, conservation and utilization for establishment and early growth of sappan wood (*Caesalpinia sappan* L.)**" is a record of research work done independently by Ms. Beena, J.S. (2003-11-04) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

20/9/05

Vellayani,
20-9-2005.

Dr. A.S. ANILKUMAR
(Chairman, Advisory Committee)
Assistant Professor (Agronomy),
Instructional Farm,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

Approved by

Chairman :

Dr. A.S. ANILKUMAR
Assistant Professor (Agronomy),
Instructional Farm,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

Members:

Dr. R. PUSHPAKUMARI
Associate Professor and Head,
Department of Agronomy,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

Dr. S. CHANDINI
Associate Professor,
Department of Agronomy,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

Dr. K. HARIKRISHNAN NAIR
Associate Professor,
Department of Soil Science and
Agricultural Chemistry,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

External Examiner :

Dr. P. SUBBIAN
Professor of Agronomy and Joint Registrar,
TNAU, Coimbatore, Tamil Nadu-3

Dedicated to

My Parents and Brothers

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LIST OF ABBREVIATIONS

%	–	Per cent
°C	–	Degree Celsius
μg	–	Microgram
@	–	At the rate of
ABA	–	Abscissic acid
AW	–	Available water
BCR	–	Benefit-cost ratio
CaO	–	Calcium oxide
CD	–	Critical difference
CGP	–	Crop growth potential
cm	–	Centimetre
cm s^{-1}	–	Centimetre per second
cm^2	–	Square centimetre
Cm^3	–	Cubic centimetre
CPE	–	Cumulative pan evaporation
Cu	–	Consumptive use
DMP	–	Dry matter production
EI	–	Erosivity index
et al.	–	And others
FC	–	Field capacity
Fig.	–	Figure
g	–	Gram
g cc^{-1}	–	Gram per cubic centimetre
g^{-1}	–	Per gram
ha^{-1}	–	Per hectare
HAI	–	Hours after irrigation
IW	–	Irrigation water
kc	–	Crop coefficient

LIST OF ABBREVIATIONS CONTINUED

kg	–	Kilogram
kg m-3	–	Kilogram per cubic metre
km3	–	Cubic kilometer
m	–	Metre
m^2	–	Square metre
m^3	–	Cubic metre
MAP	–	Months after planting
ml	–	Millilitre
mg g^{-1}	–	Milligram per gram
MgO	–	Magnesium oxide
mm	–	Millimetre
mmole kg^{-1}	–	Milli mole per kilogram
MSL	–	Mean sea level
NE	–	North East
N	–	Nitrogen
NS	–	Not significant
OD	–	Optical density
PWP	–	Permanent wilting point
RGP	–	Root growth potential
RLWC	–	Relative leaf water content
Rs	–	Rupees
RWC	–	Relative water content
SDMP	–	Stem dry matter production
SQ	–	Sturdiness quotient
SW	–	South West
WUE	–	Water use efficiency

Introduction

1. INTRODUCTION

Sappan wood, popularly known as 'pathimugham' or 'chappangam' or 'East Indian red wood' is a multipurpose tree grown for its valuable timber. It is botanically known as *Caesalpinia sappan* L. It is a natural dye yielding medicinal plant. In India, it is extensively used for biofencing of agricultural lands in rainfed areas. The officinal part of the plant is heartwood which contains water and alcohol soluble dyes, such as, brazilian, protosappanins, sappan chalcone and haematoxylin. Brazilian on oxidation yields a red dye called brazilein – the most valuable dye used in colouring leather, silk, cotton, wool, fibres of different kinds, printing, floors, feather, medicines and several handicrafts. The decoction of the wood is a powerful astringent and emmenagogue. It is prescribed as a tonic for diarrhoea, dysentery and haemorrhage from the lungs (Singh *et al.*, 1983).

In traditional Chinese medicine, sappan wood has sweet, salty and neutral properties and is associated with the heart, liver and spleen meridians. Its main functions are to invigorate the blood, promote menstruation and reduce pain and swelling. Sappan wood is often used to treat blood-related conditions such as dysmenorrheal and amenorrhea and to reduce abdominal pain following child birth. Sappan wood is also used to reduce pain and swelling caused by external injuries.

Sappan wood is sensitive to dry spells during its initial phase of establishment. Being a tree species which gives attractive returns within a span of seven years even under marginal conditions, it is preferred for planting as a neglected crop in rainfed lands. In Kerala, though water available from rainfall is in excess of meeting the evapotranspiration requirement, the crop experiences moisture stress during summer months since rain water is lost on several accounts and the effective rainfall contribution is quite inadequate.

Water harvesting systems in various forms were prevalent in India since ancient times. Numerous references of such practices are available in Vedas and other ancient scriptures (Samra *et al.*, 2002). Pandey *et al.* (2003) advocated measures to 'capture rain when it rains' rather than investing on ecologically damaging, socially intrusive and capital intensive water management projects that fail to deliver their desired benefits.

In situ harvest and *in situ* conservation of rain water may help to increase the effective rainfall contribution for meeting the crop water requirements. Development of sustainable rain water harvesting and conservation measures may help to extend the water availability periods for moisture uptake. *In situ* moisture conservation measures may help to prolong the availability of moisture not only from rainfall but irrigation as well. If appropriate measures are adopted at the time of planting for *in situ* rain water harvest and conservation, summer irrigation can be avoided and *Caesalpinia sappan* can be raised entirely on stored soil moisture.

Vertical mulching is a time tested method of overcoming environmental stresses that tree seedlings and trees face in their habitats. Holes are drilled or trenches are taken around seedlings and trees and partially filled with peat moss, organic matter or other water absorbing materials that maintain aeration and support plant growth. It creates columns of rich 'top soil' down past the roots and deep into the area where roots can take advantage of it. Vertical mulching is an appropriate method to maintain a favourable soil moisture-nutrient-oxygen balance in the rhizosphere.

Micro catchments are basins surrounded by small earth bunds with an infiltration pit in the lowest corner of each basin. Run off water is collected from within the basin and stored in the infiltration pit. Micro catchments are mainly used for growing trees or bushes. Micro catchment systems provide many advantages over alternative irrigation schemes. They are simple and inexpensive to construct and can be built rapidly using local materials and manpower.

Micro site enrichment is an appropriate method for tree planting in marginal lands of low rainfall tracts where soil is both poor in fertility and water holding capacity. Modification of the rhizosphere soil of the planting site with nutrient rich and water absorbing organic materials result in modulation of the rhizosphere for early establishment and rapid growth of the seedlings planted.

In many regions of the world, population growth, intensive agriculture, industrialization and rapid urbanization are putting pressure on water supplies. Agriculture and water projects based on high energy input and sophisticated technologies appear more and more expensive and unsustainable. At the same time, appropriate blending of traditional and modern technologies make it possible to have a new approach in *in situ* rain water harvest, conservation and utilization in commercial mediculture.

It is in this context, the present project is designed with the objective of finding out the comparative efficacy of vertical mulching, micro site enrichment, micro catchments and traditional methods of rain water harvest and conservation to extend the period of stored moisture availability for raising *Caesalpinia sappan* without summer irrigation.

Review of Literature

2. REVIEW OF LITERATURE

Sappan wood (*Caesalpinia sappan* L.), a natural dye yielding leguminous medicinal tree indigenous to India is grown for its heartwood. It is well adapted to the agro climatic situations prevailing in the Kerala.

The investigation entitled "*In situ* rain water harvest, conservation and utilization for establishment and early growth of sappan wood (*Caesalpinia sappan* L.)" was undertaken to find out the comparative efficacy of vertical mulching, micro site enrichment, micro catchments and traditional methods of rain water harvest and conservation to extend the period of stored moisture availability for raising sappan wood without summer irrigation. The literatures pertaining to the subject are reviewed here under. Wherever sufficient literature on sappan wood is not available, results on related crops and other situations are also reviewed.

2.1 THE CROP – SAPPAN WOOD

Sappan wood is native to India and Malaysia and presently found growing throughout Eastern and Western peninsula (Singh *et al.*, 1983). It is cultivated in parts of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh and West Bengal. *Caesalpinia sappan* is a small to medium sized thorny spreading tree growing up to a height of 10 m. Stems are prickly with tomentose young shoots and glabrous branches. Conspicuous spines are present on the stems and leaf rachis. Leaves are alternate and pinnately compound. Inflorescence is a terminal raceme with golden yellow coloured flowers and peduncle clothed with a ferruginous tomentum (Prajapati *et al.*, 2003 and Kennedy *et al.*, 2004). Flowers are cross-pollinated by bees, butterflies and insects. It bears 3-4 seeds per pod and is ellipsoid, brown to black coloured. Usually sappan wood is propagated through seeds (Kennedy *et al.*, 2004).

Sappan wood grows well under different soil types ranging from clay to loam and ideal soil type is red loam. Also it grows well in tropical and sub-tropical regions with dry and hot climate with well distributed rainfall of 750 mm (Kennedy *et al.*, 2004).

2.1.1 Economic Importance of Sappan Wood

Sappan wood is an important medicinal tree gaining economic significance in recent years. The economic part of the plant is the heartwood which yields a water and alcohol soluble dye called Brazilin, colourless dye which on oxidation by atmospheric oxygen yields a red dye called 'Braziliein' (Hill, 1952). The dye is non-irritant and used for facials which are resistant to light and heat. The wood also contains water soluble dyes such as protosappanins, sappan chalcone and haemotoxylin. The natural dye is used in colouring leather, silk, cotton, wood fibers of different kinds, bathik, calico-printing, furniture, floors, feather, medicines and several handicrafts. The sappan dye along with kaya (*Memecylon edule*) produced red, violet and black colour combinations. The natural mordants such as bark of Lodhra (*Symplocos racemosa*) and Ebenum (*Diospyros ebenum*) increased the binding potential of sappan dye (Kennedy *et al.*, 2004).

Sappan wood also possesses medicinal properties. Decotion of wood is a powerful astringent and emmunogogue. It is prescribed as a tonic for diarrhoea, dysentery and hemorrhage from the lungs (Singh *et al.*, 1983 and Kennedy *et al.*, 2004). The plant is used as one of the ingredients of indigenous drug 'Lukol' which is administered for the treatment of non-specific leucorrhoea and for bleeding following infra uterine device insertion (Channegowda, 1999 and Kennedy *et al.*, 2004).

Various parts of sappan wood are also used for other purposes. The wood is used in carpentry for making violin bows and for inlaying works. The pods contain 40 per cent tannin and can be used in place of sumac. They impart uniform tan and a soft touch to leather. The seeds yield an orange coloured fixed oil on contact with petroleum ether. The pleasant smelling essential oil obtained from the leaves of the tree contains d-α-phellandrene. It has antibacterial activity on both gram positive and gram negative bacteria and antifungal activity against *Aspergillus nidulans* (Kennedy *et al.*, 2004).

2.2 RAIN WATER HARVESTING

2.2.1 Rain Water Harvesting - Need

Even though average rainfall of Kerala is quite high (3000 mm), most of it is lost as surface runoff because of the highly undulating topography of the region. The erosivity of rainfall (EI-30) varies from 700-900 for 1000-2000 mm rainfall, 1000-2700 for 2000-3000 mm rainfall, 1700-3200 for 3000-4000 mm of total rainfall (Thomas and Raghunath, 1987). About 60 per cent of annual rainfall in the state is received during SW monsoon (June to August), 25 per cent during NE monsoon (September to November) and the remaining during summer months. The uneven temporal distribution of rainfall, the highly undulating topography and the low water retention capacity of soils cause moisture stress for most of the crops during summer season, which extends from January to May. Rao and Vamadevan (1988) reported that the moisture stress period varies between 14 to 15 weeks in southern parts and 18 to 21 weeks in the northern parts of the state. The water availability of plantation crops, which are mostly grown under rainfed conditions, depends on rainfall and evaporation. These are, in turn, mainly affected by the number of rainy days and air temperature during different seasons. This soil moisture stress during summer season is one of the major limiting factors for high agricultural productivity in the state. Water being the most vital input, *in situ* rain water conservation and irrigation are of great importance in this context.

Varadan (1997) quantified the water demand and water deficit of various upland crops of Kerala based on the soil and climate in different regions. The water deficit ranges from 9 to 26 per cent of mean annual rainfall for coconut, 3 to 8 per cent for cassava and 6 to 17 per cent for banana in various districts. This deficit could be overcome to a great extent by increasing the soil moisture storage by adopting *in situ* rain water harvesting techniques.

2.2.2 Rain Water Harvesting – Benefits

Conservation of rain water without loss in quality, waste etc. is known as rain water harvesting. UNESCO (2000) reported that rain water harvesting can deliver some major benefits such as augmentation of surface water sources, increases the infiltration of rain water into the subsoil, mitigation of the effects of droughts and drought proofing, reduction of run off and soil erosion, improvement in the quality of water and saving in of energy for lifting of ground water.

2.2.3 Rain Water Harvesting – Strategies

Land and water management practices are inseparable, location – specific and dependent on rainfall intensity, slope, soil type and texture. The basic concept of rain water harvesting is that instead of allowing runoff to cause erosion, rain water should be conserved at a place where it falls, i.e., *in situ* rain water conservation. The strategy should be to conserve every drop of rainfall through suitable land treatments. The soil and water conservation strategies mainly come under two categories namely mechanical / structural and agronomic / biological measures. Mechanical measures include bench terraces, Puerto Rican type of terraces, contour bunds and terrace walls, strip terracing / plat form, trenches and pits, temporary structures and check dams and percolation ponds. Agronomic / biological measures include choice of vegetation, land preparation, centripetal terraces / basins, contour farming, timely planting, crop geometry, multi-storied cropping, mixed farming, strip cropping, mulching, cover cropping, organic matter management, crop rotation, vegetative hedges and barriers and agro forestry measures (Joseph, 2004).

2.3 SOIL MOISTURE REGIMES

The improved moisture regimes in soil can be achieved in two ways namely by increasing water stored in root zone and reducing the losses due to evaporation and transpiration. The soil, up to the bottom of root zone, constitutes a moisture reservoir of vital importance to agriculture. Water that infiltrates into this reservoir can be stored with relatively little loss for fairly longer periods

(Arnon, 1975). Appropriate techniques can be adopted for increasing infiltration and soil moisture storage.

2.4 *IN SITU* RAIN WATER HARVESTING TECHNIQUES

Under rainfed condition, harvesting of rain water and conservation of soil moisture are the two ways to supplement soil moisture. Harvesting of rain water and *in situ* conservation of soil moisture are the viable alternatives to artificial irrigation. There are many reports about the different ways of rain water harvesting and their effects on growth and yield of fruit crops like plum, sweet oranges (Arora and Narayan , 1987) and ber (Pathak,1993).

2.4.1 Rain Water Pits (1.0 x 0.6 x 0.6 m)

The most popular and inexpensive rain water harvesting structure for large scale adoption in the watersheds of Kerala is the rain water pits dug out in soil. They store water during rain, which would have otherwise lost by runoff. The collected water percolates into the deeper layers of soil and ultimately recharges the underground water (Nair, 2004).

2.4.2 Vertical Mulching

Vertical mulching is helpful in *in situ* conservation of rain water for increased crop yields. Trenches of 20 cm width and 60 to 90 cm depth are taken at a spacing of 4 m and filled with sorghum or maize stubbles or stalks prior to the onset of rainy season. This would encourage infiltration, check the velocity of running water, conserve soil as well as essential plant nutrients and increase crop yields (Sharma, 2001).

Effect of *in situ* moisture conservation on yield and physico-chemical characteristics of mango fruits was reported by Ghosh and Bauri (2002). Harvesting of rain water by opening circular trenches around the trees at six feet distance with nine inches width as well as depth and mulching the trenches with dry mango leaves helped to retain sufficient moisture in the soil during flowering and fruiting and resulted in an increase in yield by 71 per cent as compared to control. The technology gave an additional income of Rs. 272/- per tree as compared to control. Physico-chemical characteristics of the fruits were significantly better due to rain water harvesting techniques.

2.4.3 Land Configuration

Appropriate land configuration such as formation of ridges and furrows, broad based beds, raised beds, sunken beds, graded border strips, pits, terracing and inter row and inter plot rain water harvesting, hold great promise for *in situ* conservation of soil, water and plant nutrients. These are more efficient in moderate to high rainfall regions where such losses are significant (Singh and Mittal, 2000).

2.4.3.1 Micro Catchments

Adoption of *in situ* moisture conservation practices improved the soil moisture status in different soil depths and WUE increased by 22 per cent and 25 per cent with the formation of compartmental bunding and ridges and furrows respectively over the flat bed system (Patil and Sheelavantar, 2000). Higher moisture availability was recorded in ridges and furrows compared to flat bed and amount of rain water conserved in surface soil increased the moisture in the range of 3-5 per cent over flat bed system (Singh *et al.*, 2004).

Gupta *et al.* (2000) conducted an experiment on *Albizia lebbek* to determine the growth under different method of micro catchments such as pits (45 cm^3), saucers of 2.5 cm diameter, trench-cum-mound, trench and mound, deep ploughing and found significant increase in plant height, collar girth and yield under different micro catchments than control where ring pits recorded maximum over other micro catchments. Soil moisture storage was also maximum under micro catchments compared to control. Ghosh and Mathew (2002) revealed the significance of micro catchments for in situ water harvesting. Preparation of micro catchment area of 1.0 m width and 15 cm height by mulching with straw followed by covering with black polythene during the initial stage resulted in efficient *in situ* moisture conservation as evidenced by better growth, yield and fruit quality of aonla at initial stage.

2.4.4 Micro Site Enrichment

Low water holding capacity, poor soil water relations, high percolation rate leading to washing away of essential plant nutrients etc. of marginal soils are some of the major constraints in establishing tree seedlings in rain fed areas. Water intake of soil can be increased by improving soil physical properties such as organic matter content, infiltration rate, permeability, bulk density, soil structure, water holding capacity, stable soil aggregates etc. This helps in better crop growth due to conservation of soil moisture and plant nutrients (Acharya and Kapur, 2000).

Organic manures as soil amendments play an important role in soil water conservation and crop growth. Application of coir pith to soil, besides increasing the water holding capacity, brings about favourable changes in drainage, mulching, crop rooting, soil reconditioning and seed germination (Ravindranath, 1991). Coir pith improves the structure and other physical properties of soil. It absorbs water in the range of 400-600 per cent of its weight and releases it to soil very slowly (Salam *et al.*, 2004). Venkitaswamy and Khan (2004) reported that surface mulching with raw coir pith in the 1.8 m basin up to height of 10 cm reduced evaporation losses and increased irrigation interval by 3-5 days in different seasons.

Vadiraj *et al.* (1993) observed that the use of vermicompost as a component of potting mixture in cardamom nursery helped in seedling growth and dry matter protection in a short span of time. Krishnakumar *et al.* (1994) reported better growth and development of seedlings in cardamom nursery due to the use of vermicompost in potting medium.

Baskaran and Sarvanan (1997) reported a spectacular increase in the water holding capacity of coir pith based potting mixture. Growth characters such as plant height, number of leaves of Anthurium were increased significantly when combination of coarse sand, coconut husk and coir pith in the ratio of 1:1:1 or coarse sand, coconut husk, dry cow dung and coir pith in the ratio of 1:1:1:1 were used as potting medium (Suharban *et al.*, 2004). Medicinal plants like

Coleus aromaticus and *Eclipta alba* expressed maximum shoot length and root length when grown under 100 per cent degraded coir pith (Vinodini *et al.*, 2005).

2.5 CONTAINING STORAGE LOSSES

Seepage and evaporation result in maximum losses of harvested rain water. To minimize these losses, storage volume should be maximized in relation to exposed surface area. Application of suitable sealant materials reduces seepage losses. Samra *et al.* (2002) suggested six sealant materials and methods, viz., sealing by compaction, bentonite, clay blankets, membranes, chemical additives and sealants, soil cement and cement concrete / stone or brick lining.

2.6 EVAPORATION CONTROL

Poldervart (1955) estimated that 6200 km^3 of water is evaporated annually from lakes and land water surfaces. More than 5 times of this quantity evaporates annually from oceans. Walton (1970) reported that evaporation accounted for 50 per cent of the water losses in open shallow reservoirs and up to 20 per cent in deep reservoirs. Materials such as gravel mulches, oil mulches, silicons, polythene oxides, gum mixtures, fatty alcohols and cationic, anionic and non ionic chemicals are not effective and economical. Liquid chemicals such as aliphatic alcohols, floating pieces of fat, blocks of light weight concrete, polystyrene, wax rubber are though effective in suppressing losses, high initial cost restrict their wider use (NAS, 1974). Most effective organic compounds are hexa decanol and octa decanol which readily spread on water and are effective in reducing evaporation loss by 50 per cent.

2.6.1 Surface Mulching

Mulching is an important agronomic practice that not only dissipates the kinetic energy of rain drops, but prevents soil erosion, but also facilitates infiltration, reduces runoff and evaporation losses. It refers to the use of crop residues, manures and other litters as well as any conveniently available manufactured material like poly ethylene sheet with or without shallow tillage for the purpose of reducing runoff, soil losses and evaporation losses to increase productivity. In regions of low rainfall, mulching helps in conserving moisture in soil profile and in high rainfall area reduces runoff and soil loss (Mittal *et al.*, 1986; Singh and Veeraputhiran, 2000; Bhuma, 2003).

2.6.1.1 Mulches

2.6.1.1.1 Coconut husk

Coconut husk is a good source of plant nutrients and contains 0.23 per cent N, 0.04 per cent P_2O_5, 0.78 per cent K_2O, 0.08 per cent CaO, 0.05 per cent MgO on dry weight basis. It has positive effects on soil structure and moisture retention capacity (Shanmugam, 2003 ; Salam *et al.*, 2004).

Coconut husk buried in a circular trench of 30 cm depth and 1.8 m away from the palm in 2-3 layers with fibrous end facing upwards conserve moisture during the rainy seasons (Shanmugam, 1973 ; Ramanathan, 1990). Experimental results indicated that husk burial in coconut gardens raised under unirrigated conditions and subject to drought, was beneficial to the palms and the effects lasted for about five to six years. Husks acted as a water reservoir in the soil and coconut palms utilize the moisture retained by the husks at the time of moisture stress. It has positive effect on soil structure and moisture retention capacity. A fully soaked husk was able to retain about 6 to 8 times its weight (Shanmugam, 2003; Salam *et al.*, 2004). Venkitaswamy and Khan (2004) reported that surface mulching with coconut husk in the 1.8 m basin of coconut up to a height of 10 cm reduces the evaporation losses and increases irrigation interval by 3.5 days.

Vincent *et al.* (2002) reported that physiological parameters such as stomatal resistance, transpiration rate, proline content and relative water content (RWC) were significantly higher in coconut palm where husk burial was practiced compared to control.

2.6.1.1.2 Polythene

Traditionally dry leaves, hay and straw have been used as mulches. But polythene sheet mulch was most efficient in conserving moisture, controlling weeds, enhancing vegetative growth and improving fruit yield of mandarin

(Mohanty *et al.*, 2002). However, use of black polythene mulches is popular due to its special capacity to arrest weed growth which leads to *in situ* moisture conservation and better yields (Jacob, 2004).

Different mulching materials like grass, lantana, plastic etc. helped bell pepper to perform better under water deficits from 25 to 75 per cent and plastic mulch increased WUE (Thankur *et al.*, 2000). Black polythene sheet mulch conserve more moisture compared to white polythene sheet and paddy straw (Mohanty *et al.*, 2002). Maximum soil moisture content was observed in polythene mulched treatment compared to control in ginger (Aggarwal *et al.*, 2003).

Black polythene mulch significantly increased the transpiration, relative leaf water content and reduced the stomatal resistance in sapota compared to other mulching treatment. This attributed to increased soil moisture status (Reddy and Khan, 1998).

2.6.1.1.3 Coir Geo-textiles

Coir is a lignocellulosic fibre extracted from coconut husks. Among the various natural fibres used for soil bio-engineering applications, coir enjoys a premium position because of its biodegradability, durability and versatility in application. Coir 'bhoovastra' has been widely acknowledged as an effective material for controlling soil erosion on the slopes and embankments. Due to its high tensile strength, coir bhoovastra is preferred over other natural geo textiles for use in steeper slopes. It provides excellent micro climate for plant establishment and growth (Pillai, 2000). Coir bhoovastra has 5-10 years longevity which allows for full plant and soil establishment, natural invasion and land stabilization (Ajithkumar, 2002). Natural and biodegradable coir fibre functions as a soil amendment, water absorbent and as mulch on the surface of soil.

Coir geo-textiles can be used as mulching mat, which prevents evaporation from the soil and helps plant to grow more successfully (Arunadevi, 2004). It has high tensile strength and durability to hold soil in place and prevent erosion. The coir mesh dissipates the force of heavy rains and runoff water and prevents top soil from drying out and thus promotes growth of new vegetation (Shylaja, 2004).

2.6.1.2 Role of Surface Mulches

2.6.1.2.1 Soil Physical Properties

Mulching improves the structure and physical properties of soil. Reduction in bulk density and day time soil temperature, retention of heat during night and conservation of soil water by mulching are beneficial to improve the yield of several tropical crops (Midmore *et al.*, 1986 and Unger *et al.*, 1991). Acharya and Sharma (1994) reported that all the mulch treatments significantly reduced the bulk density of the top soil (0-15 cm depth). The reduction in bulk density of the top soil might be due to decomposition of mulch materials resulting in top soil becoming more friable. Use of organic mulches reduce evaporation, augment water retention capacity and improve crop production through improvement in soil structure and physical soil environment.

2.6.1.2.2 Moisture Retention

Effectiveness of mulch increases with the thickness of the material applied on the surface of field. Increasing the quantity of mulches increase the grain yield of oil seed crops under rainfed condition indicating the importance of mulching in soil moisture retention (Singh *et al.*, 1996 and Mittal *et al.*, 1997).

Gupta and Gupta (1986) revealed that the improvement in soil moisture content in different soil layers was mainly attributed to reduced evaporation caused by residue mulching on the soil surface. Use of mulches on the soil surface showed considerable effect on soil water content. Green and straw mulches seemed to be beneficial for retaining higher amount of soil water from the root zone during the entire growth period of rain fed rapeseed. Nath and Sarma (1992) reported that organic mulching was helpful in conserving better soil moisture and maintaining optimum soil temperature. Tripathi and Bhan (1993) reported that mulching reduces the moisture loss by improving its availability to the plant at latter stages of crop development. Even soil dust mulching proved to be helpful in maintaining more water particularly in sub soil layers (15-50 cm). Soil dust mulch also reduced the profile water use and total water use by the crop compared with no mulch and soil mulch (Moitra and Ghosh, 1998). Gill *et al.* (2000) suggested that various types of mulches such as straw mulch, farm waste mulch or plastic mulch can be used to check the evaporation losses. Mulching materials reduce the consumptive use and increase water use efficiency. Besides it increases seedling emergence and flowering during stress period by decreasing soil temperature (Singh and Veeraputhiran, 2000).

2.6.1.2.3 Plant Response

Ghosh (1985) reported that sweet lime fruit production could be increased significantly through supplementary irrigation and mulching of tree basins with dry grasses. Plant growth and fruit yield have been found to increase significantly by various mulching treatments in different crops like pomegranate (Chattopadhyay and Patra, 1992), custard apple (Mandal and Chattopadhyay, 1994) and sapota (Reddy and Khan, 1998). A decrease in root depth and an increase in the number of primary, secondary roots and dry weight of roots over control consequent to application of mulch (organic residue) was reported by Bhan *et al.* (1995). Application of paddy straw mulch resulted in 18 per cent increase in yield over glyricidia mulch. Quality of mulch is more effective in conserving soil moisture and increasing growth and yield of turmeric (Kumar *et al.*, 2003).

2.7 IRRIGATION SCHEDULING

2.7.1 Methods of Irrigation

2.7.1.1 Pitcher Irrigation

A simple, efficient and economic way to provide localized sub surface irrigation, known as pitcher irrigation was developed at the Central Soil Salinity Research Institute, Karnal, India (Mondal, 1974). Pitcher wet the soil continuously. Water is filled in the pitcher manually through a hose or by buckets, once or twice a week depending upon the water depletion rate, which in turn depends upon the type of crop, stage of growth and climatic conditions. Pitcher constantly supplies water to the root zone which minimizes the matric stress and thus allows plant to tolerate greater osmotic stress. Pitcher irrigation can be used for raising most vegetables, fruit trees and forest trees. It is ideal for species such as cucurbits which require more space for spreading their aerial parts but have roots confined to relatively smaller areas. Baked clay pitcher can be continuously used for 3-6 years (Chhabra, 1996 ; Venkitaswamy and Khan, 2004).

Sahu (1984) conducted a study in watermelon and observed that 40 per cent irrigation water could be saved through pitcher irrigation. Soil salinity was also reduced in pitcher irrigation compared to basin irrigation. Dubey *et al.* (1991) reported that baked earthen pitchers with a capacity of 7–10 litre can be used to provide sufficient moisture for growing various vegetable crops. According to Agodzo *et al.* (1991), pitcher irrigation system have some potential advantages such as economy in water use, increased yield, energy saving and adaptability to small holdings and marginal lands. Pitcher irrigation influenced the collar diameter and biomass yield of neem, *Casuarina equisetifolia* and *Leucaena leucocephala* (Somasundaram *et al.*, 2000).

2.7.1.2 Drip Irrigation

Drip irrigation saves water up to an extent of 20-70 per cent by reducing evaporation, run off losses, deep percolation and creates optimum air and moisture levels in soil and root zone throughout the growing period, which promotes healthier and improved root penetration (Ali and Patnaik, 1998 ; Dhanapal *et al.*, 1999).

