AGRO TECHNIQUES FOR GROWTH PROMOTION AND INCREASING BARK YIELD IN ASHOKA (*Saraca asoca* Roxb.)

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DECLARATION

I hereby declare that this thesis entitled "**Agro techniques for growth promotion and increasing bark yield in ashoka (*Saraca asoca* Roxb.)**" 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.

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LIST OF ABBREVIATIONS

%	-	Per cent
^0C	-	Degree Celsius
@	-	At the rate of
AMF	-	ArbusculaMycorrhizalFungi
BCR	-	Benefit – cost ratio
CD	-	Critical difference
CGP	-	Crop growth potential
cm	-	Centimetre
cm^2	-	Square centimetre
cm^3	-	Cubic centimetre
CPE	-	Cumulative paevaporation
Cu	-	Consumptive use
et al	-	And others
FC	-	Field capacity
Fig.	-	Figure
g	-	Gram
g cc^{-1}	-	Gram per cubiccentimetre
g $plant^{-1}$	-	Gram per plant
ha^{-1}	-	Per hectare
HAI	-	Hours after irrigation
K_c	-	Crop coefficient
kg	-	Kilogram
kg m^{-3}	-	Kilogram per cubic metre
l	-	Litre
m	-	Metre
m^2	-	Square metre
m^3	-	Cubic metre
MAP	-	Months after planting
mg g^{-1}	-	Milli gram per gram
ml	-	Millilitre
mm	-	Millimetre
mmole kg^{-1}	-	Milli mole per kilogram
MSL	-	Mean sea level
N	-	Nitrogen
NAA	-	Naphthalene acetic acid
NS	-	Not significant
OD	-	Optical density
PWP	-	Permanent wilting point
RGP	-	Root growth potential
RLWC	-	Relative leaf water content
Rs	-	Rupees
SGP	-	Seedling growth potential
SQ	-	Sturdiness quotient
t ha^{-1}	-	Tonnes per hectare
WUE	-	Water use efficiency

Introduction

1. INTRODUCTION

Medicinal trees are one of the important components of biodiversity. Ashoka is one of the reputed medicinal trees recommended not only to cure various disorders, but also for its preventive promotional and corrective properties. It is said that one who lives under the tree will not get worried and people who look at the tree in full bloom will forget their worries and become happy and contented and hence the name ashoka (depriving of grieves).

The bark yields catechol and sterols, a wax containing n- alkanes, esters and free primary alcohol which is used for the preparation of ashokarishta and ahokaghrita (Sivarajan and Balachandran, 1999). The raw drug of this red listed tree is used exclusively to treat women's ailments. It has got excellent therapeutic effects on the female reproductive system, acting as a uterine tonic and also for curing the myriad ailments, afflicting the woman like irregular and scanty uterine bleeding, leucorrhoea, etc. Therefore ashoka is said to be the woman's best friend (Rajasekharan and Latha, 2007).

In India, 2250 tonnes of dried bark are used annually. In Kerala, about 70 tonnes of bark and 1 ton of flowers are used by various Ayurvedic medicine manufacturing units (Prabhu, 2007). Collections from forest and homesteads are quite insufficient to meet the ever increasing domestic and export demands. The indiscriminate use and unscientific extraction of bark have led to acute scarcity of the genuine raw drug and this in turn has led to cost escalation and wide spread adulteration / substitution of the drug. Therefore efforts are needed to conserve the existing wild populations and to enhance its availability through cultivation, besides developing techniques for sustainable utilization. Being a tree species which gives returns within a span of 7 years, it is preferred for planting as a neglected crop in marginal lands and under partial shade where irrigation facilities are lacking. Ashoka is amenable for domestication and commercial cultivation and it can be introduced into the existing cropping systems of Kerala. Insufficient availability of quality planting material is one of the major constraints for extending the area under this medicinal tree. Root trainer technology provides ideal soil environment to attain rapid development of primary roots and subsequent secondary and tertiary roots besides allowing early natural pruning of primary tap root and induction of secondary root system. Appropriate training on root system is achieved by providing porous, easily penetrable, nutrient rich medium with free drainage and proper aeration favouring population explosion of bioinoculants.

Ashoka regenerates from seeds. Several seedlings often seen growing under the mother trees later perish due to drought or other adverse factors, thus affecting their survival. In Kerala, though rainfall is in excess of meeting the evapotranspiration requirement, the crop experiences moisture stress during summer months since effective rainfall is quite inadequate. In situ rain water harvest and conservation practices help to increase the effective rainfall contribution for meeting the crop water requirements and also help to extend moisture availability periods. These measures help to increase water availability not only from the rainfall, but from irrigation also. Ashoka can be grown entirely on stored moisture if appropriate moisture conservation measures are adopted at the time of planting.

Micro site enrichment can be practiced for tree planting in marginal lands poor in fertility and water holding capacity. This practice leads to rhizosphere modulation through organic matter addition at the time of planting, which helps in accelerated growth of the seedlings. Micro catchments are smaller rain water catchment basins built around the plants which helps to harness and conserve rain water for further growth of plants. Mulching the catchment basin with organic materials like coconut husk extends moisture availability periods.

Vertical mulching is adopted to alleviate crop moisture stress during summer months. Trenches taken around the plants are filled with water absorbing organic material which maintain aeration and support plant growth. It is an appropriate method to maintain a favourable moisture- nutrient- oxygen balance in the rhizosphere.

Unsustainable harvests namely, extraction and peeling of bark from the whole stem results in the drying up of trees. Long gestation period of 7 years to extract the stem bark for making raw drug dissuades even progressive farmers from taking up ashoka cultivation on a plantation scale. Development of non destructive sustainable harvesting techniques during the juvenile phase without affecting the composition of biochemical constituents may help to increase bark productivity and conservation of biodiversity.

In this context, the present study is designed with the objective of standardizing nursery management practices for quality seedling production and developing sustainable rain water harvesting and conservation measures and rapid stem bark regeneration using plant growth regulators.

Review of Literature

2. REVIEW OF LITERATURE

Ashoka (*Saraca asoca*) is identified as one among the 36 endangered medicinal plants of South India. Bark rich in tannin and phenol is the primary medicinal part used in ayurvedic preparations (Radhakrishnan et al., 2007). It is well adapted to the agro climatic situations prevailing in Kerala.

The investigation entitled "Agro techniques for growth promotion and increasing bark yield in ashoka (*Saraca asoca* Roxb.) was undertaken to standardize root trainer techniques for improving seedling growth potential, to develop sustainable rain water harvesting and conservation measures to extend the period of stored moisture availability for establishment and early growth and to evolve techniques for rapid stem bark regeneration using plant growth regulators. The literature pertaining to the subject are reviewed hereunder. Wherever sufficient literature on ashoka is not available, results on related crops and other situations are also reviewed.

2.1 THE MEDICINAL TREE - ASHOKA

Ashoka, a medium sized evergreen leguminous tree belongs to the subfamily Caesalpiniaceae, grows upto 9 m in height with numerous spreading and drooping glabrous branches. It is grown throughout India and evergreen forests upto an elevation of 750 m (Prajapati et al., 2004). It grows well in partial shade (Bhattacharjee, 2004). The leaves are pinnate in opposite pairs on either side of the midrib having 15- 20 cm long, very short petioles and glabrous rachis, leaflets are 4- 6 pairs in number, oblong, lanceolate and initially with greyish white colour, then turns to coppery reddish and as the leaflets mature, it becomes dark green (Suni, 2007). Flowering occurs after 5 years of planting and it is maximum during January- March. There is a sigmoid type of flowering and seed setting in relation to the age of the tree. The flowers are dense axillary corymbs, orange or orange- yellow in colour. Petals absent, stamens 7 or 8 and filaments filiform, thrice as long as calyx segments. Anthers are purple, ovary pubescent and style curved into a ring. Pods are black, tapering at both the ends, woody, 15- 25 cm long (Radhakrishnan et al., 2007).

Ashoka produces large recalcitrant seeds typical to wet evergreen forest tree species with critical moisture content of 35 per cent (Kumar et al., 2007). Usually ashoka is propagated through seeds. On the contrary, Sasidharan and Pathrose (2007) demonstrated that ashoka could be mass multiplicated through stem cuttings and air layerings.

2.1.1 Economic Importance of Ashoka

Ashoka is an important medicinal tree gaining economic significance in recent years. Bark, leaves, flowers and seeds are the economic parts of the plant (Prajapati et al., 2004). The stem bark contains tannin, catechol, sterol and organic calcium compounds. Its methanol fraction contains haematoxylene, tannin and water soluble glycoside. The latter has glucose, galactose and mannose as sugars (Bhattacharjee, 2004).

The bark is bitter, astringent, sweet, refrigerant, anti helminthic, styptic, stomachic, constipating, febrifuge and demulscent. It is useful in dyspepsia, fever, dipsia, burning sensation, visceromegaly, colic, ulcers, menorrhagia, metropathy, leucorrhoea and pimples (Bhattacharjee, 2004). The bark is used in the preparation of Ashokarishta, Ashokaghrita, Madhukadyawaleha, Devadaravyarishta, Mahamarichyaditaila, Pradarari rasa and Kaisaditaila (Mathew et al., 2007).

The leaves are depurative and their juice mixed with cumin seeds is used for treating stomachalgia. The flowers are considered to be a uterine tonic and are used in vitiated conditions of pitta, syphilis, cervical adenitis, hyper dipsia, haemorrhoids, dysentery, scabies in children and inflammation. The dried flowers are used in diabetes and haemorrhagic dysentery and seeds are used for treating bone fractures, stranguary and vesical calculi (Prajapati et al., 2004).

2.2 NURSERY MANAGEMENT PRACTICES IN MEDICINAL TREE CROPS

2.2.1 Effect of Containers (Root trainers and Poly bags) on Growth Attributes of Tree Seedlings

Type of container in nursery production system is a crucial factor determining the success of the planting material production. Now a days, various types of containers are used in the nurseries of medicinal trees for quality planting materials production.

Root trainers are rigid or semi-rigid containers made up of high density poly propylene or high density poly ethylene or expanded poly styrene material with internal vertical ribs which direct the root growth straight down rather than permitting spiral growth. The container is giving training to the roots for straight growth and allows early natural pruning of primary tap root and induction of secondary root system. The root trainer seedling production system is widely used to overcome the problem of root coiling in the polythene bags (Nandeshwar and Patra, 2004).

Poly bags are the most commonly used containers in nurseries due to low cost and easy availability.

2.2.1.1 Plant Height

Preliminary observations on morphological and quality parameters on raised seedlings of *Acacia nilotica*, *Dalbergia sissoo* and *Albizia procera* were reported by Ginwal (2002). One and a half year after planting, root trainer raised seedlings recorded maximum plant height for all species. Srivastava et al. (2002)

opined that by using root trainer technology, plantable seedlings of *Acacia mangium*, *A. nilotica, Bambusa arundinacea, Ceiba pentandra, Dalbegia latifolia and Eucalyptus camaldulensis* could be obtained in five months using 150 cc block type root trainers for all the species and root trainer grown seedlings of all the species exhibited greater height. Mean while, Qaisar et al. (2008) noticed lesser plant height in *Cedrus deodara* when grown in 150 cc root trainer due to its low volume of rooting media.

The seedlings of four species *Acacia catechu, Albizia lebbek, Azadirachta indica* and *Pinus roxburgii* raised on conventional nursery and polythene bags kept on mounted angle iron beds (MAI) recorded higher values on plant height in comparison to the seedlings raised in root trainers for all the four species (Singh and Chand, 2003).

2.2.1.2 Collar Girth

The teak seedlings raised in root trainers had a large collar girth than stump origin plants (Khedkar and Subramanian, 1997). The seedlings of four species *Acacia catechu, Albizia lebbek, Azadirachta indica* and *Pinus roxburgii* raised in polythene bags recorded higher values on collar diameter in comparison to the seedlings raised in root trainers for all the four species (Singh and Chand, 2003).

2.2.1.3 Lateral Root Spread

The teak seedlings raised in root trainers gave better lateral root spread and produced multiple tap roots compared to the normal stump stock which retains a long tap root, generally (Khedkar and Subramanian, 1997).

2.2.1.4 Seedling Growth Indices

One and a half year after planting, root trainer raised seedlings of *Acacia* *nilotica*, *Dalbergia sissoo* and *Albizia procera* had higher values of sturdiness and root:shoot ratio (Ginwal, 2002). While comparing the growth performance of 75 days old root trainer planting stock and one year old stump origin stock of teak at the outplanting site, the root trainer plants had higher values of sturdiness ratio(Khedkar and Subramanian, 1997).

The seedlings of *Albizia procera, Artocarpus chaplasha, Gmelina arborea and Michelia champaca* raised in small and medium sized polybags (15 cm x10 cm and 23 cm x15 cm) established rapidly and showed higher root : shoot ratio (Matin and Banik, 1993).

The literature cited above indicate positive effect of different containers on growth attributes of tree seedlings. Eventhough some results are negative, majority of the experiments revealed the influence of containers on seedling production.

2.2.2 Effect of Rooting Media on Growth Attributes of Tree seedlings

The success of containerised nursery is equally governed by choice of growing media, preferably the locally available material.

2.2.2.1 Effect of Rock Powder on Seedling Growth

Use of sand in potting mixture is uneconomical due to shortage in availability and exhorbitant cost. Substituting sand with rock powder, a waste material obtained from the stone quarries, is more economical now a days (Thankamany et al., 2008).

According to Oldfield (1999), igneous rocks like basalt rocks are ideal for remineralisation process because they are rich in essential mineral elements such as Fe, Mn, Ca and Mg and they weather quickly. Rose (2008) suggested that the recommended dose of inorganic fertilisers for coleus could be reduced to half provided it was applied along with rock dust @ 10 t ha^{-1} and this treatment combined with FYM @ 10 t ha^{-1} produced highest yield and dry matter content of plant parts .

Thankamany et al. (2008) noticed that the rate of leaf production, leaf area and biomass of rooted cuttings of black pepper were higher for combinations of soil, rock dust and FYM in 2:1:1 proportion. Campe et al. (1997) pointed out that basalt rock dust increased the soil available Ca, Mg and K contents and slightly increased the soil pH in lettuce production.

2.2.2.2 Effect of Bio Inoculants (Rhizobium and AMF) on production of tree seedlings

In view of the possible use of biofertilizers for quality seedling production in forest nurseries, this title discusses its application with respect to the use of Rhizobia and AMF.

Arbuscular Mycorrhizal Fungi (AMF) symbiosis enhances the host roots' ability to absorb less mobile or soluble minerals such as P, Cu and Zn from the soil and such plants are better nourished and better adapted to their environment. The AMF association provides the plant with increased protection against environmental stress including cold, salinity, drought and pollution and reduction in incidence of root diseases and harmful effects of certain pathogenic agents (Gupta et al., 2007). Thapar et al. (1992) observed that *Saraca asoca* had the association of AM fungi.

According to Rao et al. (2005), inoculation of efficient strain of AMF and Rhizobium prevented the injurious effect of salinity in *Dalbergia sissoo* due to enhanced water and nutrient uptake promoting growth, nodulation and nitrogen fixation. According to Verma and Gupta (1994), the inoculation of AMF and

Rhizobium, singly or in combination, is equally effective or more beneficial than the use of chemical fertilizers in raising the seedlings of *Acacia nilotica.*

2.2.2.2.1 Plant Height

Dadwal and Chouhan (1995) observed that the shoot length, of *Dalbergia sissoo, Leucaena leucocephala, Pongamia pinnata* and *Albizia lebbeck* was greater in Rhizobium inoculated seedlings than in non- inoculated controls.

2.2.2.2.2 Biomass Production

Lal and Khanna (1996) found that the dry matter yields of all the Rhizobium inoculated plants of *Leucaena leucocephala* and *Acacia nilotica* were significantly higher than those of uninoculated controls. Aryal et al. (1999) observed higher biomass production in *Albizia procera, Leucaena leucocephala* and *Albizia lebbeck* by Rhizobium inoculation.

According to Nagaveni and Vijayalakshmi (2002) microbial inoculation using AMF and Azotobacter improved the dry matter production of *Eucalyptus camaldulensis, Wrightia tinctoria* and *Bombax ceiba.*

While inoculated with AMF and transplanted, the seedlings of *Acacia nilotica, Casuarina equisetifolia* and *Leucaena leucocephala* recorded increased biomass of 36, 39 and 41 per cent respectively over control and the colonization was 53, 53 and 58 per cent respectively (Bhat et al., 1994).

Dadwal and Chouhan (1995) reported that the fresh and dry weight of *Dalbergia sissoo, Leucaena leucocephala, Pongamia pinnata* and *Albizia lebbeck* were all greater in Rhizobium inoculated seedlings than in non- inoculated controls.

2.2.2.3 Effect of Organic Manures on Growth Attributes of Seedlings

Ginwal et al. (2001) suggested that compost is the primary ingredient of the root trainer seedling technology for raising *Acacia nilotica* seedlings where 1:4 combination of sand and compost produced the maximum values for the quality parameters of the seedlings. Srivastava et al. (2002) reported that the most effective potting media for the production of quality seedlings of *Acacia mangium, Acacia nilotica, Bambusa arundinacea, Ceiba pentandra, Dalbergia latifolia* and *Eucalyptus camaldulensis* was soil, sand and compost in 1:3:6 proportion.

2.2.2.3.1 Plant Height

Paul and Hossain (1996) found that greater plant height of *Acacia mangium* seedlings was obtained with cowdung without NPK fertilizers at a soil / cowdung ratio of 3:1. According to Biradar et al. (2001), application of FYM facilitated better shoot growth of neem seedlings.

Vadiraj et al. (1993) reported that the use of vermicompost as a component of potting mixture in cardamom nursery helped in increasing seedling height in a short span of time. Krishnakumar et al. (1994) observed better height of seedlings in cardamom nursery due to the use of vermicompost in potting medium.

According to Vinodini et al. (2005), medicinal plants like *Coleus aromaticus* and *Eclipta alba* registered maximum shoot length when grown under 100 per cent degraded coir pith. Suharban et al. (2004) reported increased plant height of Anthurium when grown under equal proportion of coarse sand, coconut husk and coir pith or coarse sand, coconut husk, dry cow dung and coir pith.

2.2.2.3.2 Root Length

According to Biradar et al. (2001), application of FYM facilitated better root growth of neem seedlings. Vinodini et al. (2005) observed maximum root length in medicinal plants like *Coleus aromaticus* and *Eclipta alba* when grown under 100 per cent degraded coir pith.

2.2.2.3.3 Biomass Production

Vadiraj et al. (1993) demonstrated the use of vermicompost as a component of potting mixture in cardamom nursery for increasing dry matter production in a short span of time. Paul and Hossain (1996) identified greater dry matter production of *Acacia mangium* seedlings by using cowdung without NPK fertilizers at a soil / cowdung ratio of 3:1.

The literature reviewed clearly indicate that under the influence of different rooting media the biomass accumulation and quality parameters of seedlings are higher.

2.3 MICRO SITE ENRICHMENT TECHNIQUES

Low water holding capacity, poor soil water retention, high percolation rate leading to washing away of essential plant nutrients are some of the major constraints in the establishment of tree seedlings in rainfed areas.

Water intake of soil can be increased by improving soil physical properties such as organic matter content, infiltration rate, permeability, bulk density, 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).

2.3.1 Effect of Micro Site Enrichment on Soil Moisture Status

Organic manures and soil amendments play an important role in soil water conservation. Coir pith application to the soil increases the water holding capacity and brings about favourable changes in drainage, and soil reconditioning (Ravindranath, 1991).

According to Rejani and Yadukumar (2006), coconut husk burial in cashew plantations increased the soil moisture content and reduced annual runoff. Ramanathan (1990) reported that coconut husk buried in a circular trench of 30 cm depth and 1.8 m away from the coconut palm in 2- 3 layers with fibrous end facing upwards conserved the moisture during rainy season.

Bhaskaran and Saravanan (1997) noticed a spectacular increase in the water holding capacity of coir pith based potting mixture. Coir pith absorbs water in the range of 400- 600 per cent of its weight and releases it to soil very slowly (Salam et al., 2004). Kumar et al. (2006) demonstrated prolonged soil moisture availability due to soil moisture conservation treatments like application of composted coir pith, FYM and husk burial which enhanced photosynthetic efficiency as well as sink capacity.

2.3.2 Effect of Micro Site Enrichment (Husk Burial and Use of FYM, Vermi compost and Composted Coir pith) on Seedling Growth Attributes

2.3.2.1 Plant Height

Saxena (2003) reported that the potting mixtures, i.e soil, sand and FYM in 1:2:2 and 1:2:1 ratios recorded higher plant height of *Dalbergia sissoo* seedlings. It was further observed that seedling height was increased on increasing FYM in all the combinations of potting mixture. According to Rejani and Yadukumar (2006), coconut husk burial in cashew plantations increased plant height. Biradar et al. (2001) identified that whenever vermicompost was more than 25 per cent in the potting media mix, higher shoot growth and subsequently higher leaf area were evident in neem seedlings.

2.3.2.2 Collar Diameter

Navamaniraj et al. (2008) noticed that the potting mixture consisting of soil, vermicompost and sand in 2:1:1 proportion enhanced the seedling stem girth of *Bixa orellana.* Saxena (2003) observed that the potting mixtures, i.e soil, sand and FYM in 1:2:2 and 1:2:1 ratios recorded higher collar girth of *Dalbergia sissoo* seedlings.

2.3.2.3 Dry Matter Production

The potting mixtures, i.e soil, sand and FYM in 1:2:2 and 1:2:1 ratios recorded higher dry weight of *Dalbergia sissoo* seedlings (Saxena, 2003). Navamaniraj et al. (2008) found that the potting mixture consisting of soil, vermicompost and sand in 2:1:1 proportion enhanced the seedling stem girth of *Bixa orellana.*

2.3.3 Effect of Micro Catchments on Soil Moisture Status

The smaller rain water catchments built around the plants are called micro catchments. Land configuration practices make the catchments easy to harvest and conserve rain water. Gupta et al. (1993) recommended that when 20 per cent inter row slope was given during the planting of neem seedlings, better moisture conservation resulted, leading to better field establishment. Arora and Mohan (1994) identified effective moisture conservation in Doon valley through the practice of micro catchments.

Gupta et al. (2000) compared different micro catchments such as pits

(45 cm x 45 cm x 45 cm), saucers of 2.5 m diameter, trench- cum- mound, trench and mound and deep ploughing where maximum soil moisture storage was under micro catchments compared to control.

2.3.4 Effect of Micro Catchments on Plant Growth

When 20 per cent inter row slope was given during the planting of neem seedlings, better establishment and maximum growth occurred (Gupta et al., 1993). Gupta et al (2000) noticed significant increase in plant height, collar girth and yield of *Albizia lebbeck* under different micro catchments such as pits (45 cm x 45 cm x 45 cm), saucers of 2.5 m diameter, trench- cum- mound, trench and mound and deep ploughing where ring pits recorded maximum over other micro catchments. Ghosh and Mathew (2002) suggested the 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, which was efficient in *in situ* rain moisture conservation as evidenced by better growth, yield and fruit quality of aonla at initial stage.

2.3.5 Effect of Vertical Mulching on Soil Moisture Status

A modification of traditional mulching called vertical mulching helps to reduce surface runoff by increasing infiltration. Trenches are dug at 5- 10 m intervals depending on slope at sizes of 30 x 60 cm across the slope on grade. They are filled with stalk or organic residue materials which allow better water intake (Reddy, 2010).

Ghosh and Bauri (2002) observed the effect of vertical mulching on yield and physico - chemical characteristics of mango fruits. Rain water harvesting by opening circular trenches around the trees at 6 feet distance with 9 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.

Adhikari et al. (2004) identified the effect of vertical mulch on runoff and soil loss in black soils. The results revealed that vertical mulching with sorghum stover controlled the overland flow which in turn reduced the runoff from 45 to 30 per cent for 1 per cent slope and 62 to 57 per cent for 2 per cent slope.

The preceding literature indicate that micro site enrichment techniques have positive effect on establishment and growth of seedlings. Literature on different in situ rain water harvesting and conservation techniques like, micro site enrichment, micro catchment and vertical mulching plays an important role in plant establishment and nutrition.

2.4 IRRIGATION SCHEDULING

An ideal irrigation schedule for optimum yield must indicate correct timing and amount of irrigation water at each irrigation (Reddy and Reddy, 2005).

2.4.1 Water saving methods of irrigation

2.4.1.1 Effect of Drip Irrigation on Water Use Efficiency

Drip irrigation system ensures considerable saving of irrigation water and high water application efficiency (Majumdar, 2006). Raveendran (1983) observed 80 per cent improvement in water use efficiency in drip irrigation system. According to Ali and Patnaik (1998) and Dhanapal et al. (1999), drip irrigation saves water upto an extent of 20 to 70 per cent by reducing evaporation, runoff losses, deep percolation and by creating optimum air and moisture levels in soil and root zone throughout the growing period, which promotes healthier and improved root penetration. Upadhyay (1985) and Sivanappan et al. (1987) estimated 75 per cent saving of irrigation water in drip as compared to control in banana. Dhanapal et al. (1999) explained the saving of 80 man days of labour per hectare by the adoption of drip irrigation compared to basin irrigation. Sivanappan (2004) observed that drip irrigation could save water upto 50 to 70 per cent and increased yield of coconut by 30 per cent.

2.5 SURFACE MULCHING

Acharya and Sharma (1994) observed that the bulk density of the top soil (0- 15 cm depth) was significantly reduced by mulch treatments. The reduction might be due to the decomposition of mulch materials resulting in top soil becoming more friable. Use of organic mulches reduced evaporation, augmented water retention capacity and improved crop production through improvement in soil structure and physical environment.

According to Gupta and Gupta (1986), the reduced evaporation caused by residue mulching on the soil surface is due to the improvement in soil moisture content in different soil layers.

Nath and Sharma (1992) found that organic mulching was helpful in conserving better soil moisture and maintaining optimum soil temperature. Tripathi and Bhan (1993) opined that mulching reduced the moisture loss by improving its availability to the plant at later stages of crop growth.

2.5.1 Effect of coconut husk mulching on physical characteristics and moisture status of soil

Coconut husk is a good source of plant nutrients and contains 0.23 % N, 0.04 % P_2O_5, 0.78 % K_2O, 0.08 % CaO and 0.05 % MgO on dry weight basis and it has positive effects on soil structure and moisture retention capacity

(Shanmugam, 2003). Salam et al. (2004) and Shanmugam (2003) identified husk burial in coconut gardens raised under unirrigated conditions and subjected to drought was beneficial to the palms and the effects lasted for about 5 to 6 years. Husks acted as a water reservoir in the soil and palms utilised the moisture retained by the husks at the time of moisture stress. A fully soaked husk was able to retain water about 6 to 8 times its weight.

Venkitaswamy and Khan (2004) found that surface mulching with coconut husk in the 1.8 m basin of coconut reduced the evaporation losses and increased the irrigation interval by 3.5 days. Vincent et al. (2002) noticed the physiological parameters such as stomatal resistance, transpiration rate, proline content and relative water content were significantly higher in coconut palm where husk burial was practiced compared to control.

2.6 EFFECT OF MOISTURE STRESS ON PLANT GROWTH

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. Counting the moisture stress injuries, it becomes obvious how it affects the physiological parameters and yield of the crop.

Mtui et al. (1981) opined that the decrease in soil moisture resulted in reduced plant water status and stomatal conductance leading to elevated leaf temperature. Ides et al. (1978) suggested that leaf temperature is an indirect measure of plant water stress. Transpiration takes place at potential rates and foliage remains relatively cool, when the plants are well supplied with water. Moisture deficit situation created a decline in transpiration rate and the concomitant increase in leaf temperature resulted in lowering of photosynthetic rate and consequent decline in total biomass production.

Itoh and Kamura (1986) identified that stress reduces leaf water potential, stomatal conductance and transpiration. Ackerson et al. (1977) observed that stomatal resistance increased in response to leaf water potential, which was necessary to maintain water flux through the plant in order to sustain growth. According to Rajagopal et al. (1989), coconut palms irrigated at IW/CPE ratio of 0.5 experienced severe moisture stress and it resulted in greater stomatal resistance (111%), transpiration rate (10%), leaf water potential (68%) and reproductive dry matter production (22%) compared with well watered palms and the palms irrigated at IW/CPE ratio of 1.0 maintained normal water relations.

Islam et al. (1998) noticed higher relative leaf water content for irrigated condition than rainfed condition. At the same time, Elamathi and Singh (2001) and Sharma et al. (2003) observed higher values of relative leaf water content in the monsoon than summer at all the stages of crop growth. According to Sarker et al. (2001), the rainfed wheat plants had lower relative leaf water and chlorophyll content compared to irrigated crop and as drought intensified, differences between the irrigated and the rainfed plants with respect to all these characters increased. The RLWC values of the irrigated plants were significantly higher in the morning but lower values were found at noon, showing some recovery in the afternoon.

2.7 EFFECT OF PLANT GROWTH SUBSTANCES ON BARK REGENERATION

By practice, the bark of ashoka trees above 20 years old is extracted for drug making (Mathew et al., 2007). In tree crops, the wound phellogen made tangential continuity with the original phellogen in the virgin bark and functioned as a single phellogen. Vasular cambial activity was enhanced due to wound stimulus and the newly differentiated sieve tubes and ray cells were larger in size. The first periderm was functional only for a short period of time, after which a new meristematic zone developed in the inner tissues. Virgin and renewed bark differed in the proportion of soft and hard bark, amount and distribution of sclereids, tannin cells and crystals (Thomas et al., 1995).

According to Hathway (1959), tannin accumulates in young plants during active photosynthesis and the enhanced level is maintained for a considerable period of time. However, proportionate increase in tannin level is not reported with increase in age of trees.

Pang et al. (2008) noticed that indole acetic acid applied @ 1000 ppm on wound surface area of *Eucommia ulmoides* (a traditional Chinese medicinal tree) after girdling, accelerated the sieve elements differentiation.

Substituted phenoxy acetic acid brings positive effect on bark renewal which is directly proportional to the concentration of stimulant applied and it is possible to control the degree of bark regeneration (Anliker and Scanlon, 1965).

Materials and Methods

3. MATERIALS AND METHODS

Three separate experiments were carried out at the Instructional Farm attached to College of Agriculture, Vellayani to develop agro techniques for growth promotion and increasing bark yield in ashoka. The nursery trial was conducted to standardize root trainer techniques for improving seedling growth potential of ashoka seedlings during the period from 15.6.2009 to 15.12.2009. Two field experiments were also conducted to develop sustainable rain water harvesting and conservation measures to extend the period of stored moisture availability for establishment and early growth and to evolve techniques for rapid stem bark regeneration using plant growth substances from 21.3.2009 to 9.4.2010 and 2.7.2009 to 10.4.2010 respectively.

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

3.1 MATERIALS

3.1.1 Experimental Site

The experiments were conducted at the Instructional Farm attached to College of Agriculture, Vellayani. The farm is located at 8^0 5' N latitude and 76^0 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 and moisture characteristics of the soil are summarized in Table 1 and chemical properties in Table 2.

3.1.3 Climate and Season

The weather data recorded during March '09 to March '10 are given in Appendix and graphically presented in Fig. 1. The abstract of weather data is given in Table 3.

Table 1. Mechanical composition and moisture characteristics of soil

Particulars	Content	Method used
A. Mechanical composition		
Coarse sand, %	16.4	
Fine sand, %	31.5	Bouyoucos hydrometer method (Bouyoucos, 1962)
Silt, %	25.8	
Clay, %	26.3	
B. Soil moisture characteristics		
Particle density, g cc $^{-1}$	2.3	Pycnometer method (Black, 1965)
Bulk density, g cc $^{-1}$	1.5	Core method (Gupta and Dakshinamoorthi, 1980)
Maximum water holding capacity, %	23.7	
Porosity, %	31.1	
Field capacity, %	21.9	
Permanent wilting point, %	9.1	

Table 2. Chemical properties of soil

Particulars	Content	Method used
Organic carbon, %	0.36 (low)	Walkley and Black rapid titration method (Jackson,1973)
Organic matter, %	0.62	
Available nitrogen, kg ha^{-1}	225.6 (low)	Alkaline KMnO4 method (Subbiah and Asija, 1956)
Available phosphorus, kg ha^{-1}	38.8 (high)	Bray's colourimetric method (Jackson, 1973)
Available potassium, kg ha^{-1}	82.5 (medium)	Ammonium acetate method (Jackson, 1973)
Soil reaction (pH)	5.2	pH meter with glass electrode (Jackson, 1973)

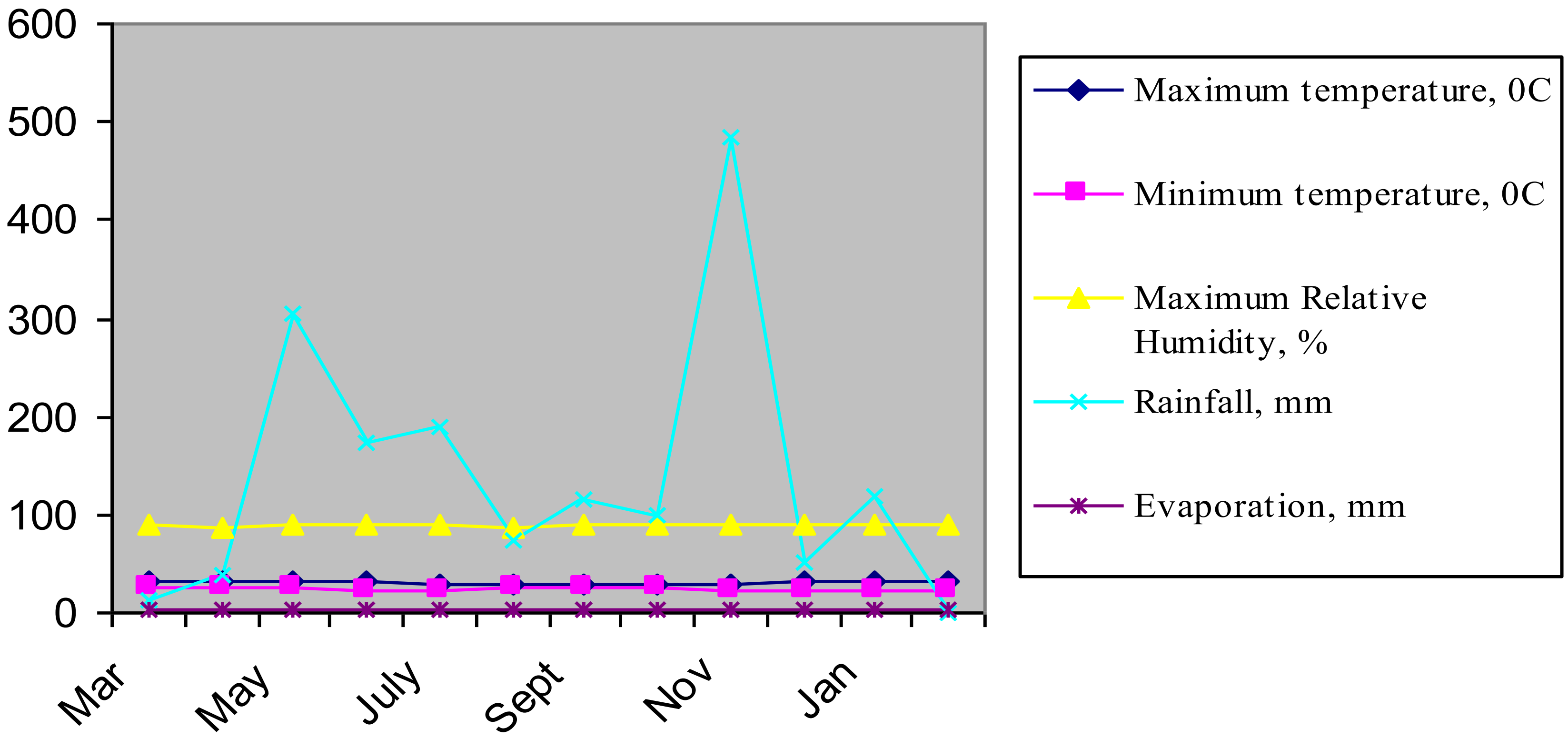


Fig 1. Weather data during the experimental period (3/09 to 3/10)

Table 3. Abstract of the weather data during the experimental period (3 / 09 to 3 / 10)

Weather elements	Range	Mean
Maximum temperature ^{0}C	29.5 – 33.3	31.18
Minimum temperature ^{0}C	23.5 – 26.0	24.36
Annual rainfall (mm)	---	1669.2
Relative humidity (%)	79.45 – 89.7	84.58
Monthly evaporation (mm)	2.8 – 4.4	3.53

3.2 METHODS

3.2.1 Nursery Trial - Techniques for Quality Planting Material Production

The main objective of the trial was to standardize the root trainer techniques for improving the seedling growth potential of ashoka seedlings.

3.2.1.1 Design and Layout

Design: Factorial CRD

Replication: 4

Number of plants per treatment: 8

Layout plan is given in Fig. 2.

3.2.1.2 Treatments

A: Root trainer techniques (4)

R_1: Root trainer (individual tubes)

R_2: Root trainer (block containers)

R_3: Poly bag (15x10 cm)

R_4: Mud pot (15X10 cm)

B: Rooting media (4)

M_1: Potting mixture (cow dung, sand and soil in 1:1:1 proportion)

M_2: M_1 + Dual inoculation with Rhizobium and AMF

M_3: M_2 + Rock powder (potting mixture: rock powder – 4:1)

M_4: M_3 + Mixture of vermi compost, FYM and composted coir pith (1:1:1) (potting mixture: rock powder: mixture of vermi compost, FYM and composted coir pith – 4:1:4)

3.2.1.3 Treatment Combinations

The treatment combinations (4x4=16) are listed in Table 4.

3.3 NURSERY DETAILS

3.3.1 Collection and Storage of Seeds

Mature seeds were collected in June 2009 from the herbal garden of Instructional Farm, Vellayani and preserved for two weeks prior to sowing.

3.3.2 Imposition of Treatments

The treatments were imposed while sowing of seeds in June 2009.

3.3.2.1 Containers

Four containers were used for the nursery trial.

3.3.2.1.1 Fabrication of Container (Individual and block)

Flexible irrigation hose of 5 cm inner diameter discarded due to wear and tear

Table 4. Treatment combinations

No.	Treatment Combinations
T_1	R_1M_1: Root trainer (individual tubes) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion)
T_2	R_1M_2: Root trainer (individual tubes) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF
T_3	R_1M_3: Root trainer (individual tubes) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1)
T_4	R_1M_4: Root trainer (individual tubes) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1) + Mixture of vermi compost, FYM and composted coir pith (1:1:1) (potting mixture: rock powder: mixture of vermi compost, FYM and composted coir pith – 4:1:4)
T_5	R_2M_1: Root trainer (block containers) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion)
T_6	R_2M_2: Root trainer (block containers) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF
T_7	R_2M_3: Root trainer (block containers) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1)
T_8	R_2M_4: Root trainer (block containers) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1) + Mixture of vermi compost, FYM and composted coir pith (1:1:1) (potting mixture: rock powder: mixture of vermi compost, FYM and composted coir pith – 4:1:4)
T_9	R_3M_1: Poly bag (15x10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion)
T_{10}	R_3M_2: Poly bag (15x10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF
T_{11}	R_3M_3: Poly bag (15x10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1)
T_{12}	R_3M_4: Poly bag (15x10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1) + Mixture of vermi compost, FYM and composted coir pith (1:1:1) (potting mixture: rock powder: mixture of vermi compost, FYM and composted coir pith – 4:1:4)
T_{13}	R_4M_1: Mud pot (15X10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion)
T_{14}	R_4M_2: Mud pot (15X10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF
T_{15}	R_4M_3: Mud pot (15X10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1)
T_{16}	R_4M_4: Mud pot (15X10 cm) and Potting mixture (cow dung, sand and soil in 1:1:1 proportion) + Dual inoculation with Rhizobium and AMF + Rock powder (potting mixture: rock powder – 4:1) + Mixture of vermi compost, FYM and composted coir pith (1:1:1) (potting mixture: rock powder: mixture of vermi compost, FYM and composted coir pith – 4:1:4)

were made into tubes of 40 cm length and four slits were made from the base to a vertical height of 5 cm with a sharp blade. The cut ends were swirled over the flame for a few seconds to make it flexible and wrapped with GI wire to change the shape of the basal portion in the form of a cone with an opening of 2 cm diameter. After removing the metal wire, tubes were immersed in water for seasoning. Inside the tube, four longitudinal ribs were provided at equal distances for training the roots vertically down. The height of the root trainer was adjusted by trimming the top so as to hold 350 cc of rooting media. Each root trainer was mounted separately on a stand. Block containers were made by tightly tieing eight individual root trainers fabricated as above with a GI wire so as to form a single unit.

3.3.2.1.2 Poly Bags

Poly bags of size 15 x 10 cm to hold 1000 cc of rooting medium were selected for the trial.

3.3.2.1.3 Mud Pots

Mud pots of size 15 x 10 cm to hold 1000 cc of rooting medium were selected for the trial.

3.3.2.2 Preparation of Rooting Media and Inoculation

3.3.2.2.1 Potting Mixture

Soil, sand and cow dung were mixed in equal proportion to prepare potting mixture.

3.3.2.2.2 Potting mixture + Dual Inoculation with Rhizobium and AMF

One kg Rhizobium was mixed with starch solution (2.5 per cent) and the seeds were soaked for 30 minutes. The treated seeds were dried under shade and sown immediately. Soil, sand and cow dung were mixed in equal proportion and filled in the root trainers. Small planting holes were made in the containers and applied AMF @ 5 g per hole followed by sowing of treated seeds.

3.3.2.2.2 Potting mixture + Dual Inoculation with Rhizobium and AMF + Rock powder

Potting mixture and rock powder were mixed in 4: 1 proportion and filled in the containers. Rhizobium and AMF inoculation were done in the same manner as above.

3.3.2.2.2 Potting mixture + Dual Inoculation with Rhizobium and AMF + Rock powder + Mixture of vermi compost, FYM and composted coir pith

Vermi compost, FYM and composted coir pith were taken in equal proportion to prepare compost mixture. Potting mixture, rock powder and compost mixture were mixed in 4:1:4 proportion and filled in the containers. Rhizobium and AMF inoculation were done in the same manner as above.

3.3.3 After Care

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

3.4 OBSERVATIONS

Observations were taken at 45, 90 and 135 DAS. The methods followed for recording observations are as follows.

3.4.1 Growth Characters

Growth characters were recorded at 45 days interval from randomly selected observation plants and mean values were worked out.

3.4.1.1 Seedling Height

The height of the seedling was recorded from the base of the plant to the tip.

3.4.1.2 Number of Leaves

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

3.4.1.3 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 Root Parameters

Representative samples were uprooted at 135 DAS. They were thoroughly washed in running water to remove the adhering soil particles. The procedures described by Misra and Ahmed (1989) were followed for the estimation of root parameters.

3.4.2.1 Root Number

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

3.4.2.2 Root Weight

The roots were washed, cleaned, weighed and dried in an oven at 75 ^{0}C and dried to a constant weight. It was expressed as g plant^{-1}

3.4.2.3 Root Length

Both vertical and lateral length of the roots were measured and expressed in cm.

3.4.2.4 Root Spread

Measured the maximum spread of roots and expressed in cm.

3.4.3 Growth Indices

3.4.3.1 Root Growth Potential

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

3.4.3.2 Root : Shoot Ratio

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

3.4.3.3 Sturdiness Quotient

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

3.4.3.4 Crop Growth Potential

$$CGP = \frac{\text{Total dry matter production}}{\text{SQ + Shoot : root ratio}}$$

3.4.4 Dry Matter Production

The seedlings were uprooted at 135 DAS. Roots, leaves and stem were separated and dried to constant weight at 75 ^{0}C in a hot air oven. The dry weight of all the plant parts were recorded separately and expressed in g plant^{-1}. Total dry matter production was worked out from leaf, stem and root dry matter.