According to Raveendran (1983), drip irrigation resulted in 80 per cent improvement in water use efficiency and is more efficient in terms of energy consumption. 75 per cent saving of irrigation water in drip as compared to control in banana was reported by Upadhayay (1985) and Sivanappan *et al.* (1987). Adoption of drip irrigation could save 80 man days of labour per ha compared to basin irrigation (Dhanapal *et al.*, 2000). Drip irrigation is highly suitable especially in sandy soils and in water scarcity areas (Mathew, 2003). Studies showed that drip irrigation could save water up to 50-70 per cent and increased yield of coconut by 30 per cent (Sivanappan, 2004). Drip irrigation at 50 per cent of surface irrigation can be very well recommended to obtain yields of tapioca on par with conventional surface irrigation with water saving of about 50 per cent (Manickasundaram *et al.*, 2002).

2.7.1.3 Traditional Subsurface Fertigation System

Micro-lined ponds (storage pits) called Konkan jalkund are recommended for catching rain water for irrigating newly planted mango grafts in Konkan, Maharashtra. A prelining cushioning bed of rice straw is put along the walls and bottom of the pits followed by lining with a silpaulin sheet and the pit is covered with grass matting in such a way that there is no room for air movement between matting and water surface. Circular trenches are taken around the tree and organic manures and fertilizers are applied at 3 locations followed by erecting hollow bamboo pieces in an upright manner just above the manured spots which serve as drip latter pipe to deliver water stored in jalkund. Micro holes are provided at the lowest internodal septum of bamboo for dripping water over manure beds. The establishment of mango grafts is reported to be better under this system of rain water collection, conservation and utilization (Samra *et al.*, 2002).

2.7.2 Plant Response to Moisture Stress

2.7.2.1 Physiological Parameters

Leaf temperature is an indirect measure of plant water stress (Ides *et al.*, 1978). When plants are well supplied with water, transpiration would take place at potential rates and foliage remains relatively cool. They also observed a declining trend in transpiration during moisture deficit situation and the concomitant increase in leaf temperature which led to a reduction in photosynthesis and consequent decline in total biomass production. Decreasing soil moisture resulted in reduced plant water status and stomatal conductance leading to elevated leaf temperature (Mtui *et al.*, 1981).

Moisture stress in plants is the resultant of the combined effects of soil moisture stress in the root zone, resistance to water movement in the plant, stomatal control and atmospheric evaporative demand. Ackerson *et al.* (1977) reported that stomatal resistance increases in response to leaf water potential, which is still necessary to maintain water flux through the plant in order to sustain growth. The stress reduces leaf water potential, stomatal conductance and transpiration (Itoh and Kamura, 1986). Rajagopal *et al.* (1989) reported that coconut palms irrigated at IW/CPE ratio of 1.0 maintained normal water relations. Coconut palms experience severe moisture stress at an irrigation level of 0.5 resulting in greater stomatal resistance (111%), transpiration rate (10%), leaf water potential (68%) and reproductive dry matter production (22%) compared with well watered palms. Relative leaf water content was higher for irrigated condition than rain fed condition (Islam *et al.*, 1998). Higher values of relative leaf water content (RLWC) were recorded in the monsoon than summer at all the stages of crop (Elamathi and Singh, 2001 ; Sharma *et al.*, 2003).

2.7.2.2 Biochemical Parameters

Free proline accumulation in the leaf is used as one of the parameters for screening the crop varieties for relative drought tolerance. In soybean, Waldren and Teare (1974) reported that accumulation of proline under water stress could be an indicator of drought resistance or susceptibility. Parameshwara and Krishnasastry (1980) observed that in Sorghum, the magnitude of proline accumulation was high when stress was given at initial vegetative phase and decreased at other stages. Mukherjee *et al.* (1982) studied the degree of drought resistance in cowpea in relation to proline accumulation and concluded that plants having an inherent capacity to accumulate proline during moisture stress can also acquire the property of drought resistance under such situations. The indication of stress in the plants has been thought to promote the accumulation of proline and it acts as a cytoplasmic osmotic solute (Levy, 1983; Newton *et al.*, 1986). In green gram, accumulation of proline during stress is considered to be an adaptive mechanism for drought tolerance (Anitha, 1989). Sharma and Kumar (1991) reported that mean free proline content was higher in stress than in non stress conditions in Indian mustard by 10.4 times at 60 days and 12 times at 80 days. Proline accumulation in the leaves also enhances osmotic adjustment (Luzano *et al.*, 1995). Mukane *et al.* (1996) reported that accumulation of free proline and carbohydrates in the leaves of pegion pea can be used as bio chemical markers of drought tolerance. In soybean, Thomas (1998) found that K is involved in the biosynthesis of proline and crop variety with high proline content are reported to have high yield stability and high productivity under moisture stress.

Materials and Methods

3. MATERIALS AND METHODS

A field experiment was conducted to find out the comparative efficacy of vertical mulching, micro site enrichment, micro catchments and traditional methods of rain water harvest and conservation to extend the period of stored moisture availability for raising sappan wood without summer irrigation at the Instructional Farm attached to the college of Agriculture, Vellayani, during 2004-2005.

The materials used and the methodology followed for the experiment are presented in this chapter.

3.1 MATERIALS

3.1.1 Experimental Site

The experiment was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani. The farm is located at 8° 5' N latitude and 76° 9' E longitude at an altitude of 29 m above MSL.

3.1.2 Soil

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

3.1.3 Climate and Season

The weather data recorded during June 2004 to June 2005 are given in Appendix and graphically presented in Fig.1. The abstract of weather data is given in Table 2.

During 2004-05, the daily maximum temperature ranged from 29.8°C to 34.5°C with a mean of 31.5°C. The minimum temperature ranged from 20.8°C to 24.1°C with a mean of 22.3°C.

Table1. Mechanical composition, soil moisture characteristics and chemical properties of soil

Particulars	Content	Method used
A. Mechanical compositions		
Coarse sand, %	16.7	Bouyoucos Hydrometer method (Bouyoucos, 1962)
Fine Sand, %	31.3	
Silt, %	25.5	
Clay, %	26.5	
B. Soil Moisture Characteristics		
Particle density, g cc^{-1}	2.2	Pycnometer method (Black, 1965)
Bulk density, g cc^{-1}	1.5	Core method (Gupta and Dakshinamoorthi, 1980)
Maximum water holding capacity, %	24.6	
Porosity, %	31.8	
Field capacity, %	22.7	
Permanent wilting point, %	9.1	
C. Chemical properties		
Organic Carbon, %	0.33	Wakley and Black rapid titration method (Jackson, 1973)
Organic matter, %	0.57	
Available nitrogen, kg ha^{-1}	219.5	Alkaline KM_nO_4 method (Subbiah and Asija, 1956)
Available phosphorus, kg ha^{-1}	32.8	Bray's colourimetric method (Jackson, 1973)
Available potassium, kg ha^{-1}	80.6	Ammonium acetate method (Jackson, 1973)
Soil reaction, pH (Soil : Water – 1: 2.5)	5.1	pH meter with glass electrode (Jackson, 1973)

Table 2. Abstract of the weather data during the experimental period (June 2004 to June 2005)

Weather elements	2004-2005	
	Range	Mean
Maximum temperature (^{0}C)	29.8 – 34.5	31.5
Minimum temperature (^{0}C)	20.8 – 24.1	22.3
Annual rainfall (mm)	-	1885
Relative humidity (%)	75.3 – 85.7	81.5
Monthly evaporation (mm)	2.7 – 4.6	3.6

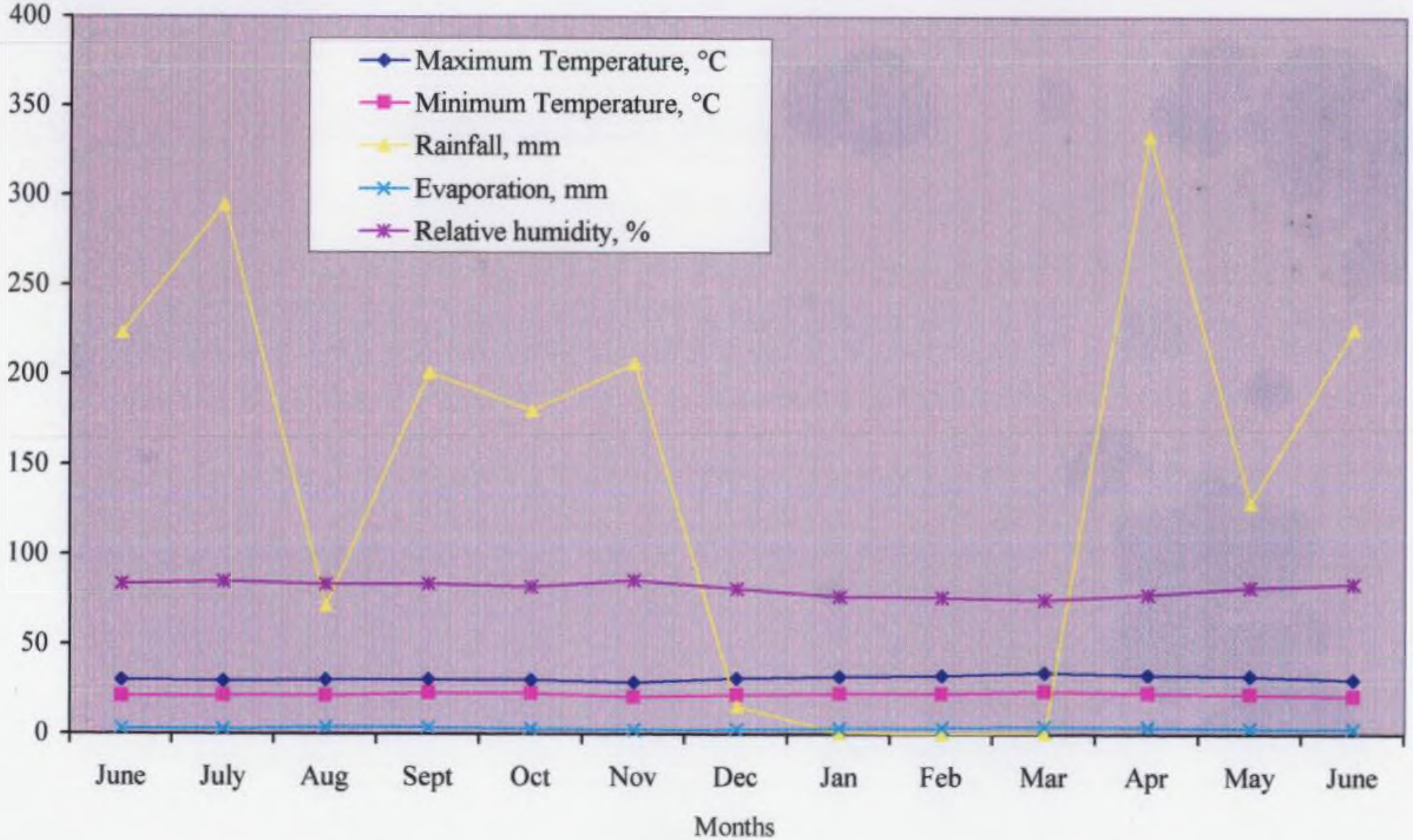

Fig. 1. Weather data during experimental period (June 2004- June 2005)

The total rainfall during 2004-05 was 1885 mm. The months January, February and March received no rainfall. The peak rainfall season coincided with June to November. The rainfall distribution pattern was bimodal.

In 2004-05, the mean RH ranged from 75.3 to 85.7 per cent with a mean of 81.5 per cent.

During 2004-05, the monthly evaporation ranged from 2.7 mm to 4.6 mm with a mean of 3.6 mm. The monthly evaporation was higher (3.9 to 4.6 mm) during February to March and lowest (2.7 to 3.0 mm) during November to December. The area enjoys a warm humid tropical climate.

3.2 METHODS

3.2.1 Field Experiment

In situ rain water harvest, conservation and utilization for establishment and early growth of sappan wood (_Caesalpinia sappan_ L.)

The main objective of the experiment was to find out the comparative efficacy of vertical mulching, micro site enrichment, micro catchments and traditional methods of rain water harvest and conservation to extend the period of stored moisture availability for raising sappan wood without summer irrigation.

3.2.1.1 Design and Layout

Design	: Split plot
Replication	: 2
Spacing	: 2.0 × 2.0 m
Plot size	: 4.0 × 4.0 m

Layout plan is given in Fig. 2 .

3.2.1.2 Treatments

Main plot treatments

M_1 - Vertical mulching with coconut husk in circular trenches

M_2 - Vertical mulching with enriched coir pith vermicompost in circular trenches

M_3 - Vertical mulching with layering mixture in circular trenches

M_4 - Vertical mulching with coconut husk in polythene lined circular trenches

M_5 - Vertical mulching with enriched coir pith - vermicompost in polythene lined circular trenches

M_6 - Vertical mulching with layering mixture in polythene lined circular trenches

M_7 . Micro site enrichment and mulching with polythene

M_8 . Micro site enrichment and mulching with coconut husk

M_9 . Micro catchments and mulching with coconut husk

M_{10} . Micro catchments and mulching with coir geo-textiles

M_{11} . Pitcher irrigation

M_{12} . Drip irrigation

Subplot treatments

S_1 - Irrigation at 50 per cent depletion of soil moisture

S_2 - Control (Life saving irrigation)

3.2.1.3 Treatment Combinations : $12 \times 2 = 24$

The treatment combinations are listed in Table 3.

M_{11} and M_{12} are the two control treatments. The data collected prior to the imposition of sub plot treatments, were analysed in RBD and after that in Split plot.

REPLICATION I

M_8S_1	M_3S_2	M_1S_1	$M_{11}S_2$	M_7S_1	M_2S_2	M_4S_1	M_9S_2	M_6S_1	M_5S_2	$M_{10}S_1$	$M_{12}S_2$
M_8S_2	M_3S_1	M_1S_2	$M_{11}S_1$	M_7S_2	M_2S_1	M_4S_2	M_9S_1	M_6S_2	M_5S_1	$M_{10}S_1$	$M_{12}S_1$

REPLICATION II

$M_{12}S_1$	M_4S_2	M_3S_1	$M_{10}S_2$	M_6S_1	M_5S_2	M_7S_1	M_9S_2	$M_{11}S_1$	M_2S_2	M_8S_1	M_2S_2
$M_{12}S_2$	M_4S_1	M_3S_2	$M_{10}S_1$	M_6S_2	M_5S_1	M_7S_2	M_9S_1	$M_{11}S_2$	M_2S_1	M_8S_2	M_2S_1

Fig. 2. Layout plan – *In situ* rain water harvest, conservation and utilization for establishment and early growth of sappan wood

Table 3. Treatment Combinations

No.	Treatment combinations
T_1	M_1S_1-Vertical mulching with coconut husk in circular trenches + irrigation at 50% depletion of soil moisture
T_2	M_1S_2-Vertical mulching with coconut husk in circular trenches + life saving irrigation
T_3	M_2S_1-Vertical mulching with enriched coir pith – vermicompost in circular trenches + irrigation at 50% depletion of soil moisture
T_4	M_2S_2-Vertical mulching with enriched coir pith vermicompost in circular trenches + life saving irrigation
T_5	M_3S_1- Vertical mulching with layering mixture in circular trenches + irrigation at 50% depletion of soil moisture
T_6	M_3S_2- Vertical mulching with layering mixture in circular trenches + life saving irrigation
T_7	M_4S_1-Vertical mulching with coconut husk in polythene lined circular trenches + irrigation at 50% depletion of soil moisture
T_8	M_4S_2-Vertical mulching with coconut husk in polythene lined circular trenches + life saving irrigation
T_9	M_5S_1-Vertical mulching with enriched coir pith–vermicompost in polythene lined circular trenches + irrigation at 50% depletion of soil moisture
T_{10}	M_5S_2-Vertical mulching with enriched coir pith–vermicompost in polythene lined circular trenches + life saving irrigation
T_{11}	M_6S_1-Vertical mulching with layering mixture in polythene line circular trenches + irrigation at 50 % depletion of soil moisture
T_{12}	M_6S_2-Vertical mulching with layering mixture in polythene lined circular trenches + life saving irrigation
T_{13}	M_7S_1-Micro site enrichment and mulching with polythene + irrigation at 50% depletion of soil moisture
T_{14}	M_7S_2-Micro site enrichment and mulching with polythene + life saving irrigation
T_{15}	M_8S_1-Micro site enrichment and mulching with coconut husk + irrigation at 50% depletion of soil moisture
T_{16}	M_8S_2-Micro site enrichment and mulching with coconut husk + life saving irrigation
T_{17}	M_9S_1-Micro catchments and mulching with coconut husk + irrigation at 50% depletion of soil moisture
T_{18}	M_9S_2-Micro catchments and mulching with coconut husk + life saving irrigation
T_{19}	$M_{10}S_1$-Micro catchments and mulching with coir geo-textiles + irrigation at 50% depletion of soil moisture
T_{20}	$M_{10}S_2$-Micro catchments and mulching with coir geo-textiles + life saving irrigation
T_{21}	$M_{11}S_1$-Pitcher irrigation + irrigation at 50% depletion of soil moisture
T_{22}	$M_{11}S_2$-Pitcher irrigation + life saving irrigation
T_{23}	$M_{12}S_1$-Drip irrigation + irrigation at 50% depletion of soil moisture
T_{24}	$M_{12}S_2$-Drip irrigation + life saving irrigation

3.3 FIELD CULTURE

3.3.1 Land Preparation

The selected area was dug twice, stubbles removed, clods broken, levelled and laid into plots as per the layout plan.

3.3.2 The Crop, Variety and Planting

East Indian sappan wood (*Caesalpinia sappan*) and American Brazil wood (*Caesalpinia brasilensis*) are used as raw material sources for the extraction of dyes. East Indian sappan wood (*Caesalpinia sappan*) was selected for the present experiment.

Mature sappan wood pods were collected in February- March 2004 from the herbal garden of Instructional Farm, Vellayani, dried under partial shade and seeds separated. Seeds were sown in polybags filled with potting mixture and maintained in herbal nursery under partial shade and sprinkler irrigation. Uniform seedlings of three months age were selected and planted on 6^{th} June 2004 at a spacing of 2.0×2.0 m as per the technical programme.

3.3.3 Imposition of Treatments

The main plot treatments were given along with planting of seedlings in June 2004 and the sub plot treatments only after six months of planting.

3.3.3.1 Vertical Mulching in Circular Trenches

For vertical mulching, a circular trench was taken by excavating soil at a radius of 60 cm from the base of the plant, 15cm wide and 30 cm deep.

3.3.3.2 Vertical mulching in polythene lined circular trenches

Similar to the above, a circular trench was taken and both the outer and inner sides and bottom of the trench were covered with polythene sheet to prevent seepage and percolation losses of stored rainwater. However, to facilitate moisture movement towards the rhizosphere and foraging of roots, pinpricks were made @ 4 per 10 cm^2 in the polythene sheet covering the inner side of trench.

3.3.3.3 Vertical Mulching with Coconut Husk

Green coconut husk from freshly harvested nuts were used @ 50 per circular trench for vertical mulching. Coconut husks were chopped into long pieces of 5 cm width and packed as per the treatments, facing concave side upwards and covered with surface soil.

3.3.3.4 Vertical Mulching with Enriched Coir Pith- Vermicompost

Enriched coir pith- vermicompost was prepared from raw coir pith, chopped banana pseudostem, fresh cowdung in 4:1:1 proportions using African night crawler (*Eudrillus euginae*). Poultry manure, bone meal and rock dust were added at the time of filling in of vermicompost trenches @ 2% of the total weight of substrate. Enriched coir pith vermicompost was recovered after 45 days of introduction of African night crawler and was applied for vertical mulching in circular trenches @ 10 kg per trench. The physico-chemical compositions of enriched coirpith-vermicompost are given in Table 4.

3.3.3.5 Vertical Mulching with Layering Mixture

Red soil, enriched coir pith - vermicompost, dried and powdered cowdung in 1:1:1 proportion were used for the preparation of layering mixture. It was packed in circular trenches @ 18 kg per trench for vertical mulching (Plate 4). The physico-chemical compositions of layering mixture are given in Table 4.

Table 4. Physico chemical composition of mulching materials

Particulars	Enriched coir pith vermicompost	Layering mixture	Farmyard manure	Coconut husk
A. Physical properties				
Bulk density, g cc^{-1}	0.20	0.60	-	-
Maximum water holding capacity, %	179.5	80.1	-	-
B. Chemical properties				
Nitrogen, %	0.91	0.5	0.5	0.23
Phosphorus, %	0.52	0.4	0.3	0.04
Potassium, %	0.88	0.4	0.2	0.78

Plate 1. General view of experimental field

Plate 2. Drip irrigation + life saving irrigation ($M_{12}S_2$)

Plate 3. Pitcher irrigation + supplemental irrigation ($M_{11}S_1$)

Plate 4. Vertical mulching with layering mixture in polythene lined circular trenches + supplemental irrigation (M_6S_1)

Plate 5. Micro site enrichment and mulching with polythene + supplemental irrigation (M_7S_1)

Plate 6. Micro site enrichment and mulching with coconut husk + supplemental irrigation (M_8S_1)

Plate 7. Micro catchments and mulching with coconut husk + life saving irrigation (M_9S_2)

Plate 8. Micro catchments and mulching with coir geo-textiles + life saving irrigation ($M_{10}S_2$)

3.3.3.6 Micro Site Enrichment

For micro site enrichment, circular pits of 60 cm diameter and 40 cm depth were taken. Coconut shells filled with river sand was spread at the bottom and covered to a height of 20 cm by putting 18 kg of layering mixture prepared as explained in the preceeding paragraph. Later it was mulched with polythene / coconut husk as per the technical programme(Plate 5 and Plate 6).

3.3.3.7 Micro Catchments

Micro catchment was prepared by modifying the land configuration around the seedling, following the concept of micro watershed. Rectangular basins of size 2.0 × 2.0 m with slope inwards and towards the seedlings were taken for catching and conserving rainfall falling over the micro catchments. Entire rectangular basin area was mulched with coconut husk @ 100 numbers per basin / coir geo- textiles @ 4 m^2 per basin as per the technical programme (Plate 7 and Plate8).

3.3.3.8 Pitcher irrigation

Capacity of the mud pots was fixed based on the following calculations.

$$d = \frac{(FC\text{-}PWP)}{100} \times \frac{50}{100} \times As_i \times D_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,

d =Depth of irrigation water in mm

FC = field capacity, %

PWP = permanent wilting point, %

As_i = Apparent specific gravity, g cc^{-1}

D_i = depth of root zone, cm

Based on destructive sampling conducted after six months of planting, the depth of roots was estimated as 42 cm.

$$\text{Capacity of the mud pot} = \pi r^2 h \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$= 3.14 \times 0.25 \times 0.25 \times 0.042$$

$$= 8.24 \text{ litre}$$

Mud pots of 8.24 litre capacity with a tiny hole inbuilt at the bottom and plugged with coir fibre was used for pitcher irrigation. An appropriate pit was dug at a radial distance of 25 cm and buried the pot in such a way that the rim of pot was in line with soil surface. It was periodically filled with water as per the technical programme and covered with coconut shell to arrest evaporation losses (Plate 3).

3.3.3.9 Drip Irrigation

The following formula was used for calculation of volume of water required for drip irrigation.

Volume of water required = Depth of irrigation water × wetted area

Drip irrigation system was installed after cessation of SW monsoon, i.e., December 2004. Two pressure compensating type drippers having discharge rate of 4 litres per hour per dripper were installed per plant and the system was operated for 2 hours for delivering 16 litres of water per plant (Plate 2).

3.3.3.10 Irrigation

The crop was irrigated from 13th December 2004 to 12th June 2005. Pretreatment irrigation was given to bring the soil to field capacity. The quantity of water applied per basin was calculated by taking the depth of irrigation as 42 mm. The volume of water to be applied to bring the soil to field capacity was calculated based on formula (1) furnished in section 3.3.3.8.

Volume of water applied per seedling = Depth of water applied × Area irrigated (m^2).

Irrigation water was measured with a water meter and applied @ 33 litre per basin during one irrigation. The details of irrigation given are furnished in Table 5.

3.3.3.11 Control

Life saving irrigation alone was given. It was given when the plants showed temporary wilting symptoms.

Table 5. Details of irrigation given during the experimental period (December to June)

Treatment combinations	Number of irrigation	Irrigation requirement, litre plant^{-1}	Pretreatment irrigation, litre plant^{-1}	Effective rainfall, litre plant^{-1}	Total quantity of water, litre plant^{-1}
T_1 - M_1S_1	34	1122	33	560	1715
T_2 - M_1S_2	5	165	33	600	798
T_3 - M_2S_1	34	1122	33	550	1705
T_4 - M_2S_2	5	165	33	600	798
T_5 - M_3S_1	34	1122	33	560	1715
T_6 - M_3S_2	5	165	33	600	798
T_7 - M_4S_1	28	924	33	520	1477
T_8 - M_4S_2	5	165	33	590	788
T_9 - M_5S_1	27	891	33	500	1424
T_{10} - M_5S_2	5	165	33	550	748
T_{11} - M_6S_1	23	759	33	460	1252
T_{12} - M_6S_2	5	165	33	475	673
T_{13} - M_7S_1	20	660	33	470	1163
T_{14} - M_7S_2	5	165	33	490	688
T_{15} - M_8S_1	20	660	33	475	1168
T_{16} - M_8S_2	5	165	33	500	698
T_{17} - M_9S_1	23	759	33	520	1312
T_{18} - M_9S_2	5	165	33	560	758
T_{19} - $M_{10}S_1$	23	759	33	510	1302
T_{20} - $M_{10}S_2$	5	165	33	560	758
T_{21} - $M_{11}S_1$	34	280	33	460	773
T_{22} - $M_{11}S_2$	10	82	33	475	590
T_{23} - $M_{12}S_1$	28	448	33	440	921
T_{24} - $M_{12}S_2$	8	128	33	470	631

3.3.4 Soil Moisture Studies

3.3.4.1 Soil Moisture

Soil sampling was done a using screw auger at a distance of 15 cm away from the base of the plant to a depth of 20 cm just before and 24 hours after irrigation and the soil moisture worked out gravimetrically.

3.3.4.2 Consumptive Use (Cu) of Water

Consumptive use of water by sappan wood under different treatments was worked out using the formula developed by Dasthane (1972).

$$Cu = \sum_{i}^{N} (Ep \times 0.6) + \sum_{i}^{n} \frac{(Ma_i - Mb_i)}{100} \times As_i \times D_i + ER$$

Where,

Cu = Consumptive use of water in mm

Ep = Pan evaporation value from USWB class A open pan evaporation from the date of irrigation to the date of soil sampling after irrigation.

0.6 = A constant used for obtaining ET value from pan evaporation value for the given period of time

Ma_i = Percentage soil moisture (w/w) of the i^{th} layer of soil at the time of sampling after irrigation

Mb_i = Percentage soil moisture (w/w) of the i^{th} layer of soil at the time of sampling before irrigation

As_i = Apparent specific gravity of i^{th} layer of soil, g cc^{-1}

D_i = Depth (mm) of the i^{th} layer of soil

ER = Effective rainfall if any within the season (mm).

N = Number of soil layers.

n = Number of days between irrigation and post irrigation soil moisture sampling.

3.3.4.3 Irrigation Requirement

Irrigation requirement was estimated by directly adding the quantity of water used for irrigation in each treatment.

3.3.4.4 Water Use Efficiency (WUE)

Crop water use efficiency and field water use efficiency were computed using the following formula and are expressed as kg m^{-3}.

$$\text{Crop WUE} = \frac{\text{Yield}}{\text{Consumptive use}}$$

$$\text{Field WUE} = \frac{\text{Yield}}{\text{Total water requirement}}$$

3.3.4.5 Crop Coefficient (kc)

Crop coefficient was worked out by dividing the consumptive use during a given period by pan evaporation value during that period.

3.3.5 Manuring

A basal dressing of 4 kg farmyard manure was uniformly given per basin.

3.3.6 After Care

All the seedlings planted established well. A uniform dose of NPK was given @ 50:25:25 kg ha^{-1} after 3 months of planting. Plant protection measures were taken as and when required. Fusarium wilt caused by *Fusarium oxysporum* was controlled by soil drenching with copper oxychloride (0.4%) @ 2 litre $plant^{-1}$.

3.4 OBSERVATIONS

Two plants from each plot were selected at random for recording all observations, unless otherwise specified for recording observations. The methods followed for recording observations are given below.

3.4.1 Growth Characters

Growth characters were recorded at monthly intervals from randomly selected observation plants and mean values were worked out.

3.4.1.1 Plant Height

The height of the plant was measured from the base of the plant to the tip of the tallest branch and expressed in cm.

3.4.1.2 Number of Functional Leaves

Number of functional leaves produced in a plant was counted from the observation plants and mean values recorded.

3.4.1.3 Number of Branches

Total number of branches per plant was counted and recorded.

3.4.1.4 Collar Girth

The girth of the main stem at the collar region was taken using a thread and measuring scale and expressed in cm.

3.4.2 Canopy Architecture

3.4.2.1 Bole Height

Bole height was measured from the ground level to the first crown forming foliage and expressed in cm.

3.4.2.2 Canopy Height

Canopy height was measured from the bottom of the foliage (not the ground) to the top of the canopy and expressed in cm.

3.4.2.3 Canopy Width

The lateral distance covered by the canopy in the north-south and east-west direction from its axis were measured and average was worked out and expressed in cm.

3.4.2.4 Canopy Size

Canopy size was estimated by multiplying canopy height with canopy width and expressed in m^2.