3.4.5 Economic Analysis

Economics of establishment of nursery was worked out after taking into account the cost of cultivation and prevailing market price of seedlings. For working out the cost involved, different variable cost items like containers, seed, bio inoculants, FYM, compost, rock powder, irrigation, labour charges, etc. were considered at prevailing market rate during 2009-2010.

Cost of the seedling was fixed based on seedling growth potential. The prevailing market rate of Rs. 10 was given to seedlings showing maximum SGP of 1.95. The factor, i.e 5 (price divided by maximum SGP i.e 10 /1.95 = 5) was multiplied with corresponding SGPs to fix the seedling price. The benefit: cost ratio was calculated as,

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

3.4.6 Statistical Analysis

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

3.5. FIELD EXPERIMENTS – MICRO SITE ENRICHMENT TECHNIQUES FOR GROWTH PROMOTION

The main objective of this experiment was to develop sustainable rain water harvesting and conservation measures to extend the period of stored moisture availability for establishment and early growth of ashoka seedlings.

3.5.1 Design and Layout

Design: RBD
Replication: 3
Spacing: 2 x 2 m
Plot size: 4 x 4 m

Layout plan is given in Fig. 2.

3.5.2 Treatments

A: In situ rain water harvest (4)

W_1: Micro site enrichment
W_2: W_1 + Micro catchment

W_3: W_2 + Vertical mulching

W_4: Package of practices recommendations.

B: Irrigation (2)

S_1: Irrigation at 50 % depletion of moisture

S_2: Control (life saving irrigation)

3.5.3. Treatment Combinations (4 x 2 =8)

The treatment combinations are listed in Table 5.

Table 5. Treatment combinations

No.	Treatment combinations
T_1	W_1S_1- Micro site enrichment and irrigation at 50 % depletion of moisture
T_2	W_1S_2- Micro site enrichment and life saving irrigation
T_3	W_2S_1- Micro site enrichment + Micro catchment and irrigation at 50 % depletion of moisture
T_4	W_2S_2- Micro site enrichment + Micro catchment and life saving irrigation
T_5	W_3S_1- Micro site enrichment + Micro catchment + Vertical mulching and irrigation at 50 % depletion of moisture
T_6	W_3S_2- Micro site enrichment + Micro catchment + Vertical mulching and life saving irrigation
T_7	W_4S_1- Package of practices recommendations and irrigation at 50 % depletion of moisture
T_8	W_4S_2- Package of practices recommendations and life saving irrigation

T_{8}	T_{2}	T_{12}	T_{4}	T_{1}	T_{6}	T_{16}	T_{4}	T_{13}	T_{1}	T_{9}	T_{11}	T_{6}	T_{11}	T_{2}	T_{14}
T_{11}	T_{14}	T_{7}	T_{8}	T_{7}	T_{4}	T_{5}	T_{3}	T_{10}	T_{12}	T_{5}	T_{16}	T_{16}	T_{10}	T_{14}	T_{2}
T_{3}	T_{7}	T_{3}	T_{4}	T_{3}	T_{1}	T_{10}	T_{2}	T_{15}	T_{14}	T_{9}	T_{11}	T_{5}	T_{8}	T_{12}	T_{15}
T_{13}	T_{10}	T_{13}	T_{5}	T_{13}	T_{16}	T_{8}	T_{7}	T_{9}	T_{15}	T_{15}	T_{6}	T_{12}	T_{9}	T_{6}	T_{1}

1. Techniques for quality planting material production.

$W_{4}S_{1}$	$W_{1}S_{2}$	$W_{4}S_{2}$	$W_{3}S_{2}$	$W_{1}S_{1}$	$W_{3}S_{1}$	$W_{2}S_{2}$	$W_{2}S_{1}$

$W_{3}S_{1}$	$W_{2}S_{1}$	$W_{4}S_{1}$	$W_{1}S_{2}$	$W_{4}S_{2}$	$W_{2}S_{2}$	$W_{1}S_{1}$	$W_{3}S_{2}$

$W_{2}S_{2}$	$W_{4}S_{2}$	$W_{1}S_{2}$	$W_{4}S_{1}$	$W_{1}S_{1}$	$W_{2}S_{1}$	$W_{3}S_{2}$	$W_{3}S_{1}$

2. Micro site enrichment techniques for growth promotion.

T_{4}	T_{2}	T_{3}	T_{1}
T_{1}	T_{4}	T_{1}	T_{2}
T_{3}	T_{2}	T_{3}	T_{4}

3. Techniques for increasing bark yield

Fig 2. Layout plans

3.6 FIELD CULTURE

3.6.1 Land Preparation

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

3.6.2 Planting

Seedlings naturally germinated around the trees were collected and transplanted in the poly bags filled with potting mixture during December 2008 and maintained in the herbal garden under partial shade. Uniform seedlings of three months age were selected and planted in the field on 21st March 2009 at a spacing of 2.0 x 2.0 m as per the technical programme.

3.6.3 Imposition of Treatments

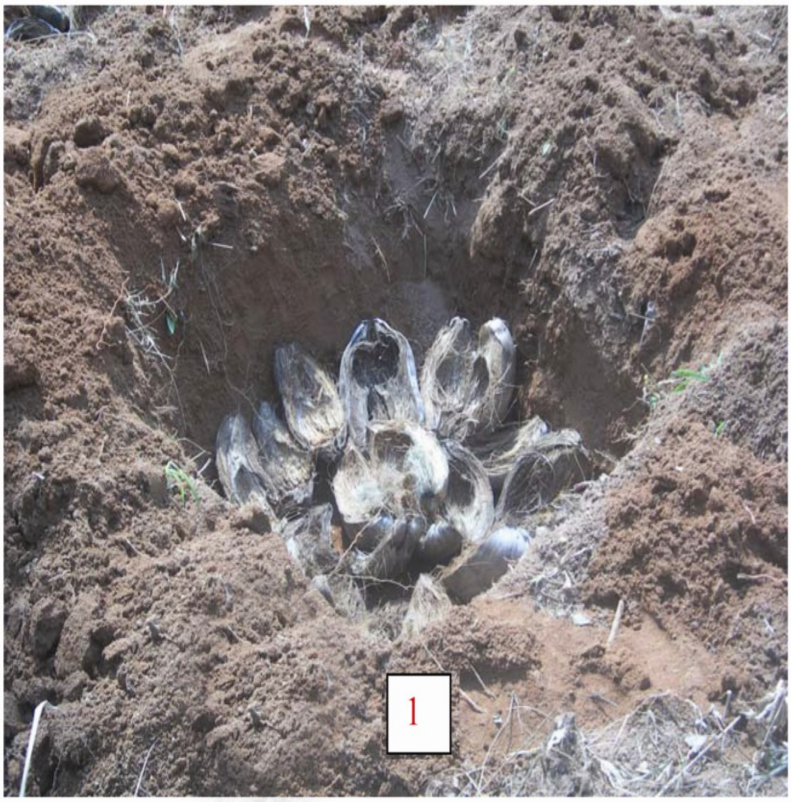
In situ rain water harvesting and irrigation treatments were given as per the technical programme.

3.6.3.1 Micro Site Enrichment

Pits of 45 cm x 45 cm x 45 cm size were taken at a spacing of 2 x 2 m and a layer of coconut husk was spread at the bottom followed by filling with a mixture of enriched vermi compost, coir pith compost and layering mixture upto the soil surface. A seedling was planted at the centre of the pit and a layer of coconut husk was spread as surface mulch (Plate 1).

3.6.3.2 Micro Catchment

Planting of seedling was done as in micro site enrichment treatment. The



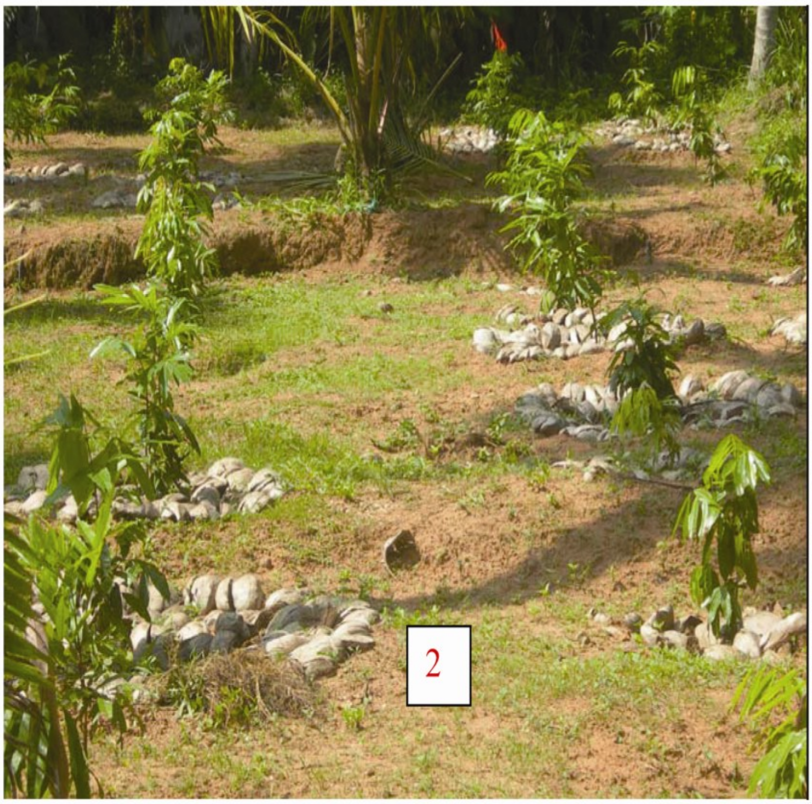


Plate 1 *In situ* rain water harvests 1. Micro site enrichment 2. Micro catchment

Plate 1 In situ rain water harvests
1. Micro site enrichment 2. Micro catchment

land configuration around the seedlings was modified by taking rectangular basins of size 2 m x 2 m with slope inwards and towards the seedlings for catching and conserving rainfall. The entire basin area was mulched with coconut husk (Plate 1).

3.6.3.3 Vertical Mulching

Planting of seedling and land configuration were carried out as in micro catchment treatment. Circular trench was taken around the seedlings by excavating soil beyond a radius of 45 cm from the base of the plant, 15 cm wide and 30 cm deep. Then the trench was filled with coconut husk facing the concave side upwards.

3.6.3.4 Package of Practices Recommendations

45 cm x 45 cm x 45 cm size pits were taken and seedlings were planted after filling with top soil, sand and cow dung.

3.6.3.5 Irrigation

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

Volume of water required = depth of irrigation water x wetted area

Drip irrigation system was installed after the planting of seedlings, during March 2009. One pressure compensating type dripper having discharge rate of 4 litres per hour was installed per plant and the system was operated for 3 hours 45 minutes (15 l) for the first six months after planting and 6 hours (24 l) thereafter. The details of irrigations are given in Table 6.

Table 6. Details of irrigation given during the experimental period (3/09 to 3 /10)

Treatments	No. of irrigations	Irrigation requirement (l $plant^{-1}$)	Pretreatment irrigation (l $plant^{-1}$)	Effective rainfall (l $plant^{-1}$)	Total water requirement (l $plant^{-1}$)
W_1S_1	25	465	30	207	702
W_1S_2	3	45	30	246	321
W_2S_1	17	318	30	201	549
W_2S_2	3	45	30	231	306
W_3S_1	14	264	30	183	477
W_3S_2	3	45	30	207	282
W_4S_1	30	558	30	264	852
W_4S_2	5	75	30	483	588

The crop was irrigated from 24.3.'09 to 31.3.'10. Pretreatment irrigation was given to bring the soil to the field capacity. The quantity of water required per plant to bring the basin area to field capacity was calculated based on the following formula by taking the depth of irrigation as 2.40 cm for the first sixth and 3.84 cm for the second six months.

$$d = \frac{FC - PWP}{100} \times \frac{50}{100} \times Asi \times Di$$

Where, d = depth of irrigation water in mm.

FC = Field capacity, %

PWP = Permanent wilting point, %

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

Di = Depth of root zone, cm

Based on destructive sampling conducted on bulk ashoka plants of 3 and 6 months age, the depth of root zone was estimated as 25 cm and 40 cm for the first and second half year periods respectively. Therefore,

volume of water applied per seedling = depth of water applied x Basin area

3.6.3.6 Control (life saving irrigation)

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

3.7 OBSERVATIONS

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

3.7.1 Morphological Characters

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

3.7.1.1 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.

3.7.1.2 Number of Functional Leaves

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

3.7.1.3 Number of Branches

The number of branches per plant were counted and recorded.

3.7.1.4 Collar Girth

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

3.7.2 Canopy Architecture

3.7.2.1 Bole Height

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

3.7.2.2 Canopy Height

Canopy height was measured from the bottom of the foliage to the top of the canopy and expressed in cm.

3.7.2.3 Canopy Width

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

3.7.2.4 Canopy Size

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

3.7.3 Root Studies

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

3.7.3.1 Root Number

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

3.7.3.2 Root Weight

The roots were washed, cleaned, weighed and dried in an oven at 75 ^{0}C for about 10 – 20 hours and weighed. It was expressed as g plant $^{-1}$

3.7.3.3 Root Length

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

3.7.3.4 Root Spread

Measured the maximum spread of roots and expressed in cm.

3.7.3.5 Root Volume

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

3.7.3.6 Root Surface Area

Root surface area was calculated using the formula,

$$\text{Area} = 2\,[\text{volume (cm}^3) \times 3.14 \times \text{length (cm)}]^{1/2}$$

3.7.4 Growth Indices

Growth indices except LAI were estimated after one year of planting by destructive sampling.

3.7.4.1 Root Growth Potential, Root : Shoot Ratio, Sturdiness Quotient and Crop Growth Potential

The above growth indices were estimated as furnished under section 3.4.3.

3.7.4.2 Leaf Area Index (LAI)

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

Leaf area was measured by using the formula length x breadth x a correction factor (0.8), which was found out graphically.

3.7.5 Physiological Parameters

Third fully opened leaf from the top was taken as index leaf for recording physiological parameters.

3.7.5.1 Relative Leaf Water Content (RLWC)

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

$$RLWC = \frac{\text{Fresh Weight} - \text{Dry Weight}}{\text{Turgid Weight} - \text{Dry Weight}} \times 100$$

3.7.5.2 Osmotic Potential

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

3.7.5.3 Canopy Temperature

Canopy temperature was measured using an infra red thermo meter between 9 am and 11 am and expressed in degree celsius (^{0}C)

3.7.6 Total Dry Matter Production and Partitioning

The plants were uprooted after one year of planting and roots, stem bark, stem and leaves were separated and dried to a constant weight at 80 ^{0}C in a hot air oven.

The dry weight of all the plant parts were recorded separately and expressed in g $plant^{-1}$. Total dry matter production was worked out from leaf, stem, stem bark and root dry matter.

3.7.7 Biochemical Parameters

3.7.7.1 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.

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

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

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

3.7.7.2 Tannin and Total Phenol Content

Tannin and total phenol content of leaves and stem bark were estimated by the method proposed by Sadasivam and Manickam (1976).

3.7.8 Soil Moisture Studies

3.7.8.1 Soil Moisture

Soil sampling was done using a screw auger at a distance of 15 cm away from the base of the plant to a depth of 20 cm just before and 48 hours after irrigation and the soil moisture worked out gravimetrically.

3.7.8.2 Consumptive Use (Cu) of Water

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

$$Cu = \sum_{1}^{N} (Ep \times 0.6) + \sum_{1}^{n} \frac{(Mai - Mbi)}{100} \times Asi \times Di + ER$$

Where, Cu = Consumptive use of water in mm.

Ep = Pan evaporation value from USWB class A open pan evaporimeter 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.

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

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

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

Di = 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 sampling.

3.7.8.3 Irrigation Requirement

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

3.7.8.4 Water Use Efficiency

Crop water use efficiency (CWUE) and field water use efficiency (FWUE) were worked out using the following formula and are expressed as g m^{-3}

$$CWUE = \frac{\text{Yield}}{\text{Consumptive use}}$$

$$FWUE = \frac{\text{Yield}}{\text{Total water requirement}}$$

3.7.8.5 Water Productivity (WP)

Water productivity was estimated using the formula proposed by Kijne et al. (2003) and expressed as g m^{-3}.

$$WP = \frac{\text{Total biomass}}{\text{Total water depleted}}$$

3.7.8.6 Crop Coefficient (K_c)

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

3.9. FIELD EXPERIMENT - TECHNIQUES FOR INCREASING BARK YIELD

The main objective of the study was to evolve techniques for rapid stem bark regeneration using plant growth substances.

3.9.1 Design and Layout

Design: CRD

Replication: 3

Layout plan is given in Fig. 2.

3.9.2 Treatments

T_1: NAA 50 mg l^{-1}

T_2: Kinetin 50 mg l^{-1}

T_3: Combination of NAA 50 mg l^{-1} and kinetin 50 mg l^{-1}.

T_4: Control

3.9.3 Imposition of Treatments

Ten year old ashoka trees with a uniform bole height of 5 m and canopy height of 4 m were selected for the study. 50 % of the bark from the bole was extracted in alternate strips of 1.5 m length and 3 cm width and plant growth substances were applied on the exposed patches.

3.9.3.1 NAA 50 mg l^{-1}

50 mg NAA was dissolved in distilled water and made up the volume to 1000
ml. This solution was applied to the exposed patches.

3.9.3.2 Kinetin 50 mg l^{-1}

50 mg kinetin was weighed out and made up the volume to 1000 ml and applied as above.

3.9.3.3 Combination of NAA 50 mg l^{-1} and kinetin 50 mg l^{-1}

50 mg l^{-1} solutions of NAA and kinetin were prepared separately, mixed and applied as above.

Plate 2 Effect of growth regulators on bark regeneration
1- Extraction of virgin bark
2- Bark regeneration
3-Extraction of regenerated bark

3.9.3.4 Control

Distilled water was applied on the exposed patches as above.

3.10 OBSERVATIONS

The tested plants were used for recording observations. The methods followed for recording observations are given below.

3.10.1 Bark Yield

After extracting bark from each plant, bark yield was recorded separately.

3.10.2 Bark Regeneration

The regenerated bark was extracted and yield recorded (Plate 2).

3.10.3 Quality Parameters of Bark

The extracted bark before and after the imposition of treatments were used for analysing the quality parameters, i.e. total phenol and tannin contents. The method proposed by Sadasivam and Manickam (1976) was used to determine these constituents.

Results

4. RESULTS

Three separate experiments were carried out at the Instructional Farm attached to College of Agriculture, Vellayani to develop agro techniques for growth promotion and increasing bark yield in ashoka. The nursery trial was conducted to standardize the root trainer techniques for improving the seedling growth potential of ashoka seedlings during the period from 15.6.2009 to 15.12.2009. Two field experiments were also conducted to develop sustainable rain water harvesting and conservation measures to extend the period of stored moisture availability for establishment and early growth and to evolve techniques for rapid stem bark regeneration using plant growth substances from 21.3.2009 to 9.4.2010 and 2.7.2009 to 10.4.2010 respectively.

4.1 TECHNIQUES FOR QUALITY PLANTING MATERIAL PRODUCTION

Effects of root trainer techniques namely, root trainer (individual tubes/ containers - R_1), root trainer (block containers - R_2), poly bags (15 cm x 10 cm - R_3) and mud pots (15 cm x 10 cm - R_4) and rooting media namely, potting mixture (M_1), potting mixture + dual inoculation with Rhizobium and AMF (M_2), potting mixture + dual inoculation with Rhizobium and AMF + rock powder (M_3), potting mixture + dual inoculation with Rhizobium and AMF + rock powder + mixture of vermicompost, FYM and composted coir pith (M_4) were studied to evolve appropriate nursery management techniques for quality planting material production.

4.1.1 Seedling Height

Data on seedling height recorded at 45, 90 and 135 DAS are furnished in Table 7.

At 45 and 90 DAS, R_3 (15.03 and 21.86 cm), which was on par with R_4 (14.38 and 21.31 cm) recorded maximum height and it differed significantly from R_2 (13.28 and 16.91 cm) and R_1 (11.46 and 15.24 cm). R_4 registered maximum seedling height of 33.71 cm at 135 DAS and it was found to be significantly superior to all other treatments.

Rooting media didn't exert any significant difference in seedling height at 45, 90 and 135 DAS. M_4 registered superior values at 45 (14.27 cm) and 135 (28.14 cm) DAS. Interaction effects were insignificant and R_3M_1 at 45 (16.52 cm) and 90 (23.58 cm) DAS and R_4M_4 at 135 DAS (36.45 cm) produced taller seedlings. Mean seedling height ranged from 10.73 cm to 16.52 cm, 13.95 cm to 23.58 cm and 19.78 cm to 36.45 cm at 45, 90 and 135 DAS respectively.

Sowing seeds inoculated with Rhizobium and AMF in mudpots filled with enriched rooting medium containing potting mixture, rock powder and mixture of vermicompost, FYM and composted coirpith was found to be beneficial for the production of taller seedlings.

4.1.2 Collar Girth

Girth measurements recorded at 90 and 135 DAS are given in Table 7.

At 90 DAS, R_4 (1.81 cm) was found to be on par with R_3 (1.77 cm) and registered significant difference from R_2 (1.19 cm) and R_1 (1.18 cm). When compared to other treatments, R_4 (2.78 cm) showed its significant superiority at 135 DAS. Similar to seedling height, collar girth was not found to be significantly influenced by rooting medium. M_1 (1.59 cm) followed by M_2 (1.46 cm) and M_4 (1.46 cm) showed higher values compared to M_3 (1.44 cm).