3.4.3 Root Parameters

Representative samples were uprooted at 6 and 12 months after planting. They were thoroughly washed in running water to remove adhering soil particles. The procedures described by Misra and Ahmed (1989) were followed for the estimation of root parameters.

3.4.3.1 Root Number

The whole plant was uprooted and total number of roots were counted.

3.4.3.2 Root Weight

The roots were washed, cleaned, weighed and dried in an oven at 70 ± 5°C for about 10-20 hours and weighed. It was expressed as g plant $^{-1}$.

3.4.3.3 Root Length

Root length was measured from the collar region to the farther most tip of the root system and expressed in cm.

3.4.3.4 Root Spread

Measured the maximum spread of roots and expressed in cm.

3.4.3.5 Root Volume

Volume of roots per plant was estimated by displacement method and expressed in cm^3 plant $^{-1}$.

3.4.3.6 Root Surface Area

Root surface area was calculated using the following formula.

$$\text{Area} = 2\,[\text{Volume (cm}^3) \times \pi \times \text{length (cm)}]^{1/2}$$

Where, length (cm) = weight (mg) × 0.89

3.4.4 Growth Indices

3.4.4.1 Root Growth Potential (RGP)

$$RGP = \frac{\text{Root length}}{\text{Number of roots}}$$

3.4.4.2 Root : Shoot Ratio

The dry weight of root and shoot were separately recorded from the uprooted plants and root: shoot ratio was worked out.

3.4.4.3 Sturdiness Quotient (SQ)

$$SQ = \frac{\text{Plant height (cm)}}{\text{Collar girth (mm)}}$$

3.4.4.4 Crop growth potential (CGP)

$$CGP = \frac{\text{Total dry matter production}}{\text{Sturdiness quotient + Shoot: Root ratio}}$$

3.4.5 Physiological Parameters

For recording physiological parameters third fully opened leaf from the top was taken as index leaf.

3.4.5.1 Relative Water Content (RWC)

The method proposed by Weatherley (1950), which was later modified and described in detail by Slatyer and Barrs (1965) was used to determine relative water content and expressed in percentage.

$$RWC = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.4.5.2 Leaf Water Potential

Leaf water potential was measured by using pressure chamber apparatus between 11 am and 1 pm and expressed in bars.

3.4.5.3 Osmotic Potential

Osmotic potential was measured using vapour pressure osmometer and expressed as m mole kg^{-1}.

3.4.5.4 Transpiration Ratio

Briggs and Shantz (1914) estimated transpiration ratio as ratio between the weight of water used and the dry matter produced by a plant.

3.4.5.5 Stomatal Conductance

Stomatal conductance was measured using Delta time (□T) porometer between 11 am and 1 pm and expressed in cm s^{-1}.

3.4.5.6 Canopy Temperature

Canopy temperature was measured using an infrared thermometer between 9 am and 11 am and expressed in degree Celsius (°C).

3.4.6 Biochemical Parameters

3.4.6.1 Chlorophyll Content

The chlorophyll content was estimated by the method prescribed by Reddy *et al.* (1990). The amount of pigments was calculated using the formula detailed below and expressed in mg g^{-1} of fresh weight.

$$\text{Total Chlorophyll} = [20.2\,(\text{OD at }645) + 8.01(\text{OD at }663) \times \frac{V}{W \times 1000}$$

$$\text{Chlorophyll a} = [12.7(\text{OD at }663) - 2.69(\text{OD at }645)] \times \frac{V}{W \times 1000}$$

$$\text{Chlorophyll b} = [22.9(\text{OD at }645) - 4.68\,(\text{OD at }663)] \times \frac{V}{W \times 1000}$$

3.4.6.2 Proline Accumulation

Proline content was estimated from the fully opened leaves by the technique suggested by Bates *et al.* (1973). The quantity of proline was worked out using the formula given below and expressed in $\mu g\ g^{-1}$ fresh weight.

$$\text{Proline} = \frac{\mu g \text{ Proline/ml} \times \text{ml toluene}}{115.5} \times \frac{0.5}{\text{g sample}}$$

Where, 115.5 is the molecular weight of proline

3.4.7 Dry Matter Production (DMP) and Partitioning

The plants were uprooted after six and twelve months of planting and roots, leaves and stems separated and dried to constant weight at 80 ± 5°C in a hot air oven. The dry weight of all the plant parts were recorded separately and expressed in kg ha^{-1}. Total dry matter production was worked out from leaf, stem and root dry matter.

3.4.8 Development of Heart Wood

Recorded the extent of development of heartwood in each treatments.

3.4.9 Seed Production Potential

3.4.9.1 Days for First Flowering

The date of first flowering was recorded for each treatment and the period taken recorded as number of days.

3.4.9.2 Number of Pods Per Plant

The total number of pods obtained from observational plants of each treatments were counted and average worked out.

3.4.9.3 Number of Seeds Per Pod

The number of seeds per pod of each treatment were counted and means worked out.

3.4.9.4 Seed Yield

Mean number of seeds per pod multiplied with total number of pods in each treatment gives seed yield and expressed as numbers in lakhs ha^{-1}.

3.4.10 Economic Analysis

Economics of establishment of the plantation was worked out after taking into account the cost of cultivation and prevailing market price of seeds. In working out the cost involved, different variable cost items like planting material, manures and fertilizers, plant protection chemicals, irrigation, labour charges etc., were considered at prevailing market rate during 2004-05. Sappan wood takes a long gestation period and the wood is harvested only after seven years when it attains the desirable wood qualities. However, it yields seeds even during first year itself, which fetches very good price in the market. The economics of cultivation is worked out for the first year only, i.e., only for the establishment and early growth of the crop. The benefit: cost ratio (BCR) was calculated as follows.

$$BCR = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.4.11 Statistical Analysis

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

Results

4. RESULTS

A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani during the period from June 2004 to June 2005 to study the comparative efficacy of different *in situ* rain water harvesting techniques and moisture conservation for early growth and establishment of sappan wood. The results obtained from study are presented in this chapter.

4.1 FIELD EXPERIMENT

4.1.1 Growth Characters

4.1.1.1 Plant Height

Data relating to height of plant as influenced by *in situ* rain water harvesting techniques at 1,2,3,4,5 and 6 MAP are presented in Table 6. The influence of *in situ* rain water harvesting techniques and summer irrigation on plant height recorded at monthly intervals from 7 to 12 MAP are furnished in Tables 7 and 8.

In situ rain water harvesting techniques significantly influenced plant height at all stages of growth. Vertical mulching with layering mixture in polythene lined circular trenches (M_6) recorded maximum plant height (100.05 cm) at 6 MAP and it differed significantly from all other treatments. M_6 recorded 148.3 per cent increase in height over control mean (40.29 cm). At 6 MAP, M_2 (71.40 cm), M_3 (69.98 cm), M_7 (65.77cm) and M_8 (62.10 cm) were on par and increase in plant height was 77.2, 73.7, 63.2 and 54.1 per cent over control mean (40.29 cm) respectively.

In situ rain water harvesting techniques and supplemental irrigation exerted significant influence on plant height at all stages of growth. Vertical mulching with layering mixture in polythene lined circular trenches (M_6) was on par with M_7 at all growth stages except at 12 MAP and recorded superior values.

Table 6. Plant height (cm) at monthly intervals (1 to 6 MAP) as influenced by *in situ* rain water harvesting techniques

Treatments	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
M_1	21.55	22.97	28.40	32.75	35.1	36.05
M_2	20.8	22.90	38.75	45.65	64.08	71.40
M_3	20.17	22.88	31.10	37.08	64.95	69.98
M_4	23.10	24.28	29.98	37.28	47.58	52.53
M_5	25.90	27.23	34.03	39.68	48.28	49.95
M_6	26.83	28.80	40.50	50.85	79.48	100.05
M_7	26.28	28.73	38.22	48.38	61.58	65.77
M_8	24.58	26.73	36.13	43.38	57.03	62.10
M_9	20.08	21.70	29.05	35.45	42.25	45.30
M_{10}	20.35	22.20	25.08	27.83	32.05	33.58
M_{11}	22.53	24.15	28.48	34.10	37.00	38.75
M_{12}	20.98	21.80	26.93	31.63	37.00	41.83
$F_{(11,11)}$	9.42**	8.67**	3.59*	6.89**	9.03**	13.81**
SE	0.87	0.90	2.71	2.70	4.94	5.17
CD	2.70	2.79	8.42	8.40	15.37	16.11

Table 7. Plant height (cm) at monthly intervals (7 to 12 MAP) as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
Main plots (M)						
M_1	47.95	58.73	67.15	92.23	116.18	121.98
M_2	90.38	114.30	129.28	167.80	199.43	214.58
M_3	86.93	105.40	124.18	155.83	187.50	203.58
M_4	62.98	82.15	95.18	134.33	151.73	171.38
M_5	60.00	75.3	85.28	139.23	170.05	188.53
M_6	135.65	151.73	177.50	226.35	260.78	298.75
M_7	116.58	134.13	147.38	183.83	210.73	239.13
M_8	88.60	109.25	120.50	150.35	180.50	199.68
M_9	53.03	67.50	75.23	85.65	109.18	129.03
M_{10}	42.23	49.15	55.03	67.83	87.10	103.70
M_{11}	55.90	74.55	86.80	99.35	133.48	151.50
M_{12}	47.63	57.63	66.05	82.23	105.35	127.45
$F_{(11,11)}$	20.52**	12.10**	8.85**	11.14**	9.52**	11.85**
SE	6.564	9.364	12.546	14.345	16.676	16.437
CD	20.433	29.146	39.050	44.651	51.907	51.164
Sub plots (S)						
S_1	89.08	110.91	126.18	158.18	186.87	209.80
S_2	58.89	69.06	78.74	105.99	131.79	148.35
$F_{(1,11)}$	223.92**	267.3**	175.95**	137.55**	162.27**	279.14**
SE	1.426	1.810	2.529	3.146	3.057	2.601
CD	4.396	5.578	7.794	9.696	9.422	8.015

MAP – Months after planting ** Significant at 1 per cent

Table 8. Effect of treatment combinations on plant height (cm) at monthly intervals (7 to 12 MAP)

Treatment combinations	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
M_1S_1	53.55	67.05	77.10	99.40	124.30	131.40
$M_1 S_2$	42.35	50.40	57.20	85.05	108.05	112.55
$M_2 S_1$	110.15	135.15	155.80	192.00	226.35	241.15
M_2S_2	70.60	93.45	102.75	143.60	172.50	188.00
$M_3 S_1$	110.30	143.30	155.50	185.25	207.50	233.40
$M_3 S_2$	63.55	67.50	92.85	126.40	167.50	173.00
$M_4 S_1$	75.85	105.50	124.50	154.35	170.90	191.40
$M_4 S_2$	50.10	58.80	65.85	114.30	132.55	151.35
$M_5 S_1$	68.30	91.60	103.85	167.20	202.95	227.45
$M_5 S_2$	51.70	59.05	66.70	111.25	137.15	149.60
$M_6 S_1$	164.75	183.10	220.70	270.20	319.35	368.95
$M_6 S_2$	106.55	120.35	134.70	182.50	202.20	228.55
$M_7 S_1$	146.55	164.55	181.00	221.40	259.65	298.85
$M_7 S_2$	86.60	103.70	113.75	146.25	161.80	179.40
$M_8 S_1$	105.60	126.80	138.60	174.70	198.60	219.35
$M_8 S_2$	71.60	91.70	102.40	126.00	162.40	180.00
$M_9 S_1$	63.85	89.20	100.20	110.60	137.35	160.75
$M_9 S_2$	42.20	45.80	50.25	60.70	81.00	97.30
$M_{10}S_1$	45.75	55.95	61.50	81.30	94.95	107.50
$M_{10} S_2$	38.70	42.35	48.55	54.35	79.25	99.90
$M_{11} S_1$	69.10	99.20	114.10	132.10	172.05	186.50
$M_{11} S_2$	42.70	49.90	59.50	66.60	94.90	116.50
$M_{12} S_1$	55.20	69.55	81.75	109.60	128.50	150.90
$M_{12} S_2$	40.05	45.70	50.35	54.85	82.20	104.00
$F_{(11,12)}$	6.44**	4.53**	2.80*	3.76*	4.17*	8.89**
SE	4.941	6.270	8.761	10.899	10.591	9.009
CD	15.227	19.322	26.999	33.588	32.367	27.764

MAP – Months after planting
** Significant at 1 per cent   * Significant at 5 per cent

There was gradual increase in plant height from 135.65 cm at 7 MAP to298.75 cm at 12 MAP. At 12 MAP, M_6 was significantly different from all other treatments and improvement in plant height was 134.4 per cent over drip irrigation (M_{12}). At 12 MAP, M_7, M_2, M_3, M_8 and M_5 were on par and showed significant difference from M_9, M_{12}, M_{10} and M_1. After one year of planting, height of plant ranged from 103.70 cm (M_{10}) to 298.75 cm (M_6).

Supplemental irrigation also showed significant difference and irrigation at 50 per cent depletion of soil moisture (S_1) recorded higher values at all stages of growth.

The interaction between *in situ* rain water harvesting techniques and supplemental irrigation on plant height also showed significant variation from 7 to 12 MAP. The treatment combination, M_6S_1 (Vertical mulching with layering mixture in polythene lined circular trenches + irrigation at 50 % depletion of soil moisture) was significantly different from all other treatment combinations and showed higher values at all stages of growth except at 8 MAP. At 8 MAP, M_6S_1 was on par with M_7S_1 and significantly differed from other treatment combinations. The mean plant height ranged from 97.3 cm (M_9S_2) to 368.95 (M_6S_1) at 12 MAP and per cent increase in plant height was 254.8 compared to $M_{12}S_2$ (drip irrigation + life saving irrigation) at 12 MAP. At 12 MAP, M_6S_1 and M_7S_1 followed by M_2S_1, M_3S_1, M_6S_2, M_5S_1 and M_8S_1 were on par and significantly differed from other treatment combinations.

4.1.1.2 Number of Functional Leaves

The mean data on number of functional leaves per plant at different growth stages (1 to 6 MAP) as influenced by *in situ* rainwater harvesting techniques are given in Table 9. The main effects and interactions on number of functional leaves recorded at 7, 8, 9, 10, 11 and 12 MAP are presented in Tables 10 and 11.

Table 9. Number of functional leaves at monthly intervals (1 to 6 MAP) as influenced by *in situ* rain water harvesting techniques

Treatments	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
M_1	7.88	8.75	9.00	9.13	10.25	10.88
M_2	6.75	7.88	7.75	9.00	13.88	14.75
M_3	6.75	7.88	8.38	8.88	13.63	15.63
M_4	7.285	7.75	8.50	9.38	13.88	14.63
M_5	6.38	7.38	7.75	9.25	10.63	12.63
M_6	6.50	7.25	8.50	10.38	18.75	20.75
M_7	6.38	7.38	9.13	10.63	16.00	17.88
M_8	6.63	8.13	8.88	10.00	15.00	15.50
M_9	6.50	7.00	7.50	8.13	10.25	10.50
M_{10}	7.00	7.13	7.50	8.38	9.75	10.13
M_{11}	7.25	7.63	8.00	8.88	11.13	12.00
M_{12}	6.63	7.56	8.00	8.63	11.50	12.63
$F_{(11,11)}$	1.58^{NS}	1.13^{NS}	1.82^{NS}	3.82*	6.08**	5.39**
SE	0.36	0.46	0.42	0.39	1.13	1.37
CD	-	-	-	1.12	3.51	4.26

Table 10. Number of functional leaves at monthly intervals (7 to 12 MAP) as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
Main plots(M)						
M_1	11.38	12.13	13.13	14.75	22.13	24.00
M_2	18.50	19.88	23.38	27.50	43.13	46.88
M_3	17.88	19.75	22.63	25.00	31.88	41.00
M_4	16.25	17.50	18.75	22.13	30.38	34.00
M_5	13.50	14.38	15.13	18.75	27.88	32.13
M_6	23.00	25.25	28.38	33.25	49.25	54.63
M_7	19.75	21.88	24.13	29.50	45.00	51.00
M_8	17.00	18.88	21.88	26.13	35.25	40.25
M_9	11.63	13.25	14.25	16.63	21.00	24.25
M_{10}	11.13	12.25	13.38	15.13	19.13	21.50
M_{11}	13.00	14.25	15.75	17.88	26.75	29.13
M_{12}	13.13	14.00	17.13	18.63	23.75	26.25
$F_{(11,11)}$	4.84**	4.63**	4.70**	7.66**	21.59**	24.89**
SE	1.727	1.957	2.296	2.197	2.146	2.247
CD	5.377	6.092	7.146	6.838	6.681	6.996
Sub plots(S)						
S_1	18.58	20.33	23.15	26.52	36.04	41.21
S_2	12.44	13.56	14.83	17.69	26.54	29.63
$F_{(1,11)}$	49.31**	41.43**	44.16**	36.20**	114.88**	135.82**
SE	0.619	0.744	0.884	1.038	0.627	0.703
CD	1.907	2.292	2.726	3.199	1.931	2.166

MAP – Months after planting *Significant at 5 per cent ** Significant at 1 per cent NS-Not significant

Table 11. Effect of treatment combinations on number of functional leaves at monthly intervals (7 to 12 MAP)

Treatment combinations	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
M_1S_1	13.00	13.75	15.00	17.25	23.50	25.75
$M_1 S_2$	9.75	10.50	11.25	12.25	20.75	22.25
$M_2 S_1$	22.50	23.75	28.25	32.75	54.00	58.50
M_2S_2	14.50	16.00	18.50	22.25	32.25	35.25
$M_3 S_1$	21.75	25.25	30.25	32.50	37.50	53.75
$M_3 S_2$	14.00	14.25	15.00	17.50	26.25	28.25
$M_4 S_1$	18.25	20.00	22.00	27.50	37.25	41.75
$M_4 S_2$	14.25	15.00	15.50	16.75	23.50	26.25
$M_5 S_1$	16.75	17.50	18.25	21.00	28.00	32.00
$M_5 S_2$	10.25	11.25	12.00	16.50	27.75	32.25
$M_6 S_1$	28.00	30.50	34.00	40.00	59.75	66.50
$M_6 S_2$	18.00	20.00	22.75	26.50	38.75	42.75
$M_7 S_1$	26.00	28.25	31.25	36.50	55.25	62.25
$M_7 S_2$	13.50	15.50	17.00	22.50	34.75	39.75
$M_8 S_1$	19.50	22.50	27.25	31.00	39.75	46.50
$M_8 S_2$	14.50	15.25	16.50	21.25	30.75	34.00
$M_9 S_1$	13.50	15.00	16.50	19.25	23.25	27.00
$M_9 S_2$	9.75	11.50	12.00	14.00	18.75	21.50
$M_{10}S_1$	13.00	14.25	15.50	17.00	20.50	22.25
$M_{10} S_2$	9.25	10.25	11.25	13.25	17.75	20.75
$M_{11} S_1$	16.00	17.50	19.00	21.50	28.25	30.00
$M_{11} S_2$	22.00	11.00	12.50	14.25	5.25	28.25
$M_{12} S_1$	14.75	15.75	20.50	22.00	25.50	28.25
$M_{12} S_2$	11.50	12.25	13.75	15.25	22.00	24.25
$F_{(11,12)}$	0.94^{NS}	0.78^{NS}	0.79^{NS}	0.61^{NS}	6.79**	8.52**
SE	2.144	2.576	3.064	3.596	2.171	2.435
CD	-	-	-	-	6.690	7.502

MAP – Months after planting
** Significant at 1 per cent NS - Not significant

Number of functional leaves per plant was not at all influenced by *in situ* rainwater harvesting techniques during the early stages of growth, *i.e.*, first three months after planting.

In situ rainwater harvesting techniques registered significant influence on number of functional leaves from 4 month onwards. At 4 MAP, micro site enrichment and mulching with polythene sheet (M_7) produced maximum number of functional leaves (10.63), which was on par with M_6 and M_8 and increase in leaf number was 21.5 per cent when compared to control mean (8.75). At 6 MAP (M_6) vertical mulching with layering mixture in polythene lined circular trenches recorded maximum number of functional leaves (20.75) and increase in number of functional leaves compared to control mean (12.31) was 68.6 per cent.

In situ rain water harvesting techniques and supplemental irrigation significantly influenced number of leaves at 7, 8, 9, 10, 11 and 12 MAP. At all growth stages M_6 (Vertical mulching with layering mixture in polythene lined circular trenches) followed by M_7 and M_2 showed higher maximum number of functional leaves.

Supplemental irrigation significantly influenced the functional leaf number of sappan wood at all growth stages. Irrigation at 50 per cent depletion of soil moisture (S_1) registered maximum values at all stages of growth.

Interaction effects showed significant variation on number of functional leaves only at 11 and 12 MAP. At both stages M_6S_1 and M_7S_1 were on par and recorded higher number of functional leaves (59.75 and 66.50) and per cent increase was 171.6 and 174.2 respectively over $M_{12}S_2$ (drip irrigation + life saving irrigation). But the treatment combinations failed to express interaction effects on leaf number from 7 to 10 MAP. However, M_6S_1 was superior during the above stages of growth.

4.1.1.3 Collar Girth

The collar girth of sappan wood influenced by *in situ* rain water harvesting techniques at 1, 2, 3, 4, 5 and 6 MAP are depicted in Table 12. Main effects and interaction effects recorded at monthly intervals from 7 to 12 MAP are given in Tables 13 and 14.

Table 12. Collar girth (cm) at monthly intervals (1 to 6 MAP) as influenced by *in situ* rain water harvesting techniques

Treatments	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	6 MAP
M_1	1.31	2.31	2.44	2.56	3.13	3.31
M_2	1.25	1.88	2.38	2.69	4.50	4.69
M_3	1.13	1.81	2.25	2.44	4.44	4.63
M_4	1.25	2.13	2.25	2.44	3.63	4.13
M_5	1.19	1.94	2.19	2.50	3.56	3.81
M_6	1.31	1.94	2.44	2.94	5.25	5.75
M_7	1.38	1.81	2.38	2.69	4.50	4.81
M_8	1.38	1.88	2.31	2.63	4.31	4.69
M_9	1.31	1.88	2.13	2.19	3.06	3.44
M_{10}	1.13	1.88	1.88	2.06	3.06	3.31
M_{11}	1.13	1.50	1.75	2.13	3.31	3.31
M_{12}	1.06	1.69	2.13	2.25	3.25	3.69
$F_{(11,11)}$	0.41^{NS}	1.46^{NS}	2.35^{NS}	1.13^{NS}	3.46*	6.27**
SE	0.17	0.17	0.14	0.25	0.39	0.31
CD	-	-	-	-	1.23	0.97

Table 13. Collar girth (cm) at monthly intervals (7 to 12 MAP) as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
Main plots(M)						
M_1	3.44	3.63	3.94	4.25	4.81	5.19
M_2	4.75	5.06	5.63	6.63	7.44	8.00
M_3	4.94	5.13	5.44	5.63	6.94	8.00
M_4	4.44	4.88	5.44	5.69	6.31	6.69
M_5	4.00	4.13	4.50	5.25	5.94	6.81
M_6	6.25	6.56	7.19	8.88	11.25	13.00
M_7	5.25	5.63	6.38	7.31	9.06	10.44
M_8	4.88	5.06	5.50	6.00	7.19	8.13
M_9	3.50	3.75	3.94	4.38	5.19	5.63
M_{10}	3.50	3.69	3.88	4.19	4.75	5.13
M_{11}	3.75	4.06	4.50	4.63	5.81	6.25
M_{12}	3.81	3.94	4.23	4.44	5.13	5.81
$F_{(11,11)}$	7.45**	6.56**	6.91**	6.47**	11.66**	19.75**
SE	0.317	0.356	0.402	0.564	0.564	0.259
CD	0.988	1.108	1.252	1.754	1.754	0.798
Sub plots(S)						
S_1	4.73	5.02	5.56	6.34	7.39	8.31
S_2	4.02	4.23	4.53	4.87	5.92	6.53
$F_{(1,11)}$	29.64**	38.51**	37.23**	57.28**	25.46**	23.64**
SE	0.092	0.090	0.119	0.138	0.206	0.524
CD	0.283	0.278	0.367	0.426	0.634	1.632

MAP – Months after planting *Significant at 5 per cent ** Significant at 1 per cent NS-Not significant

Table 14. Effect of treatment combinations on collar girth (cm) at monthly intervals (7 to 12 MAP)

Treatment combinations	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
M_1S_1	3.63	3.75	4.25	4.63	5.13	5.63
M_1S_2	3.25	3.50	3.63	3.88	4.50	4.75
M_2S_1	5.13	5.25	6.13	7.63	8.50	9.25
M_2S_2	4.38	4.88	5.13	5.63	6.38	6.75
M_3S_1	5.63	5.88	6.25	6.63	8.00	9.25
M_3S_2	4.25	4.38	4.63	4.63	5.88	6.75
M_4S_1	4.75	5.38	6.25	6.63	7.38	7.63
M_4S_2	4.13	4.38	4.63	4.75	5.25	5.75
M_5S_1	4.38	4.50	4.88	5.63	6.50	7.25
M_5S_2	3.63	3.75	4.13	4.88	5.38	6.38
M_6S_1	6.88	7.25	8.00	10.75	11.75	14.25
M_6S_2	5.63	5.88	6.38	7.00	10.75	11.75
M_7S_1	5.63	6.00	7.00	8.25	10.75	12.50
M_7S_2	4.88	5.25	5.75	6.38	7.38	8.38
M_8S_1	5.00	5.38	6.00	7.00	7.88	9.13
M_8S_2	4.75	4.75	5.00	5.00	6.50	7.13
M_9S_1	3.88	4.13	4.38	4.75	5.75	6.25
M_9S_2	3.13	3.38	3.50	4.00	4.63	5.00
$M_{10}S_1$	3.63	3.88	4.00	4.50	4.88	5.38
$M_{10}S_2$	3.38	3.50	3.75	3.88	4.63	4.88
$M_{11}S_1$	4.25	4.63	5.13	5.13	6.50	6.88
$M_{11}S_2$	3.25	3.50	3.88	4.13	5.13	5.63
$M_{12}S_1$	4.00	4.25	4.45	4.63	5.63	6.38
$M_{12}S_2$	3.63	3.63	4.00	4.25	4.63	5.25
$F_{(11,12)}$	0.66^{NS}	0.79^{NS}	0.63^{NS}	1.99^{NS}	0.69^{NS}	0.64^{NS}
SE	0.319	0.313	0.412	0.479	0.713	0.897
CD	-	-	-	-	-	-

MAP – Months after planting NS - Not significant

The treatment did not influence collar girth during the first 4 months of planting. Collar girth of sappan wood was found to be significantly influenced by *in situ* rain water harvesting techniques at 5 and 6 MAP. At 5 MAP, M_6 (vertical mulching with layering mixture in polythene lined circular trenches) recorded maximum girth of 5.25 cm and it was found to be on par with M_7, M_2, M_3 and M_8. The per cent increase in girth over control mean (3.28 cm) was 60.1 per cent. At 6 MAP, M_6 followed by M_4 recorded higher values. Maximum collar girth of 5.75 cm was observed in vertical mulching with layering mixture in polythene lined circular trenches (M_6) and 64.28 per cent increase in collar girth was noted when compared to control mean (3.50 cm) after 6 months of planting.

Effects of *in situ* rain water harvesting techniques and supplemental irrigation were remarkable on collar girth. M_6 (vertical mulching with layering mixture in polythene lined circular trenches) followed by M_7 showed maximum girth at all stages of growth. Maximum girth of 6.25, 6.56, 7.19, 8.88, 11.25 and 13.00 cm at 7, 8, 9, 10, 11 and 12 MAP respectively were recorded by M_6 and per cent increase over drip irrigation (M_{12}) were 64.0, 66.5, 69.9, 100.0, 119.3 and 123.8 at 7, 8, 9, 10, 11 and 12 MAP respectively. Collar girth ranged from 5.13 cm to 13.00 cm after one year of planting.

Irrigation at 50 per cent depletion of sol moisture (S_1) enhanced collar girth to the extent of 17.7, 18.7, 22.7, 30.2, 24.8 and 27.3 per cent at 7, 8, 9, 10, 11 and 12 MAP respectively compared to life saving irrigation (S_2). After 1 year of planting, scheduling of irrigation at 50 per cent depletion of soil moisture (S_1) resulted in collar girth of 8.13 cm compared to 6.53 cm under life saving irrigation (S_2).

Interaction effects were non significant on collar girth at any of the stages of growth. Values ranged from 3.25 to 6.88 cm, 3.38 to 7.25 cm, 3.50 to 8.00 cm, 3.88 to 10.75 cm, 4.50 to 11.75 cm and 4.75 to 14.25 cm at 7, 8, 9, 10, 11 and 12 MAP respectively. The highest value at all growth stages was recorded by vertical mulching with layering mixture in polythene lined circular trenches + irrigation at 50 per cent depletion of soil moisture (M_6 S_1).

4.1.1.4 Number of Branches

The number of branches per plant as influenced by treatments at 1, 2, 3, 4, 5 and 6 MAP are presented in Table 15. The main effects and their interactions recorded at 7, 8, 9, 10, 11 and 12 MAP are given in Tables 16 and 17.

Number of branches of sappan wood was not at all influenced by *in situ* rainwater harvesting techniques. However, M_7 (Micro site enrichment and mulching with polythene sheet) produced maximum numbers of branches (1.75) after 6 months of planting and it was 33.6 per cent higher over control mean (1.31).