R_4M_2 (1.90 cm) followed by R_4M_1 (1.88 cm) and R_4M_1 (3.1 cm) followed by R_4M_2 (2.98 cm) registered maximum collar girth at 90 and 135 DAS respectively. Though interaction effects were not significant, mean collar girth values ranged from 1.00 cm to 1.90 cm and 1.25 cm to 3.1 cm at 90 and 135 DAS.

Combined inoculation of seeds with Rhizobium and AMF and sowing in mudpots filled with potting mixture resulted in better collar girth at the time of transplanting.

4.1.3 Leaf Number

Main and interaction effects of treatments on leaf number recorded at 45, 90 and 135 DAS are summarised in Table 7.

At 45 DAS, root trainer techniques had no significant effect on leaf number. However R_2 (2.06) followed by R_1 (1.75) registered maximum number. At 90 DAS, R_4 (4.56) followed by R_3 (4.19) produced maximum number of leaves and were found to be significantly superior to R_1 (3.38) and R_2 (3.19). The trend was almost similar at 135 DAS. However, R_4 (7.00), R_3 (6.50) and R_2 (6.00) were on par. R_1 (5.25) which was on par with R_2 showed the minimum leaf number.

The effect of rooting media on leaf production was not consistent and varied with growth stages. Though not significant, M_1 (2.06), M_3 (4.25) and M_4 (6.38) produced maximum number of leaves at 45, 90 and 135 DAS, respectively. Interaction effects of root trainer techniques and rooting media had no significant effect on leaf number. Mean values ranged from 1.00 to 2.25, 2.75 to 5.25 and 5.00 to 7.75 at 45, 90 and 135 DAS, respectively. R_4M_1 (2.25) followed by R_2M_4 (2.25), R_4M_3 (5.25) followed by R_4M_1 (4.50) and R_4M_1 (7.75) followed by R_3M_1 (7.25) showed higher leaf number at 45, 90 and 135 DAS, respectively. Sowing seeds in mud pots filled with potting mixture was found to improve leaf production.

Table 7. Seedling height (cm), collar girth (cm), number of leaves and leaf area (cm^2) as influenced by root trainer techniques and rooting media.

Treat-ments	Height(cm)			Collar girth (cm)		Leaf No.			Leaf area (cm^2)
	45DAS	90DAS	135DAS	90DAS	135DAS	45DAS	90DAS	135DAS	135DAS
R. Root trainer techniques (4)									
R1	11.46	15.24	21.21	1.18	1.44	1.75	3.38	5.25	426.67
R2	13.28	16.91	21.38	1.19	1.41	2.06	3.19	6.00	479.61
R3	15.03	21.86	30.13	1.77	2.38	1.75	4.19	6.50	588.06
R4	14.38	21.31	33.71	1.81	2.78	1.75	4.56	7.00	842.45
F	7.31**	25.44**	50.02**	74.02**	30.04**	1.11	7.03**	3.56*	9.34**
SE	0.57	0.64	0.89	0.04	0.12	0.14	0.24	0.39	60.45
CD	1.63	1.83	2.53	0.11	0.35	0.41	0.70	1.12	171.68
M. Rooting media (4)									
M1	13.93	19.15	26.61	1.59	2.14	2.06	3.75	5.81	559.03
M2	12.68	18.23	24.64	1.46	2.08	1.69	3.50	6.19	556.70
M3	13.27	18.95	27.03	1.44	1.95	2.00	4.25	6.38	556.36
M4	14.27	18.98	28.14	1.46	1.85	1.56	3.81	6.38	664.70
F	1.49 NS	0.39 NS	2.67 NS	3.04 NS	1.07 NS	2.67 NS	1.59 NS	0.45 NS	0.78 NS
SE	0.57	0.64	0.89	0.04	0.12	0.14	0.24	0.39	60.45
CD	-	-	-	-	-	-	-	-	-
Treatment combinations (RXM=16)									
R1M1	11.10	15.43	22.15	1.30	1.60	2.00	3.25	5.00	415.54
R1M2	11.18	13.95	19.78	1.03	1.35	1.25	2.75	5.25	438.45
R1M3	10.73	16.63	19.98	1.15	1.38	2.00	4.25	5.00	414.05
R1M4	12.85	14.95	22.95	1.23	1.45	1.75	3.25	5.75	438.66
R2M1	12.15	16.63	21.65	1.38	1.60	2.00	3.00	5.00	431.24
R2M2	13.73	18.95	21.30	1.13	1.35	2.00	2.75	6.00	486.41
R2M3	12.25	14.68	20.50	1.00	1.25	2.00	3.25	6.50	430.37
R2M4	15.00	17.40	22.05	1.28	1.45	2.25	3.75	6.50	570.41
R3M1	16.52	23.58	29.28	1.83	2.25	2.00	4.25	5.50	518.89
R3M2	14.28	20.11	27.35	1.78	2.65	2.00	4.25	6.75	575.42
R3M3	14.50	21.57	32.75	1.83	2.25	2.00	4.25	7.25	663.25
R3M4	14.82	22.16	31.13	1.65	2.38	1.00	4.00	6.50	594.70
R4M1	15.94	20.98	33.38	1.88	3.10	2.25	4.50	7.75	870.46
R4M2	11.54	19.91	30.15	1.90	2.98	1.50	4.25	6.75	726.53
R4M3	15.62	22.94	34.88	1.80	2.93	2.00	5.25	6.75	717.76
R4M4	14.41	21.40	36.45	1.68	2.13	1.25	4.25	6.75	1055.0
F	1.44 NS	1.46 NS	0.74 NS	1.89 NS	1.06 NS	1.39 NS	0.58 NS	0.45 NS	0.49 NS
SE	1.52	1.29	1.78	0.08	0.25	0.29	0.49	0.79	120.91
CD	-	-	-	-	-	-	-	-	-

NS – Not significant DAS – Days After Sowing * Significant at 5 per cent * * Significant at 1 per cent

4.1.4 Leaf Area

Main and interaction effects of treatments on leaf area estimated at 135 DAS are furnished in Table 7.

Root trainer techniques influenced leaf area and R_4 (842.45 cm^2) recorded the maximum value which was significantly different from R_1 (426.67 cm^2), R_2 (479.61 cm^2) and R_3 (588.06 cm^2). Effect of rooting media on leaf area was not remarkable. However M4 registered maximum value of 664.70 cm^2. The interaction effects of root trainer techniques and rooting media on leaf area were similar to other biometric characters. Though the values ranged from 414.05 cm^2 to 1055.00 cm^2, interaction had no significant effect on leaf area. R_4M_4 (1055.00 cm^2) followed by R_4M_1 (870.46 cm^2) and R_4M_2 (726.53 cm^2) registered higher values at 135 DAS.

Sowing seeds inoculated with Rhizobium and AMF in mud pots filled with enriched rooting media containing potting mixture, rock powder and mixture of vermicompost, FYM and composted coirpith improved leaf area at 135 DAS.

4.1.5 Seedling Root Characters

Seedling root characters namely, length of tap root (straight, coiled and total), root numbers (classified based on length as short, medium and long), rootlet production and root spread recorded at 135 DAS are furnished in Table 8.

4.1.5.1 Length of Tap root

Total length of tap root was found to be influenced by root trainer techniques and R_1 (31.38 cm) produced significantly longer tap roots which was on par with R_4 (28.70 cm). Root trainer techniques also significantly influenced root coiling and maximum coiling was registered in R_4 (18.96 cm) followed by

R_3 (15.28 cm), whereas R_1 and R_2 produced straight roots free from coiling. 65 per cent of the tap root was coiled in R_4, followed by R_3 (63 %).

Rooting media didn't exert any significant effect on total length of tap root. M_4 (28.67 cm) produced the longest tap root followed by M_3 (28.19 cm), M_2 (27.30 cm) and M_1 (26.03 cm). Significant influence of rooting media on uncoiling was observed and M_4 (20.81 cm) produced maximum length of straight roots followed by M_3 (18.55 cm), M_2 (18.46 cm) and M_1 (18.13 cm). M_4 registered minimum portion of coiled roots of 7.86 cm. Integration of root trainer techniques and rooting media indicated the superiority of treatment combination, R_1M_4 (33.33 cm) in increasing the length of tap root. R_4M_3 (75.74 %) showed maximum coiling whereas R_3M_4 (55.37 %) registered minimum coiling. Treatment combinations R_1M_1, R_1M_2, R_1M_3, R_1M_4, R_2M_1, R_2M_2, R_2M_3 and R_2M_4 didn't coil at all. Total length of tap root ranged from 21.55 cm to 33.33 cm.

4.1.5.2 Root Number

Total root number was found to be significantly influenced by root trainer techniques, rooting media and their interaction effects. R_4 (186.44) registered maximum total root number and was significantly different from all other treatments. M_4 (164.50) which was on par with M_2 (157.06) and M_3 (153.19) produced maximum number of roots and was significantly different from M_1 (138.88). Among the treatment combinations, R_4M_1 (192.75) followed by R_4M_3 (191.50) showed maximum root number. The effect of root number on rootlet production was similar to that of total root production. R_4 (106.13) which was significantly different from all other treatments recorded maximum number of rootlets. Among the rooting media, M_4 (93.69) showed remarkable effect in increasing rootlet production.

Table 8. Seedling root characters at 135 DAS as influenced by root trainer techniques and rooting media

Treat-ments	Length of taproot (cm)			Percentage of	Root number					Root spread (cm)
	Uncoiled	Coiled	Total		Based on length			Rootlets	Total	
					Short	Medium	Long			
R. Root trainer techniques (4)										
R_1	31.38	0.00	31.38	0.00	52.88	11.88	2.81	70.19	136.94	8.04
R_2	26.27	0.00	26.27	0.00	48.25	15.25	2.00	63.44	128.94	8.16
R_3	8.56	15.28	23.84	63.56	50.13	18.38	4.94	87.88	161.31	12.14
R_4	9.74	18.96	28.70	65.47	52.13	20.06	8.13	106.13	186.44	12.28
F	332.84**	167.43**	9.53**	412.57**	1.26^{NS}	22.41**	43.99**	29.89**	42.08**	39.20**
SE	0.63	0.77	1.04	1.83	1.96	0.76	0.41	3.50	4.00	0.37
CD	1.79	2.19	2.97	5.21	-	2.16	1.17	9.94	11.36	1.07
M. Rooting media (4)										
M_1	18.13	7.90	26.03	32.83	48.44	15.25	3.63	71.56	138.88	10.90
M_2	18.46	8.84	27.30	33.34	52.56	16.13	4.00	84.38	157.06	9.21
M_3	18.55	9.64	28.19	34.14	55.50	16.25	4.25	78.00	153.19	9.54
M_4	20.81	7.86	28.67	28.72	46.88	17.94	6.00	93.69	164.50	10.95
F	3.74*	1.21^{NS}	1.22^{NS}	1.74^{NS}	3.99*	2.16^{NS}	6.52*	7.25**	7.23**	5.68**
SE	0.63	0.77	1.04	1.83	1.96	0.76	0.41	3.50	4.00	0.37
CD	1.79	-	-	-	5.57	-	1.17	9.94	11.36	1.07
Treatment combinations (RXM=16)										
R_1M_1	28.28	0.00	28.28	0.00	45.25	11.00	1.50	56.00	113.75	9.02
R_1M_2	31.65	0.00	31.65	0.00	51.50	10.25	2.25	61.75	125.75	7.88
R_1M_3	32.25	0.00	32.25	0.00	52.00	12.00	2.75	70.25	133.75	7.15
R_1M_4	33.33	0.00	33.33	0.00	62.75	14.25	4.75	92.75	174.50	8.10
R_2M_1	28.43	0.00	28.43	0.00	51.75	12.50	2.25	47.25	113.75	9.38
R_2M_2	25.03	0.00	25.03	0.00	46.00	15.75	1.50	90.00	153.25	7.00
R_2M_3	26.33	0.00	26.33	0.00	61.25	14.50	1.00	51.50	128.25	7.20
R_2M_4	25.30	0.00	25.30	0.00	34.00	18.25	3.25	65.00	120.50	9.05
R_3M_1	6.58	16.80	23.38	71.44	42.00	16.50	4.50	72.25	135.25	13.25
R_3M_2	7.68	16.40	24.08	66.61	50.50	20.25	5.25	92.25	168.25	10.68
R_3M_3	7.70	13.85	21.55	60.82	56.75	18.25	4.25	80.00	159.25	11.45
R_3M_4	12.30	14.08	26.38	55.37	51.25	18.50	5.75	107.00	182.50	13.18
R_4M_1	9.25	14.80	24.05	59.89	54.75	21.00	6.25	110.75	192.75	11.95
R_4M_2	9.50	18.98	28.48	66.77	62.25	18.25	7.00	93.50	181.00	11.30
R_4M_3	7.93	24.70	32.63	75.74	52.00	20.25	9.00	110.25	191.50	12.38
R_4M_4	12.30	17.35	29.65	59.49	39.50	20.75	10.25	110.00	180.50	13.48
F	2.28^{NS}	2.38^{NS}	1.40^{NS}	2.06^{NS}	5.36**	1.09^{NS}	1.12^{NS}	3.91**	5.02**	0.76^{NS}
SE	1.26	1.54	2.09	3.67	3.92	1.52	0.82	7.01	8.00	0.75
CD	-	-	-	-	11.14	-	-	19.89	22.73	-

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

Interaction effects influenced rootlet production and maximum number of rootlets were produced by R_4M_1 (110.75) followed by R_4M_3 (110.25), R_4M_4 (110.00), R_3M_4 (107.00), R_4M_2 (93.50), R_1M_4 (92.75) and R_3M_2 (92.25) which were on par. Total number of rootlets ranged from 47.25 to 110.75. Medium and long root production were significantly influenced by root trainer techniques and R_4 (20.06, 8.13) in both cases produced maximum values. Number of short and long roots were significantly influenced by rooting media and M_3 (55.50) and M_4 (6.00) recorded maximum number of short and long roots respectively. .

Integration of root trainer techniques and rooting media significantly influenced the production of short roots, whereas production of medium and long roots were unaffected. The treatment combination, R_1M_4 (62.75) recorded maximum number of short roots. Root trainer techniques and rooting media significantly influenced the root spread. R_4 (12.28 cm) and M_4 (10.95 cm) showed higher values. Though integration of root trainer techniques and rooting media had no remarkable effect on root spread, R4M4 recorded maximum value of 13.48 cm.

4.1.6 Biomass Production

Data on total biomass production and its partitioning into leaf, stem and root (fresh and dry) estimated at 135 DAS are furnished in Table 9.

Total biomass production was found to be significantly influenced by root trainer techniques. The effect of mud pot on total biomass production, both fresh and dry were remarkable and showed significant superiority over all other treatments. The trend was almost similar with respect to fresh and dry matter production of leaf, stem and root. R4 (13.3 g, 5.7 g) followed by R_3 (10.4 g, 4.4 g) were on par with respect to fresh and dry matter production of leaf. Fresh and dry weight of stem were also found to be significantly influenced by root trainer techniques and the influence of R_4 (3.3 g, 1.5 g) was remarkable and it showed its

Table 9. Seedling biomass production and partitioning at 135 DAS as influenced by root trainer techniques and rooting media

Treatments	Biomass production (g)								Percentage dry matter production		
	Leaf		Stem		Root		Total				
	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry	Leaf	Stem	Root
R. Root trainer techniques (4)											
R_1	2.4	0.9	2.0	0.8	2.9	1.1	7.3	2.8	31.58	29.11	39.31
R_2	2.7	1.0	1.9	0.9	2.9	1.3	7.5	3.2	32.50	27.72	39.78
R_3	2.9	1.1	2.9	1.3	4.6	2.0	10.4	4.4	25.29	30.91	43.80
R_4	3.2	1.3	3.3	1.5	6.8	2.9	13.3	5.7	22.39	26.73	50.88
F	4.18**	4.74**	45.83**	43.19**	45.43**	41.77**	52.62**	55.86**	10.84**	1.76 NS	7.27**
SE	0.18	0.07	0.09	0.05	0.27	0.12	0.39	0.16	1.45	1.17	2.01
CD	0.52	0.20	0.27	0.14	0.78	0.34	1.11	0.48	4.12	-	5.73
M. Rooting media (4)											
M_1	2.6	1.0	2.5	1.1	3.8	1.6	8.9	3.7	27.42	30.29	42.29
M_2	2.8	1.1	2.3	1.0	4.4	1.9	9.5	4.0	27.83	26.48	45.69
M_3	2.9	1.1	2.6	1.2	4.5	1.9	10.0	4.2	27.91	28.54	43.55
M_4	2.9	1.1	2.7	1.2	4.5	1.9	10.1	4.2	28.10	29.70	42.20
F	0.39 NS	0.59 NS	2.65 NS	1.99 NS	1.48 NS	1.47 NS	1.71 NS	1.95 NS	0.04 NS	2.24 NS	0.65 NS
SE	0.18	0.07	0.09	0.05	0.27	0.12	0.39	0.16	1.45	1.17	2.01
CD	-	-	-	-	-	-	-	-	-	-	-
Treatment combinations (RXM=16)											
R_1M_1	2.2	0.8	2.1	0.9	2.6	1.0	6.9	2.7	30.20	31.97	37.83
R_1M_2	2.3	0.9	1.9	0.7	3.1	1.2	7.3	2.8	32.20	25.51	42.29
R_1M_3	2.3	0.8	2.0	0.8	2.9	1.2	7.2	2.8	29.74	29.55	40.71
R_1M_4	2.6	1.0	2.2	0.9	2.9	1.2	7.7	3.1	32.70	29.89	37.41
R_2M_1	2.2	0.8	1.9	0.8	2.9	1.2	7.0	2.8	28.87	28.72	42.41
R_2M_2	2.7	1.0	1.8	0.8	3.2	1.4	7.7	3.2	31.37	26.13	42.50
R_2M_3	2.9	1.1	2.0	0.9	3.0	1.3	7.9	3.3	34.51	27.30	38.19
R_2M_4	2.9	1.1	2.1	0.9	2.6	1.1	7.6	3.1	35.26	28.72	35.02
R_3M_1	2.5	1.0	2.7	1.2	3.8	1.7	9.0	3.9	25.13	31.37	43.50
R_3M_2	3.1	1.2	2.7	1.3	4.7	2.0	10.5	4.5	25.68	28.11	46.21
R_3M_3	3.2	1.3	3.2	1.5	5.2	2.3	11.6	5.1	26.08	30.55	43.37
R_3M_4	2.9	1.1	3.0	1.4	4.6	1.9	10.5	4.4	24.75	32.12	43.13
R_4M_1	3.6	1.4	3.3	1.5	5.9	2.4	12.8	5.3	25.49	28.60	45.91
R_4M_2	3.2	1.2	3.0	1.4	6.6	2.8	12.8	5.4	22.58	25.17	52.25
R_4M_3	3.1	1.2	3.4	1.5	7.1	2.9	13.6	5.6	21.80	26.51	51.69
R_4M_4	3.2	1.2	3.5	1.6	7.8	3.3	14.5	6.1	19.70	26.66	53.64
F	0.58 NS	0.55 NS	0.39 NS	0.39 NS	0.70 NS	0.64 NS	0.53 NS	0.53 NS	0.64 NS	0.18 NS	0.48 NS
SE	0.36	0.14	0.09	0.10	0.54	0.24	0.78	0.33	2.90	2.35	4.03
CD	-	-	-	-	-	-	-	-	-	-	-

NS – Not significant * * Significant at 1 per cent significant superiority over all other treatments. Exactly a similar trend was observed with respect to fresh and dry matter production of root as well.

The effect of rooting media was not significant in influencing biomass production and its partitioning. M_4 (10.1 g, 4.2 g) registered maximum total fresh and dry matter production followed by M_3 (10.0 g, 4.2 g), M_2 (9.5 g, 4.0 g) and M_1 (8.9 g, 3.7 g). A similar trend was evident on fresh and dry matter production of leaves and roots. With respect to fresh and dry matter production of stem, M_4 (2.7 g, 1.2 g) recorded maximum value followed by M_3 (2.6 g, 1.2 g), M_1 (2.5 g, 1.1 g) and M_2 (2.3 g, 1.0 g).

Interaction effects were insignificant with respect to biomass production and partitioning. Though fresh weight ranged from 6.9 g to 14.5 g and total dry matter production from 2.7 g to 6.1 g, R_4M_4 (6.1 g) followed by R_4M_3 (5.6 g) showed higher biomass production. A similar trend was observed with respect to fresh and dry matter production of stem and root. Interaction effects were insignificant with respect to fresh and dry matter production of leaves and R_4M_1 (3.6 g, 1.4 g) followed by R_3M_3 (3.2 g, 1.3 g) showed higher production.

Dual inoculation of seeds with Rhizobium and AMF and sowing in mud pots containing enriched rooting medium containing potting mixture, rock powder and mixture of vermicompost, FYM and composted coirpith was found to be beneficial for improving biomass accumulation in ashoka seedlings.

4.1.7. Seedling Growth Indices

Seedling growth indices namely, root shoot ratio, root growth potential, sturdiness quotient and seedling growth potential estimated at 135 DAS are given in Table 10.

Significant effect of root trainer techniques was observed on root shoot ratio and R_4 registered the maximum value of 2.02 and it differed significantly from all other treatments. Though the effect of rooting media was not significant, M_2 (1.78) showed maximum root shoot ratio. Among the different treatment combinations, maximum root shoot ratio was registered by R_4M_4 (2.29) followed by R_4M_2 (2.11). The mean values of root shoot ratio ranged from 1.20 to 2.29.

Significant effect of root trainer was observed on root growth potential and R_1 which was significantly different from all other treatments registered maximum value of 0.24 followed by R_2 (0.21). Though the effect was insignificant, M_1 showed maximum RGP. Interaction effects were insignificant and R_1M_2 followed by R_1M_1 registered maximum value of root growth potential.

The effects of root trainer techniques and rooting media on sturdiness quotient were remarkable and R_2 (1.53) which was on par with R_1 (1.49) registered the maximum value and it was significantly different from R_3 (1.31) and R_4 (1.19). M_3 (1.49) and M_4 (1.45) were on par and significantly different from M_1 (1.29) and M_2 (1.28). Though not significant among the different combinations, higher values of sturdiness quotient were shown by R_2M_3 (1.67) followed by R_1M_4 (1.59).