In situ rain water harvesting techniques and supplemental irrigation had no influence on branch number after 7, 8, 9, and 10 months of planting. However, maximum number of branches recorded by M_6 (Vertical mulching with layering mixture in polythene lined circular trenches) was 1.63, 2.00, 2.25 and 2.38 at 7, 8, 9 and 10 MAP respectively. At 11 MAP, M_6 (3.00) followed by M_7 (2.88) had maximum values and were on par and compared to drip irrigation (M_{12}), the per cent increase on number of branches were 59.6 and 53.2 at 11 MAP. At 12 MAP, M_6 (4.00), M_7 (3.25) and M_3 (3.25) were on par. There was 87.8 per cent increase in number of branches in M_6 after 12 months of planting compared to drip irrigation (M_{12}).

The trend was also similar in subplot treatments. No significant influence on number of branches was observed at 8 and 9 MAP. Irrigation at 50 per cent depletion of soil moisture (S_1) recorded 17.6, 20.7, 24.1 and 3.19 per cent increase in branch number after 7, 11 and 12 months of planting respectively compared to life saving irrigation (S_2).

Interaction effects did not influence number of branches of sappan wood at any stages of growth. However at 12 MAP, the values ranged from 1.50 to 4.75 and maximum number of branches (4.75) was produced by the treatment combinations, M_6S_1 (Vertical mulching with mixture in polythene lined circular branches + irrigation at 50% depletion of soil moisture) and M_3S_1(Vertical mulching with mixture in circular branches + irrigation at 50% depletion of soil moisture) and it was 137.5 per cent higher over $M_{12}S_2$ (drip irrigation + life saving irrigation).

Table 15. Branch number at 5 and 6 MAP as influenced by *in situ* rain water harvesting techniques

Treatments	Branch number	
	5 MAP	6 MAP
M_1	1.13	1.13
M_2	1.13	1.13
M_3	1.13	1.13
M_4	1.13	1.38
M_5	1.25	1.25
M_6	1.25	1.63
M_7	1.38	1.75
M_8	1.38	1.50
M_9	1.25	1.38
M_{10}	1.25	1.50
M_{11}	1.13	1.13
M_{12}	1.38	1.50
$F_{(11,11)}$	0.28^{NS}	1.22^{NS}
SE	0.20	0.20
CD	-	-

Table 16. Branch number at monthly intervals (7 to 12 MAP) as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
Main plots(M)						
M_1	1.12	1.38	1.63	1.63	1.88	2.00
M_2	1.38	1.63	1.88	2.00	2.25	2.38
M_3	1.25	1.38	1.50	1.63	2.00	3.25
M_4	1.50	1.50	1.50	1.63	1.88	2.50
M_5	1.38	1.50	1.50	1.63	2.13	2.25
M_6	1.63	2.00	2.25	2.38	3.00	4.00
M_7	1.75	2.00	2.00	2.13	2.88	3.25
M_8	1.50	1.75	1.75	1.88	2.13	2.38
M_9	1.38	1.38	1.38	1.38	1.63	1.88
M_{10}	1.63	1.75	1.75	1.88	1.88	2.13
M_{11}	1.13	1.25	1.25	1.38	1.38	1.50
M_{12}	1.50	1.63	1.63	1.75	1.88	2.13
$F_{(11,11)}$	1.42^{NS}	1.31^{NS}	1.78^{NS}	1.89^{NS}	4.14*	6.12**
SE	0.164	0.214	0.209	0.215	0.229	0.283
CD	-	-	-	-	0.713	0.879
Sub plots(S)						
S_1	1.54	1.69	1.79	1.96	2.27	2.81
S_2	1.31	1.50	1.54	1.58	1.88	2.13
$F_{(1,11)}$	6.37*	3.86^{NS}	3.27^{NS}	9.52**	10.93**	17.85**
SE	0.064	0.068	0.098	0.086	0.085	0.115
CD	0.198	-	-	0.265	0.261	0.355

MAP – Months after planting *Significant at 5 per cent ** Significant at 1 per cent NS-Not significant

Table 17. Effect of treatment combinations on branch number at monthly intervals (7 to 12 MAP)

Treatment combinations	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP
M_1S_1	1.25	1.50	2.00	2.00	2.25	2.50
$M_1 S_2$	1.00	1.25	1.25	1.25	1.50	1.50
$M_2 S_1$	1.50	1.75	2.00	2.25	2.50	2.50
M_2S_2	1.25	1.50	1.75	1.75	2.00	2.25
$M_3 S_1$	1.25	1.50	1.75	2.00	2.50	4.75
$M_3 S_2$	1.25	1.25	1.25	1.25	1.50	1.75
$M_4 S_1$	1.50	1.50	1.50	1.75	2.00	2.75
$M_4 S_2$	1.50	1.50	1.50	1.50	1.75	2.25
$M_5 S_1$	1.50	1.75	1.75	1.75	2.25	2.25
$M_5 S_2$	1.25	1.25	1.25	1.50	2.00	2.25
$M_6 S_1$	2.00	2.25	2.50	2.75	3.25	4.75
$M_6 S_2$	1.25	1.75	2.00	2.00	2.75	3.25
$M_7 S_1$	2.00	2.25	2.25	2.50	3.25	3.75
$M_7 S_2$	1.50	1.75	1.75	1.75	2.50	2.75
$M_8 S_1$	1.50	1.75	1.75	2.00	2.25	2.50
$M_8 S_2$	1.50	1.75	1.75	1.75	2.00	2.25
$M_9 S_1$	1.50	1.50	1.50	1.50	1.75	2.00
$M_9 S_2$	1.25	1.25	1.25	1.25	1.50	1.75
$M_{10}S_1$	1.75	1.75	1.75	2.00	2.00	2.25
$M_{10} S_2$	1.50	1.75	1.75	1.75	1.75	2.00
$M_{11} S_1$	1.00	1.00	1.00	1.25	1.25	1.50
$M_{11} S_2$	1.25	1.50	1.50	1.50	1.50	1.50
$M_{12} S_1$	1.75	1.75	1.75	1.75	2.00	2.25
$M_{12} S_2$	1.25	1.50	1.50	1.75	1.75	2.00
$F_{(11,12)}$	0.74^{NS}	0.74^{NS}	0.49^{NS}	0.61^{NS}	0.63^{NS}	2.33^{NS}
SE	0.222	0.234	0.339	0.298	0.293	0.399
CD	-	-	-	-	-	-

MAP – Months after planting NS - Not significant

4.1.2 Canopy Architecture

4.1.2.1 Bole Height

Bole height of sappan wood recorded at 11 and 12 MAP are furnished in Table 18 and interaction effects in Table 19.

Both at 11 and 12 MAP, bole height registered significant difference due to treatment effects. M_6 (vertical mulching with layering mixture in polythene lined circular trenches) recorded maximum bole height of 71.58 and 94.98 cm and per cent increase over drip irrigation (M_{12}) was 145.9 and 191.5 cm at 11 and 12 MAP respectively. The bole height ranged from 29.10 to 71.58 cm and 32.58 to 94.98 cm at 11 and 12 MAP respectively.

Supplemental irrigation showed variation on bole height at 11 and 12 MAP. Irrigation at 50 per cent depletion of soil moisture (S_1) recorded maximum values (50.37 cm and 59.35 cm) compared to life saving irrigation (42.46 cm and 48.43 cm) at 11 and 12 MAP.

Interaction effects had significant influence on bole height only at 12 MAP. However, maximum bole height (83.00 cm) was noticed in M_6S_1 (vertical mulching with layering mixture in polythene lined circular trenches + irrigation 50% depletion of soil moisture) and the per cent increase over drip irrigation ($M_{12}S_2$) was 264.0 at 11 MAP. The bole height ranged from 25.75 cm to 119.45 cm at 12 MAP. At 12 MAP, the treatment combination, M_6S_1 (119.45 cm) was found to be superior and significantly different from all other treatment combinations with 363.9 per cent increase over $M_{12}S_2$. M_6S_1 followed by M_3S_1, M_7S_1, M_2S_1, M_6S_1, M_6S_2 and M_7S_2 recorded higher values and were on par and the per cent increase were 237.9, 200.9, 184.7, 173.8 and 157.1 respectively.

4.1.2.2 Canopy Height

Mean values on canopy height estimated at 11 and 12 MAP are furnished in Tables 18 and 19.

Table 18. Canopy architecture at 11 MAP and 12 MAP as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Bole height, cm		Canopy height, cm		Canopy width, cm		Canopy size, m^2	
	11 MAP	12 MAP	11 MAP	12 MAP	11 MAP	12 MAP	11 MAP	12 MAP
Main plots (M)								
M_1	34.18	36.13	82.00	85.85	92.83	96.30	0.76	0.83
M_2	55.95	66.08	143.48	148.50	106.43	117.20	1.54	1.75
M_3	65.30	69.15	122.20	134.05	95.48	104.20	1.17	1.39
M_4	54.40	61.33	97.33	110.05	86.95	90.48	0.86	1.02
M_5	40.73	46.80	129.33	141.73	90.85	93.05	1.18	1.32
M_6	71.58	94.98	189.20	203.78	109.75	113.05	2.10	2.33
M_7	61.40	71.85	149.33	167.28	99.48	106.00	1.52	1.79
M_8	46.65	55.13	133.85	144.55	96.40	101.55	1.29	1.49
M_9	33.28	35.50	75.90	93.53	83.05	85.73	0.65	0.82
M_{10}	30.95	38.08	56.15	65.63	76.30	78.70	0.43	0.52
M_{11}	33.50	39.08	99.98	112.43	93.85	100.98	0.96	1.14
M_{12}	29.10	32.58	76.25	94.73	81.80	85.38	0.63	0.82
$F_{(11,11)}$	14.61**	4.08*	12.18**	17.79**	3.19*	2.93*	10.85**	11.87**
SE	6.919	9.524	10.987	9.218	5.506	6.782	0.144	0.150
CD	21.538	29.644	34.198	28.692	17.139	21.112	0.449	0.468
Sub plots(S)								
S_1	50.37	59.35	136.50	150.45	97.48	102.05	1.37	1.58
S_2	42.46	48.43	89.33	99.89	88.04	93.38	0.81	0.96
$F_{(1,11)}$	10.39**	15.32**	203.98**	304.87**	24.84**	13.38**	108.82**	88.04**
SE	1.734	1.972	2.336	2.048	1.339	1.677	0.038	0.047
CD	5.344	6.077	7.197	6.310	4.128	5.169	0.117	0.144

MAP – Months after planting ** Significant at 1 per cent * Significant at 5 percent

Table 19. Effect of treatment combinations on canopy architecture at 11 MAP and 12 MAP

Treatments	Bole height, cm		Canopy height, cm		Canopy width, cm		Canopy size, m^2	
	11 MAP	12 MAP	11 MAP	12 MAP	11 MAP	12 MAP	11 MAP	12 MAP
M_1S_1	37.00	39.10	87.3	92.30	98.95	102.40	0.86	0.95
$M_1 S_2$	31.35	33.15	76.7	79.40	86.70	90.20	0.67	0.71
$M_2 S_1$	63.90	73.30	162.45	167.85	117.40	128.75	1.89	2.15
M_2S_2	48.00	58.85	124.50	129.15	95.45	105.65	1.19	1.36
$M_3 S_1$	81.35	87.00	126.15	146.40	93.95	103.55	1.19	1.53
$M_3 S_2$	49.25	51.30	118.25	121.70	97.00	104.85	1.15	1.27
$M_4 S_1$	52.90	58.15	118.00	133.25	92.35	95.39	1.09	1.28
$M_4 S_2$	55.90	64.50	76.65	86.85	81.55	85.55	0.62	0.77
$M_5 S_1$	35.50	43.20	167.45	184.25	90.00	93.00	1.52	1.72
$M_5 S_2$	45.95	50.40	91.20	99.20	91.70	93.10	0.84	0.93
$M_6 S_1$	83.00	119.45	236.55	249.50	118.15	120.95	2.77	3.01
$M_6 S_2$	60.15	70.50	142.05	158.05	101.35	105.15	1.43	1.65
$M_7 S_1$	64.95	77.50	194.70	221.35	105.30	109.50	2.06	2.44
$M_7 S_2$	57.85	66.20	103.95	113.20	93.65	105.50	0.98	1.16
$M_8 S_1$	46.60	57.35	152.000	162.00	97.55	104.20	1.49	1.71
$M_8 S_2$	46.70	52.90	115.70	127.10	95.25	98.89	1.10	1.28
$M_9 S_1$	37.40	39.10	99.85	121.65	88.15	90.20	0.89	1.10
$M_9 S_2$	29.15	31.90	51.85	65.40	77.95	81.25	0.41	0.54
$M_{10}S_1$	28.00	33.55	66.95	73.95	80.90	83.15	0.54	0.61
$M_{10} S_2$	33.90	42.60	45.35	57.30	71.70	74.25	0.32	0.43
$M_{11} S_1$	38.45	45.05	133.60	141.45	101.30	104.30	1.35	1.47
$M_{11} S_2$	28.55	33.10	66.30	83.40	86.40	97.65	0.56	0.81
$M_{12} S_1$	35.40	39.40	93.10	111.50	85.80	89.25	0.80	1.00
$M_{12} S_2$	22.80	25.75	59.40	77.95	77.80	81.50	0.46	0.64
$F_{(11,12)}$	2.03^{NS}	3.10*	6.47**	9.21**	1.24^{NS}	0.63^{NS}	4.11*	2.84^{NS}
SE	6.007	6.832	8.090	7.093	4.641	5.810	0.132	0.162
CD	-	21.053	24.931	21.051	-	-	0.406	-

MAP – Months after planting

** Significant at 1 per cent * Significant at 5 per cent NS-Not significant

In situ rain water harvesting techniques and supplemental irrigation significantly influenced canopy height at 11 and 12 MAP. Maximum canopy height of 189.20 cm was recorded by vertical mulching with layering mixture in polythene lined circular trenches (M_6) at 11 MAP and significantly different from all other treatments. At 12 MAP, maximum height of 203.78 cm was recorded by M_6 and significantly different from all other treatments and per cent increase was 115.1 in canopy height over drip irrigation (M_{12}).

Sub plot treatments significantly influenced canopy height at 11 and 12 MAP. Irrigation at 50 per cent depletion of soil moisture (S_1) registered maximum values at 11 and 12 MAP.

Both at 11 and 12 MAP, treatment combinations also exerted significant influence on canopy height and M_6S_1 (vertical mulching with layering mixture in polythene lined circular trenches + irrigation at 50% depletion of soil moisture) registered maximum values at both stages of observation.

4.1.2.3 Canopy Width

Mean canopy width of sappan wood at 11 and 12 MAP are depicted in Tables 18 and 19.

Treatments had significant influence on canopy width. Maximum canopy width of 109.75 cm was noticed in M_6 (vertical mulching with layering mixture in polythene lined circular trenches) and it was on par with M_2, M_7, M_8, M_3, M_{11} and M_1 at 11 MAP and when compared to drip irrigation (M_{12}) the per cent increase of canopy width was 34.2. At 12 MAP, M_2 (Vertical mulching with enriched coir pith -vermicompost in circular trenches) recorded a canopy width of 117.20 cm, which was on par with M_6, M_7, M_3, M_8, M_{11} and M_1 and per cent increase over drip irrigation (M_{12}) was 37.3.

Supplemental irrigation registered significant difference on canopy width at 11 and 12 MAP. Irrigation at 50% depletion of soil moisture (S_1) recorded maximum values of 97.48 cm and 102.05 cm at 11 and 12 MAP respectively compared to life saving irrigation (S_2).

Interaction effects had no significant influence on canopy width both at 11 and 12 MAP. However, maximum width was observed in M_6S_1, vertical mulching with layering mixture in polythene lined circular trenches + irrigation at 50% depletion of soil moisture (118.15 cm) at 11 MAP and in M_2S_1, vertical mulching with enriched coir pith vermicompost in circular trenches + irrigation at 50% depletion of soil moisture (128.75 cm) at 12 MAP.

4.1.2.4 Canopy Size

Mean data on canopy size recorded at 11 and 12 MAP are given in Tables 18 and 19.

In situ rain water harvesting techniques and levels of irrigation had significant influence on canopy size at 11 and 12 MAP. At both stages of growth vertical mulching with layering mixture in polythene lined circular trenches (M_6) registered maximum values of 2.10 and 2.33 m^2 respectively. Compared to drip irrigation (M_{12}), M_6 recorded 233.3 and 184.1 per cent increase in canopy size at 11 and 12 MAP respectively.

Irrigation levels exerted significant influence on canopy size at 11 and 12 MAP. Both at 11 and 12 MAP, irrigation at 50 per cent depletion of soil moisture (S_1) recorded higher values of canopy size (1.37 and 1.58 m^2).

Among the different treatment combinations, M_6S_1 (vertical mulching with layering mixture in polythene lined circular trenches + irrigation at 50% depletion of soil moisture) recorded canopy size of 2.77 m^2 at 11 MAP, which was found to be significantly different from all other treatment combinations. Treatment combinations had no significant influence on canopy size after 12 months of planting. However, M_6S_1 registered maximum canopy size of 3.01 m^2.

4.1.3 Root Parameters

Root parameters viz., root number, root length, root spread, root surface area, root volume and root dry weight recorded after 6 MAP are furnished in Table 20.

Among the various root parameters *in situ* rain water harvesting techniques registered significant influence on root length, root spread, root surface area and root dry weight. Longest root (62.7cm) was produced by M_6 (vertical mulching with layering mixture in polythene lined circular trenches) and it differed significantly from all other treatments. The per cent increase in root length over control mean (39.58 cm) was 58.4.

M_6 followed by M_3, M_7 and M_9 showed higher root spread and were on par and all the treatments differed significantly from M_1, M_2, and M_{10}.

In M_6 (vertical mulching with layering mixture in polythene lined circular trenches), root surface area increased to the extent of 192.3 per cent over control mean (1930.70 cm^2) and differed significantly from all other treatments. M_6 followed by M_7 and M_8 had higher values of root surface area.

A similar trend was observed with respect to root volume. The per cent increase over control mean (11.75 cm^3 $plant^{-1}$) was 265.5.

Root dry weight also registered significant influence due to treatments and similar to other root parameter, here also M_6 (vertical mulching with layering mixture in polythene lined circular trenches) was superior. With respect to root dry weight M_6 recorded maximum value (29.70 g $plant^{-1}$) and 98 per cent increase over control mean (15.00 g $plant^{-1}$) and differed significantly from all other treatments.

Though *in situ* rain water harvesting techniques positively influence many of the root parameters, root number was not at all influenced by the treatments. However, vertical mulching with layering mixture in polythene lined circular trenches (M_6) showed maximum number of roots (18.00).

Observations on root parameters viz., root number, root length, root spread, root volume, root surface area, root dry weight and root shoot ratio recorded after 1 year of planting are furnished in Tables 21 and 22.

Table 20. Root parameters at 6MAP as influenced by *in situ* rain water harvesting techniques

Treatments	Root number	Root length, cm	Root spread, cm	Root surface area, m^2	Root volume, cm^3 $plant^{-1}$	Root dry weight, g $plant^{-1}$
M_1	12.50	31.30	58.30	1487.60	9.45	9.40
M_2	10.50	33.20	52.70	988.00	6.80	4.55
M_3	11.00	45.10	126.85	1179.30	5.95	9.85
M_4	13.00	43.60	98.05	2565.90	14.75	20.85
M_5	14.50	37.60	100.00	1874.80	11.50	12.05
M_6	18.00	62.70	137.10	5643.00	42.95	29.70
M_7	8.50	41.70	120.95	3680.65	24.10	21.00
M_8	15.00	33.70	111.75	2998.75	18.50	20.15
M_9	14.50	44.20	119.60	1641.97	10.10	8.40
M_{10}	12.00	32.55	46.95	1013.90	6.15	6.55
M_{11}	12.50	39.40	128.50	1879.55	11.80	15.10
M_{12}	11.50	39.75	132.80	1981.85	11.70	14.90
$F_{(11,11)}$	1.63^{NS}	9.09**	23.34**	17.58**	12.60**	9.24**
SE	1.90	2.7	6.45	306.27	2.80	2.32
CD	-	8.41	20.07	953.32	8.73	7.23

Table 21. Root parameters at 12 MAP as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Root number	Root length, cm	Root spread, cm	Root surface area, m^2	Root volume, cm^3 $plant^{-1}$	Root dry weight, g $plant^{-1}$
Main plots (M)						
M_1	33.75	53.63	91.38	0.83	56.80	63.03
M_2	42.25	79.70	123.38	1.52	101.48	94.33
M_3	31.25	77.43	127.50	2.20	149.13	149.80
M_4	37.50	52.65	91.13	1.36	94.48	95.10
M_5	42.50	87.98	138.50	1.34	93.23	82.55
M_6	49.75	149.90	251.55	2.84	195.63	173.05
M_7	51.25	118.48	195.73	2.69	183.95	165.98
M_8	46.25	86.73	141.63	2.44	165.03	155.45
M_9	24.75	54.58	90.38	0.73	56.55	36.30
M_{10}	25.75	68.83	117.70	0.69	55.35	33.43
M_{11}	18.75	63.08	75.00	0.84	61.78	44.85
M_{12}	27.75	65.43	120.80	1.01	77.85	62.15
$F_{(11,11)}$	43.82**	43.27**	47.26**	221.22**	120.55**	129.50**
SE	1.600	4.396	7.231	0.054	4.749	4.572
CD	4.983	13.682	22.502	0.167	14.785	14.231
Sub plots (S)						
S_1	31.88	92.98	150.72	2.09	145.75	133.39
S_2	40.04	66.75	110.06	0.99	69.45	59.27
$F_{(1,11)}$	77.14**	54.81**	85.50**	1687.49**	2096.16**	822.36**
SE	0.658	2.506	3.109	0.019	1.187	1.828
CD	2.026	7.722	9.581	0.058	3.657	5.632

MAP – Months after planting ** Significant at 1 per cent NS-Not significant

Table 22. Effect of treatment combinations on root parameters at 12 MAP

Treatments	Root number	Root length, cm	Root spread, cm	Root surface area, m^2	Root volume, cm^3 $plant^{-1}$	Root dry weight, g $plant^{-1}$
M_1S_1	30.00	58.20	101.45	1.14	78.70	93.40
$M_1 S_2$	37.50	49.05	81.30	0.52	34.90	32.65
$M_2 S_1$	39.50	85.30	134.45	2.08	142.95	133.90
M_2S_2	45.00	74.10	112.30	0.97	60.00	54.75
$M_3 S_1$	24.50	97.65	154.45	3.15	211.75	22.80
$M_3 S_2$	38.00	57.20	100.55	1.26	86.50	76.50
$M_4 S_1$	33.00	56.80	102.50	1.95	135.10	144.55
$M_4 S_2$	42.00	48.50	79.75	0.77	53.85	45.65
$M_5 S_1$	34.50	108.45	174.50	1.89	129.60	118.50
$M_5 S_2$	50.50	67.50	102.50	0.79	56.85	46.60
$M_6 S_1$	45.50	178.45	285.55	3.88	266.95	235.85
$M_6 S_2$	54.00	121.35	217.55	1.81	124.30	110.25
$M_7 S_1$	48.00	140.10	230.75	3.73	254.60	229.50
$M_7 S_2$	54.50	96.85	160.70	1.66	113.30	102.45
$M_8 S_1$	44.00	102.60	167.15	3.26	217.35	210.05
$M_8 S_2$	48.50	70.85	116.10	1.62	112.70	100.85
$M_9 S_1$	23.50	62.45	101.30	0.91	73.25	42.65
$M_9 S_2$	26.00	46.70	79.45	0.56	39.85	29.95
$M_{10}S_1$	19.50	78.15	134.95	0.85	71.50	37.90
$M_{10} S_2$	32.00	59.50	100.45	0.55	39.20	28.95
$M_{11} S_1$	16.00	70.15	81.10	1.04	77.60	54.15
$M_{11} S_2$	21.50	56.00	68.90	0.64	45.95	35.55
$M_{12} S_1$	24.50	77.50	140.45	1.21	89.65	77.50
$M_{12} S_2$	31.00	53.35	101.15	0.81	66.05	46.80
$F_{(11,12)}$	1.53^{NS}	1.72^{NS}	2.02^{NS}	55.77**	57.87**	29.09**
SE	2.278	6.8681	10.771	0.065	4.110	6.331
CD	-	-	-	0.201	12.666	19.511

MAP – Months after planting ** Significant at 1 per cent NS - Not significant

All the recorded root parameters were significantly influenced by *in situ* rain water harvesting techniques. Among the various root parameters, maximum root length, root spread, root dry weight, root volume and root surface area were recorded by vertical mulching with layering mixture in polythene lined circular trenches (M_6) followed by M_7. The improvement in root length, root spread, root dry weight, root volume and root surface area were 129.1, 108.2, 178.4, 117.8 and 181.2 per cent respectively when compared to drip irrigation (M_{12}). Maximum number of roots (51.25) was registered by M_7 (micro site enrichment and mulching with polythene) and when compared to drip irrigation (M_{12}), per cent increase in root number 84.7.

With respect to levels of irrigation significant influence was observed in root length, root number, root spread, root dry weight, root volume and root surface area. Life saving irrigation (S_2) enhanced root number to the tune of 25.6 per cent compared to supplemental irrigation at 50 per cent depletion of soil moisture (S_1). S_1 enhanced root length (98.98 cm), root spread (150.72 cm), root dry weight (133.39 g plant^{-1}), root volume (145.75 cm^3 plant^{-1}) and root surface area (2.09 m^2) to the extent of 39.3, 36.9, 125.1, 109.9 and 111.1 per cent respectively over life saving irrigation (S_2).

Interaction effects between *in situ* rain water harvesting techniques and supplemental irrigation had no significant influence on root number, root length and root spread. However, root dry weight, root volume and root surface area were found to be significantly influenced by different treatment combinations. With respect to root dry weight, root volume and root surface area, vertical mulching with layering mixture in polythene lined circular trenches + irrigation at 50 per cent depletion of soil moisture (M_6S_1) recorded higher values viz., 235.85 g plant^{-1}, 266.95 cm^3 plant^{-1} and 3.88 m^2 respectively and was on par with M_7S_1.

4.1.4 Growth Indices

Growth indices *viz.,* root growth potential, root: shoot ratio sturdiness quotient and crop growth potential estimated at 6 MAP in Table 23 and after 1 year of planting are given in Tables 24 and 25.

Table 23. Growth indices at 6 MAP as influenced by *in situ* rain water harvesting techniques

Treatments	Root growth potential	Root: shoot ratio	Sturdiness quotient	Crop growth potential
M_1	2.50	0.37	1.09	23.63
M_2	3.16	0.12	1.52	10.85
M_3	4.10	0.30	1.51	22.38
M_4	3.35	0.39	1.27	41.19
M_5	2.59	0.29	1.31	65.65
M_6	3.48	1.18	1.74	191.32
M_7	4.90	1.26	1.36	121.89
M_8	2.25	1.34	1.32	98.84
M_9	3.05	1.32	1.32	42.96
M_{10}	2.71	1.28	1.06	41.27
M_{11}	3.15	0.42	1.17	36.75
M_{12}	3.46	0.42	1.13	37.45
$F_{(11,11)}$	#	2.27^{NS}	#	#
SE	#	0.18	#	#
CD	#	-	#	#

Table 24. Growth indices at 12 MAP as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Root growth potential	Root: shoot ratio	Sturdiness quotient	Crop growth potential
Main plots (M)				
M_1	1.58	0.24	2.35	123.48
M_2	1.89	0.12	2.68	196.02
M_3	2.48	0.20	2.54	284.46
M_4	1.40	0.30	2.56	166.32
M_5	2.07	0.25	2.77	164.49
M_6	3.01	0.15	2.30	379.82
M_7	2.31	0.16	2.29	338.65
M_8	1.88	0.17	2.46	305.21
M_9	2.21	0.23	2.29	82.15
M_{10}	2.67	0.25	2.02	78.88
M_{11}	3.36	0.15	2.42	100.50
M_{12}	2.36	0.24	2.19	135.06
$F_{(11,11)}$	#	11.94**	#	#
SE	#	0.016	#	#
CD	#	0.049	#	#
Sub plots(S)				
S_1	2.92	0.21	2.52	283.55
S_2	1.67	0.20	2.27	147.85
$F_{(1,11)}$	#	0.01^{NS}	#	#
SE	#	0.007	#	#
CD	#	-	#	#

Data not analyzed MAP Months after planting ** Significant at 1 percent

Table 25. Effect of treatment combinations on growth indices

Treatment combinations	Root growth potential	Root: shoot ratio	Sturdiness quotient	Crop growth potential
M_1 S_1	1.94	0.25	2.33	185.04
M_1 S_2	1.31	0.23	2.37	65.22
M_2 S_1	2.14	0.15	2.61	282.85
M_2 S_2	1.65	0.09	2.79	121.84
M_3 S_1	3.99	0.27	2.52	412.30
M_3 S_2	1.51	0.14	2.56	166.18
M_4 S_1	1.72	0.41	2.51	253.09
M_4 S_2	1.15	0.19	2.63	139.62
M_5 S_1	3.14	0.22	3.14	211.40
M_5 S_2	1.34	0.26	2.34	72.68
M_6 S_1	3.92	0.15	2.59	738.62
M_6 S_2	2.25	0.14	1.95	246.59
M_7 S_1	2.92	0.19	2.39	479.72
M_7 S_2	1.78	0.14	2.14	285.37
M_8 S_1	2.33	0.19	2.40	431.00
M_8 S_2	1.46	0.16	2.52	204.02
M_9 S_1	2.66	0.17	2.57	89.74
M_9 S_2	1.79	0.29	1.95	61.50
M_{10} S_1	4.01	0.17	1.99	83.57
M_{10} S_2	1.86	0.33	2.04	57.54
M_{11} S_1	4.38	0.13	2.71	118.33
M_{11} S_2	2.60	0.18	2.07	78.09
M_{12} S_1	3.16	0.19	2.37	156.25
M_{12} S_2	1.72	0.29	1.98	72.39
$F_{(11,12)}$	#	10.89**	#	#
SE	#	0.023	#	#
CD	#	0.069	#	#

** Significant at 1 per cent # Data not analyzed MAP Months after planting

Treatments had significant influence on root:shoot ratio. Vertical mulching with coconut husk in polythene lined circular trenches (M_4) showed maximum root: shoot ratio at 6 MAP and 12 MAP. Levels of irrigation had no significant influence on root:shoot ratio. However, irrigation at 50 per cent depletion of soil moisture (S_1) registered maximum values. Interaction effects had significant influence on root:shoot ratio. M_4S_1 (vertical mulching with coconut husk in polythene lined circular trenches + 50% depletion of soil moisture) showed maximum root shoot ratio (0.41) and differed significantly from all other treatment combinations. Compared to $M_{12}S_2$ (drip irrigation + life saving irrigation) root shoot ratio was 41.4 per cent higher in M_4S_1.