Root trainer techniques showed remarkable influence on seedling growth potential and R_4 (1.78) registered maximum potential and it was significantly different from all other treatments. However rooting media did not influence seedling growth potential. Though not significant M_4 (1.47) recorded maximum value of seedling growth potential. Though the interaction of root trainer techniques and rooting media were insignificant with respect to seedling growth potential, R_4M_4 (1.95) followed by R_4M_1 (1.84) registered higher values at 135 DAS.

Table 10. Seedling growth indices at 135 DAS as influenced by root trainer techniques and rooting media

Treatments	Root:shoot ratio	Root growth potential	Sturdiness quotient	Seedling growth potential
R. Root trainer techniques (4)				
R1	1.39	0.24	1.49	0.99
R2	1.47	0.21	1.53	1.05
R3	1.50	0.15	1.31	1.55
R4	2.02	0.15	1.19	1.78
F	4.70*	20.12**	7.02**	33.97**
SE	0.13	0.009	0.06	0.07
CD	0.37	0.02	0.17	0.19
M. Rooting media (4)				
M1	1.46	0.20	1.29	1.28
M2	1.78	0.19	1.28	1.27
M3	1.60	0.18	1.49	1.36
M4	1.54	0.18	1.45	1.47
F	1.03 NS	0.62 NS	3.35*	1.98 NS
SE	0.13	0.09	0.06	0.07
CD	-	-	0.17	-
Treatment combinations (RXM=16)				
R1M1	1.20	0.25	1.39	0.99
R1M2	1.60	0.26	1.49	0.89
R1M3	1.45	0.24	1.48	1.01
R1M4	1.32	0.19	1.59	1.09
R2M1	1.51	0.24	1.36	0.96
R2M2	1.71	0.20	1.58	0.98
R2M3	1.44	0.18	1.67	1.07
R2M4	1.20	0.22	1.53	1.18
R3M1	1.42	0.18	1.32	1.32
R3M2	1.69	0.15	1.04	1.54
R3M3	1.55	0.14	1.49	1.71
R3M4	1.36	0.15	1.37	1.65
R4M1	1.71	0.12	1.08	1.84
R4M2	2.11	0.16	1.08	1.66
R4M3	1.97	0.17	1.33	1.67
R4M4	2.29	0.17	1.33	1.95
F	0.39 NS	1.96 NS	0.91 NS	0.59 NS
SE	0.26	1.87	0.12	0.13
CD	-	-	-	-

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

4.1.8 Economics of Seedling Production

The economic analysis of seedling production in terms of price of seedling, gross income, net income and BCR as influenced by root trainer techniques and rooting media are given in Table 11.

Root trainer techniques significantly influenced price of seedling, gross income, net income and BCR. Among the different root trainer techniques, mud pots registered significantly higher values for all the above four parameters and it differed significantly from all other treatments which was followed by poly bag. Poly bag was significantly superior compared to both individual and block root trainers. Seedling price, gross income, net income and BCR ranged from Rs. 5.40 to 9.00, Rs. 43.50 to 72.50, Rs. 20.10 to 45.90 and 1.86 to 2.75 respectively. Price per seedling and gross income were unaffected by rooting media. However, a combination of potting mixture + dual inoculation with Rhizobium and AMF + rock powder + mixture of vermicompost, FYM and composted coir pith registered maximum seedling price of Rs. 7.50 and gross income of Rs. 60.00 which were 8.70 and 9.00 % higher compared to potting mixture. Maximum gross income of Rs. 37.50 and BCR of 2.61 were recorded by the above treatment which was significantly different from both individual and block root trainers.

Integration of root trainer techniques and rooting media had no significant effect on any of the economic characters studied. However, R_4M_4 combination was more appropriate in increasing price of seedling, gross income, net income and BCR. Maximum seedling price of Rs. 9.75, gross income of Rs. 78.00, net income of Rs. 56.00 and BCR of 3.33 were estimated when ashoka seeds were inoculated with Rhizobium and AMF and sown in mud pots filled with potting mixture containing a mixture of vermin compost, FYM and composted coir pith.

Table 11. Economics of seedling production as influenced by root trainer techniques and rooting media

Treatments	Cost of seedling production per plot (Rs.)	Price of seedling based on SGP (Rs.)	Gross income per plot (Rs.)	Net income per plot (Rs.)	BCR
R. Root trainer techniques (4)					
R1	23.4	5.40	43.50	20.10	1.86
R2	24.2	5.70	45.50	20.30	1.89
R3	26.6	8.30	66.50	39.90	2.51
R4	26.6	9.00	72.50	45.90	2.75
F	#	58.63**	58.63**	54.00**	40.76**
SE	-	0.24	1.91	1.81	0.07
CD	-	0.68	5.44	5.16	0.20
M. Rooting media (4)					
M1	26.2	6.90	55.00	28.30	2.06
M2	27.4	6.90	55.00	27.60	1.98
M3	24.2	7.20	58.00	32.80	2.38
M4	23.0	7.50	60.00	37.50	2.61
F	#	1.63^{NS}	1.63^{NS}	6.39**	17.05**
SE	-	0.24	1.91	1.81	0.07
CD	-	-	-	5.16	0.20
Treatment combinations (R x M=16)					
R1M1	24.00	5.75	46.00	22.00	1.92
R1M2	24.80	5.00	40.00	15.20	1.61
R1M3	23.20	5.50	44.00	20.80	1.89
R1M4	21.60	5.50	44.00	22.40	2.03
R2M1	24.80	5.50	44.00	19.20	1.77
R2M2	25.60	5.25	42.00	16.40	1.64
R2M3	24.00	5.75	46.00	18.00	1.92
R2M4	22.40	6.25	50.00	27.60	2.23
R3M1	28.00	7.50	60.00	32.00	2.14
R3M2	29.60	8.50	68.00	38.40	2.29
R3M3	24.80	8.75	70.00	45.20	2.80
R3M4	24.00	8.50	68.00	44.00	2.83
R4M1	28.00	8.75	70.00	40.00	2.42
R4M2	29.60	8.75	70.00	40.40	2.36
R4M3	24.80	9.00	72.00	47.20	2.90
R4M4	24.00	9.75	78.00	56.00	3.33
F	#	0.63^{NS}	0.63^{NS}	1.31^{NS}	1.50^{NS}
SE	-	0.48	3.83	3.63	0.14
CD	-	-	-	-	-

data not analysed NS – Not significant * * Significant at 1 per cent

4.2 MICRO SITE ENRICHMENT TECHNIQUES FOR GROWTH PROMOTION

4.2.1 Plant Height

Data on plant height as influenced by micro site enrichment techniques and levels of irrigation recorded at monthly intervals from 3 to 12 MAP are furnished in Table 12.

Micro site enrichment techniques didn't significantly influence plant height at any of the plant growth stage. However, during the initial stages of establishment, that is upto 7 MAP, POP recommendations (W_4) registered maximum plant height. At 8^{th} and 10^{th} MAP, micro site enrichment + micro catchment (W_2) produced taller plants. At other growth stages, micro site enrichment + micro catchment + vertical mulching (W_3) resulted in increasing plant height. After one year of planting, plant height ranged from 109.00 to 119.67 cm and maximum value was recorded by micro site enrichment + micro catchment + vertical mulching (W_3) followed by micro site enrichment + micro catchment (W_2), micro site enrichment (W_1) and POP recommendations (W_4). The per cent increase in plant height after one year in W_3 over W_4 was 9.79.

Similar to micro site enrichment techniques, levels of irrigation also didn't exert any significant influence on plant height at any of the growth stages. However scheduling irrigation at 50 % depletion of moisture resulted in improvement of plant height at 3, 4, 5, 8, 9 and 12 MAP. After one year of planting, irrigation at 50 % depletion of moisture resulted in taller plants (114.73 cm) compared to life saving irrigation (112.20 cm) and the per cent increase was 2.25.

Interaction effects of micro site enrichment techniques and levels of irrigation also didn't significantly influence plant height at any of the growth stages. However, upto 9 MAP, integration of POP recommendations and

Table 12. Plant height (cm) at monthly intervals (3 to 12 MAP) as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	3MAP	4MAP	5MAP	6MAP	7MAP	8MAP	9MAP	10MAP	11MAP	12MAP
W. Micro site enrichment techniques (4)										
W_1	33.91	39.23	48.43	55.90	63.43	71.25	80.90	94.00	100.93	109.00
W_2	34.52	42.31	50.75	56.78	63.27	74.83	85.98	105.25	110.20	116.18
W_3	31.54	41.56	47.23	57.97	65.00	72.13	89.32	103.96	111.70	119.67
W_4	41.62	46.17	52.10	59.67	66.12	74.38	85.07	95.78	103.57	109.00
F	1.82^{NS}	0.52^{NS}	0.15^{NS}	0.05^{NS}	0.04^{NS}	0.04^{NS}	0.01^{NS}	0.17^{NS}	0.13^{NS}	0.12^{NS}
SE	3.22	4.00	5.60	7.00	7.00	8.86	10.65	13.59	14.50	15.50
CD	-	-	-	-	-	-	-	-	-	-
S. Soil moisture regimes (2)										
S_1	36.75	43.59	51.13	57.13	64.38	74.90	86.91	98.17	105.94	114.73
S_2	34.05	41.04	48.13	58.03	64.53	71.40	83.73	101.33	107.26	112.20
F	0.71^{NS}	0.41^{NS}	0.29^{NS}	0.02^{NS}	0.001 NS	0.16^{NS}	0.08^{NS}	0.05^{NS}	0.008^{NS}	0.03^{NS}
SE	2.28	2.83	3.96	4.95	4.95	6.27	7.53	9.61	10.25	10.96
CD	-	-	-	-	-	-	-	-	-	-
Treatment combinations (WxS=8)										
W_1S_1	31.90	37.63	48.10	52.43	56.90	62.00	69.73	80.33	87.67	97.67
W_1S_2	35.92	40.83	48.77	59.37	69.97	80.50	92.07	107.67	114.20	120.33
W_2S_1	38.43	45.95	54.00	58.10	66.40	83.50	95.07	113.50	118.10	126.57
W_2S_2	30.60	38.67	47.50	55.47	60.13	66.17	76.90	97.00	102.30	105.80
W_3S_1	28.33	36.28	42.83	53.10	58.83	65.60	86.07	90.83	97.37	104.67
W_3S_2	34.75	46.83	51.63	62.83	71.17	78.67	92.57	117.08	126.03	134.67
W_4S_1	48.33	54.50	59.57	64.87	75.40	88.50	96.77	108.00	120.63	130.00
W_4S_2	34.92	37.83	44.63	54.47	56.83	60.27	73.37	83.57	86.50	88.00
F	2.17^{NS}	2.22^{NS}	0.82^{NS}	0.43^{NS}	1.20^{NS}	1.66^{NS}	1.01^{NS}	1.02^{NS}	1.16^{NS}	1.24^{NS}
SE	4.55	5.66	7.92	9.91	9.90	12.53	15.06	19.22	20.50	21.93
CD	-	-	-	-	-	-	-	-	-	-

NS – Not significant MAP – Months after planting

irrigation at 50 % depletion of moisture was beneficial for increasing plant height. The trend was different from 10 MAP onwards and integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation resulted in taller plants. At 12 MAP, plant height ranged from 88.00 cm to 134.67 cm and micro site enrichment + micro catchment + vertical mulching and life saving irrigation recorded the maximum value and the per cent increase over POP recommendations and life saving irrigation was 53.03.

4.2.2 Number of Functional Leaves

Effect of micro site enrichment techniques and levels of irrigation on the number of functional leaves recorded at monthly intervals (3 to 12 MAP) are given in Table 13.

Effect of micro site enrichment techniques was insignificant on functional leaf production throughout the period of study. In general, POP recommendations (W_4) favoured functional leaf production upto 7 MAP, thereafter micro site enrichment (W_1) at 9 and 10 MAP and micro site enrichment + micro catchment + vertical mulching (W_3) at 8, 11 and 12 MAP registered maximum number of functional leaves. At 12 MAP, micro site enrichment + micro catchment + vertical mulching (W_3) produced 24.17 numbers of functional leaves and it was 22.88 % higher over control.

Functional leaves was not at all significantly influenced by levels of irrigation. Irrigation at 50 % depletion of moisture enhanced functional leaf number at 5, 6, 7, 8, 9 and 12 MAP, whereas life saving irrigation increased functional leaf number at other growth stages. At 12 MAP, irrigation at 50 % depletion of moisture resulted in the production of 22 functional leaves, which was 3.52 % higher over control.

Table 13. Number of functional leaves at monthly intervals (3 to 12 MAP) as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	3MAP	4MAP	5MAP	6MAP	7MAP	8MAP	9MAP	10MAP	11MAP	12MAP
W. Micro site enrichment techniques (4)										
W_1	9.83	11.00	14.17	14.83	15.83	17.00	17.50	18.50	20.17	21.83
W_2	9.67	11.50	14.67	15.17	16.00	16.33	16.83	18.33	18.83	21.17
W_3	10.33	12.00	13.50	14.17	15.50	17.17	17.17	18.33	20.33	24.17
W_4	11.33	12.67	14.17	15.83	16.50	16.83	16.17	17.33	18.00	19.67
F	1.35^{NS}	1.11^{NS}	0.13^{NS}	0.26^{NS}	0.08^{NS}	0.06^{NS}	0.10^{NS}	0.08^{NS}	0.30^{NS}	0.66^{NS}
SE	0.64	0.67	1.35	1.36	1.44	1.43	1.83	1.85	2.02	2.30
CD	-	-	-	-	-	-	-	-	-	-
S. Soil moisture regimes (2)										
S_1	10.17	11.58	14.42	15.17	16.33	16.83	16.92	17.83	19.17	22.08
S_2	10.42	12.00	13.83	14.83	15.58	16.83	16.92	18.42	19.50	21.33
F	0.15^{NS}	0.38^{NS}	0.19^{NS}	0.06^{NS}	0.27^{NS}	0.001 NS	0.001 NS	0.10^{NS}	0.03^{NS}	0.11^{NS}
SE	0.46	0.48	0.95	0.96	1.02	1.01	1.29	1.31	1.43	1.63
CD	-	-	-	-	-	-	-	-	-	-
Treatment combinations (WxS=8)										
W_1S_1	9.33	10.00	14.33	14.67	16.00	16.67	16.67	16.67	18.67	20.67
W_1S_2	10.33	12.00	14.00	15.00	15.67	17.33	18.33	20.33	21.67	23.00
W_2S_1	9.67	11.33	16.33	16.33	17.67	17.00	17.67	19.33	19.67	23.00
W_2S_2	9.67	11.67	13.00	14.00	14.33	15.67	16.00	17.33	18.00	19.33
W_3S_1	9.00	10.67	11.33	12.33	13.33	15.33	16.00	16.67	19.00	23.00
W_3S_2	11.67	13.33	15.67	16.00	17.67	19.00	18.33	20.00	21.67	25.33
W_4S_1	12.67	14.33	15.67	17.33	18.33	18.33	17.33	18.67	19.33	21.67
W_4S_2	10.00	11.00	12.67	14.33	14.67	15.33	15.00	16.00	16.67	17.67
F	3.00^{NS}	3.96^{NS}	1.73^{NS}	1.24^{NS}	1.66^{NS}	1.00^{NS}	0.41^{NS}	0.84^{NS}	0.52^{NS}	0.60^{NS}
SE	0.91	0.95	1.90	1.93	2.03	2.03	2.58	2.61	2.86	3.25
CD	-	-	-	-	-	-	-	-	-	-

NS – Not significant MAP – Months after planting

Interaction effects also didn't significantly influence the production of functional leaves and the trend was inconsistent. POP recommendations and irrigation scheduled at 50 % depletion of moisture (W_4S_1) at 3, 4, 6 and 7 MAP, micro site enrichment + micro catchment and irrigation scheduled at 50 % depletion of moisture (W_2S_1) at 5 MAP, micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2) at 8 and 12 MAP and micro site enrichment and life saving irrigation (W_1S_2) at 9, 10 and 11 MAP registered maximum functional leaf number. It is observed that the treatment combinations W_3S_2 and W_1S_2 were beneficial for improving the production of functional leaves after 8 months of planting. After one year of planting, integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_4S_2) was found favourable for increasing functional leaf production and this treatment combination registered 43.35 % higher leaf number (25.33) over control (17.67).

4.2.3 Collar Girth

Data on the effect of micro site enrichment techniques and levels of irrigation on collar girth recorded at monthly intervals from 3 MAP to 12 MAP are summarised in Table 14.

Though the effect of micro site enrichment techniques was insignificant, micro site enrichment + micro catchment recorded thicker stems from 5 MAP to 11 MAP and at 12 MAP, the above combination + vertical mulching registered maximum collar girth (5.93 cm) and it was 16.96 per cent higher compared to POP recommendations.

Similar to micro site enrichment techniques, the effect of irrigation levels was also insignificant. However, the effect of life saving irrigation improved collar girth at all stages of crop growth except at 4 MAP. After one year of planting, improvement in collar girth due to life saving irrigation was to

Table 14. Collar girth (cm) at monthly intervals (3 to 12 MAP) as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	3MAP	4MAP	5MAP	6MAP	7MAP	8MAP	9MAP	10MAP	11MAP	12MAP
W. Micro site enrichment techniques (4)										
W_1	1.98	2.57	3.20	3.53	3.97	4.37	4.47	4.58	4.68	5.25
W_2	2.03	2.35	3.40	3.70	4.08	4.45	4.63	4.82	5.17	5.75
W_3	1.95	2.26	2.95	3.28	3.63	4.02	4.32	4.63	5.15	5.93
W_4	2.29	2.58	3.13	3.48	3.78	4.23	4.37	4.53	4.77	5.07
F	0.78^{NS}	1.29^{NS}	0.46^{NS}	0.38^{NS}	0.39^{NS}	0.35^{NS}	0.17^{NS}	0.12^{NS}	0.37^{NS}	0.84^{NS}
SE	0.18	0.14	0.27	0.28	0.32	0.32	0.34	0.36	0.42	0.45
CD	-	-	-	-	-	-	-	-	-	-
S. Soil moisture regimes (2)										
S_1	2.04	2.46	3.17	3.48	3.84	4.19	4.34	4.53	4.81	5.41
S_2	2.08	2.42	3.18	3.52	3.89	4.34	4.55	4.76	5.08	5.59
F	0.07^{NS}	0.11^{NS}	0.001 NS	0.01^{NS}	0.02^{NS}	0.22^{NS}	0.38^{NS}	0.42^{NS}	0.41^{NS}	0.17^{NS}
SE	0.13	0.10	0.19	0.20	0.23	0.23	0.24	0.26	0.29	0.31
CD	-	-	-	-	-	-	-	-	-	-
Treatment combinations (WxS=8)										
W_1S_1	2.02	2.57	3.00	3.33	3.73	4.03	4.17	4.23	4.37	4.93
W_1S_2	1.93	2.57	3.40	3.73	4.20	4.70	4.77	4.93	5.00	5.57
W_2S_1	1.92	2.35	3.57	3.83	4.23	4.60	4.77	4.93	5.20	5.80
W_2S_2	2.13	2.35	3.23	3.57	3.93	4.30	4.50	4.70	5.13	5.70
W_3S_1	1.75	2.10	2.87	3.17	3.47	3.77	4.00	4.33	4.87	5.67
W_3S_2	2.15	2.42	3.03	3.40	3.80	4.27	4.63	4.93	5.43	6.20
W_4S_1	2.47	2.83	3.23	3.60	3.93	4.37	4.43	4.60	4.80	5.23
W_4S_2	2.12	2.33	3.02	3.37	3.63	4.10	4.30	4.47	4.73	4.90
F	0.86^{NS}	1.42^{NS}	0.37^{NS}	0.36^{NS}	0.41^{NS}	0.62^{NS}	0.49^{NS}	0.45^{NS}	0.22^{NS}	0.28^{NS}
SE	0.25	0.20	0.39	0.39	0.45	0.45	0.48	0.51	0.59	0.63
CD	-	-	-	-	-	-	-	-	-	-

NS – Not significant MAP – Months after planting

the tune of 3.33 % higher over scheduling irrigation at 50 % depletion of moisture.

Among the different treatment combinations, POP recommendations and irrigation scheduled at 50 % depletion of moisture (W_4S_1) at 3 MAP, micro site enrichment and life saving irrigation (W_1S_2) at 5, 6 and 7 MAP, micro site enrichment and life saving irrigation (W_1S_2) at 8 and 9 MAP and micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2) at 10, 11 and 12 MAP recorded maximum collar girth. After one year of planting, micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2) resulted in 26.53 % increase in collar girth compared to control.

4.2.4 Leaf Area Index

Mean data on leaf area index as influenced by micro site enrichment techniques and levels of irrigation recorded at monthly intervals from 3MAP to 12 MAP are furnished in Table 15.

The effect of micro site enrichment techniques was insignificant in influencing leaf area index at any of the growth stages. POP recommendations at 3 MAP, micro site enrichment + micro catchment at 4, 5, 6, 10, 11 and 12 MAP and micro site enrichment at 7, 8 and 9 MAP registered maximum leaf area index. At 12 MAP, micro site enrichment + micro catchment resulted in 23.91 % increase in leaf area index over POP recommendations.

Though the effect of levels of irrigation was insignificant in influencing leaf area index, life saving irrigation was found beneficial for increasing leaf area index at all stages of growth except at 6 MAP. After one year of planting, life saving irrigation increased leaf area index by 10.42 % over irrigation scheduled at 50% depletion of moisture.