Maximum values of root growth potential, sturdiness quotient and crop growth potential were recorded by M_{11} (Pitcher irrigation), M_5 (Vertical mulching with enriched coir pith vermicompost in polythene lined circular trenches) and M_6(Vertical mulching with layering mixture in polythene lined circular trenches)respectively. With respect of levels of irrigation, irrigation at 50 per cent depletion of soil moisture (S_1) was found to improve the above parameters. Vertical mulching with enriched coir pith vermicompost in polythene lined circular trenches +irrigation at 50% depletion soil moisture (M_5S_1), pitcher irrigation + irrigation at 50% depletion soil moisture ($M_{11}S_1$) and Vertical mulching with layering mixture in polythene lined circular trenches +irrigation at 50% depletion soil moisture (M_6S_1) were recorded significantly higher values of root growth potential, sturdiness quotient and crop growth potential respectively.

4.1.5 Physiological Parameters

4.1.5.1 Leaf Water Potential, Osmotic Potential, Relative Water Content, Transpiration Ratio

Physiological parameters *viz.*, leaf water potential, osmotic potential, relative water content, transpiration ratio estimated at 12 MAP are given in Tables 26 and 27.

Table 26. Physiological parameters at 12 MAP as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Leaf water potential, bars	Osmotic potential, m mole kg^{-1}	Relative water content, %	Transpiration ratio
Main plots (M)				
M_1	-15.60	320.50	67.50	3.78
M_2	-15.95	221.75	76.30	1.03
M_3	-15.25	262.25	61.88	1.45
M_4	-15.90	309.00	69.60	1.98
M_5	-18.80	271.75	65.20	1.63
M_6	-16.55	290.75	72.88	0.46
M_7	-17.75	288.25	81.68	0.40
M_8	-16.75	413.75	71.33	0.58
M_9	-16.05	355.25	70.05	3.39
M_{10}	-17.93	252.75	61.30	3.43
M_{11}	-17.73	358.50	83.13	1.00
M_{12}	-18.78	325.75	73.95	1.50
$F_{(11,11)}$	14.59**	28.59**	54.58**	89.18**
SE	0.323	9.922	0.937	0.127
CD	1.006	30.885	2.916	0.394
Sub plots (S)				
S_1	-19.06	228.54	76.64	2.53
S_2	-14.78	383.17	65.84	0.91
$F_{(1,11)}$	496.64**	1413.33**	517.03**	1352.57**
SE	0.136	2.908	0.336	0.031
CD	0.419	8.962	1.037	0.096

MAP – Months after planting ** Significant at 1 per cent

Table 27. Effect of treatment combinations on physiological parameters at 12 MAP

Treatment combinations	Leaf water potential, bars	Osmotic potential, m mole kg^{-1}	Relative water content, %	Transpiration ratio
M_1S_1	-20.70	243.50	73.10	6.14
$M_1 S_2$	-10.50	397.50	61.90	1.42
$M_2 S_1$	-18.95	211.50	77.85	1.74
M_2S_2	-12.95	232.00	74.75	0.32
$M_3 S_1$	-16.45	223.00	70.55	2.57
$M_3 S_2$	-14.05	301.50	53.20	0.34
$M_4 S_1$	-17.85	251.00	71.70	2.98
$M_4 S_2$	-13.95	367.00	67.50	0.98
$M_5 S_1$	-18.75	155.50	71.15	2.07
$M_5 S_2$	-18.85	388.00	59.25	1.19
$M_6 S_1$	-20.20	156.00	80.35	0.64
$M_6 S_2$	-12.90	425.50	65.40	0.28
$M_7 S_1$	-21.55	158.00	86.10	0.54
$M_7 S_2$	-13.95	418.50	77.25	0.27
$M_8 S_1$	-18.10	300.00	80.15	0.84
$M_8 S_2$	-15.40	527.50	62.50	0.32
$M_9 S_1$	-17.70	262.50	71.75	4.73
$M_9 S_2$	-14.40	448.00	68.35	2.06
$M_{10}S_1$	-19.55	229.00	70.55	4.55
$M_{10} S_2$	-16.30	276.50	52.05	2.31
$M_{11} S_1$	-18.95	308.50	86.85	1.51
$M_{11} S_2$	-16.50	408.50	79.40	0.49
$M_{12} S_1$	-20.00	244.00	79.60	2.09
$M_{12} S_2$	-17.55	407.50	68.30	0.92
$F_{(11,12)}$	18.88**	34.28**	11.39**	67.29**
SE	0.471	10.074	1.166	0.108
CD	1.452	31.046	3.592	0.334

MAP – Months after planting ** Significant at 1 per cent

In situ rain water harvesting techniques and supplemental irrigation significantly influenced on leaf water potential. Leaf water potential ranged from 15.25 bars (M_3) to 18.80 bars (M_5). Irrigation at 50 per cent depletion of soil moisture (S_1) enhanced leaf water potential to the extent of 29 per cent over life saving irrigation (S_2). Interaction effects had significant influence on leaf water potential. M_7S_1 (Micro site enrichment and mulching with polythene + irrigation at 50% depletion of soil moisture) followed by M_1S_1 and M_6S_1 expressed maximum leaf water potential and were on par.

In situ rain water harvesting techniques and supplemental irrigation registered significant influence on osmotic potential. Osmotic potential ranged from 221.75 m mole kg^{-1} to 413.75 m mole kg^{-1}. Vertical mulching with enriched coir pith- vermicompost in circular trenches (M_2) and micro site enrichment and mulching with coconut husk (M_8) recorded the lowest and highest osmotic potential respectively. Increase in interval of irrigation enhanced osmotic potential and under life saving irrigation (S_2) increase in the osmotic potential was 67.7 per cent compared to irrigation at 50% depletion of soil moisture (S_1). Interaction effects also showed significant influence on osmotic potential. Maximum osmotic potential of 527.50 m mole kg^{-1} was registered by the treatment combination, M_8S_2 (Micro site enrichment and mulching with coconut husk + life saving irrigation) and was significantly different from all other treatment combinations.

Treatments had significant influence on relative water content. Lowest (61.30%) and highest (83.13%) values were recorded by micro catchments and mulching with coir geo-textiles (M_{10}) and pitcher irrigation (M_{11}) respectively. With respect to subplot treatments, irrigation at 50 per cent depletion of soil moisture (S_1) showed higher relative water content (76.64%) compared to life saving irrigation (65.82%). Interaction effects had significant influence on relative water content. Among the different treatment combinations, pitcher irrigation + irrigation at 50% depletion of soil moisture ($M_{11}S_1$) followed by micro site enrichment and mulching with polythene + irrigation at 50% depletion of soil moisture (M_7S_1) recorded higher values and were on par.

Transpiration ratio ranged from 0.40 to 3.78 and it was significantly influenced by *in situ* rain water harvesting techniques. M_1 (Vertical mulching with coconut husk in circular trenches) and micro site enrichment and mulching with polythene (M_7) recorded the highest and lowest transpiration ratio respectively. Levels of irrigation recorded significant influence on transpiration ratio. Maximum transpiration ratio was recorded by irrigation at 50 per cent depletion of soil moisture (S_1) and compared to life saving irrigation (S_2), per cent increase in transpiration ratio was 155.7. Transpiration ratio registered significant difference due to treatment combinations. M_1S_1 (Vertical mulching with coconut husk in circular trenches + irrigation at 50% depletion of soil moisture) recorded maximum value of 6.14 and was significantly different from all other treatment combinations.

4.1.5.2 Stomatal Conductance

Mean data on stomatal conductance recorded 24 and 48 hour after irrigation of one year old sappan wood are summarised in Tables 28 and 29.

Significant influence of treatments on stomatal conductance was observed at all stages of observation and vertical mulching with layering mixture in polythene lined circular trenches (M_6) followed by micro site enrichment and mulching with polythene (M_7) had maximum conductance at all stages and was significantly different from all other treatments.

Levels of irrigation also showed significant variation on stomatal conductance. Irrigation at 50 per cent depletion soil moisture (S_1) registered higher values of 0.25, 0.24 and 0.23 cm s^{-1} after 24, 48 and 72 hours of irrigation respectively.

Interaction effects had significant influence on stomatal conductance. M_6S_1 (Vertical mulching with layering mixture + irrigation at 50% depletion of soil moisture) registered maximum conductance of 0.39 and 0.38 cm s^{-1} at 24 and 48 hours after irrigation respectively. M_7S_1 (0.34 cm s^{-1}) followed by M_6S_1 (0.33 cm s^{-1}) recorded maximum values after 72 hour of irrigation.

Table 28. Stomatal conductance (cm s^{-1}) at 24, 48 and 72 HAI and canopy temperature (^0C) at 24 and 48 HAI as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Stomatal conductance, cm s^{-1}			Canopy temperature, ^0C		
	24 HAI	48 HAI	72 HAI	24 HAI	48 HAI	Difference
Main plots (M)						
M_1	0.14	0.13	0.14	32.08	33.58	1.5
M_2	0.17	0.16	0.15	32.45	33.58	1.13
M_3	0.14	0.15	0.14	34.18	35.10	0.92
M_4	0.19	0.17	0.16	32.03	32.88	0.85
M_5	0.18	0.17	0.15	31.38	33.00	1.62
M_6	0.27	0.26	0.23	31.08	32.13	1.05
M_7	0.24	0.23	0.22	30.85	31.80	0.95
M_8	0.19	0.18	0.17	31.70	33.08	1.38
M_9	0.09	0.08	0.07	32.75	34.20	1.45
M_{10}	0.08	0.07	0.06	33.43	34.78	1.35
M_{11}	0.16	0.15	0.14	32.40	33.93	1.53
M_{12}	0.19	0.18	0.17	31.90	33.88	1.98
$F_{(11,11)}$	54.55**	21.09**	25.04**	22.32**	7.21**	#
SE	0.007	0.011	0.009	0.201	0.364	#
CD	0.023	0.035	0.029	0.627	1.134	#
Subplots (S)						
S_1	0.25	0.24	0.23	31.52	33.51	1.37
S_2	0.09	0.08	0.07	32.85	35.13	1.24
$F_{(1,11)}$	475.22**	613.22**	1118.99**	303.77**	65.95**	#
SE	0.005	0.005	0.003	0.054	0.097	#
CD	0.017	0.015	0.010	0.166	0.299	#

HAI – Hours after irrigation ** Significant at 1 per cent # Data not analyzed

Table 29. Effect of treatment combinations on stomatal conductance (cm s^{-1}) at 24, 48 and 72 HAI and canopy temperature (^{0}C) at 24 and 48 HAI

Treatment combinations	Stomatal conductance, cm s^{-1}			Canopy temperature, ^{0}C		
	24 HAI	48 HAI	72 HAI	24 HAI	48 HAI	Difference
M_1S_1	0.22	0.20	0.28	31.45	33.20	1.75
$M_1 S_2$	0.07	0.06	0.06	32.70	33.95	1.25
$M_2 S_1$	0.28	0.27	0.25	31.80	32.95	1.15
M_2S_2	0.07	0.06	0.07	33.10	34.20	1.10
$M_3 S_1$	0.22	0.25	0.22	33.65	34.70	1.05
$M_3 S_2$	0.07	0.06	0.06	34.70	35.50	0.80
$M_4 S_1$	0.31	0.27	0.26	31.65	32.40	0.75
$M_4 S_2$	0.09	0.08	0.06	32.40	33.35	0.95
$M_5 S_1$	0.29	0.27	0.24	30.75	31.95	1.20
$M_5 S_2$	0.08	0.07	0.06	32.00	34.05	2.05
$M_6 S_1$	0.39	0.38	0.33	30.65	31.60	0.95
$M_6 S_2$	0.14	0.13	0.12	31.50	32.65	1.15
$M_7 S_1$	0.35	0.35	0.34	30.05	31.00	0.95
$M_7 S_2$	0.12	0.11	0.11	31.65	32.60	0.95
$M_8 S_1$	0.28	0.27	0.25	30.75	32.60	1.85
$M_8 S_2$	0.09	0.09	0.08	32.65	33.55	0.90
$M_9 S_1$	0.12	0.11	0.10	31.80	33.65	1.85
$M_9 S_2$	0.06	0.05	0.04	33.70	34.75	1.05
$M_{10}S_1$	0.11	0.10	0.09	32.90	34.45	1.55
$M_{10} S_2$	0.05	0.04	0.04	33.95	35.10	1.15
$M_{11} S_1$	0.22	0.21	0.19	31.75	33.20	1.45
$M_{11} S_2$	0.10	0.10	0.09	33.05	34.65	1.60
$M_{12} S_1$	0.28	0.27	0.25	31.05	33.00	1.95
$M_{12} S_2$	0.12	0.11	0.10	32.75	34.75	2.00
$F_{(11,12)}$	5.98**	7.74**	12.39**	2.09^{NS}	0.75^{NS}	#
SE	0.019	0.016	0.011	0.186	0.362	#
CD	0.058	0.050	0.035	-	-	#

HAI – Hours after irrigation
** Significant at 1 per cent # Data not analysed NS - Not significant

4.1.5.3 Canopy Temperature

Canopy temperature recorded after 24 and 48 hours of irrigation and their variation are presented in Tables 28 and 29.

Treatments had significant influence on canopy temperature at 24 and 48 hours after irrigation. The highest and lowest temperatures were recorded by vertical mulching with layering mixture in circular trenches (M_3) and micro site enrichment and mulching with polythene (M_7) respectively after 24 and 48 hours of irrigation. The minimum variation in canopy temperature of 0.85^0C was recorded by vertical mulching with coconut husk in polythene lined circular trenches (M_4) and maximum value of 1.98^0C in drip irrigation (M_{12}).

Levels of irrigation significantly influenced canopy temperature and heat load was more under life saving irrigation (S_2) both at 24 and 48 hours of irrigation. Irrigation at 50% depletion of soil moisture (S_1) increased the difference in canopy temperature over a period of 24 hours compared to the life saving irrigation.

Interaction effects had no significant influence on canopy temperature both at 24 and 48 hours after irrigation.

4.1.6 Biochemical Parameters

Data on chlorophyll a, chlorophyll b, Total chlorophyll and proline estimated after one year of planting are furnished in Tables 30 and 31.

In situ rain water harvesting techniques and supplemental irrigation significantly influenced all the biochemical parameters of sappan wood studied after 1 year of planting. Maximum chlorophyll a content of 0.76 and 0.72 mg g^{-1} fresh weight were recorded by M_8 (Micro site enrichment and mulching with coconut husk) and M_6 (vertical mulching with layering mixture in polythene lined circular trenches) respectively and were on par and differed significantly from all other treatments. The highest chlorophyll b content of 0.24 mg g^{-1}fresh weight was estimated in M_3 (vertical mulching with layering mixture in circular trenches) and M_1 (vertical mulching with coconut husk in circular trenches).

Table 30. Biochemical parameters at 12 MAP as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Chlorophyll a, mg g^{-1}	Chlorophyll b, mg g^{-1}	Total chlorophyll, mg g^{-1}	Proline, µg g^{-1}
Main plots (M)				
M_1	0.58	0.24	0.81	22.38
M_2	0.38	0.20	0.58	17.26
M_3	0.43	0.24	0.67	30.48
M_4	0.53	0.20	0.74	20.81
M_5	0.55	0.23	0.78	26.86
M_6	0.72	0.22	0.94	20.82
M_7	0.65	0.22	0.87	13.40
M_8	0.76	0.19	0.93	21.73
M_9	0.52	0.17	0.69	25.97
M_{10}	0.52	0.20	0.72	34.11
M_{11}	0.56	0.18	0.74	18.33
M_{12}	0.64	0.16	0.80	20.56
$F_{(11,11)}$	35.13**	5.63**	46.69**	183.65**
SE	0.018	0.011	0.016	0.426
CD	0.057	0.035	0.049	1.326
Sub plots (S)				
S_1	0.65	0.23	0.89	5.91
S_2	0.48	0.18	0.66	39.54
$F_{(1,11)}$	292.22**	42.55**	210.10**	10996.6**
SE	0.007	0.006	0.011	0.227
CD	0.022	0.019	0.035	0.699

MAP – Months after planting
** Significant at 1 per cent

Table 31. Effect of treatment combinations on biochemical parameters at 12 MAP

Treatment combinations	Chlorophyll a, mg g^{-1}	Chlorophyll b, mg g^{-1}	Total chlorophyll, mg g^{-1}	Proline, µg g^{-1}
M_1S_1	0.66	0.30	0.95	6.59
M_1S_2	0.50	0.18	0.67	38.18
M_2S_1	0.40	0.22	0.62	5.66
M_2S_2	0.36	0.17	0.53	28.87
M_3S_1	0.46	0.30	0.76	6.99
M_3S_2	0.41	0.18	0.50	53.96
M_4S_1	0.62	0.20	0.82	6.26
M_4S_2	0.45	0.20	0.65	35.36
M_5S_1	0.63	0.25	0.88	9.23
M_5S_2	0.47	0.22	0.69	44.49
M_6S_1	0.87	0.23	1.10	2.60
M_6S_2	0.57	0.21	0.78	39.05
M_7S_1	0.75	0.30	1.05	1.48
M_7S_2	0.55	0.14	0.69	25.32
M_8S_1	0.91	0.20	1.11	3.80
M_8S_2	0.59	0.18	0.76	39.66
M_9S_1	0.55	0.19	0.74	9.34
M_9S_2	0.48	0.16	0.64	42.61
$M_{10}S_1$	0.65	0.22	0.87	9.78
$M_{10}S_2$	0.39	0.19	0.58	58.44
$M_{11}S_1$	0.62	0.21	0.82	3.89
$M_{11}S_2$	0.49	0.16	0.65	32.76
$M_{12}S_1$	0.77	0.17	0.94	5.32
$M_{12}S_2$	0.52	0.14	0.66	35.80
$F_{(11,12)}$	7.04**	2.87*	2.85*	50.16**
SE	0.025	0.021	0.039	0.786
CD	0.077	0.065	0.119	2.421

MAP – Months after planting ** Significant at 1 per cent * Significant at 5 per cent

Similar to chlorophyll a content, total chlorophyll content was higher in M_6 and M_8. Total chlorophyll content ranged from 0.58 mg g^{-1} of fresh weight (M_2, vertical mulching with enriched coir pith vermicompost in circular trenches) to 0.94 mg g^{-1} fresh weight (M_6). Micro catchments and mulching with coir geo-textiles (M_{10}) resulted in maximum proline accumulation (34.11 µg g^{-1}fresh weight) and differed significantly from all other treatments. Vertical mulching with layering mixture in circular trenches (M_3) also had higher value (30.48 µg g^{-1}fresh weight) of proline content and was significantly different from other treatments. Micro site enrichment and mulching with polythene (M_7) resulted in poor accumulation of proline (13.40 µg g^{-1} fresh weight).

Supplemental irrigation enhanced chlorophyll a content to the tune of 35.4 per cent when irrigation was given at 50 per cent depletion of soil moisture. Accumulation of chlorophyll a and total chlorophyll were also higher under irrigated condition when compared to life saving irrigation (S_2) with 27.7 and 34.8 per cent improvement respectively. Contrary to chlorophyll accumulation, proline production was higher in life saving irrigation (39.54 µg g^{-1} fresh weight) compared to supplemental irrigation at 50% depletion of soil moisture and improvement in proline content was 569 per cent.

Interaction effects showed significant difference with respect to all the biochemical parameters studied. M_8S_1 (Micro site enrichment and mulching with coconut husk + irrigation at 50% depletion of soil moisture) followed by M_6 S_1 registered higher values of chlorophyll a (0.91 and 0.87 mg g^{-1} fresh weight) and were significantly different from all other treatment combinations. M_3S_1 (Vertical mulching with layering mixture in circular trenches + irrigation at 50% depletion of soil moisture) followed by M_7S_1, M_1S_1 and M_5S_1 registered higher values of chlorophyll b. Total chlorophyll concentration was associated with treatment combinations, M_8S_1, M_6S_1 and M_7S_1. Significant interaction effects were observed on proline accumulation. The treatment combination, $M_{10}S_2$ (micro catchments and mulching with coir geo-textiles + life saving irrigation) recorded maximum value (58.44 µg g^{-1} fresh weight) of proline content and differed significantly from all other treatment combinations. $M_{10}S_2$ closely followed by M_3S_2 (53.96 mg g^{-1} fresh weight) recorded higher values and were significantly different from all other treatment combinations.

4.1.7 Dry matter Production and Partitioning

4.1.7.1 Stem Dry Matter Production

Data on stem dry matter production at 6 MAP as influenced by *in situ* rain water harvesting techniques are furnished in Table 32.

Stem dry matter production recorded significant influence on treatments. Positive and significant influence of vertical mulching with layering mixture in polythene lined circular trenches (M_6) was evident on stem dry matter production, which differed significantly from all other treatments. When compared to control mean (93.55 kg ha^{-1}), increase in stem DMP was 338.8 per cent. M_6 followed by M_7, M_8 and M_4 produced higher stem DMP and were on par and increase in stem DMP over control mean was to the extent of 118.4, 64.5 and 52.1 per cent respectively.

4.1.7.2 Total Dry Matter Production (DMP)

Table 32 indicates the data on total DMP at 6 MAP as influenced by *in situ* rain water harvesting techniques.

Total DMP of sappan wood was significantly influenced by *in situ* rain water harvesting treatments. The treatment M_6 (vertical mulching with layering mixture in polythene lined circular trenches) showed superiority over all other treatments and improvement in total DMP was to the tune of 270 per cent over control mean (131.00 kg ha^{-1}). M_7, M_8 and M_4 were on par and recorded lower values compared to M_6.

4.1.4.3 Dry Matter Production (DMP) and Partitioning

Data on total dry matter production and partitioning estimated after one year of planting are given in Tables 33 and 34.

Table 32. Dry matter production (kg ha^{-1}) at 6 MAP as influenced by *in situ* rain water harvesting techniques

Treatments	Stem DMP	Total DMP
M_1	66.15	89.63
M_2	95.55	106.88
M_3	83.80	108.38
M_4	142.30	194.38
M_5	111.55	141.63
M_6	410.55	484.75
M_7	204.30	256.75
M_8	153.90	204.25
M_9	68.30	89.25
M_{10}	59.65	76.00
M_{11}	92.80	130.50
M_{12}	94.30	131.50
$F_{(11,11)}$	9.98**	9.93**
SE	29.48	34.50
CD	91.76	107.38

Table 33. Dry matter production (kg ha^{-1}) and partitioning at 12 MAP as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Root DMP	Leaf DMP	Stem DMP	Total DMP
Main plots (M)				
M_1	157.55	384.70	262.70	805.10
M_2	235.80	813.23	1109.88	2158.90
M_3	374.50	729.15	1032.43	2136.08
M_4	237.75	310.15	432.35	980.13
M_5	206.35	296.60	609.70	1113.65
M_6	432.68	1218.48	1754.70	3405.90
M_7	414.98	985.28	1491.83	2892.05
M_8	388.65	880.03	1277.43	2546.10
M_9	90.73	247.84	206.73	545.33
M_{10}	83.43	204.10	187.18	474.70
M_{11}	112.15	358.83	442.40	913.38
M_{12}	155.33	355.40	347.75	858.48
$F_{(11,11)}$	129.41**	322.60**	304.01**	709.86**
SE	11.437	18.979	31.278	37.647
CD	35.598	59.076	97.359	117.182
Sub plots(S)				
S_1	333.49	752.24	978.93	2064.82
S_2	148.15	378.38	546.91	1073.48
$F_{(1,11)}$	821.22**	2923.74**	313.88**	1669.79**
SE	4.573	4.889	17.243	17.154
CD	14.093	15.066	53.134	52.863

** Significant at 1 per cent   MAP Months after planting

Table 34. Effect of treatment combinations on dry matter production (kg ha^{-1}) and partitioning at 12 MAP

Treatment combinations	Root DMP	Leaf DMP	Stem DMP	Total DMP
M_1S_1	233.55	541.60	396.30	1171.25
M_1S_2	81.55	227.80	129.10	438.95
M_2S_1	334.80	1019.65	1269.60	2624.05
M_2S_2	136.80	606.80	950.15	1693.75
M_3S_1	557.00	931.90	1188.55	2677.45
M_3S_2	192.00	526.40	876.30	1594.70
M_4S_1	361.45	389.15	502.00	1252.60
M_4S_2	114.05	231.15	362.70	707.65
M_5S_1	296.20	449.55	920.85	1668.60
M_5S_2	116.50	143.65	298.55	558.70
M_6S_1	589.60	1707.90	2271.10	4569.30
M_6S_2	275.75	729.05	1237.70	2242.50
M_7S_1	573.85	1263.15	1834.50	3671.45
M_7S_2	256.10	707.40	1149.15	2112.65
M_8S_1	525.10	1114.40	1663.45	3302.95
M_8S_2	252.20	645.65	891.40	1789.25
M_9S_1	106.65	353.28	298.65	758.60
M_9S_2	74.80	142.40	114.80	332.05
$M_{10}S_1$	94.60	290.80	272.35	657.75
$M_{10}S_2$	72.25	117.40	102.00	291.65
$M_{11}S_1$	135.40	457.15	638.60	1231.15
$M_{11}S_2$	88.89	260.50	246.20	595.60
$M_{12}S_1$	193.70	508.40	490.60	1192.70
$M_{12}S_2$	116.95	202.40	204.90	524.25
$F_{(11,12)}$	29.04**	90.04**	11.10**	46.49**
SE	15.842	16.936	59.729	59.425
CD	48.818	52.189	184.062	183.122

** Significant at 1 per cent MAP Months after planting

Partitioning of dry matter into root, leaf, stem and total DMP were found to be significantly influenced by *in situ* rain water harvesting techniques. Vertical mulching with layering mixture in polythene lined circular trenches (M_6) recorded maximum root DMP (432.68 kg ha^{-1}) and was on par with M_7, but significantly differed from all other treatments. *In situ* rain water harvesting techniques increased root DMP to the extent of 178.6 per cent over drip irrigation (M_{12}). Almost a similar trend was observed with respect to leaf, stem and total DMP and M_6 recorded maximum dry matter production of 1218.48, 1754.70 and 3405.90 kg ha^{-1} respectively and significantly differed from other treatments. Compared to drip irrigation (M_{12}) per cent increase in leaf, stem, total DMP were 242.9, 404.6 and 296.7 respectively.

Dry matter partitioning was also significantly influenced by the levels of irrigation. Irrigation at 50 per cent depletion of soil moisture (S_1) was found beneficial for increase in root, leaf, stem and total DMP and per cent increase being 125.1, 98.8, 78.9 and 92.1 respectively.

Treatment combinations had significant influence on root, leaf, stem and total DMP. M_6S_1 (Vertical mulching with layering mixture in polythene lined circular trenches + irrigation at 50% depletion of soil moisture) followed by $M_7S_1$and M_3S_1 registered maximum root DMP. Interaction effects also indicated similar trend with respect to leaf, stem and total DMP. Integration of *in situ* rain water harvesting techniques and irrigation levels exerted positive and significant effects on total DMP and several fold increase in total DMP was observed. Vertical mulching with layering mixture in polythene lined circular trenches +irrigation at 50% depletion of soil moisture (M_6S_1) registered maximum DMP and differed significantly from all other treatment combinations. M_6S_1 recorded a total DMP of 4569.30 kg ha^{-1} compared to drip irrigation + life saving irrigation, $M_{12}S_2$ (524.25 kg ha^{-1}) and per cent increase over $M_{12}S_2$ was 771.5.

4.1.8 Seed Production Potential

Data on days for first flowering, number of pods per plant, number of seeds per pods and seed yield are presented in Tables 35 and 36.