Table 15. Leaf area index at monthly intervals (3 to 12 MAP) as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	3MAP	4MAP	5MAP	6MAP	7MAP	8MAP	9MAP	10MAP	11MAP	12MAP
W. Micro site enrichment techniques (4)										
W_1	0.05	0.07	0.10	0.15	0.19	0.22	0.27	0.28	0.36	0.48
W_2	0.06	0.09	0.12	0.16	0.19	0.21	0.24	0.30	0.41	0.57
W_3	0.05	0.07	0.09	0.11	0.13	0.15	0.18	0.23	0.38	0.52
W_4	0.06	0.08	0.10	0.14	0.18	0.19	0.21	0.27	0.33	0.46
F	0.65^{NS}	0.33^{NS}	0.87^{NS}	0.62^{NS}	0.69^{NS}	1.00^{NS}	0.69^{NS}	0.28^{NS}	0.17^{NS}	0.31^{NS}
SE	1.15	0.01	0.02	0.03	0.03	0.03	0.04	0.05	0.08	0.09
CD	-	-	-	-	-	-	-	-	-	-
S. Soil moisture regimes (2)										
S_1	0.05	0.07	0.10	0.14	0.16	0.17	0.21	0.25	0.32	0.48
S_2	0.06	0.08	0.10	0.13	0.18	0.21	0.24	0.29	0.41	0.53
F	0.13^{NS}	0.44^{NS}	0.21^{NS}	0.08^{NS}	0.32^{NS}	1.00^{NS}	0.64^{NS}	0.33^{NS}	1.14^{NS}	0.25^{NS}
SE	8.10	0.01	0.01	0.02	0.02	0.02	0.03	0.04	0.06	0.06
CD	-	-	-	-	-	-	-	-	-	-
Treatment combinations (WxS=8)										
W_1S_1	0.04	0.06	0.08	0.11	0.12	0.13	0.16	0.16	0.17	0.29
W_1S_2	0.05	0.09	0.12	0.19	0.25	0.31	0.37	0.40	0.54	0.66
W_2S_1	0.07	0.09	0.13	0.18	0.20	0.22	0.28	0.35	0.45	0.66
W_2S_2	0.05	0.08	0.11	0.14	0.17	0.19	0.20	0.25	0.36	0.48
W_3S_1	0.03	0.05	0.07	0.10	0.12	0.13	0.17	0.20	0.28	0.43
W_3S_2	0.06	0.08	0.10	0.11	0.14	0.16	0.20	0.26	0.48	0.61
W_4S_1	0.07	0.08	0.10	0.17	0.19	0.20	0.22	0.31	0.39	0.54
W_4S_2	0.06	0.08	0.09	0.11	0.16	0.17	0.20	0.23	0.26	0.37
F	0.79^{NS}	0.79^{NS}	0.65^{NS}	1.07^{NS}	1.48^{NS}	2.44^{NS}	2.10^{NS}	2.07^{NS}	2.02^{NS}	2.28^{NS}
SE	1.62	0.02	0.02	0.04	0.04	0.04	0.06	0.08	0.12	0.13
CD	-	-	-	-	-	-	-	-	-	-

NS – Not significant MAP – Months after planting

Among the different treatment combinations, micro site enrichment + micro catchment and scheduling irrigation at 50 % depletion of moisture resulted in maximum leaf area index at 3, 4 and 5 MAP and thereafter micro site enrichment and life saving irrigation improved leaf area index at all stages. At 12 MAP, leaf area index was 0.66 and the per cent increase over control was 78.38.

4.2.5 Number of Branches

Number of branches as influenced by micro site enrichment techniques levels of irrigation at 7, 8, 9, 10, 11 and 12 MAP are depicted in Table 16.

Micro site enrichment techniques did not significantly influence the number of branches from 7 to 12 MAP. However micro site enrichment at 7, 8, 9 and10 MAP, micro site enrichment + micro catchment at 11 MAP and micro site enrichment + micro catchment + vertical mulching at 12 MAP registered maximum number of branches. Micro site enrichment + micro catchment + vertical mulching resulted in maximum number of branches at 12 MAP (2.83) and it was 13.20 % higher over POP recommendations.

Scheduling irrigation at 50 % depletion of moisture was found favourable for increasing number of branches at 7, 8 and 9 MAP, whereas at 10^{th} and 11^{th} MAP, the trend was different where the life saving irrigation registered maximum values.

The interaction effect of treatment combinations didn't significantly affect the production of branches. But micro site enrichment + micro catchment and scheduling irrigation at 50 % depletion of moisture at 7, 10 and 11 MAP, micro site enrichment and scheduling irrigation at 50 % depletion of moisture at 8 and 9 MAP and micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2) at 12 MAP recorded maximum number of branches. After one year of planting integration of micro site enrichment + micro catchment

Table 16. Number of branches at monthly intervals (7 to 12 MAP) as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	7MAP	8MAP	9MAP	10MAP	11MAP	12MAP
W. Micro site enrichment techniques (4)						
W_1	1.00	1.83	2.00	2.17	2.17	2.17
W_2	0.83	1.67	1.67	2.00	2.33	2.67
W_3	0.67	1.17	1.50	2.00	2.17	2.83
W_4	0.67	1.83	2.00	2.17	2.33	2.50
F	0.24^{NS}	0.45^{NS}	0.27^{NS}	0.05^{NS}	0.04^{NS}	0.27^{NS}
SE	0.32	0.47	0.48	0.44	0.47	0.55
CD	-	-	-	-	-	-
S. Soil moisture regimes (2)						
S_1	1.00	1.83	2.00	2.17	2.17	2.42
S_2	0.58	1.42	1.58	2.00	2.33	2.67
F	1.67^{NS}	0.78^{NS}	0.76^{NS}	0.14^{NS}	0.13^{NS}	0.21^{NS}
SE	0.23	0.33	0.34	0.31	0.33	0.39
CD	-	-	-	-	-	-
Treatment combinations (WxS=8)						
W_1S_1	1.00	2.33	2.33	2.33	2.33	2.33
W_1S_2	1.00	1.33	1.67	2.00	2.00	2.00
W_2S_1	1.67	2.33	2.33	2.67	2.67	3.00
W_2S_2	0.67	1.00	1.00	1.33	2.00	2.33
W_3S_1	0.67	1.00	1.33	1.67	1.67	2.00
W_3S_2	0.67	1.33	1.67	2.33	2.67	3.67
W_4S_1	0.67	1.67	2.00	2.00	2.00	2.33
W_4S_2	0.67	2.00	2.00	2.33	2.67	2.67
F	1.67^{NS}	0.87^{NS}	0.60^{NS}	0.99^{NS}	0.71^{NS}	0.89^{NS}
SE	0.46	0.67	0.68	0.63	0.67	0.77
CD	-	-	-	-	-	-

NS – Not significant MAP – Months after planting

+ vertical mulching and life saving irrigation (W_3S_2) resulted in maximum number of branches (3.67) and it was 37.45 % higher over control.

4.2.6 Canopy Architecture

Bole height, canopy height, canopy spread, canopy width and canopy size as influenced by the main effects and their interactions at 12 MAP are presented in Table 17.

Micro site enrichment + micro catchment + vertical mulching followed by micro site enrichment + micro catchment registered maximum bole height. Between the two levels of irrigation, irrigation at 50 % depletion of moisture enhanced bole height and the per cent increase over life saving irrigation was 0.69. Among the different treatment combinations, integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2) registered maximum bole height and it was 72.02 % over control.

Main effects and the interaction didn't significantly influence the canopy height at 12 MAP. Micro site enrichment followed by micro site enrichment + micro catchment + vertical mulching enhanced canopy height. Compared to control, the improvement in canopy height due to micro site enrichment + micro catchment + vertical mulching was 7.84 %. between the two levels of irrigation, scheduling irrigation at 50 % depletion of moisture registered 2.72 % increase in canopy height over life saving irrigation. Interaction effects indicated the superior performance of micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2) in increasing canopy height to the extent of 47.37 % over control.

Significant influence of micro site enrichment techniques on canopy spread was observed at 12 MAP and micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment and POP recommendations registered the maximum spread of 68.6 cm. Though not significant, life saving irrigation increased canopy spread to the tune of 4.05 % over scheduling irrigation at 50 % depletion of moisture. Integration of micro site enrichment + micro catchment + vertical mulching and scheduling irrigation at 50 % depletion of moisture (W_3S_1) recorded maximum spread and it was 15.85 % higher over control.

With respect to canopy width, effect of micro site enrichment techniques was also similar as that of canopy spread. Micro site enrichment + micro catchment + vertical mulching recorded maximum width followed by micro site enrichment, POP recommendations, micro site enrichment + micro catchment. Life saving irrigation improved canopy width to the tune of 4.07 % compared to irrigation at 50 % depletion of moisture. Maximum improvement in canopy width was brought about by the treatment combination micro site enrichment + micro catchment + vertical mulching and life saving irrigation and it was 31.50 % higher compared to control.

Similar to canopy spread and canopy width, the effect of micro site enrichment + micro catchment + vertical mulching was remarkable in increasing canopy size. The values ranged from 0.37 to 0.52 m^2 and in micro site enrichment + micro catchment + vertical mulching the increased canopy size over control was 31.50 %. The effect of levels of irrigation on canopy size was similar to that of canopy spread and width. Life saving irrigation recorded maximum size and it was 4.76 % higher over irrigation scheduled at 50 % depletion of moisture.

Similar to canopy width, maximum canopy size was also recorded by the treatment combination, micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2). The values ranged from 0.30 m^2 to 0.60 m^2 and in micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2), the improvement was 87.5 % higher over control.

Table 17. Canopy architecture at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	Bole height (cm)	Canopy height (cm)	Canopy spread (cm)	Canopy width (cm)	Canopy size (m^2)
W. Micro site enrichment techniques (4)					
W_1	18.90	90.10	58.5	52.00	0.45
W_2	28.10	88.08	33.0	38.58	0.37
W_3	30.57	89.10	68.6	61.25	0.52
W_4	26.38	82.62	58.5	48.67	0.38
F	1.64 ^{NS}	0.05 ^{NS}	5.34*	1.73 ^{NS}	0.56 ^{NS}
SE	3.92	14.78	6.58	14.78	0.09
CD	-	-	19.97	-	-
S. Soil moisture regimes (2)					
S_1	26.08	88.65	53.58	49.13	0.42
S_2	25.90	86.30	55.75	51.13	0.44
F	0.002 ^{NS}	0.03 ^{NS}	0.11 ^{NS}	0.08 ^{NS}	0.04 ^{NS}
SE	2.77	10.45	4.65	5.03	0.07
CD	-	-	-	-	-
Treatment combinations (WxS=8)					
W_1S_1	17.13	80.53	55.00	50.00	0.37
W_1S_2	20.67	99.67	62.00	54.00	0.54
W_2S_1	28.30	98.27	32.67	39.33	0.43
W_2S_2	27.90	77.90	33.33	37.83	0.30
W_3S_1	26.33	78.33	70.67	58.50	0.44
W_3S_2	34.80	99.87	66.67	64.00	0.60
W_4S_1	32.53	97.47	56.001	48.67	0.45
W_4S_2	20.23	67.77	61.00	48.67	0.32
F	1.28 ^{NS}	0.80 ^{NS}	0.14 ^{NS}	0.05 ^{NS}	0.82 ^{NS}
SE	5.55	20.91	9.31	10.05	0.13
CD	-	-	-	-	-

NS – Not significant * Significant at 5 per cent

4.2.7 Root Parameters

The main and interaction effects of micro site enrichment techniques and levels of irrigation on root parameters namely, number, spread, length, volume and surface area recorded after one year of planting are furnished in Table 18.

Significant effect of micro site enrichment techniques on root number was observed and the treatments micro site enrichment + micro catchment + vertical mulching increased root number which was 147.68 % higher compared to POP recommendations. Micro site enrichment + micro catchment + vertical mulching was on par with micro site enrichment + micro catchment and the total number of roots ranged from 31.67 to 117.33. Though the effect of levels of irrigation was insignificant, irrigation scheduled at 50 % depletion of moisture enhanced root number (91.25) which was 29.75 % higher over life saving irrigation. Among the different treatment combinations, integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation was found to enhance root number to the tune of 270.48 % over control.

The effect of micro site enrichment techniques and levels of irrigation on root length was similar to that of root number. Wide variation in root length was observed (50.43 cm to 83.83 cm) due to interaction effects of treatments. Maximum root length was observed when micro site enrichment + micro catchment + vertical mulching was combined with irrigation scheduled at 50 % depletion of moisture (W_3S_1) and the increase over control was 66.23 %.

Micro site enrichment + micro catchment was found favourable for enhancing root spread and it was 74.56 % higher over POP recommendations. Similar to root number, root spread was found to be 26.93 % higher when irrigation was scheduled at 50 % depletion of moisture over life saving irrigation. Among the different treatment combinations, integration of micro site enrichment

+ micro catchment + vertical mulching and irrigation at 50 % depletion of moisture (W_3S_1) enhanced root spread which was found to be 171.31 % higher over control.

The effect of micro site enrichment techniques on root volume was almost similar to that of root number. Significant influence was noted and micro site enrichment + micro catchment + vertical mulching registered maximum root volume (59.52 cm^3) which was 129.19 % higher over POP recommendations. Between the two levels of irrigation, life saving irrigation promoted root volume to the extent of 18.40 % over irrigation scheduled at 50 % depletion of moisture. Though the interaction effects were insignificant, micro site enrichment + micro catchment and life saving irrigation (W_2S_2) was found to be beneficial for enhancing root volume to the tune of 206.3 % over control.

The influence of micro site enrichment techniques on root surface area was similar to that of root length and micro site enrichment + micro catchment + vertical mulching expanded root surface area (166.31 cm^2) which was 79.66 % higher over POP recommendations. The effect of levels of irrigation on root surface area was exactly similar to that of root volume and life saving irrigation promoted root surface area to the tune of 2.54 % over irrigation scheduled at 50 % depletion of moisture. Integration of different factors showed the superior performance of treatment combination, micro site enrichment + micro catchment and life saving irrigation in enlarging root surface area (169.84 cm^2) which was 106.97 % higher over control.

4.2.8 Growth Indices

Growth indices namely, root shoot ratio, root growth potential, sturdiness quotient, and crop growth potential as influenced by the main effects and interaction effects of micro site enrichment techniques and levels of irrigation estimated after one year of planting are furnished in Table 19.

Table 18. Root parameters at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	Root Number	Root Spread (cm)	Root Length (cm)	Root Volume (cm^3/plant)	Root Surface area (cm^2)
W. Micro site enrichment techniques (4)					
W_1	55.17	60.73	61.58	26.28	138.15
W_2	104.00	77.80	75.13	26.67	155.30
W_3	116.83	71.42	75.38	29.52	166.31
W_4	47.17	44.57	53.48	12.88	92.57
F	3.50*	2.16 ^{NS}	1.66 ^{NS}	4.44*	3.31 ^{NS}
SE	18.58	9.89	8.34	3.53	17.85
CD	56.00	-	-	10.72	-
S. Soil moisture regimes (2)					
S_1	91.25	71.18	69.00	21.68	136.35
S_2	70.33	56.08	63.79	26.00	139.81
F	1.27 ^{NS}	2.33 ^{NS}	0.39 ^{NS}	1.49 ^{NS}	0.04 ^{NS}
SE	13.14	6.99	5.89	2.50	12.62
CD	-	-	-	-	-
Treatment combinations (WxS=8)					
W1S1	69.33	57.10	58.13	24.07	132.58
W1S2	41.00	64.37	65.03	28.50	143.72
W2S1	116.67	78.20	77.50	20.47	140.76
W2S2	91.33	77.40	72.77	32.87	169.84
W3S1	116.33	95.50	83.83	27.13	169.00
W3S2	117.33	47.33	66.93	31.90	163.62
W4S1	62.67	53.93	56.53	15.03	103.08
W4S2	31.67	35.20	50.43	10.73	82.06
F	0.16 ^{NS}	1.54 ^{NS}	0.34 ^{NS}	0.93 ^{NS}	0.36 ^{NS}
SE	26.25	13.99	11.79	4.99	25.24
CD	-	-	-	-	-

NS – Not significant * Significant at 5 per cent

Table 19. Growth indices at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation.

Treatments	Root:shoot ratio	Root growth potential	Sturdiness quotient	Crop growth potential
W. Micro site enrichment techniques (4)				
W_1	1.01	1.07	2.06	84.72
W_2	0.86	0.76	1.98	99.78
W_3	1.29	0.74	1.94	94.61
W_4	1.61	1.31	2.15	23.01
F	3.39*	2.19 ^{NS}	0.39 ^{NS}	6.67**
SE	0.18	0.18	0.15	13.77
CD	0.55	-	-	41.77
S. Soil moisture regimes (2)				
S_1	1.38	0.89	2.08	63.46
S_2	1.00	1.04	1.98	87.60
F	4.58 ^{NS}	0.64 ^{NS}	0.49 ^{NS}	3.07 ^{NS}
SE	0.13	0.13	0.11	9.74
CD	-	-	-	-
Treatment combinations (WxS=8)				
W_1S_1	1.21	1.06	1.96	72.74
W_1S_2	0.80	1.08	2.16	92.71
W_2S_1	0.76	0.71	2.16	82.59
W_2S_2	0.95	0.81	1.79	116.97
W_3S_1	1.68	0.92	1.71	76.29
W_3S_2	0.91	0.56	2.16	112.92
W_4S_1	1.88	0.89	2.50	22.21
W_4S_2	1.34	1.73	1.79	23.81
F	1.28 ^{NS}	1.84 ^{NS}	3.04 ^{NS}	0.34 ^{NS}
SE	0.25	0.26	0.21	19.47
CD	-	-	-	-

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

The effect of micro site enrichment techniques on root shoot ratio was significant and POP recommendations registered the maximum value of 1.61. Irrigation scheduled at 50 % depletion of moisture enhanced root shoot ratio which was 38 % higher over life saving irrigation. Integration of treatments again confirmed the superior performance of treatment combination, POP recommendations and irrigation scheduling at 50 % depletion of moisture in improving root shoot ratio.

The effect of micro site enrichment techniques was insignificant in influencing root growth potential. However, POP recommendations registered maximum root growth potential of 1.31 followed by micro site enrichment, micro site enrichment + micro catchment and micro site enrichment + micro catchment + vertical mulching. With respect to the effects of levels of irrigation, life saving irrigation improved root growth potential to the extend of 16.85 % over irrigation scheduled at 50 % depletion of moisture. Integration of treatments indicated the better performance of the treatment combination, POP recommendations and life saving irrigation in improving root growth potential.

The effect of micro site enrichment techniques on sturdiness quotient was similar to that of root growth potential. Sturdiness quotient values ranged from 1.94 to 2.15. POP recommendations recorded the maximum value whereas the minimum was shown by micro site enrichment + micro catchment + vertical mulching. Scheduling irrigation at 50 % depletion of moisture enhanced the sturdiness quotient by 5.05 % over life saving irrigation. The minimum sturdiness quotient value of 1.71 was recorded by the treatment combination, micro site enrichment + micro catchment + vertical mulching and irrigation scheduled at 50 % depletion of moisture (W_3S_1) which was 4.68 % lower compared to control.

Crop growth potential was significantly influenced by micro site enrichment techniques. Micro site enrichment + micro catchment which was on par with micro site enric hment + micro catchment + vertical mulching and micro site enrichment recorded maximum crop growth potential and it was 333.64 % higher over POP recommendations. Though the effect of levels of irrigation on crop growth potential was insignificant, life saving irrigation was found beneficial to the extent of 38.04 % compared to irrigation scheduled at 50 % depletion of moisture. Integration of treatments also confirmed the superior performance of the treatment combination, micro site enrichment + micro catchment and life saving irrigation in improving crop growth potential by 391.26 % compared to control.

4.2.9 Physiological Parameters

Data on physiological parameters namely, osmotic potential, relative leaf water content and canopy temperature at 24 and 48 hours after irrigation and their difference due to main and interaction effects recorded at 12 MAP are furnished in Table 20.

Main and interaction effects had no significant effect on osmotic potential. However, POP recommendations registered maximum osmotic potential (590.67 m mol kg^{-1}). Life saving irrigation increased osmotic potential by 10.79 % over the irrigation at 50 % depletion of moisture. Maximum osmotic potential of 669.67 m mol kg^{-1} was registered when POP recommendations was combined with life saving irrigation.

Significant influence of micro site enrichment techniques on relative leaf water content was observed. Micro site enrichment which was on par with micro site enrichment + micro catchment + vertical mulching and POP recommendations recorded the highest relative leaf water content. Between the two levels of irrigation, irrigation at 50 % depletion of moisture enhanced relative leaf water content by 0.70 % over life saving irrigation. Among the different treatment combinations, micro site enrichment and irrigation at 50 % depletion of moisture increased relative leaf water content to the extent of 3.49 % over control.

Canopy temperatures recorded at 24 and 48 hours after irrigation were not all influenced by micro site enrichment techniques. The values ranged from 33.27 to 33.87 ^{0}C at 24 hours after irrigation and 34.93 to 36.37 ^{0}C at 48 hours after irrigation. Micro site enrichment + micro catchment + vertical mulching at 24 hours after irrigation and micro site enrichment at 48 hours after irrigation registered lower canopy temperatures. The difference in temperature between 24 and 48 HAI was minimum with respect to micro site enrichment. POP recommendations resulted in maximum variation in canopy temperature over 24 hour interval. Levels of irrigation significantly influenced canopy temperature at 24 and 48 hours after irrigation. The values were 32.57 and 34.38 at 24 hours after irrigation and 34.68 and 36.35 ^{0}C at 48 hours after irrigation. At both stages, irrigation at 50 % depletion of moisture recorded significantly lower values. Compared to irrigation at 50 % depletion of moisture, life saving irrigation resulted in minimum difference in temperature between 24 and 48 hours after irrigation.

Interaction effects didn't significantly influence the canopy temperature either at 24 or 48 hours after irrigation. At 24 hours after irrigation, micro site enrichment + micro catchment + vertical mulching and irrigation at 50 % depletion of moisture (W_3S_1) recorded the minimum value of 31.93 ^{0}C and POP recommendations and life saving irrigation, the maximum value of 34.80 ^{0}C. The trend was similar with respect to 48 hours after irrigation as well. Over a period of 24 hours, the canopy temperature variation ranged from 1.60 to 2.73 ^{0}C. Minimum temperature variation of 1.60 ^{0}C was recorded by micro site enrichment and irrigation at 50 % depletion of moisture which was 70.63 % higher over control.