Table 35. Seed production potential as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Days for first flowering	Number of pods per plant	Number of seeds per plant	Seed yield, Number in lakhs
Main plots (M)				
M_1	347.25	22.25	3.00	0.66
M_2	343.25	48.50	3.25	0.90
M_3	347.75	21.75	3.00	1.64
M_4	347.75	39.75	3.00	2.99
M_5	352.75	22.50	3.75	2.16
M_6	343.75	60.50	4.00	6.05
M_7	339.00	50.50	4.50	5.81
M_8	350.50	24.00	3.75	2.10
M_9	371.75	13.75	3.00	1.03
M_{10}	358.75	16.75	3.00	1.26
M_{11}	362.25	14.25	3.00	1.07
M_{12}	358.25	11.50	3.00	0.87
$F_{(11,11)}$	15.03**	8.50**	6.78**	7.21**
SE	2.412	5.684	0.198	0.672
CD	7.508	16.156	0.617	1.911
Sub plots (S)				
S_1	348.80	28.54	3.42	2.57
S_2	354.90	29.13	3.29	2.52
$F_{(1,11)}$	26.18**	0.03^{NS}	3.00^{NS}	0.03^{NS}
SE	0.852	6.699	0.051	0.515
CD	2.625	-	-	-

** Significant at 1 per cent NS Not significant

Table 36. Effect of treatment combinations on seed production potential

Treatment combinations	Days for first flowering	Number of pods per plant	Number of seeds per plant	Seed yield, Number in lakhs
M_1S_1	349.00	21.00	3.00	1.58
$M_1 S_2$	345.50	23.50	3.00	1.74
$M_2 S_1$	343.00	45.00	3.50	3.90
M_2S_2	343.50	52.00	3.00	3.90
$M_3 S_1$	346.50	22.00	3.00	1.66
$M_3 S_2$	349.00	21.50	3.00	1.62
$M_4 S_1$	346.00	44.00	3.00	3.31
$M_4 S_2$	349.50	35.50	3.00	2.67
$M_5 S_1$	349.50	16.50	3.50	1.48
$M_5 S_2$	355.00	28.50	4.00	2.85
$M_6 S_1$	339.50	52.50	4.00	5.25
$M_6 S_2$	347.00	68.50	4.00	6.85
$M_7 S_1$	337.00	58.50	4.50	6.79
$M_7 S_2$	341.00	42.50	4.50	4.83
$M_8 S_1$	348.00	18.00	4.50	1.95
$M_8 S_2$	353.00	30.00	4.50	2.25
$M_9 S_1$	367.00	17.00	3.00	1.28
$M_9 S_2$	376.50	10.50	3.00	0.79
$M_{10}S_1$	354.50	11.50	3.00	0.87
$M_{10} S_2$	363.00	22.00	3.00	1.65
$M_{11} S_1$	357.00	19.00	3.00	1.43
$M_{11} S_2$	367.50	9.50	3.00	0.72
$M_{12} S_1$	348.00	17.50	3.00	1.32
$M_{12} S_2$	368.50	5.50	3.00	0.42
$F_{(11,12)}$	2.06^{NS}	1.33^{NS}	3.73*	1.26^{NS}
SE	2.950	2.368	0.177	0.805
CD	-	-	0.545	-

** Significant at 1 per cent NS Not significant

Treatments had significant effect on all the seed production potential characters studied. Sappan wood is propagated through seeds and precocity in flowering was observed in M_7 (Micro site enrichment and mulching with polythene); 339 days followed by M_6 (Vertical mulching with layering mixture in polythene lined circular trenches); 343 days. Number of pods per plant also higher in M_6 and M_7. Seed yield of 6.05 lakh seeds ha^{-1} was recorded by M_6 followed by 5.81 lakh seeds ha^{-1} in M_7. Levels of irrigation also influenced in number of days taken for first flowering and seed yield. Summer irrigation at 50 per cent depletion soil moisture imparted precocity in flowering and higher number of seeds per pod and seed yield. However, number of pods per plant was higher under life saving irrigation. Among the various treatment combinations maximum seed yield was recorded by M_6S_2, M_6S_1, M_7S_1 and M_7S_2.

4.1.9 Soil Moisture Studies

Mean data on moisture content of soil before and after irrigation, consumptive use, mean daily Cu, Crop coefficient, crop WUE and field WUE are furnished in Tables 37 and 38.

Significant variation was observed on soil moisture content as influenced by *in situ* rain water harvesting techniques and supplemental irrigation at before and after irrigation. Before irrigation, soil moisture ranged from 12.15 % to 13.29 %. M_5 (Vertical mulching with enriched coir pith vermicompost in polythene lined circular trenches) followed by M_8 and M_{12} registered maximum moisture content of soil of 13.29, 13.04 and 12.99 % respectively and were on par. Soil moisture content after irrigation ranged from 18.78 % to 22.32 %. Micro site enrichment and mulching with polythene (M_7) recorded maximum moisture content of soil (22.32 %) after irrigation and significantly different from all other treatments. The per cent increase in moisture content in M_7 over drip irrigation (M_{12}) was 11.0.

Irrigation at 50% depletion of soil moisture (S_1) registered 44.7 and 0.9 per cent higher values before and after irrigation respectively, when compared to life saving irrigation (S_2).

Table 37. Soil moisture studies as influenced by *in situ* rain water harvesting techniques and supplemental irrigation

Treatments	Soil moisture, %		Consumptive use, mm	Mean daily CU, mm	Crop coefficient	Crop WUE, kg m^{-3}	Field WUE, kg m^{-3}
	Before	After					
Main plots (M)							
M_1	12.51	18.78	445.00	2.46	0.65	0.28	0.08
M_2	12.86	19.46	444.50	2.45	0.64	1.38	0.39
M_3	12.15	19.07	464.00	2.55	0.67	1.23	0.36
M_4	12.51	21.30	478.25	2.62	0.69	0.48	0.16
M_5	13.29	18.99	359.50	1.98	0.52	0.80	0.21
M_6	12.73	20.74	398.75	2.19	0.58	2.30	0.73
M_7	12.54	22.30	418.00	2.30	0.60	1.82	0.64
M_8	13.04	21.90	405.75	2.23	0.59	1.60	0.53
M_9	12.75	20.22	398.50	2.19	0.58	0.25	0.05
M_{10}	12.79	20.61	402.75	2.22	0.58	0.22	0.13
M_{11}	12.64	18.96	473.50	2.61	0.69	0.46	0.26
M_{12}	12.99	20.10	459.00	2.52	0.66	0.38	0.14
$F_{(11,11)}$	6.70**	330.12**	48.21**	51.45**	58.52**	570.19**	60.73**
SE	0.115	0.066	5.328	0.028	0.007	0.029	0.029
CD	1.358	0.206	15.144	0.081	0.020	0.084	0.083
Sub plots (S)							
S_1	15.06	20.30	555.67	3.06	0.80	0.91	0.30
S_2	10.41	20.11	302.25	1.66	0.46	0.95	0.32
$F_{(1,11)}$	4311.83**	28.00**	4856.98**	6041.98**	6311.47**	2.33^{NS}	1.50^{NS}
SE	0.050	0.026	2.571	0.013	0.003	0.019	0.011
CD	0.155	0.081	7.309	0.036	0.009	-	-

** Significant at 1 per cent NS Not significant

Table 38. Effect of treatment combinations on soil moisture studies

Treatment combinations	Soil moisture, %		Consumptive use, mm	Mean daily Cu, mm	Crop coefficient	Crop WUE, kg m^{-3}	Field WUE, kg m^{-3}
	Before	After					
M_1S_1	14.19	18.81	617.50	3.42	0.90	0.33	0.09
$M_1 S_2$	10.83	18.75	272.50	1.49	0.40	0.24	0.07
$M_2 S_1$	15.19	19.64	600.00	3.30	0.87	1.08	0.30
M_2S_2	10.52	19.29	289.00	1.59	0.42	1.68	0.48
$M_3 S_1$	14.59	19.29	632.50	3.48	0.92	0.96	0.28
$M_3 S_2$	9.72	18.84	295.50	1.63	0.43	1.51	0.44
$M_4 S_1$	15.31	21.20	628.00	3.44	0.91	0.41	0.14
$M_4 S_2$	9.71	21.40	328.50	1.81	0.48	0.56	0.19
$M_5 S_1$	15.18	19.07	443.50	2.44	0.64	1.06	0.26
$M_5 S_2$	11.41	18.92	275.50	1.52	0.40	0.55	0.16
$M_6 S_1$	15.37	21.04	530.00	2.92	0.77	2.18	0.73
$M_6 S_2$	10.10	20.45	267.50	1.47	0.39	2.42	0.74
$M_7 S_1$	15.87	22.35	530.00	2.91	0.77	1.76	0.63
$M_7 S_2$	9.22	22.29	306.00	1.69	0.44	1.88	0.66
$M_8 S_1$	15.62	21.95	524.00	2.89	0.76	1.62	0.56
$M_8 S_2$	10.46	21.87	287.50	1.58	0.42	1.58	0.50
$M_9 S_1$	15.16	20.28	487.00	2.68	0.71	0.31	0.03
$M_9 S_2$	10.34	20.16	310.00	1.71	0.45	0.19	0.07
$M_{10}S_1$	15.29	20.81	508.50	2.80	0.74	0.27	0.07
$M_{10} S_2$	10.30	20.41	297.00	1.63	0.43	0.18	0.20
$M_{11} S_1$	14.19	19.03	606.00	3.35	0.88	0.54	0.29
$M_{11} S_2$	11.09	18.89	341.00	1.88	0.50	0.38	0.23
$M_{12} S_1$	14.83	20.18	561.00	3.09	0.81	0.45	0.20
$M_{12} S_2$	11.17	20.03	357.00	1.96	0.52	0.30	0.08
$F_{(11,12)}$	17.33**	2.78^{NS}	22.64**-	28.39**	29.37**	11.14**	3.36*
SE	0.174	0.091	8.249	0.042	0.011	0.055	0.039
CD	0.536	-	23.449	0.120	0.030	0.157	0.113

** Significance at 1 per cent   NS - Not significant

The interaction effects of treatment combinations significantly influenced moisture content of soil before irrigation. $M_7 S_1$ (15.87 %), M_8S_1 (15.62 %) and M_6S_1 *(15.37 %) retained maximum moisture in soil and were on par with* 42.1, 39.8 and 37.6 per cent higher soil moisture over M_{12} S_2 (drip irrigation + life saving irrigation) respectively. The moisture content of soil before irrigation ranged from 9.22 % to 15.87 %. Interaction effects of treatment combinations had no significant influence on moisture content of soil after irrigation. However, maximum value (22.35 %) was observed in M_7S_1 (micro site enrichment and mulching with polythene + irrigation at 50% depletion of soil moisture).

Among the different main plot treatments, M_{11} recorded maximum value for consumptive use, mean daily Cu, Crop coefficient and values were 473.50 mm, 2.61 mm and 0.69 respectively and differed significantly from all other treatment combinations. The lowest value for the above parameters were expressed by M5 (359.50 mm, 1.98 mm and 0.52) and differed significantly from all other treatment combinations. Effect of irrigation at 50 per cent depletion of soil moisture was spectacular *in influencing consumptive use, mean daily Cu and* crop coefficient and maximum values of 555.67 mm, 3.06 mm and 0.80 were recorded. When compared to life saving irrigation, the per cent increase was 43, 43 and 42.5 respectively.

Among the various treatment combinations M_3S_1 followed by M_4S_1 expressed maximum values for consumptive use, mean daily Cu, Crop coefficient.

Maximum crop WUE of 2.30 kg m^{-3} *was recorded by* M_6 *followed by* M_7 (1.82 kg m^{-3}). M6 recorded 400 and 505 per cent increase in crop WUE over pitcher irrigation (M_{11}) and drip irrigation (M_{12}). Crop WUE was found to be higher when plants were given life saving irrigation (0.95 kg m^{-3}) when compared to irrigation at 50% depletion of soil moisture. Significant difference was observed with respect to field WUE. With respect to field WUE, almost a similar trend as that of crop WUE. Field WUE for M_6 and M_7 were 0.73 kg m^{-3} and 0.64 kg m^{-3} respectively.

Table 39. Economics of establishment of sappan wood plantation (first year) as influenced by in situ rain water harvesting techniques and supplemental irrigation

Treatments	Cost of cultivation, Rs.	Gross income, Rs.	Benefit-Cost ratio
Main Plots (M)			
M_1	66750.00	82875.00	1.27
M_2	66750.00	195000.00	2.95
M_3	61750.00	81750.00	1.34
M_4	70250.00	149250.00	2.12
M_5	70000.00	108125.00	1.59
M_6	64000.00	302500.00	4.79
M_7	60250.00	290375.00	4.79
M_8	70750.00	105000.00	1.49
M_9	89000.00	51625.00	0.58
M_{10}	439000.00	62875.00	0.14
M_{11}	93000.00	53625.00	0.57
M_{12}	81000.00	43250.00	0.53
$F_{(11,11)}$	#	7.21**	8.99**
SE	#	47528.957	0.743
CD	#	95533.203	1.493
Sub Plots (S)			
S_1	107791.67	128270.83	1.73
S_2	97625.00	126104.17	1.96
$F_{(1,11)}$	#	0.03^{NS}	1.72^{NS}
SE	#	12818.818	0.174
CD	#	-	-

Data not analyzed NS – Not significant **Significant at 1 per cent level

Table 40. Economics of establishment of sappan wood *plantation (first year)* as influenced by the treatment combinations

Treatment combinations	Cost of cultivation, Rs.	Gross income, Rs.	Benefit-Cost ratio
M_1S_1	74000.00	78750.00	1.07
$M_1 S_2$	59500.00	87000.00	1.47
$M_2 S_1$	74000.00	195000.00	2.63
M_2S_2	59500.00	195000.00	3.28
$M_3 S_1$	69000.00	82750.00	1.19
$M_3 S_2$	54500.00	80750.00	1.49
$M_4 S_1$	76000.00	165250.00	2.18
$M_4 S_2$	64500.00	133250.00	2.07
$M_5 S_1$	75500.00	73750.00	0.98
$M_5 S_2$	64500.00	142500.00	2.21
$M_6 S_1$	68500.00	262500.00	3.84
$M_6 S_2$	59500.00	342500.00	5.76
$M_7 S_1$	64000.00	339500.00	5.31
$M_7 S_2$	56500.00	241250.00	4.27
$M_8 S_1$	74500.00	97500.00	1.31
$M_8 S_2$	67000.00	112500.00	1.68
$M_9 S_1$	93500.00	63750.00	0.68
$M_9 S_2$	84500.00	39500.00	0.47
$M_{10}S_1$	443500.00	43250.00	0.10
$M_{10} S_2$	434500.00	82500.00	0.19
$M_{11} S_1$	99000.00	71500.00	0.72
$M_{11} S_2$	87000.00	35750.00	0.41
$M_{12} S_1$	82000.00	65750.00	0.81
$M_{12} S_2$	80000.00	20750.0000	0.26
$F_{(11,12)}$	#	1.27^{NS}	1.72^{NS}
SE	#	569664.322	0.857
CD	#	-	-

Data not analyzed ** Significant at 1 per cent NS Not significant

Interaction effects of treatment combinations revealed the superior performance of M_6S_2 (2.42 kg m-3) and M_6S_1 (2.18 kg m^{-3}) in influencing crop WUE. M_6S_2 (0.74 kg m^{-3}), M_6S_1 (0.73 kg m^{-3}) and M_7S_2 (0.66 kg m^{-3}) recorded significantly higher field WUE compared to other treatment combinations.

4.1.10 Economic Analysis

The economic analysis of establishment of sappan wood plantation in terms of cost of cultivation, gross income and benefit- cost ratio are given in Tables 39 and 40.

Vertical mulching with layering mixture in polythene lined circular trenches (M_6) and micro site enrichment and mulching with polythene (M_7) were found economical and showed their superiority over other treatments in terms of gross income and benefit – cost ratio. However, no significant difference could be observed between supplemental irrigation and life saving irrigation treatments.

Though, the interaction effects were not significant, the treatment combination, M_6S_2 (*Vertical mulching with layering mixture in polythene lined circular trenches* + life saving irrigation) recorded the maximum benefit – cost ratio of 5.76 during first year.

Discussion

5. DISCUSSION

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

5.1 FIELD EXPERIMENT

5.1.1 Growth Characters

The effect of *in situ* rain water harvest and conservation on the growth and development of sappan wood was found remarkable and vertical mulching with layering mixture in polythene lined circular trenches followed by micro site enrichment and mulching with polythene resulted in luxuriant growth. Plant height, leaf number, collar girth, number of branches, bole height, canopy height, canopy width and canopy size were found to improve significantly due to the treatment effects (Fig.3). Sturdiness quotient for the above two treatments were 1.74 and 1.36; and 2.30 and 2.29 at 6 MAP and 12 MAP respectively, indicating the superiority of the treatments in the developmental physiology of the crop. The significance of soil moisture in influencing the growth and development of sappan wood was quite evident and irrigation at 50 per cent depletion of soil moisture improved all the growth characters compared to life saving irrigation. The sturdiness quotient for the above two treatments were 2.52 and 2.27 at 12 MAP. The sturdiness quotient which indicates the tolerance of the crop to adverse environmental conditions suggests that life saving irrigation was superior to regular irrigation in withstanding stress situations (Fig. 4).

Height measures both the photosynthetic capacity of the seedlings and their transpirational area and it is related to field establishment. Collar girth is related to field performance. It is generally accepted as a better measure of growth and survival. The growth of a plant is influenced by the metabolic activities which require adequate amounts of nutrients and water. Application of layering mixture and regular irrigation are beneficial for maintaining optimum moisture-nutrient-oxygen regime in soils. Polythene lining of the trenches

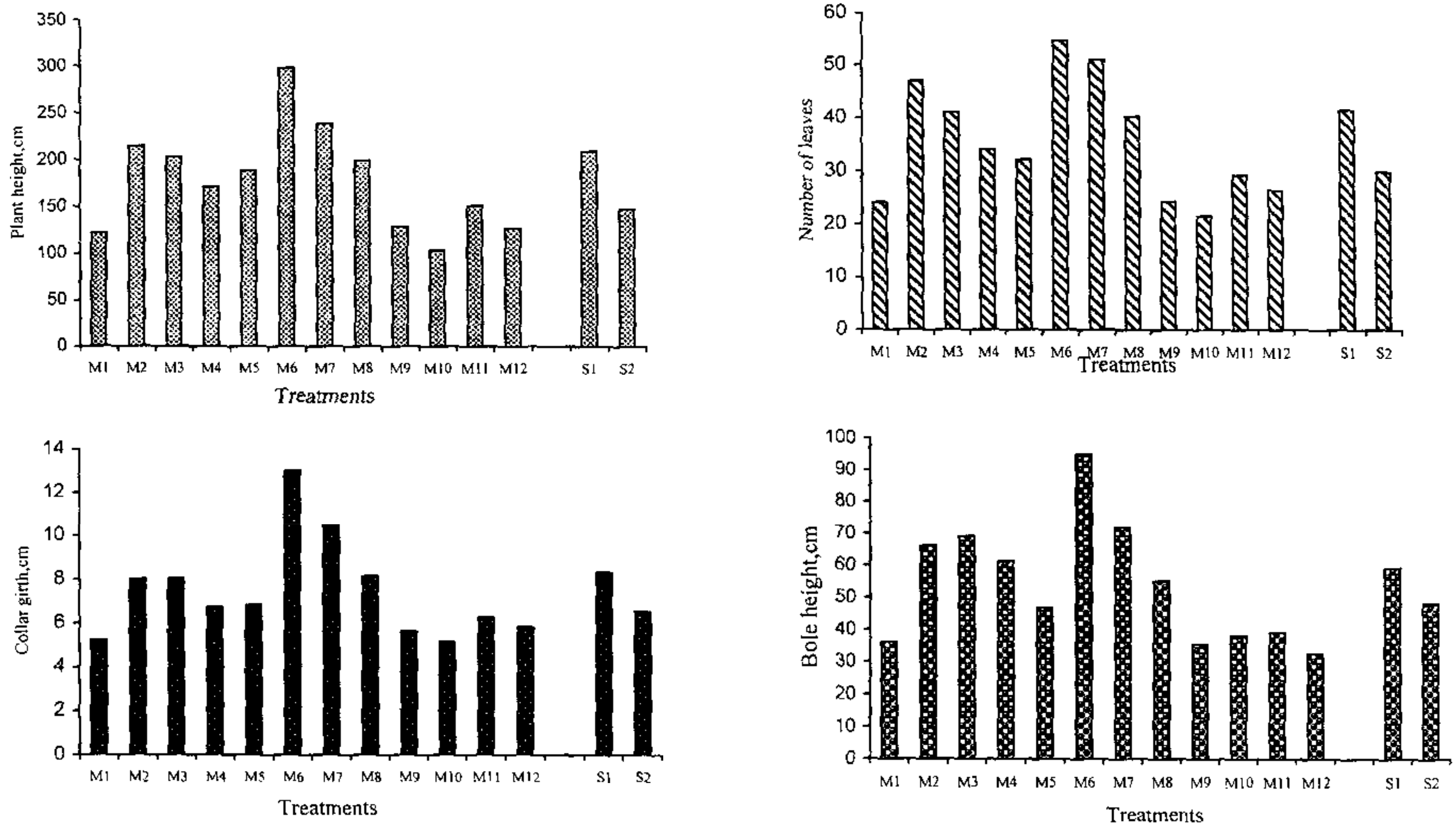

Fig. 3. Growth characters as influenced by *in situ* rain water harvesting techniques and irrigation

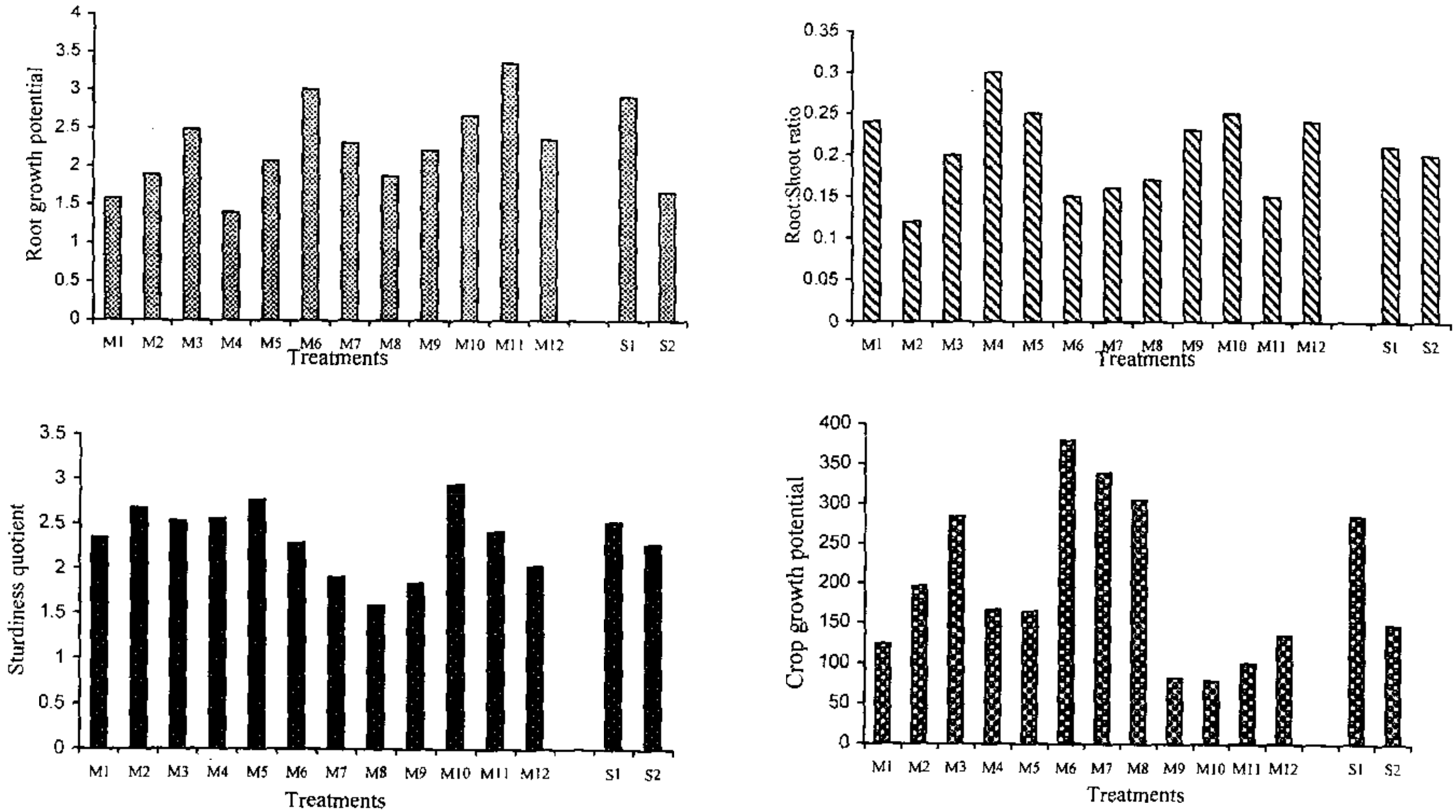

Fig. 4. Growth indices as influenced by *in situ* rain water harvesting techniques and irrigation

prevents the loss of nutrients and water through lateral movement beyond the basin area. Similarly, spreading river sand filled coconut shells reduces percolation losses of nutrients and water to a greater extent. So there is better conservation and efficient utilization of both rain and irrigation water and nutrients due to treatment effects which might have resulted in better growth of sappan wood.

Reduction in plant height under life saving irrigation was due to reduced stem growth, cell elongation and reduced photosynthesis (Begg and Turner, 1976). The primary plant process affected by water stress is cell elongation due to reduction in turgor pressure. Cell expansion is also adversely affected due to reduced turgor pressure resulting in reduced plant height under water stress (Nath, 1993). Reduction in leaf number under life saving irrigation might be due to water stress inhibition of cell division and cell expansion for effectively conserving water by reducing transpiration because of limited water supply in the soil over a period of time. One of the mechanisms of water stress tolerance is to reduce the transpirational surface area which helps the plants to reduce the heat load on the leaves (Nath, 1993).

Water stress induces senescence and early abscission which when combined with reduced primordial initiation result in reduced number of leaves per plant. Decrease in leaf number may be a mechanism of the species to reduce water loss in response to restricted water availability. The leaf dry weight showed significant reductions due to water stress during different growth stages. The reduction in leaf dry weight could be attributed to the reduction in the number of leaves per plant and the leaf area (Shubhra *et al.*, 2003).

Collar girth decreases with increasing stress levels. Upto 90 per cent of annual variation in xylem increment of forest trees has been attributed to water deficits in arid regions and 80 per cent in humid regions. Several aspects of cambial activity, including division of fusiform cambial cells and xylem mother cells as well as enlargement and differentiation of cambial derivatives, are very sensitive to changes in water balance. The adverse interference on cambial growth due to water stress was observed by Kramer and Kozlowski (1960). Girth increment showed good correlation with other water stress responses like high stomatal resistance and lower water potentials. So the decrease in the collar girth might be the result of reduced cambial activity due to water stress.

5.1.2 Root Parameters

In general, vertical mulching with layering mixture in polythene lined circular trenches followed by micro site enrichment and mulching with polythene encouraged root length, root spread, root weight, root volume and root surface area. However, root number production was found to be maximum in micro site enrichment treatment. Root growth potential (RGP) at 6 and 12 MAP also indicated the significance of the above two treatments. Similar to biometric characters, summer irrigation also influenced root parameters. Root number production was found to be higher under life saving irrigation system whereas other root parameters were improved when regular irrigation was carried out.

The purpose of providing a special rooting medium is to enable vigorous and healthy seedling growth during the early stages. The rooting medium physically supports a growing seedling, and stores and supplies nutrients, water and air to the root system. The better the medium, the better will be the development of a healthy, fibrous root system and the crop establishment and development.

Layering mixture, a proper blend of enriched coir pith vermicompost, cowdung and soil in equal proportion constituted an excellent medium for efficient root growth. The properties of the different components of the layering mixture are worth mentioning in this context. Enriched coir pith vermicompost has several advantages for root development. It contains significant quantities of available nutrients, beneficial micro organisms and biologically active metabolites particularly gibberellins, cytokinins, auxins and group B vitamins (KAU, 2001). Coir pith has high surface area, low bulk density, low thermal conductivity and high porosity. There are several reports about its suitability in rain water conservation (Joseph, 1995; Gopinathan, 1996; Salam *et al.*, 2004; Venkitaswamy

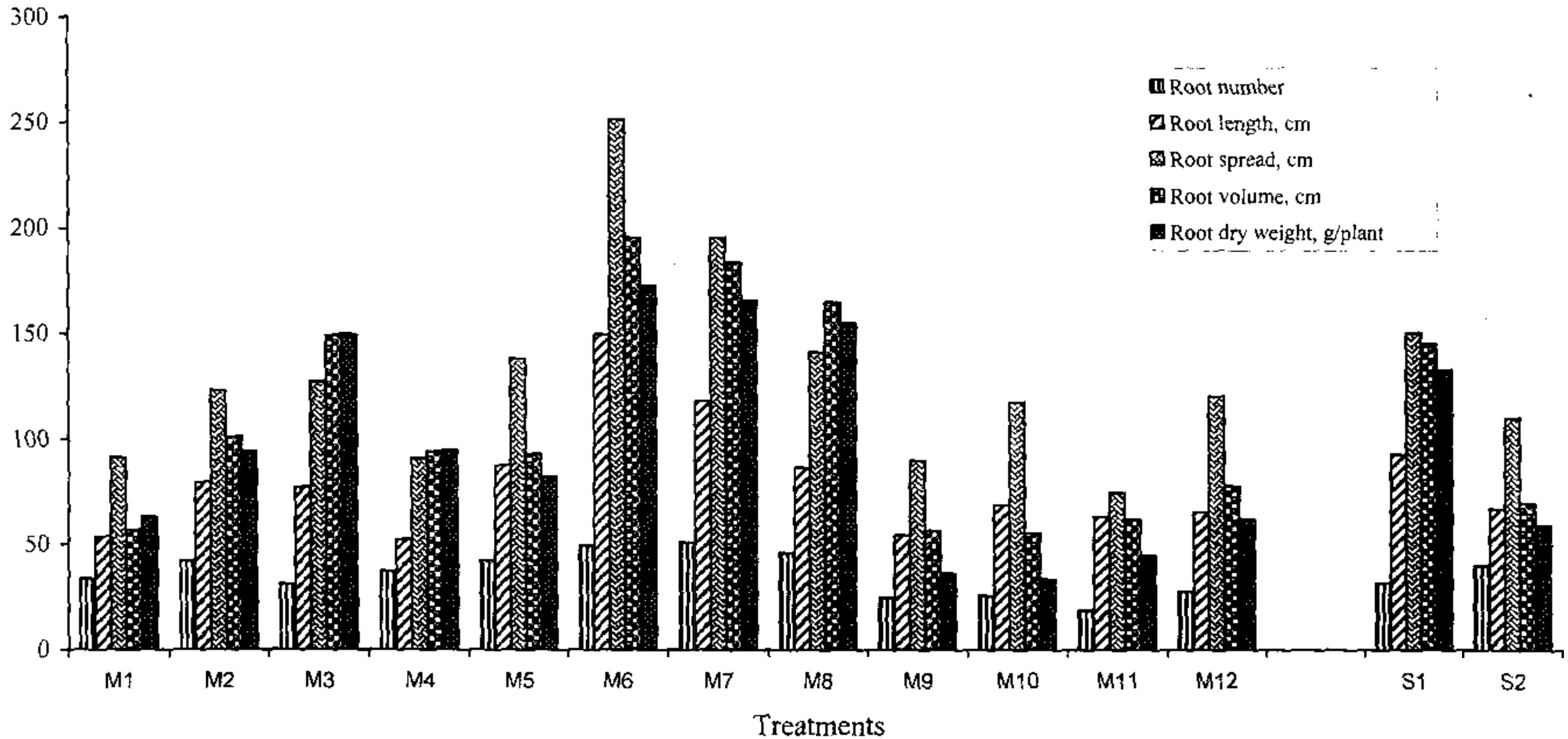

Fig. 5. Root parameters as influenced by in situ rain water harvesting techniques and irrigation

and Khan, 2004). The above rooting medium induced secondary root system so as to attain 'forced multiple tap roots' in sappan wood resulting in better root development.