Table 20. Physiological parameters at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation.

Treatments	Osmotic potential (mmole kg^{-1})	Relative leaf water content,%	Canopy Temperature (^{0}C)		
			24 HAI	48HAI	Difference
W. Micro site enrichment techniques (4)					
W_1	520.17	94.94	33.27	34.93	1.67
W_2	570.50	90.48	33.48	35.33	1.85
W_3	572.00	94.42	33.27	35.43	2.17
W_4	590.67	92.66	33.87	36.37	2.50
F	0.89 ^{NS}	5.70**	0.48 ^{NS}	2.19 ^{NS}	1.48 ^{NS}
SE	32.06	0.84	0.41	0.41	0.30
CD	-	2.55	-	-	-
S. Soil moisture regimes (2)					
S_1	534.50	93.45	32.57	34.68	2.12
S_2	592.17	92.80	34.38	36.35	1.98
F	3.23 ^{NS}	0.61 ^{NS}	19.50**	16.52**	0.22 ^{NS}
SE	22.67	0.59	0.29	0.29	0.21
CD	-	-	0.88	0.88	-
Treatment combinations (WxS=8)					
W_1S_1	542.67	97.06	32.53	34.13	1.60
W_1S_2	497.67	92.82	34.00	35.73	1.73
W_2S_1	557.00	89.54	32.87	34.80	1.93
W_2S_2	584.00	91.43	34.10	35.87	1.77
W_3S_1	526.67	95.68	31.93	34.13	2.20
W_3S_2	617.33	93.15	34.60	36.73	2.13
W_4S_1	511.67	91.54	32.93	35.67	2.73
W_4S_2	669.67	93.79	34.80	37.07	2.27
F	1.83 ^{NS}	3.68*	0.59 ^{NS}	0.65 ^{NS}	0.17 ^{NS}
SE	45.35	1.19	0.58	0.58	0.43
CD	-	3.61	-	-	-

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

4.2.10 Biochemical Parameters

Biochemical parameters namely, chlorophyll a, chlorophyll b, total chlorophyll, tannin content of stem bark and leaves and total phenol concentration of stem bark and leaves estimated at 12 MAP are depicted in Table 21.

Chlorophyll a, chlorophyll b and total chlorophyll content were not at all significantly influenced by micro site enrichment techniques. In all cases, POP recommendations registered maximum values of 0.45, 0.17 and 0.62 mg $100g^{-1}$ respectively. The treatment combination, POP recommendations and life saving irrigation registered maximum values of chlorophyll a, chlorophyll b and total chlorophyll. The values of chlorophyll a ranged from 0.35 to 0.53 mg $100g^{-1}$, chlorophyll b from 0.12 to 0.20 mg $100g^{-1}$ and total chlorophyll from 0.47 to 0.73 mg $100g^{-1}$.

Tannin content of stem bark and leaves ranged from 0.28 to 0.30 mg $100g^{-1}$ and 0.51 to 0.61 mg $100g^{-1}$ respectively and micro site enrichment + micro catchment + vertical mulching recorded maximum values. The influence of levels of irrigation on tannin content was insignificant, though life saving irrigation was found to favour its production. Integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation enhanced the tannin production both in the bark and leaves. The per cent increase over control were 6.90 and 24.00 respectively. The values ranged from 0.27 to 0.31 mg 100 g^{-1} in stem bark and 0.50 to 0.62 mg 100 g^{-1} in leaves.

Micro site enrichment techniques significantly influenced the total phenol production of stem bark and the values ranged from 2.52 to 2.98 mg 100 g-1. Micro site enrichment and micro site enrichment + micro catchment + vertical mulching were on par and the per cent increase over control were 18.25 and 7.89 respectively for stem bark and leaves. Though the effects of levels of irrigation

Table 21. Biochemical parameters at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	Chlorophyll a (mgg^{-1})	Chlorophyll b (mgg^{-1})	Total chlorophyll (mgg^{-1})	Tannin (mg $100g^{-1}$)		Total phenol($mg100g^{-1}$)	
				Stem bark	Leaves	Stem bark	Leaves
W. Micro site enrichment techniques (4)							
W_1	0.40	0.15	0.55	0.28	0.56	2.98	7.68
W_2	0.43	0.17	0.60	0.28	0.57	2.58	7.25
W_3	0.38	0.15	0.53	0.29	0.61	2.88	7.30
W_4	0.45	0.17	0.62	0.30	0.51	2.52	7.12
F	0.35^{NS}	0.39^{NS}	0.34^{NS}	0.39^{NS}	1.46^{NS}	8.04**	1.15^{NS}
SE	0.05	0.02	0.06	0.02	0.03	0.07	0.23
CD	-	-	-	-	-	0.24	-
S. Soil moisture regimes (2)							
S_1	0.38	0.14	0.52	0.29	0.56	2.77	7.46
S_2	0.45	0.17	0.62	0.29	0.57	2.72	7.22
F	2.26^{NS}	3.75^{NS}	2.57^{NS}	0.04^{NS}	0.02^{NS}	0.39^{NS}	1.13^{NS}
SE	0.04	0.01	0.04	0.01	0.02	0.05	0.16
CD	-	-	-	-	-	-	-
Treatment combinations (WxS=8)							
W_1S_1	0.35	0.12	0.47	0.27	0.55	3.00	7.87
W_1S_2	0.45	0.17	0.62	0.28	0.57	2.97	7.50
W_2S_1	0.40	0.16	0.56	0.28	0.56	2.53	7.17
W_2S_2	0.46	0.17	0.63	0.29	0.58	2.63	7.33
W_3S_1	0.39	0.15	0.54	0.29	0.61	2.97	7.33
W_3S_2	0.38	0.15	0.53	0.28	0.62	2.80	7.27
W_4S_1	0.37	0.13	0.50	0.31	0.52	2.57	7.47
W_4S_2	0.53	0.20	0.73	0.29	0.50	2.47	6.77
F	0.50^{NS}	0.79^{NS}	0.57^{NS}	0.15^{NS}	0.06^{NS}	0.51^{NS}	0.69^{NS}
SE	0.07	0.02	0.09	0.03	0.05	0.11	0.32
CD	-	-	-	-	-	-	-

NS – Not significant   * * Significant at 1 per cent was insignificant, irrigation scheduled at 50 % depletion of moisture enhanced total phenol production of stem bark and leaves which were 1.84 and 3.32 % higher over life saving irrigation. Among the different treatment combinations, micro site enrichment and irrigation scheduled at 50 % depletion of moisture produced maximum phenol content both in the stem bark and leaves which were 21.46 and 16.25 % respectively higher compared to control. Stem bark and the leaf phenol contents ranged from2.47 to 3.00 mg $100g^{-1}$ and 6.77 to 7.87 mg 100 g^{-1} respectively.

4.2.11 Biomass Production and its Partitioning

Mean data on biomass production namely, root, stem, stem bark, leaf and total both fresh and dry recorded at 12 MAP are given in Table 22.

Micro site enrichment techniques significantly influenced the root biomass production. The fresh and dry root biomass production values ranged from 60.17 to 141.33 g and 29.33 to 71.00 g respectively. Micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment + micro catchment and micro site enrichment produced maximum root biomass both fresh and dry which were 134.88 and 142.07 % higher respectively compared to control. Life saving irrigation registered maximum root biomass production and fresh and dry root production were 17.87 and 15.94 % higher over irrigation at 50 % depletion of moisture. The effect of treatment combination on root biomass production varied widely and the values of root biomass production varied 49.67 to 158.00 g $plant^{-1}$ and 24.00 to 80.00 g $plant^{-1}$ respectively. In both the cases, micro site enrichment + micro catchment recorded maximum production which were 218.10 and 233.33 % higher compared to control.

Significant influence of micro site enrichment techniques on stem biomass production both fresh and dry was observed. Micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment + micro catchment and micro site enrichment increased stem biomass production both fresh and dry to the tune of 296.21 and 301.86 % over control. The values ranged from 30.33 to 120.17 g plant-1 for fresh and 18.83 to 75.67 g plant-1 for dry stem biomass production respectively. Life saving irrigation enhanced stem biomass production both fresh and dry to the extent of 37.85 and 39.57 % compared to irrigation scheduled at 50 % depletion of moisture. Treatment combinations showed wide variations in stem biomass production. The combined effect of micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_3S_2) was found favourable for enhancing stem biomass production both fresh and dry to the tune of 417.86 and 416.67 % respectively. The values ranged from 28.00 to 145.00 g plant^{-1} for fresh and 18.00 to 93.00 g plant^{-1} for dry stem biomass production.

Significant variation in stem bark production was observed due to the main effects of micro site enrichment techniques. Stem bark yield both fresh and dry ranged from 13.93 to 49.89 g plant^{-1} and 7.40 to 26.84 g plant^{-1} respectively. Micro site enrichment + micro catchment which was on par with micro site enrichment + micro catchment + vertical mulching and micro site enrichment produced maximum bark yield both fresh and dry and were 88.24 and 85.88 % higher over control. Though the effect of irrigation was insignificant, life saving irrigation improved bark yield both fresh and dry (40.19 and 21.32 g plant^{-1}) and were 4.44 and 3.55 % higher over irrigation scheduled at 50 % depletion of moisture. Wide variation in bark production was observed due to interaction effects and the fresh and dry bark yield ranged from 10.78 to 55.36 g plant^{-1} and 5.60 to 29.41 g plant^{-1} respectively. Micro site enrichment + micro catchment + vertical mulching combined with life saving irrigation (W_3S_2) was found favourable for improving both fresh and dry bark yield to the tune of 413.54 and 425.18 % respectively over control.

Table 22. Biomass production and its partitioning at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	Root (g)		Stem (g)		Stem bark (g)		Leaf (g)		Total (g)	
	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry
W. Micro site enrichment techniques (4)										
W_1	122.17	60.33	104.50	65.00	44.65	23.59	240.00	105.50	511.32	254.43
W_2	127.33	65.33	120.00	75.67	49.89	26.84	257.00	114.67	554.23	280.67
W_3	141.33	71.00	120.17	75.67	48.87	26.01	267.83	120.00	578.19	292.68
W_4	60.17	29.33	30.33	18.83	13.93	7.40	73.00	31.17	177.43	86.73
F	4.87*	4.57*	4.26*	4.15*	4.89*	4.99*	8.95**	9.34*	6.90**	6.62*
SE	16.80	8.71	20.79	13.40	7.72	4.09	30.64	13.59	71.28	37.28
CD	49.15	26.43	62.66	40.36	23.27	12.42	92.34	41.23	216.23	113.09
S. Soil moisture regimes (2)										
S_1	103.50	52.33	78.83	49.08	38.48	20.59	189.00	82.33	409.81	204.34
S_2	122.00	60.67	108.67	68.50	40.19	21.32	229.92	103.33	500.77	252.91
F	1.29 ^{NS}	0.91 ^{NS}	2.06 ^{NS}	2.13 ^{NS}	0.05 ^{NS}	0.03 ^{NS}	1.78 ^{NS}	2.39 ^{NS}	1.63 ^{NS}	1.69 ^{NS}
SE	11.53	6.16	14.70	9.41	5.46	2.89	21.67	9.61	50.40	26.36
CD	-	-	-	-	-	-	-	-	-	-
Treatment combinations (WxS=8)										
W_1S_1	116.00	57.33	80.67	50.67	44.01	23.36	205.67	90.67	446.34	222.03
W_1S_2	128.33	63.33	128.33	79.33	45.29	23.83	274.33	120.33	576.29	286.83
W_2S_1	96.67	50.67	106.67	67.67	50.47	27.21	231.67	99.00	485.47	244.54
W_2S_2	158.00	80.00	133.33	83.67	49.33	26.46	282.33	130.33	622.99	316.79
W_3S_1	130.67	66.67	95.33	58.33	42.37	22.61	237.00	105.67	505.37	253.28
W_3S_2	152.00	75.33	145.00	93.00	55.36	29.41	298.67	134.33	651.03	332.07
W_4S_1	70.67	34.67	32.67	19.67	17.07	9.19	81.67	34.00	202.07	97.53
W_4S_2	49.67	24.00	28.00	18.00	10.78	5.60	64.33	28.33	152.78	75.94
F	1.29 ^{NS}	0.89 ^{NS}	2.06 ^{NS}	2.13 ^{NS}	0.28 ^{NS}	0.29 ^{NS}	0.42 ^{NS}	0.43 ^{NS}	0.43 ^{NS}	0.39 ^{NS}
SE	23.06	12.32	14.70	18.82	10.92	5.79	43.33	19.22	100.81	52.72
CD	-	-	-	-	-	-	-	-	-	-

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

Significant influence of micro site enrichment techniques was observed on leaf production. Fresh and dry leaf yield ranged from 73.00 to 267.83 g plant^{-1} and 31.17 to 120.00 g plant^{-1} respectively. Micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment + micro catchment and micro site enrichment registered maximum fresh and dry leaf yield that were 266.89 and 284.99 % higher over control. Life saving irrigation was also beneficial for increasing leaf yield both fresh and dry to the tune of 21.65 and 25.51 % respectively over irrigation scheduled at 50 % depletion of moisture. Fresh and dry leaf yield ranged from 64.33 to 298.67 and 28.33 to 134.33 g plant^{-1} respectively due to interaction effects. Maximum leaf production was observed when micro site enrichment + micro catchment + vertical mulching was coupled with life saving irrigation (W_3S_2). This treatment combination enhanced fresh and dry leaf yield to the tune of 364.28 and 374.16 % respectively over control.

Total biomass production was significantly influenced by micro site enrichment techniques. Total fresh and dry biomass production ranged from 177.43 to 578.19 and 86.73 to 292.68 g plant^{-1} respectively. Micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment + micro catchment and micro site enrichment recorded maximum production. The increase in total fresh and dry biomass production were 225.87 and 237.46 % higher over POP recommendations. Life saving irrigation improved total biomass production and the increase over irrigation scheduled at 50 % depletion of moisture were 22.19 and 23.77 % respectively for total fresh and dry biomass production. Total fresh and dry biomass production per plant ranged from 152.78 to 651.03 and 75.94 to 332.07 g plant^{-1} respectively due to interaction effects. Maximum total fresh and dry biomass production were observed when micro site enrichment + micro catchment + vertical mulching was combined with life saving irrigation (W_3S_2) and the improvement over control were 326.12 and 337.28 % respectively.

4.2.12 Per Cent Dry Matter Production

Data on per cent dry biomass production estimated at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation are given in Table 23.

Micro site enrichment techniques caused significant variation in partitioning of biomass in favour of roots. POP recommendations enhanced partitioning in favour of roots and it was significantly different from all other treatments.

Although no significant variation was observed with respect to partitioning of dry matter into stem, stem bark and leaves micro site enrichment + micro catchment, micro site enrichment + micro catchment and micro site enrichment + micro catchment + vertical mulching improved partitioning in favour of stem, stem bark and leaves respectively.

Irrigation at 50 % depletion of moisture enhanced biomass partitioning in favour of roots, stem bark and leaves and the effect was significant with respect to partitioning of the stem bark alone. However, life saving irrigation enhanced biomass partitioning in favour of stem.

Though biomass partitioning was not significantly influenced by interaction effects, integration of POP recommendations and irrigation at 50% depletion of moisture, micro site enrichment and life saving irrigation, micro site enrichment + micro catchment and irrigation scheduled at 50 % depletion of moisture and micro site enrichment + micro catchment + vertical mulching and irrigation scheduled at 50 % depletion of moisture resulted in improving partitioning in favour of root, stem, stem bark and leaves.

Table 23. Per cent dry matter production at 12 MAP as influenced by micro site enrichment techniques and levels of irrigation.

Treatments	Root	Stem	Stem bark	Leaves
W. Micro site enrichment techniques (4)				
W_1	24.21	25.19	9.46	41.14
W_2	22.67	26.63	9.58	41.75
W_3	25.89	23.57	8.65	41.89
W_4	33.94	21.88	8.61	35.57
F	5.39*	1.21 ^{NS}	0.71 ^{NS}	2.56 ^{NS}
SE	2.16	1.86	0.61	1.89
CD	6.55	-	-	-
S. Soil moisture regimes (2)				
S_1	28.08	22.37	9.89	39.66
S_2	25.27	26.27	8.26	40.51
F	1.69 ^{NS}	4.38 ^{NS}	6.98*	0.20 ^{NS}
SE	1.53	1.32	0.43	1.34
CD	-	-	1.32	-
Treatment combinations (WxS=8)				
W_1S_1	26.64	22.49	10.69	40.18
W_1S_2	21.77	27.89	8.23	42.10
W_2S_1	20.58	27.07	10.84	41.50
W_2S_2	24.50	26.18	8.32	41.00
W_3S_1	28.70	20.15	8.37	42.78
W_3S_2	23.09	26.99	8.92	40.99
W_4S_1	36.41	19.76	9.65	34.18
W_4S_2	31.48	23.98	7.58	36.96
F	1.17 ^{NS}	0.82 ^{NS}	1.42 ^{NS}	0.28 ^{NS}
SE	3.06	2.63	0.87	2.68
CD	-	-	-	-

NS – Not significant   * Significant at 5 per cent

4.2.13 Soil Moisture

Mean data on moisture content of soil before and after irrigation, seasonal consumptive use, mean daily consumptive use, crop coefficient, crop water use efficiency, field water use efficiency and water productivity are presented in Table 24.

After irrigation, though micro site enrichment techniques didn't significantly influence soil moisture status, micro site enrichment + micro catchment + vertical mulching registered the maximum value of 23.05 which was 14.33 % higher compared to POP recommendations. The effect of micro site enrichment was significant before irrigation and maximum moisture content of 19.26 % was observed in micro site enrichment + micro catchment + vertical mulching which was 26.79 % higher compared to control.

Levels of irrigation didn't significantly influence moisture content before and after irrigation. However, life saving irrigation enhanced moisture content 48 hours after irrigation to the extent of 0.09 % over irrigation scheduled at 50 % depletion of moisture. The trend was just reverse before irrigation and the improvement was 4.74 % over life saving irrigation.

Interaction effects showed the superiority of micro site enrichment + micro catchment + vertical mulching combined with irrigation scheduled at 50 % depletion of moisture with respect to moisture content both before and after irrigation.

Both micro site enrichment techniques and life saving irrigation significantly influenced seasonal consumptive use and mean daily consumptive use. The peak consumptive use of 918.85 mm was recorded by the treatment, POP recommendation, which was significantly different from other treatments.

Micro site enrichment techniques were instrumental in reducing seasonal consumptive use. Scheduling irrigation at 50 % depletion of moisture significantly enhanced seasonal consumptive use to the tune of 51.56 % over life saving irrigation. The trend was similar with respect to mean daily consumptive use as well.

Combinations of the above two treatments, i.e POP recommendation and scheduling irrigation at 50 % depletion of moisture recorded maximum seasonal consumptive use and mean daily consumptive use. Crop coefficient (K_c) values ranged from 0.47 to 0.72 and the main and interaction effects of treatments on this parameter were exactly similar to their effects on consumptive use.

Significant variations on crop water use efficiency, field water use efficiency and water productivity were observed due to main effects of treatments. In all cases, the trend was exactly similar. Micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment + micro catchment and micro site enrichment but significantly different from POP recommendations improved crop water use efficiency, field water use efficiency and water productivity.

The effect of life saving irrigation was conspicuous and it enhanced all the above three parameters considerably compared to scheduling irrigation at 50 % depletion of moisture.

Interaction effects indicated the significance of the treatment combination micro site enrichment + micro catchment + vertical mulching and life saving irrigation (W_4S_2) in enhancing crop water use efficiency, field water use efficiency and water productivity to the tune of 1144.90, 987.16 and 837.00 % respectively over control. However, the least efficiency and productivity values were registered by POP recommendations with life saving irrigation or 50 % depletion of moisture.

Table 24. Soil moisture studies as influenced by micro site enrichment techniques and levels of irrigation.

Treat-ments	Soil Moisture (%)		Seasonal Cu (mm)	Mean Daily Cu (mm)	K_c	CWUE (g m^{-3})	FWUE (g m^{-3})	WP (g m^{-3})
	Before	After						
W. Micro site enrichment techniques (4)								
W_1	17.19	21.65	682.64	1.89	0.54	199.34	56.39	636.63
W_2	17.53	22.24	597.65	1.66	0.47	252.32	71.32	750.30
W_3	19.26	23.05	479.70	1.47	0.38	317.26	76.56	861.17
W_4	15.19	20.16	918.85	2.55	0.72	40.16	10.22	104.18
F	10.17**	2.48 NS	16.02**	10.51**	15.62**	4.82*	8.04**	10.49**
SE	0.52	0.77	46.41	0.15	0.04	53.84	10.64	103.55
CD	1.58	-	140.57	0.44	0.11	163.11	32.22	313.66
S. Soil moisture regimes (2)								
S_1	17.69	21.77	806.97	2.24	0.63	151.97	36.67	344.99
S_2	16.89	21.79	532.45	1.54	0.42	252.58	70.58	831.15
F	2.32 NS	0.001 NS	34.99**	22.84**	35.37**	3.49 NS	10.16**	22.04**
SE	0.37	0.055	32.81	0.10	0.02	38.07	7.52	73.22
CD	-	-	99.40	0.31	0.008	-	22.79	221.79
Treatment combinations (WxS=8)								
W_1S_1	17.34	21.55	914.71	2.54	0.72	127.44	33.37	317.17
W_1S_2	17.04	21.77	450.56	1.25	0.36	271.23	79.42	956.09
W_2S_1	17.67	22.33	764.87	2.12	0.61	194.96	54.41	444.62
W_2S_2	17.39	22.16	430.43	1.19	0.34	309.67	88.23	1055.97
W_3S_1	19.76	23.05	578.82	1.61	0.46	237.03	48.11	536.37
W_3S_2	18.76	23.05	380.59	1.06	0.30	397.50	105.02	1185.97
W_4S_1	16.30	20.15	969.47	2.69	0.76	48.47	10.79	81.81
W_4S_2	14.09	20.18	868.23	2.41	0.68	31.93	9.66	126.56
F	1.06 NS	0.01 NS	2.92 NS	2.92 NS	2.95 NS	0.56 NS	1.40 NS	2.03 NS
SE	0.74	1.09	65.63	0.21	0.005	76.15	15.04	146.43
CD	-	-	-	-	-	-	-	-

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

4.3 TECHNIQUES FOR INCREASING BARK YIELD

4.3.1 Bark Regeneration

The mean data on the effect of growth regulators on thickness, yield and quality parameters namely, tannin and total phenol of bark are furnished in Table 25.