If the natural habit of the root is disturbed by manipulation of the planting site the root growth form can be permanently altered with positive or negative effects. Root weight, root volume, root length and root surface area are common measurements. Root weight and volume do not give any accurate representation of root fibrosity because seedlings with many fine roots may weigh or displace the same amount as one with a large tap root. Total root length is a better measure of fibrosity or absorptive surface. Plants possessing large root systems comprising of high percentage of fibrous roots have large surface area for absorption of water and nutrients (Fig.5).

Root growth potential (RGP) is the ability of a tree seedling to initiate and elongate roots when placed into an environment favourable for root growth. RGP is often affected by soil temperature, soil moisture and other factors. High RGP is an important seedling quality attribute presumably because it enables the seedlings to become established rapidly after planting. The rationale for this is that when a seedling is planted it has a finite root system. Although it is capable of exploiting moisture and nutrients in its immediate vicinity, these reserves are soon depleted. For establishment to occur, new soil reserves must be tapped, hence new roots must be grown. Seedlings which are unable to grow roots are doomed to water stress and ultimately, death occur. The condition of the seedling shoot and foliage is also important for RGP. Since, leaves of many tree species export an essential rooting co-factor, removal of, or damage to the foliage can impede root growth. RGP represents only a potential to grow roots and its expression depends on many factors, viz., soil moisture, soil fertility, soil temperature, etc. Decrease in root weight might be the result of the decreased root regeneration under high soil water stress. Decrease root regeneration with increasing soil moisture tension was reported by Taylor and Ratliff (1989).

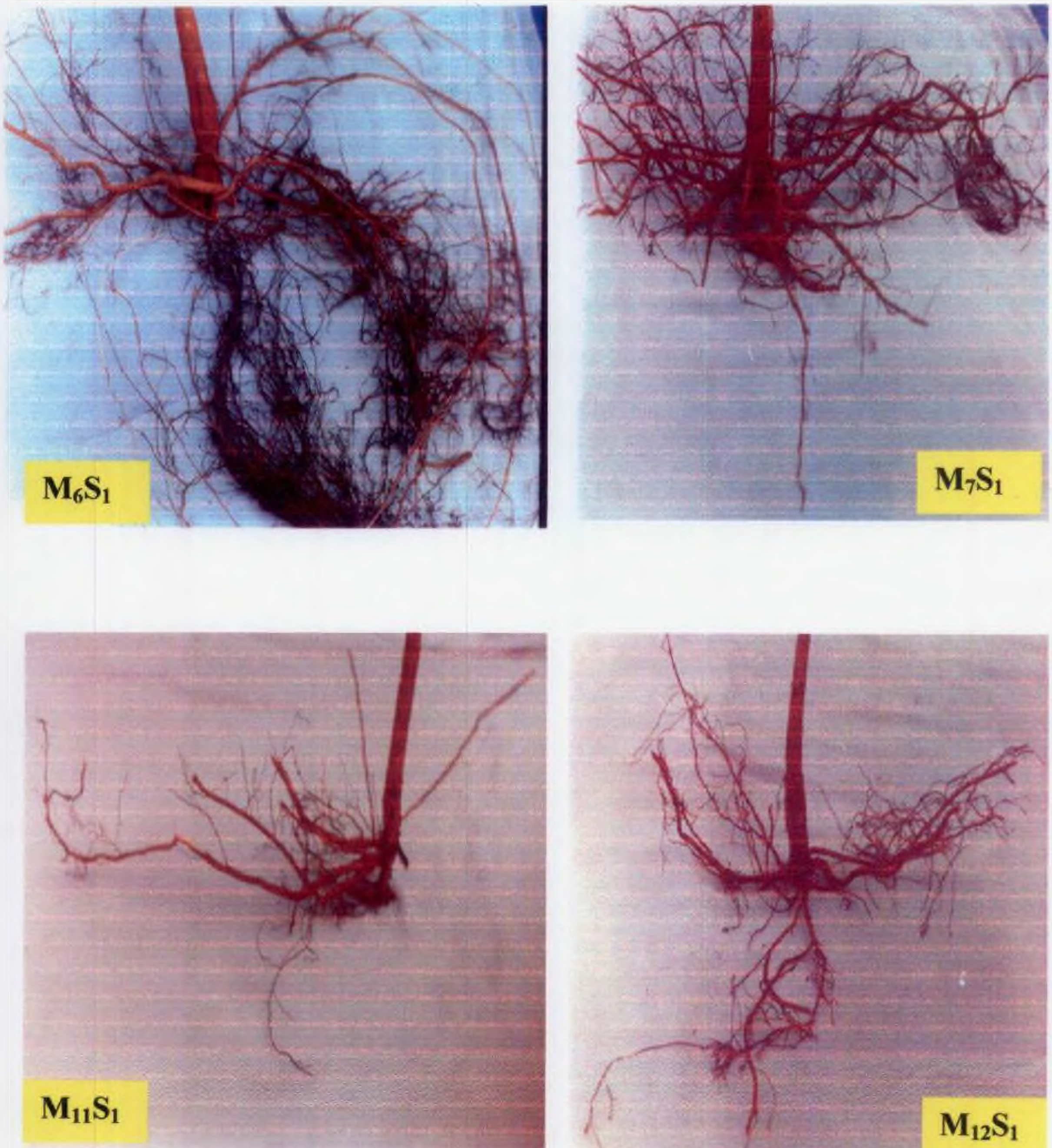

Plate 9. Rooting pattern of sappan wood after 12 months of planting

Various soil factors, particularly moisture, penetrability, and porosity play an important part in the development of the root system. Depending upon the soil environment, spear shaped, club shaped or heart shaped root system is formed. In heart shaped root system, primary root ceases to grow when it reaches middle horizons and energy is diverted towards the development of secondary roots. In appropriate soil environment, these maintain the initial angle of inclination and tend to develop parallel to primary root or tap root. This helps in giving rise to a multiple tap root and practically, functions of single primary tap root gets not only replaced but multiplied by the secondary roots. These are termed 'forced multiples'. Tertiary roots follow more or less the same course and thus increase the surface area of absorption. Mineral nutrient uptake is enhanced and forced multiples reaching deeper horizons exert root pressure and induce capillary rise of water. This provides optimum opportunities for better survival during critical spells of growth period and higher mineral nutrient absorption. Layering mixture and micro site enrichment provided appropriate soil environment to attain rapid development of primary roots and subsequent secondary and tertiary roots (Plate 9).

5.1.3 Physiological Parameters

Water constitutes more than 80 per cent of the fresh weight of actively growing shoots of woody plants forming a continuous liquid phase from the root hairs to the leaf mesophyll cells. Living cells require a high degree of internal water saturation to function efficiently and tissue water content can fluctuate only within narrow limits if growth and development are to continue unimpaired. Water potential is the most widely used indicator of plant water status because it is the major determinant for water movement through the plant.

Leaf water potential in regularly irrigated plants was 28.9 Per cent higher compared to life saving irrigation. Maximum leaf water potential of -18.8 bars was recorded by vertical mulching with enriched coir pith vermicompost in polythene lined circular trenches. Water stressed plants showed much lower potential compared to well watered plants. It may be noted that plant biometric characters like height, leaf number, collar girth and number of branches decreased in response to soil moisture stress indicating that the crop was unable to maintain leaf turgor under life saving irrigation resulting in differences in growth. Leaf water potential is considered as a direct indicator of leaf turgor and hence a good indicator of water stress of plants. Though there was a reduction in water potential under life saving irrigation compared to irrigation at 50 per cent depletion of soil moisture, the plant was able to maintain water potential well above - 15.0 bars, which shows the ability of the crop species to tolerate mild water stress on account of extending irrigation intervals. Hence, from the present study, it is inferred that, sappan wood has no difficulty in tolerating mild water stress which indicates that life saving irrigation is sufficient for normal growth and development.

Plants under life saving irrigation showed a higher leaf temperature than well watered plants. The elevation in leaf temperature could be due to the decreased transpiration rate caused by water stress as against a well watered plant which transpires at optimum level and makes the leaves cool. Elevation in leaf temperature was observed by Mtui *et al.* (1981) due to moisture deficit situation. Such situation would lead to a reduction in photosynthesis resulting in the decline of total dry matter production. Nevertheless, the leaf temperature alone can not be considered as a good indicator of water stress as there was no consistent pattern of variation.

Osmotic potential is an indication of the concentration of solutes which reflects the accumulation of biochemical constituents in the officinal parts of medicinal plants. Integration of vertical mulching and life saving irrigation (M_6S_2) and micro site enrichment and life saving irrigation (M_7S_2) increased the osmotic potential to the tune of 74.18 and 71.3 per cent respectively when compared to the drip irrigation scheduled at 50 per cent depletion of soil moisture. This indicates that life saving irrigation is beneficial for promoting the accumulation of biochemical constituents in sappan wood compared to the normal summer irrigation scheduled at 50 % depletion of soil moisture. The effect of soil

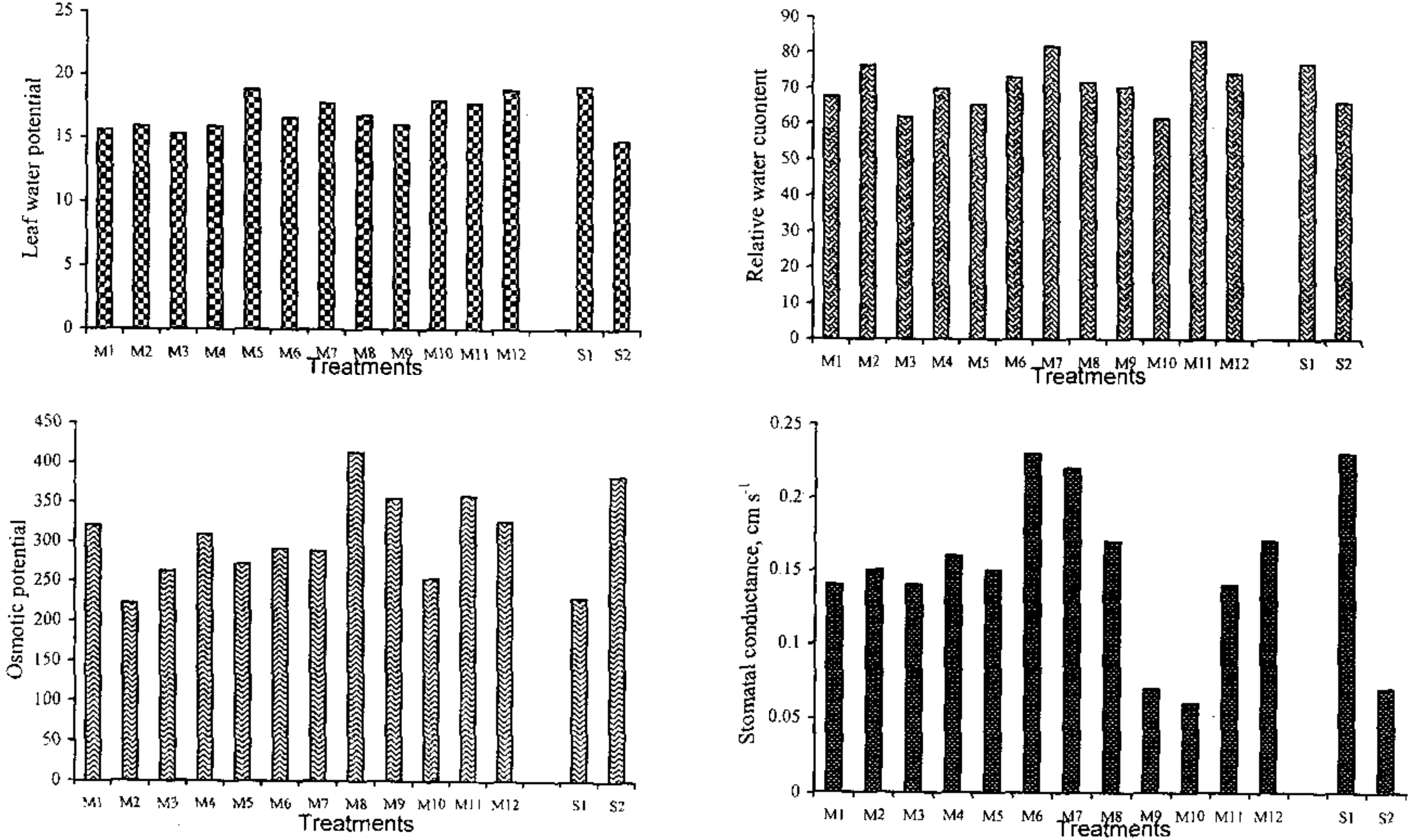

Fig. 6. Physiological parameters as influenced by *in situ* rain water harvesting techniques and irrigation

moisture stress on the accumulation of biochemical constituents especially proline in sappan wood has been reported and it is well known that development of heart wood and accumulation of biochemical principles take place at a faster rate in moisture stress environment. Hence, it is advisable to resort to life saving irrigation (Fig. 6).

Relative water content is an alternative measure of plant water status (Elamathi and Singh, 2001). The RWC of well watered plants and plants under life saving irrigation were 76.6 and 65.8 per cent respectively. A reduction in the soil moisture content from 20.11 to 10.41 % might have lowered RWC (Table 37).

Stomatal conductance showed an increasing trend with increase in soil moisture availability. There was drastic reduction in stomatal conductance under life saving irrigation compared to plants under irrigation at 50 per cent depletion of soil moisture. The stomatal closure is usual when the turgor of guard cell decreases during relatively early stages of leaf water deficits, often long before leaves wilt (Nath, 1993). Reduction in stomatal conductance could be due to water deficit situation that might have developed in the leaves due to reduction in soil moisture availability. This reduction in stomatal conductance was due to chemical signal-ABA arriving from the roots that cause stomatal closure and in turn decrease in stomatal conductance (Else *et al.*, 1996). It is clear from the results that under life saving irrigation system, plants reduce their water loss by stomatal regulation. This indicates a reduction in the absorption of soil moisture under life saving irrigation. This is also corroborated by the low root weight observed under life saving irrigation (Table 21).

5.1.4 Biochemical Parameters

Chlorophyll a, b and total chlorophyll were reduced under life saving irrigation compared to regular summer irrigation which indicates that synthesis / disintegration of chlorophyll is also sensitive to variations in soil moisture. The decrease in chlorophyll content could possibly be by the loosing of chloroplast

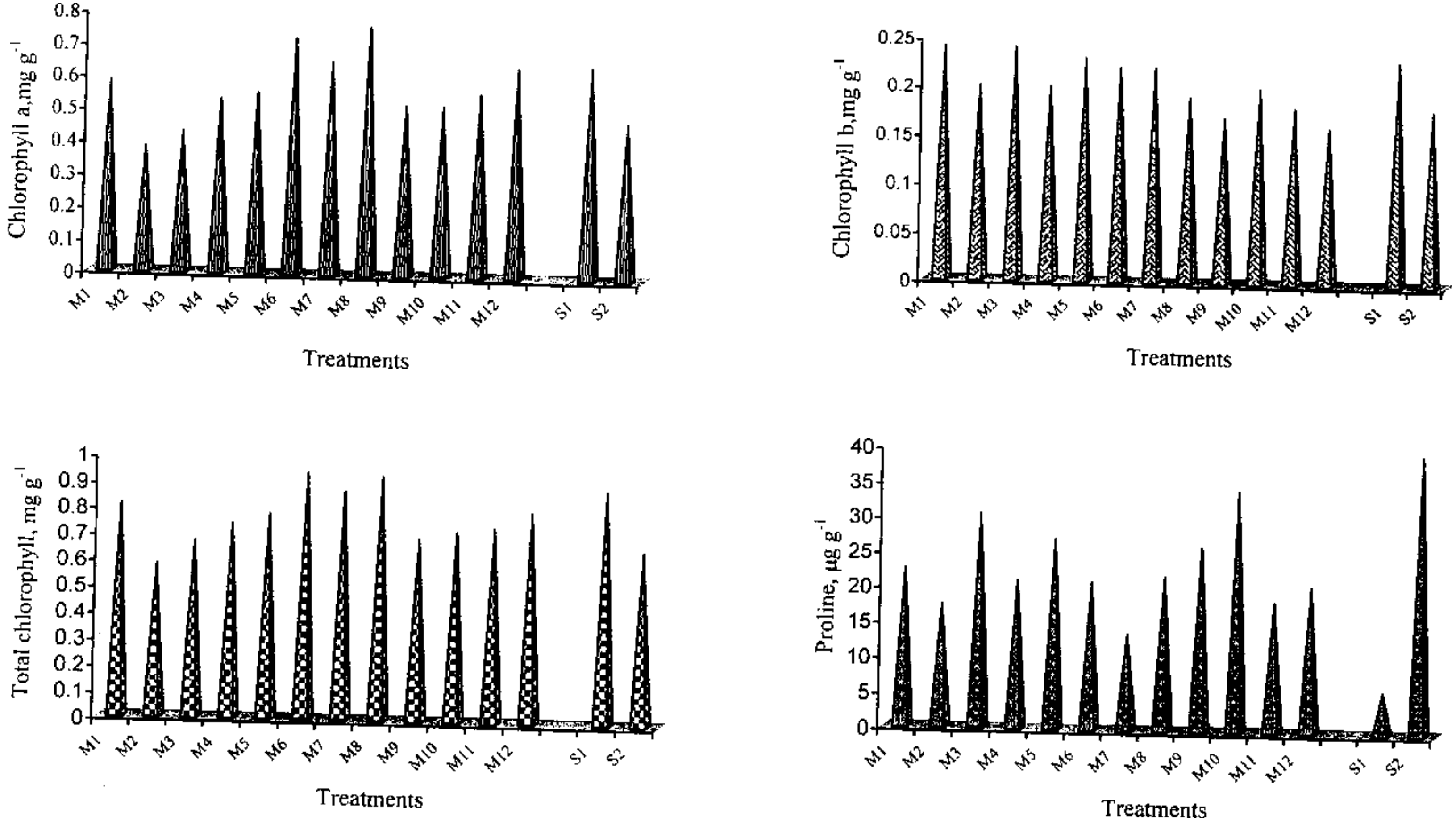

Fig. 7. Biochemical parameters as influenced by *in situ* rain water harvesting techniques and irrigation

membrane integrity or due to inhibition of biosynthesis of the precursors of chlorophyll (Dekov *et al.*, 2000).

The free proline content in the leaves showed an increasing trend under life saving irrigation. It can be considered as an after effect of water stress rather than an adaptation to mitigate water stress (Fig. 7).

5.1.5 Dry matter Production and Partitioning

Stem dry matter production (SDMP) is the main economic criterion deciding the profitability of sappan wood plantations. Among the different twenty four treatment combinations involving twelve *in situ* rain water harvesting and conservation approaches and two levels of irrigation, M_6S_1 recorded the maximum SDMP (2271 kg ha^{-1}) followed by M_7S_1 (1834 kg ha^{-1}), M_8S_1 (1663 kg ha^{-1}), M_2S_1 (1269 kg ha^{-1}), M_6S_2 (1237 kg ha^{-1}), M_3S_1 (1188 kg ha^{-1}), M_7S_2 (1149 kg ha^{-1}) etc.. The increase in SDMP as a result of summer irrigation is estimated at 84 (M_6S_1), 60 (M_7S_1), 87 (M_8S_1), 34 (M_2S_1) and 36 (M_3S_1) per cent for the different promising treatment combinations. Avoiding summer irrigation and restricting moisture supply through life saving irrigation alone, the reduction in SDMP in treatment combinations, viz., M_6S_2 and M_7S_2 were 45 and 37 per cent respectively (Fig.9).

Under life saving irrigation, dry matter production was reduced considerably due to the effect of water stress. Water deficits generally have a negative effect on the dry matter production in plants as it impairs many of the physiological processes which determine the growth. The reduction in dry matter production could be due to the decrease in the plant characters like leaf area, leaf dry weight, shoot dry weight, root dry weight etc., which are positively correlated with the total dry matter production in different species.

Mulching has been widely practised for many fruit trees and tropical plantation crops with superficial root systems. It affects both the diurnal and seasonal fluctuations in soil temperature. Its principal effects on diurnal temperature is to reduce the mid day maximum temperature under hot and dry conditions. The mulched soil is much cooler during the heat of the day rather warmer during the night. The mulches slow down the rate of evaporation from a wet soil very considerably. The rate of evaporation is controlled by the proportion of energy absorbed by the soil which is used for evaporating water and by the rate of removal of water vapour from the region where it is being produced. So long as the wet soil is exposed to air, water vapour is rapidly removed by the general turbulence of the air, but if the water vapour must diffuse through a mulch which keeps the air almost stationary, then the rate of diffusion limits the rate of evaporation (Russell, 1973). From the present study, it is clear that vertical mulching and micro site enrichment can conserve soil moisture on account of umpteen similar attributes.

SDMP is a function of total length of stem, collar girth and unit stem weight. Plant height which is an indication of length of stem was found to be influenced by the effect of treatment combinations and the increase in plant height in vertical mulching (M_6S_2) and micro site enrichment (M_7S_2) were 52 and 19 per cent respectively over drip irrigation ($M_{12}S_1$). Similarly, remarkable improvement in collar girth was noticed in vertical mulching (M_6S_2) and micro site enrichment (M_7S_2) to the tune of 84 and 31 per cent respectively, over drip irrigation ($M_{12}S_1$). Bole height, an indicator of stem development, was also found to be significantly influenced by the interaction effects and the per cent increases over $M_{12}S_1$ were 79 and 68 respectively for M_6S_2 and M_7S_2. Substitution of the modern method of irrigation, i.e., drip system and the traditional pitcher irrigation with vertical mulching or micro site enrichment integrated with life saving irrigation was found worth popularizing for improving the growth characters of sappan wood.

Compared to drip irrigation system, vertical mulching (M_6S_2) and micro site enrichment (M_7S_2) created ideal environments for root development and the increase in root dry matter production was to the tune of 42 and 32 per cent respectively, which resulted in better absorption leading to luxuriant growth of sappan wood yielding higher SDMP.

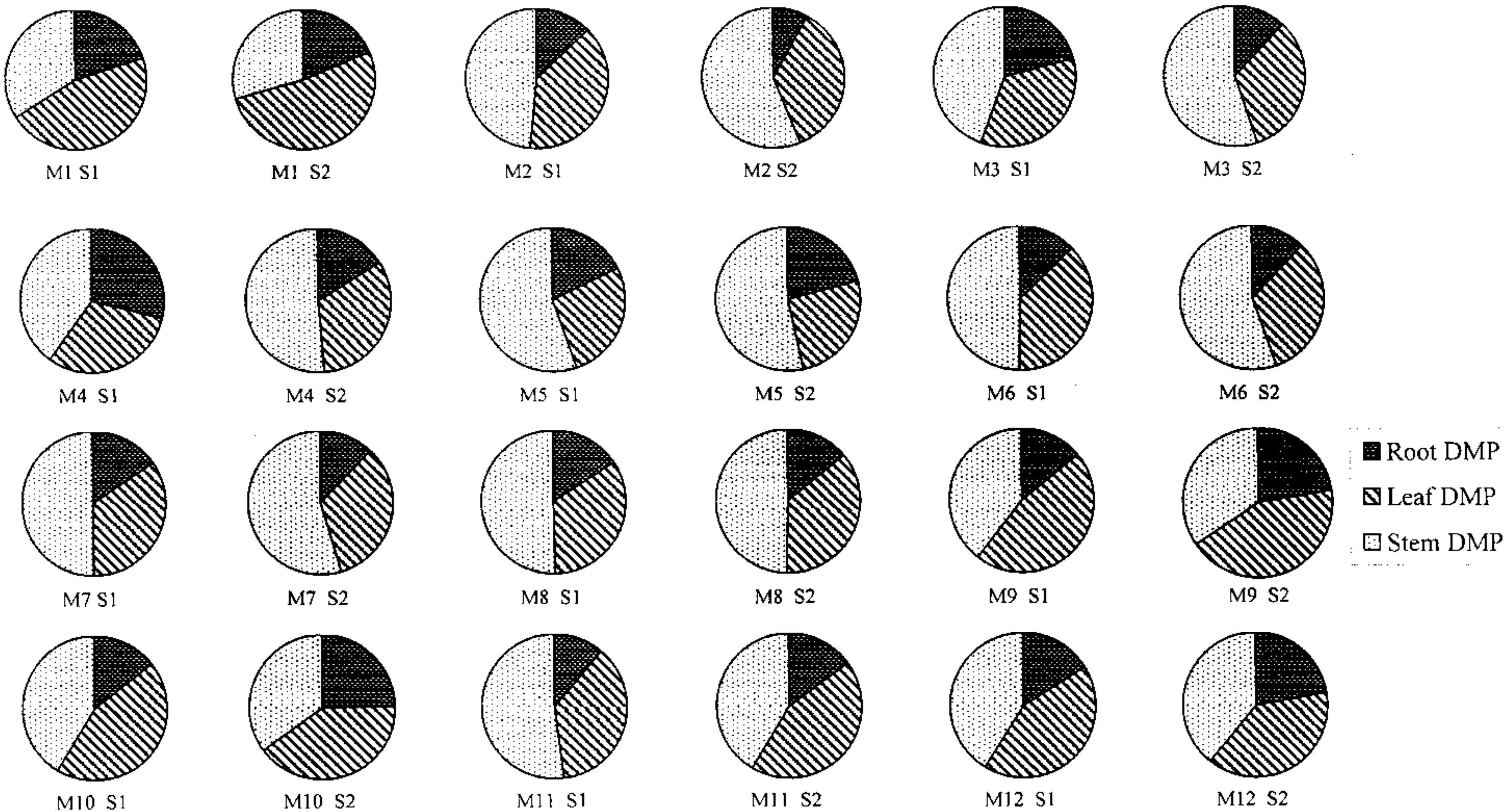

Fig. 8. Effect of treatment combinations on dry matter production (kg ha^{-1}) and partitioning

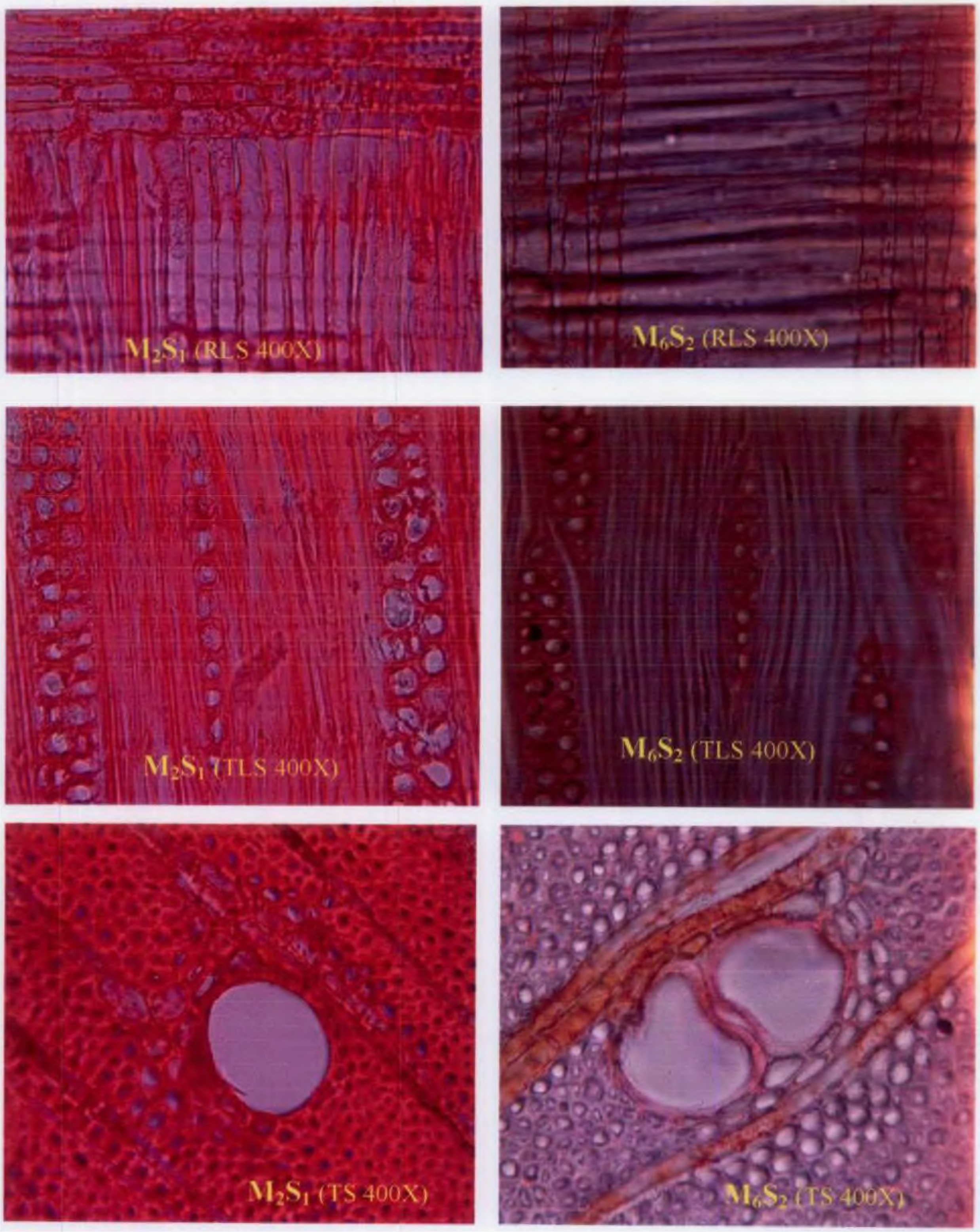

Plate 10. Anatomical sections of stem

Dry matter production and partitioning in sappan wood was also found to be influenced by rain water harvesting techniques and levels of irrigation. SDMP was found to improve under moisture stress environments. Depletion of soil moisture beyond PWP once in three to four weeks was found beneficial for dry matter partitioning in favour of the economic product. In M_6S_2 and M_7S_2, 55 and 54 per cent of total DMP was diverted for SDMP whereas in $M_6S_1$and M_7S_1, the per cent contribution of total DMP towards SDMP was to the tune of 49 per cent only (Fig.8).

Secondary thickening and development of heartwood were observed in M_6S_2 and M_7S_2 treatment combinations after twelve months of planting (Plate 10). The effect of vertical mulching and micro site enrichment in providing a favourable rhizosphere was evident from Table 21. Layering mixture specially made for rhizosphere modulation not only released macro and micro nutrients in plant available forms but modified the physical condition of the soil by improving the porosity and soil structure (Table 4). There was a significant and positive influence on the water holding capacity of the rhizosphere soil subsequent to application of special layering mixture comprising of enriched coir pith vermicompost : cowdung : red soil (1:1:1).

When we compare the root development in M_6 and M_7 and the pattern of soil moisture extraction, it is seen that the root development was confined in M_7 where as it was unconfined in M_6 (Table 21). The bottom lining with sand filled coconut shells given in M_7 might have restricted the foraging of roots to lower horizons (Plate 9).

The crop growth potential (CGP) estimated from total dry matter production, stem dry matter production, root dry matter production and sturdiness quotient reveals the positive influence of vertical mulching with layering mixture in polythene lined circular trenches and micro site enrichment and mulching with polythene and irrigation at 50 per cent depletion of soil moisture in increasing biomass production. Interaction effects also revealed that integration of vertical mulching and irrigation at 50 per cent depletion of soil moisture; and micro site

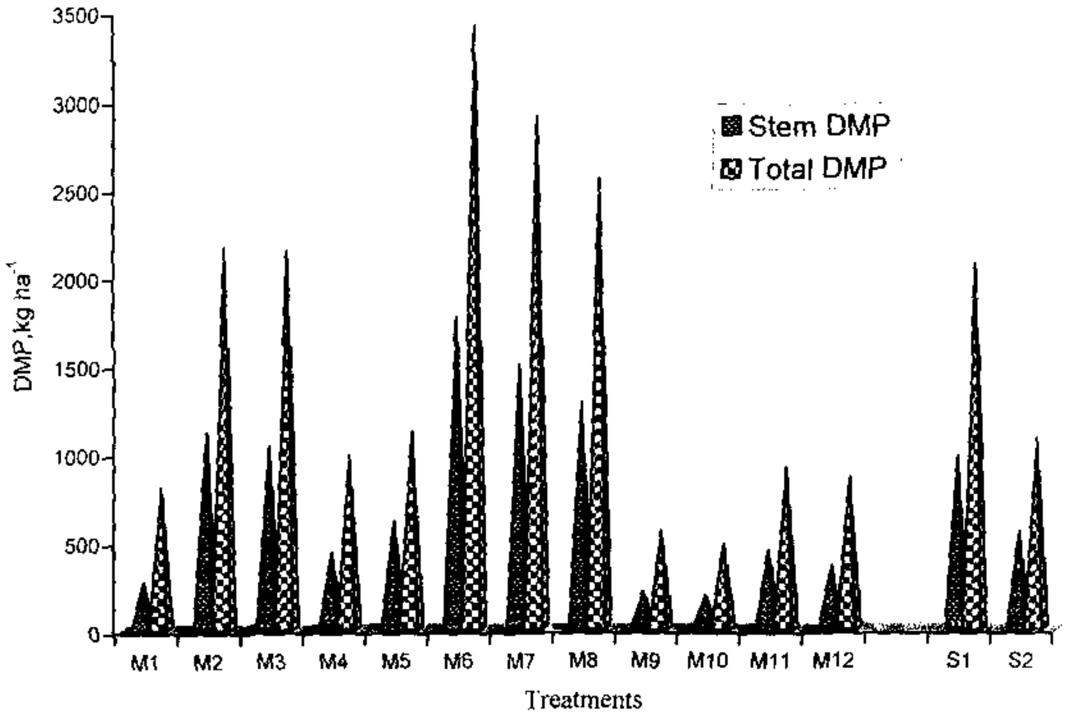

Fig. 9. Dry matter production as influenced by *in situ* rain water harvesting techniques and irrigation

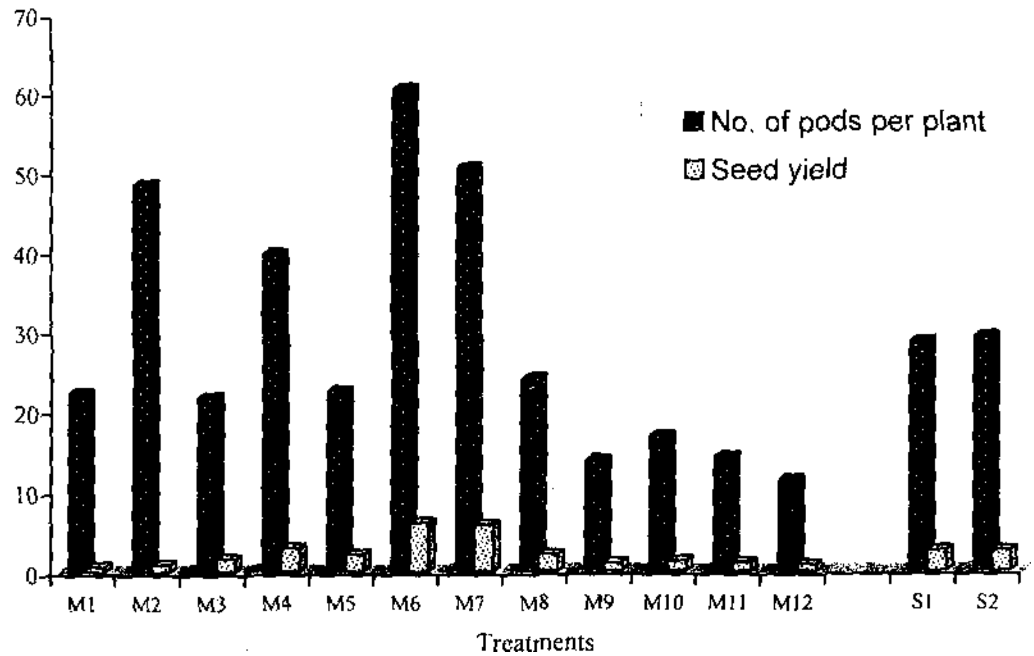

Fig. 10. Seed production potential as influenced by *in situ* rain water harvesting techniques and irrigation

enrichment and irrigation at 50 per cent depletion of soil moisture were found beneficial for improving crop growth potential (738.62 and 479.72). Among the various treatment combinations, crop growth potential was higher when life saving irrigation was integrated with either vertical mulching with layering mixture or micro site enrichment and mulching with polythene suggesting the significance of vertical mulching and micro site enrichment in improving crop growth and production. There was significant improvement in crop growth potential on account of higher total biomass production, lower sturdiness quotient which is a desirable trait and balanced partitioning of dry matter between shoot and root. Factors governing the above characters are discussed in sections of 5.1.1 and 5.1.2

5.1.6 Seed Production Potential

Sappan wood is propagated through seeds. Flowering and pod formation began towards the fag end of the experimental period. Precocity in flowering was observed in M_7S_1, M_6S_1 and M_7S_2 and M_6S_2. The treatment combinations, M_7S_1 and M_6S_1 registered maximum pod numbers. Seed production potential of sappan wood was found to be influenced by the interaction effects and M_6S_2 and M_7S_2 were significant in influencing seed production. Favourable rhizosphere conditions for growth and development might have contributed for precocity in flowering. Higher number of pods per plant and seeds per pod have contributed for prolific seed production. Similar results have been reported in several crop plants (Chattopadhay and Patra, 1992; Mandal and Chattopadhyay, 1994; Reddy and Khan, 1998; Mohanty *et al.*, 2002). Sappan wood produces terminal inflorescence and its emergence coincides with hot summer which necessitates supplemental irrigation to mitigate moisture stress. So regular irrigation at 50 per cent depletion of soil moisture and provisions for conservation of irrigation or rain water for a longer period might have contributed to maximize seed production (Fig.10).

5.1.7 Soil Moisture Studies

The seasonal Cu of sappan wood for M_6S_2 and M_7S_2 were 267 and 306 mm respectively whereas it was found to be much higher for M_6S_2, M_7S_2 and other treatment combinations receiving summer irrigation at 50 per cent depletion of soil moisture. This indicates the superiority of M_6 in conserving water available from life saving irrigation (Table 38).

Though the mean daily Cu of the promising treatment combinations (M_6S_1, M_6S_2, M_7S_1, M_7S_2) varied from 1.47 mm to 2.92 mm; the range was very narrow and Cu use rate lower for treatment combinations receiving life saving irrigation (1.47 to 1.96 mm), however, it was wide and higher for those combinations receiving summer irrigation at 50 per cent depletion of soil moisture (2.44 to 3.48 mm).

The kc values of the above treatment combinations were estimated and it is seen that the lower values, i.e., 0.39 and 0.44 were expressed by M_6S_2 and M_7S_2 respectively. This again indicates the positive effect of the treatment combination M_6S_2 and M_7S_2 in extracting water even around PWP compared to treatment combinations receiving frequent summer irrigations showing higher kc. The physiological, morphological, anatomical and biochemical characteristics of sappan wood were modulated for economizing water use.

The data on per cent utilization of available water (FC - PWP) varies with the rhizosphere environment. In general, the utilization was 25 to 30 per cent when irrigation was scheduled at 50 per cent depletion of soil moisture where as it was around 50 per cent in the case of life saving irrigation. In M_6S_2, the utilization was 50.61 per cent where as in M_7S_2, it exceeded 50 per cent and it was 58.64 per cent. In M_6S_1, M_7S_1 and M_8S_1 the utilization were 26.9, 28.9 and 28.8 per cent respectively which clearly indicates that sappan wood can extract moisture even beyond PWP if the rhizosphere is suitably modified by appropriate micro site enrichment treatments.

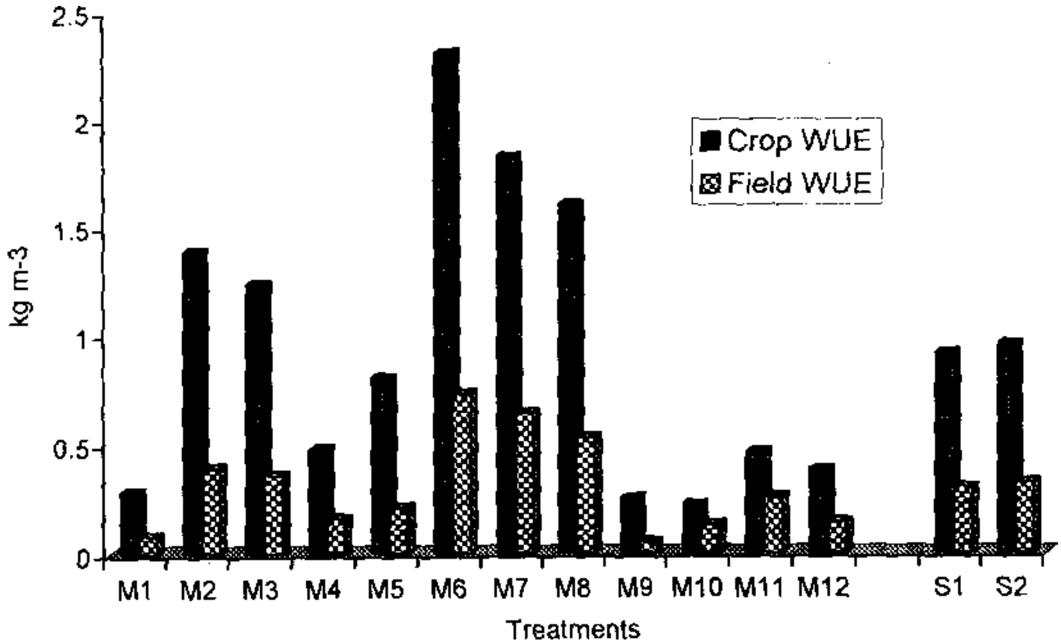

Fig. 11. Water use efficiency as influenced by *in situ* rain water harvesting techniques and irrigation

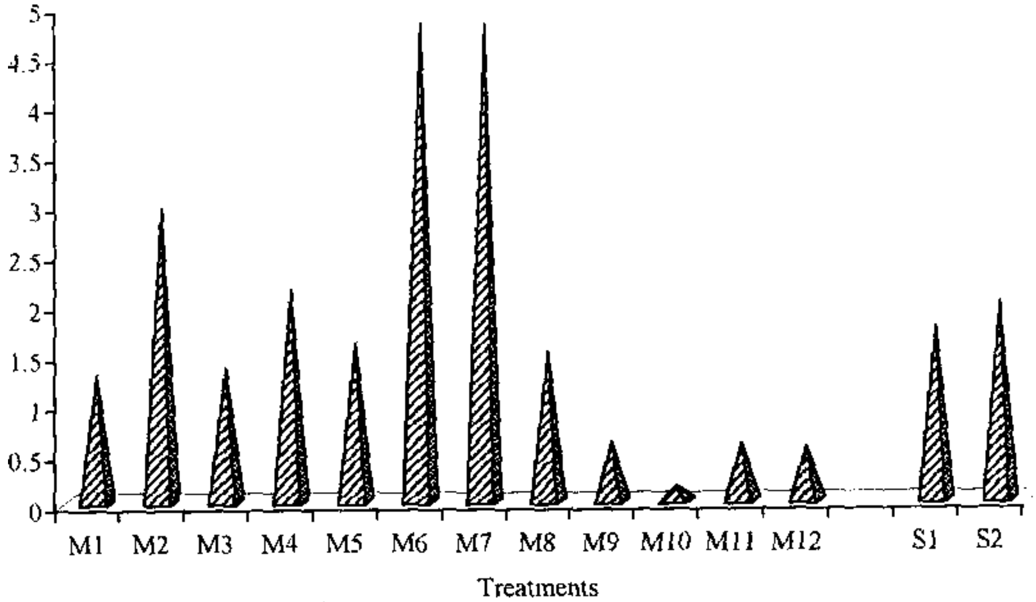

Fig. 12. Benefit - cost ratio as influenced by *in situ* rain water harvesting techniques and irrigation

Crop WUE was studied and the values were 2.18, 2.42, 1.76, 1.88, 1.62 and 1.58 kg m^{-3} for M_6S_1, M_6S_2, M_7S_1, M_7S_2, M_8S_1 and M_8S_2 respectively. This again indicates the superiority of the treatment combinations involving M_6, M_7 and M_8 and life saving irrigation (M_6S_2, M_7S_2 and M_8S_2) in increasing crop WUE compared to similar rain water harvesting treatments but with a different irrigation schedule, i.e., irrigation at 50 per cent depletion of soil moisture (S_1) (Fig.11).

The trend was almost similar with respect to field WUE as well. However, M_6S_2 recorded maximum efficiency followed by M_6S_1, M_7S_2 and M_7S_1. Treatment combinations receiving similar *in situ* rain water harvesting treatments but with summer irrigation at 50 per cent depletion of soil moisture registered lower efficiencies. Again, the superiority of life saving irrigation was pronounced in improving field WUE.

Economy in the use of irrigation water, especially conserved rain water particularly during hot summer is possible by the adoption of in situ rain water harvesting and conservation techniques. When we compared the four promising treatments, 1898, 1650, 412 and 412 m^3 of water were consumed by the treatment combinations, viz., M_6S_1, M_7S_1, M_6S_2 and M_7S_2 respectively which again indicate the significance of life saving irrigation in economizing water use. Additional cost involved in providing necessary infrastructure for in situ collection and conservation of rain water is insignificant when compared to the huge volume of water that would have additionally made available for extending irrigation to rain fed areas.

Vertical mulching with layering mixture in polythene lined circular trenches and providing life saving irrigation once in three weeks with thirty three litres of water or micro site enrichment and mulching with polythene and providing life saving irrigation once in four weeks with thirty three litres of water is found beneficial for establishment and early growth of sappan wood.

The economic analysis of the system also proved the superiority of the above two treatment combinations in respect of gross income and benefit – cost ratio (Fig. 12).

Adoption of appropriate techniques of conservation of rain water without loss in quality and waste will enable to augment rain water harvesting. This is of vital importance especially for crops grown in rainfed situations to overcome soil moisture stress.

Summary

6. SUMMARY

A field experiment was conducted at the Instructional Farm, Vellayani for a period of one year from June 2004 to find out the comparative efficacy of vertical mulching, micro site enrichment, micro catchments and traditional methods of rain water harvest and conservation to extend the period of stored moisture availability for raising *Caesalpinia sappan* without summer irrigation.

Vertical mulching with layering mixture in polythene lined circular trenches (M_6) registered maximum plant height at all growth stages. Supplemental summer irrigation at 50 per cent depletion of soil moisture produced taller plants. With respect to treatment combinations, M_6S_1 (integration of vertical mulching with layering mixture in polythene lined circular trenches and irrigation at 50 per cent depletion of soil moisture) resulted in taller plants.

Micro site enrichment and mulching with polythene recorded maximum number of functional leaves at 4 MAP. From five months on wards, vertical mulching with layering mixture in polythene lined circular trenches produced maximum number of functional leaves at all growth stages. Supplemental irrigation was found to improve the production of functional leaves throughout the summer months. The superiority of M_6S_1 was evident on functional leaf production at 11 and 12 MAP.

From five month onwards, vertical mulching with layering mixture in polythene lined circular trenches recorded maximum collar girth. Scheduling of irrigation at 50 per cent depletion of soil moisture increased collar girth throughout the summer months. Interaction effects between *in situ* rain water harvesting techniques and summer irrigation had no significant influence on collar girth at any of the growth stages.

The effects of *in situ* rain water harvesting techniques had significant influence on number of branches only after 11 months of planting. In general, irrigation at 50 per cent depletion of moisture resulted in profuse branching after

10 months of planting. Integration of *in situ* rain water harvesting techniques and levels of irrigation had no significant effect on branching behavior of sappan wood.

Main effects of treatments influenced bole height, canopy height, canopy width and canopy size both at 11 and 12 MAP. In general, vertical mulching with layering mixture in polythene lined circular trenches (M_6) registered maximum values. Effect of summer irrigation in influencing canopy architecture was evident from the data on above parameters. Integration of *in situ* rain water harvesting techniques and summer irrigation influenced bole height at 11 MAP and canopy height both at 11 and 12 MAP and M_6S_1 registered maximum values of bole height and canopy height at both stages. Interaction effects had no significant influence on canopy width at any of the growth stages whereas, M_6S_1 registered maximum values of bole height and canopy height at both stages. Interaction effects had no significant influence on canopy width at any growth stages whereas, M_6S_1 registered maximum canopy size at 11 MAP.

Significant improvement in root dry weight, root length, root surface area, root volume and root spread were brought about by the effects of vertical mulching with layering mixture in polythene lined circular trenches at 6 MAP. Main effects didn't influence root number during the initial phase of establishment. However, after 12 months of planting, micro site enrichment and mulching with polythene (M_7) resulted in maximum root proliferation. Life saving irrigation was found beneficial for improving root number where as, all other root parameters viz., root length, root spread, fresh and dry root weight, root surface area were positively influenced by irrigation scheduling at 50% depletion of soil moisture. Though root shoot ratio was not influenced by the effects of *in situ* rain water harvesting techniques after 6 months of planting, its influence was significant after 12 months of planting and vertical mulching with coconut husk in polythene lined circular trenches (M_4) recorded maximum root : shoot ratio. Integration of *in situ* rainwater harvesting techniques and irrigation levels significantly influenced the root dry weight, root volume and root surface area and

M_6S_1 followed by M_7S_1 recorded higher values at 12 MAP. However, treatment combinations had no significant difference on root number, root length and root spread after 12 months of planting.

Maximum values of root growth potential, sturdiness quotient and crop growth potential were recorded by M_6 followed by M_7. Irrigation at 50 per cent depletion of soil moisture improved all the above parameters.

Maximum leaf water content, leaf water potential, osmotic potential and transpiration ratio were registered by pitcher irrigation (M_{11}), vertical mulching with enriched coir pith - vermicompost in polythene lined circular trenches (M_5), micro site enrichment and mulching with coconut husk in circular trenches (M_1) respectively after 12 months of planting. All the above parameters were higher for irrigation at 50 per cent depletion of soil moisture. Integration of *in situ* rain water harvesting techniques and irrigation levels resulted in significant variation on relative water content, leaf water potential, osmotic potential and transpiration ratio. $M_{11}S_1$, M_8S_2, M_7S_1 and M_1S_1 registered higher values of relative water content, leaf water potential, osmotic potential and transpiration ratio respectively.

Main effects showed significant influence on biochemical parameters. Micro site enrichment and mulching with coconut husk (M_8), vertical mulching with layering mixture in circular trenches (M_3), vertical mulching with layering mixture in polythene lined circular trenches (M_6) and micro catchments and mulching with coir geo–textiles (M_{10}) produced maximum chlorophyll a, Chlorophyll b, total chlorophyll and proline respectively. Irrigation at 50 per cent depletion of soil moisture registered maximum chlorophyll a, Chlorophyll b and total chlorophyll where as proline accumulation was heighest under life saving irrigation.

Vertical mulching with layering mixture in polythene lined circular trenches (M_6) followed by M_7 and M_8 produced maximum total DMP both at 6 and 12 MAP. The effects of irrigation at 50 per cent depletion of soil moisture was remarkable in improving total DMP, M_6S_1 followed by M_7S_1, M_8S_1, M_3S_1, M_2S_1, M_6S_2, M_2S_2, M_8S_2 and M_2S_2 produced maximum total dry matter after

12 months of planting. Almost a similar trend was observed with respect to root, leaf and stem DMP.

Seed production potential was highest in M_6 followed by M_7. The treatment combinations, M_6S_2, M_7S_2, M_6S_1 and M_7S_1 recorded maximum seed yield.

Maximum soil moisture content after irrigation was recorded by micro site enrichment and mulching with polythene (M_7) and minimum by vertical mulching with coconut husk in circular trenches (M_1). Vertical mulching with enriched coir pith - vermicompost (M_5) recorded maximum soil moisture before irrigation. Irrigation at 50 per cent depletion of soil moisture resulted in maximum moisture content both after and before irrigation. Soil moisture content after irrigation was not at all influenced by treatment combinations whereas, M_7S_1 and M_7S_2 treatment combinations recorded maximum and minimum values before irrigation respectively.

Maximum consumptive use, mean daily consumptive use and crop coefficient were recorded by M_6. Irrigation at 50 per cent depletion of soil moisture was also beneficial for improving the above parameters. Maximum crop WUE and field WUE were recorded by M_6.

Economic analysis of the system for the establishment of sappan wood plantation revealed the superiority of M_6 and M_7 over other treatments in terms of gross income and benefit- cost ratio. Among the different treatment combinations, M_6S_2 recorded maximum benefit- cost ratio.

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*Original not seen

***IN SITU* RAIN WATER HARVEST, CONSERVATION AND UTILIZATION FOR ESTABLISHMENT AND EARLY GROWTH OF SAPPAN WOOD (*Caesalpinia sappan* L.)**

BEENA, J.S.

**Abstract of the
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**Department of Agronomy
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM 695522**

ABSTRACT

Caesalpinia sappan popularly is a leguminous perennial crop grown for its valuable timber, which exhibits medicinal properties. Though the crop is sensitive to dry spells during its initial phase of establishment, it is preferred for planting as a neglected crop in marginal lands. Hence, development of sustainable rain water harvesting and conservation measures are necessary to prolong the availability of conserved moisture.

The experiment entitled, '*In situ* rain water harvest, conservation and utilization for establishment and early growth of sappan wood (*Caesalpinia sappan* L.)' was conducted in split plot design at the Instructional Farm, College of Agriculture, Vellayani during 2004–05 to find out the comparative efficacy of vertical mulching, micro site enrichment, micro catchments and traditional methods of rain water harvest and conservation. The treatments consisted of combinations of twelve main plot treatments, *viz.*, vertical mulching with coconut husk in circular trenches (M_1), vertical mulching with enriched coir pith vermicompost in circular trenches (M_2), vertical mulching with layering mixture in circular trenches (M_3), vertical mulching with coconut husk in polythene lined circular trenches (M_4), vertical mulching with enriched coir pith vermicompost in polythene lined circular trenches (M_5), vertical mulching with layering mixture in polythene lined circular trenches (M_6), micro site enrichment and mulching with polythene (M_7), micro site enrichment and mulching with coconut husk (M_8), micro catchments and mulching with coconut husk (M_9), micro catchments and mulching with coir geo-textiles (M_{10}), pitcher irrigation (M_{11}) and drip irrigation (M12); and two sub plot treatments, *viz.*, irrigation at 50 per cent depletion of soil moisture (S_1) and life saving irrigation (S_2).

The treatments, (M_6) followed by M_7 resulted in luxuriant growth. Growth characters viz., plant height, leaf number, collar girth, number of branches, bole height, canopy height, canopy width and canopy size and root characters, *viz.*, root length, root spread, root weight, root volume and root surface area were found to

improve significantly due to the treatment effects. Sturdiness quotient and root growth potential also indicated the superiority of the treatments in the developmental physiology of the crop. Irrigation at 50 per cent depletion of soil moisture improved all the growth characters compared to life saving irrigation.

M_6S_1 recorded the maximum stem dry matter production (SDMP) followed by M_7S_1, M_8S_1, M_2S_1, M_6S_2, M_3S_1 and M_7S_2. The reduction in SDMP in treatment combinations, *viz.*, M_6S_2 and M_7S_2 were 45 and 37 per cent respectively when summer irrigation was avoided and moisture supply was restricted through life saving irrigation alone. The treatment combinations, M_6S_1 and M_7S_1 were found beneficial for improving crop growth potential as well. Among the various treatment combinations, crop growth potential was higher when life saving irrigation was integrated with either vertical mulching with layering mixture or microsite enrichment and mulching with polythene. Seed production potential of sappan wood was found to be influenced by the interaction effects and M_6S_2 and M_7S_2 were significant in influencing seed production.

M_6S_2 and M_7S_2 increased the osmotic potential to the tune of 74.18 and 71.3 per cent respectively when compared to $M_{12}S_2$.

The seasonal Cu, mean daily Cu and crop coefficient for M_6S_2 and M_7S_2 were found to be lower when compared to M_6S_1, M_7S_1 and other treatment combinations receiving summer irrigation at 50 per cent depletion of soil moisture.

Vertical mulching with layering mixture in polythene lined circular trenches and providing life saving irrigation once in three weeks with thirty three litres of water or micro site enrichment and mulching with polythene and providing life saving irrigation once in four weeks with thirty three litres of water is found beneficial for establishment and early growth of sappan wood.

The economic analysis of the system also proved the superiority of the above two treatment combinations.

Appendix

APPENDIX – I

Weather data during the experimental period (June 2004 – June 2005)

Period	Maximum Temperature, °C	Minimum Temperature, °C	Rainfall, mm	Evaporation, mm	Relative Humidity, %
June	30.4	21.0	223.5	3.2	83.7
July	29.8	21.5	295.0	3.1	85.2
August	30.2	21.3	71.7	3.8	83.6
September	30.6	23.0	201.4	3.8	83.9
October	30.5	22.7	180.1	3.4	82.3
November	29.1	20.8	206.6	2.7	85.7
December	31.5	22.1	16.0	3.0	81.2
January	32.5	22.7	1.0	3.6	76.9
February	32.9	22.9	0.2	3.9	76.7
March	34.5	24.1	1.1	4.6	75.3
April	33.3	23.2	333.8	4.2	78.3
May	32.7	22.5	128.9	3.7	82.1
June	30.8	21.6	225.8	3.3	84.2