Thickness of regenerated bark ranged from 0.87 to 1.30 cm and application of kinetin resulted in increasing bark thickness to the tune of 30.00 % over control. Fresh yield of bark ranged from 115.00 to 221.67 g $tree^{-1}$ and the highest yield was recorded by kinetin which was 106.31 % higher over control. A similar trend followed with respect to dry bark yield.

Quality parameters of bark namely, tannin and total phenol content ranged from 0.39 to 0.40 mg 100 g^{-1} and 2.73 to 3.03 mg 100 g^{-1} respectively. Combination of NAA + kinetin resulted in increasing tannin and phenol content of bark by 2.56 and 10.99 % respectively over control.

Table 25. Thickness, yield and quality parameters of regenerated bark as influenced by plant growth regulators.

Treat-ments	Thickness (mm)		Yield (g)		Tannin (mg $100g^{-1}$)		Total phenol ($mg100g^{-1}$)	
	Regenerated bark	Normal bark	Fresh	Dry	Stem bark	Leaves	Stem bark	Leaves
T_1	1.00	1.60	212.00	152.67	0.39	0.70	2.97	7.83
T_2	1.30	1.33	221.67	126.67	0.39	0.72	2.73	7.67
T_3	0.87	1.03	164.33	104.00	0.40	0.72	3.03	7.93
T_4	1.00	1.07	115.00	74.00	0.39	0.72	2.73	7.80
Young branch	-	-	-	-	0.40	0.70	3.00	8.03
Normal bark	-	-	-	-	0.42	-	3.23	-
F	2.81 ^{NS}	2.21 ^{NS}	0.51 ^{NS}	1.39 ^{NS}	0.57 ^{NS}	2.07 ^{NS}	3.06 ^{NS}	0.63 ^{NS}
SE	0.11	0.18	68.69	28.37	0.01	0.01	0.11	0.17
CD	-	-	-	-	-	-	-	-

NS – Not significant

Discussion

5. DISCUSSION

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

5.1 TECHNIQUES FOR QUALITY PLANTING MATERIAL PRODUCTION

The quality of the planting stock is an important prerequisite in ashoka as it determines field establishment and subsequent growth of seedlings. Ensuring seed quality alone is not sufficient as inappropriate methods of raising nursery may lead to poor quality of planting stock. Hence there is an urgent need to standardize nursery techniques for ashoka, a perennial species for production of quality seedlings in the nursery. The effect of root trainer techniques and rooting media on biometric characters, dry matter production, root characters and growth indices were studied in detail.

5.1.1 Root Trainer Techniques

Among the four containers used for raising ashoka seedlings, the performance of mud pots was found to be superior with respect to biometric characters such as seedling height, collar girth, and leaf number at 135 DAS (Plate 3). Seedling leaf area was also significantly high in mud pots at 135 DAS. The performance of the seedlings with respect to biometric characters was inferior at 135 DAS when root trainers were used as containers. The effect of rooting media in influencing biometric characters were remarkable though not consistent at all stages. At 135 DAS, combination of potting mixture + dual inoculation with Rhizobium and AMF + rock powder + mixture of vermi compost, FYM and composted coir pith enhanced seedling height and leaf number. The superior performance of above rooting medium was also evident with respect leaf area as well. Interaction effects also showed the importance of

Plate 4 Performance of seedlings in nursery

1- mudpots.
2- poly bags
3- root trainers(block containers)

integration of appropriate rooting media and containers for improving biometric characters.

Composition of rooting media influenced total length of tap root, total root number including number of rootlets and root spread at 135 DAS. Rooting medium consisting of potting mixture + dual inoculation with Rhizobium and AMF + rock powder + mixture of vermi compost, FYM and composted coir pith was found to improve the above root characters remarkably at the time of pulling out of seedlings. Above treatments had a negative effect on root coiling which is a desirable character for field establishment of seedlings.

Integration of root trainer techniques and rooting media indicated the superiority of treatment combination R_1M_4 in increasing the length of tap root without coiling (Fig. 3). With respect to other root characters, interaction effects were not consistent. Raising seedlings in mud pots filled with potting mixture resulted in root proliferation (total number of rootlets and total number of roots) (Fig. 4). However, inoculation with Rhizobium and AMF and addition of rock powder and mixture of coir pith compost, vermi compost and FYM to potting mixture in mud pots was found to favour root spread at 135 DAS (Plate 4).

The root trainer is a specially designed container for the development of proper root system. It is a cylindrical container with two open ends of which the lower end tapers gradually with a smaller open end. The container is made up of opaque material to provide favourable conditions for root development. Inside the root trainer are provided with ridges/ ribs running longitudinally from one end to other to prevent root coiling which impede plant growth. When a root starts to coil inside the container and it touches the ridge, it immediately changes its course due to thigmotropism and traverses down avoiding coiling. Root pruning in root trainer takes place as the roots which protrude out of the trainer died out due to air pruning which stimulates the development of several actively growing root tips. This process continues resulting in a larger volume of root system in a

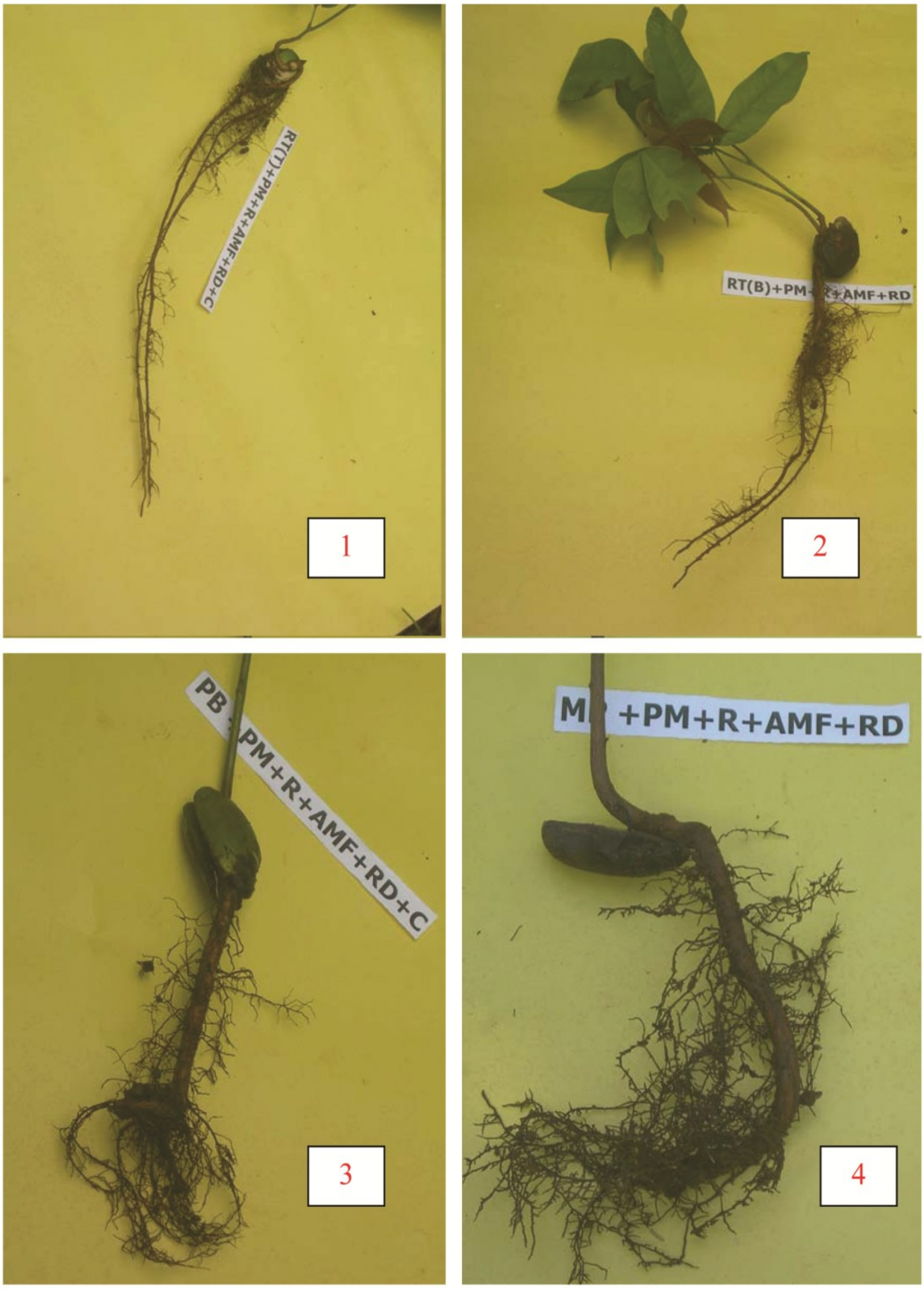


Plate 4 Root development in nursery

1. Root trainer (individual tubes) 2. Root trainer (block container)
3. Poly bags 4. Mud pots

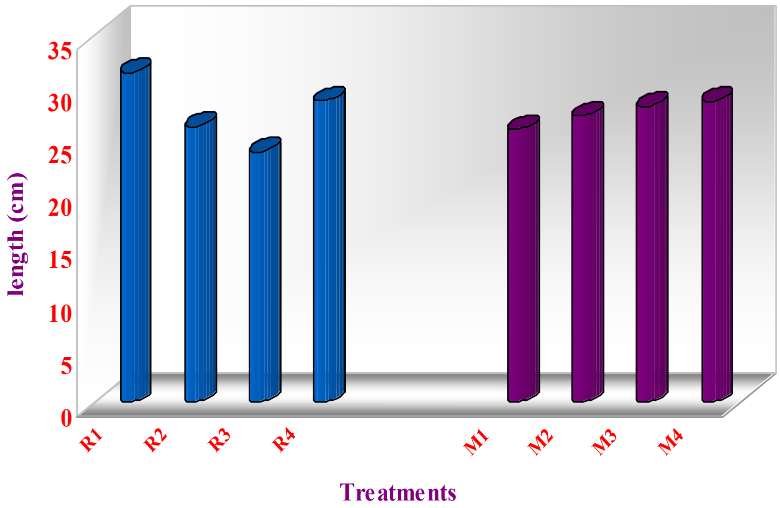


Fig. 3 Effects of root trainer techniques and rooting on totallengthoftaproot(cm)

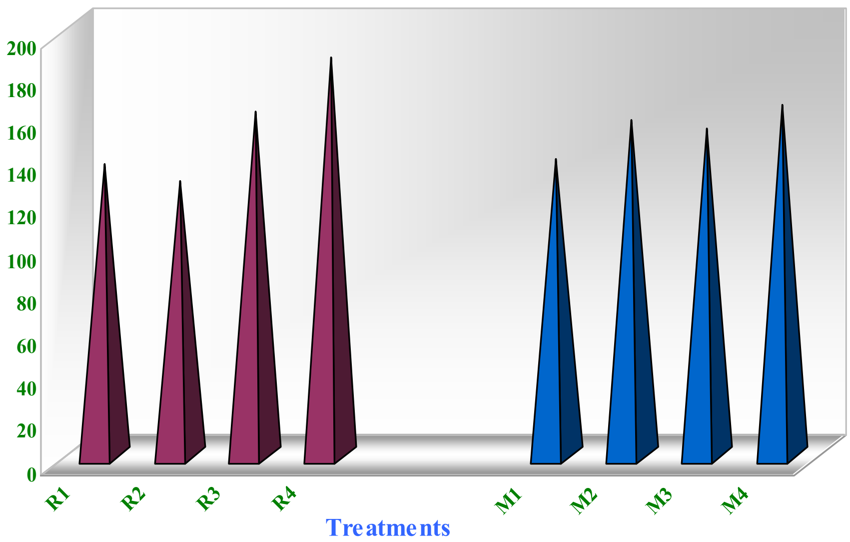


Fig. 4 Effects of root trainer techniques and rooting media on total number of roots

small volume of potting medium. The container size has an impact on growth of seedlings. The distance between the seedlings also affect the seedling growth, seedlings at closer spacing grow taller and has smaller stem diameter than grown further apart. So the quality of plants grown in mud pots increased as the growing density was less compared to other containers. The volume is one of the most obvious and important characteristics of a container because in general, in larger containers larger seedlings are produced (Kinghorn, 1974).

In general, quality of the seedlings increases with a corresponding decrease in growing density. Shoot height increases with increasing density probably for greater competition for light between the seedlings. Collar girth, shoot weight, root weight increased with closer spacing which is also reflected by the larger shoot root ratio at greater densities (Timmis and Tanaka, 1974). It is reported that seedlings grown at lower densities receive ten times more photosynthetically active radiation in their lower leaves and had lower water potential than seedlings grown at closer spacings.

One of the most serious problems in poly bag and mud pot grown planting material is the tendency of seedling roots to spiral inside the containers. Seedling roots grow geotropically, but if they do not meet any physical obstruction they may tend grow laterally around the side of the container. Root spiraling will not adversely affect growth while seedlings remain in the nursery. But it can seriously affect field establishment of the planting stock. Spiral roots prevent the seedling from becoming properly established in the field, often results in strangulation (Burdett, 1979).

Use of appropriate rooting media is very important for the success of quality planting material production. Providing good supply of nutrients, water and air to the root system results in the better development of roots leading to better survival after transplanting in the main field. Miller and Jones (1995) reported characteristics such as light weight, porous, well drained yet capable of

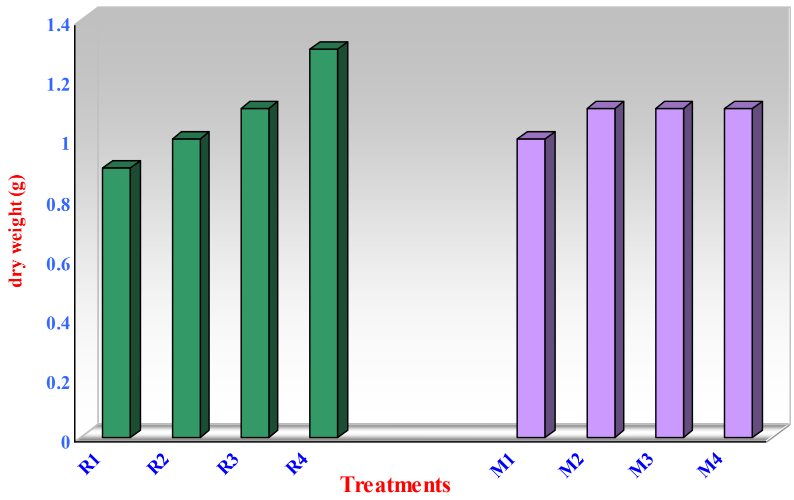


Fig. 5 Effects of root trainer techniques and rooting media on leaf biomass production (g)

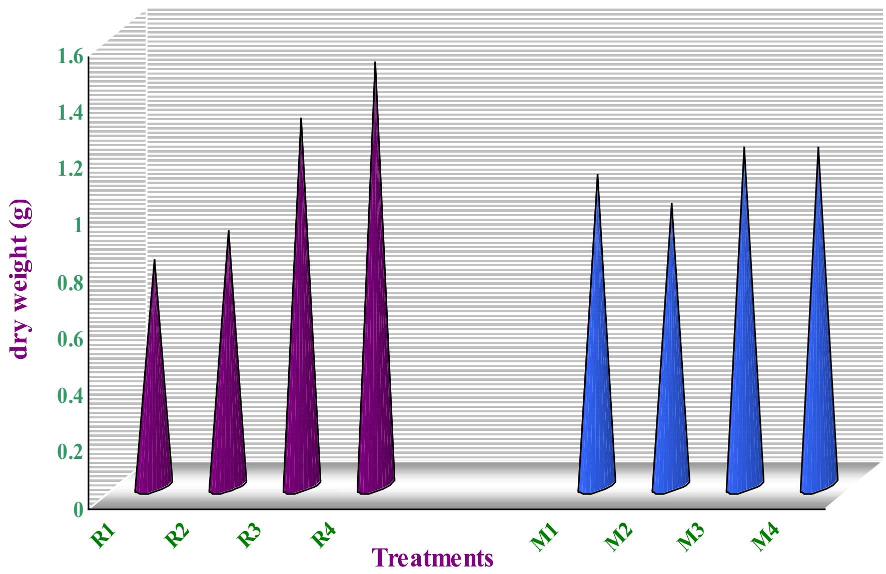


Fig. 6 Effects of root trainer techniques and rooting media on stem biomass production (g)

retaining moisture, maintaining volume when wet or dry and free from soil born pathogens as desirable traits of rooting medium.

5.1.2 Biomass Production and Partitioning

Total biomass production was found to be significantly influenced by root trainer techniques and the effect of mud pots was remarkable when compared to individual and block root trainers and poly bags (Fig. 8). A similar trend was observed with respect to leaf (Fig. 5), stem (Fig. 6) and root (Fig. 7) biomass production at 135 DAS. Though the composition of rooting media didn't influence total biomass production and its partitioning, combination of potting mixture + dual inoculation with Rhizobium and AMF + rock powder + mixture of vermi compost, FYM and composted coir pith was found favourable for achieving higher biomass productivity.

In general, dual inoculation of seeds with Rhizobium and AMF and sowing in mud pots filled with enriched rooting medium containing potting mixture + rock powder + mixture of vermi compost, FYM and composted coir pith was found beneficial for improving biomass accumulation in ashoka seedlings. This result is in confirmity with the findings of Thankamany et al. (2008), Nagaveni and Vijayalakshmi (2002), Vadiraj et al. (1993) and Vinodini et al. (2005) who reported the beneficial effects of enriched rooting media for quality planting material production.

5.1.3 Seedling Growth Indices

Seedling growth indices namely, root shoot ratio, root growth potential, sturdiness quotient and seedling growth potential evaluated at the time of transplanting indicated significant improvement in mud pot grown seedlings compared to root trainers and poly bags. However the effect of root trainer was conspicuous in improving root growth potential (Fig. 10). In general, potting

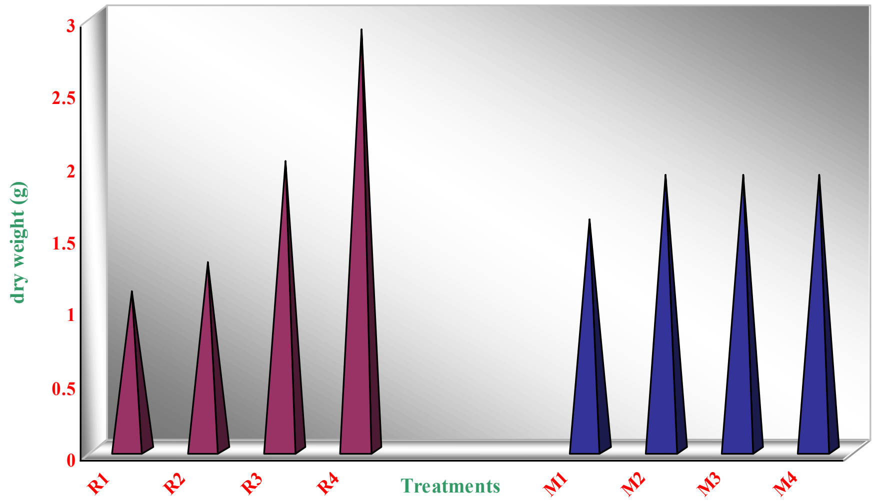


Fig. 7 Effects of root trainer techniques and rooting media on root biomass production (g)

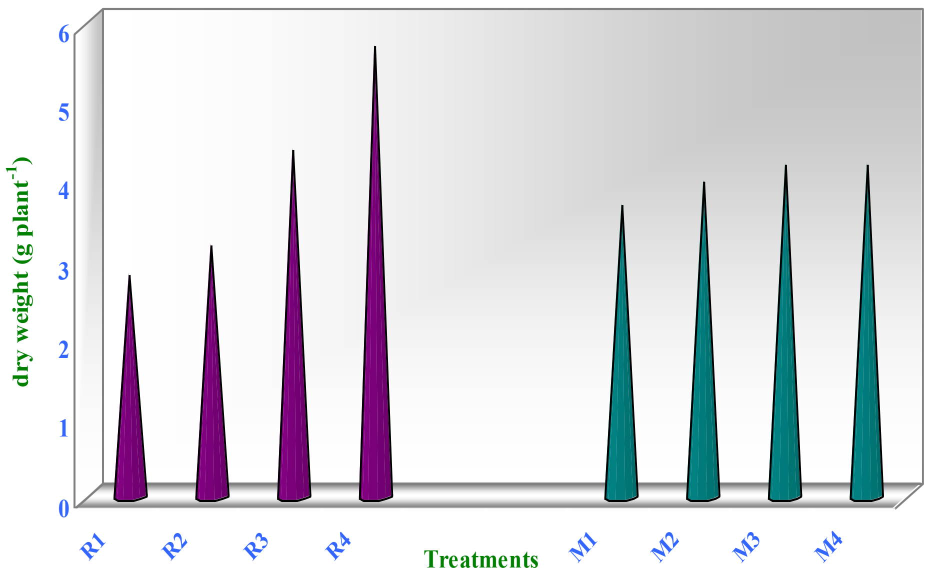


Fig. 8 Effects of root trainer techniques and rooting media on total biomass production (g per plant)

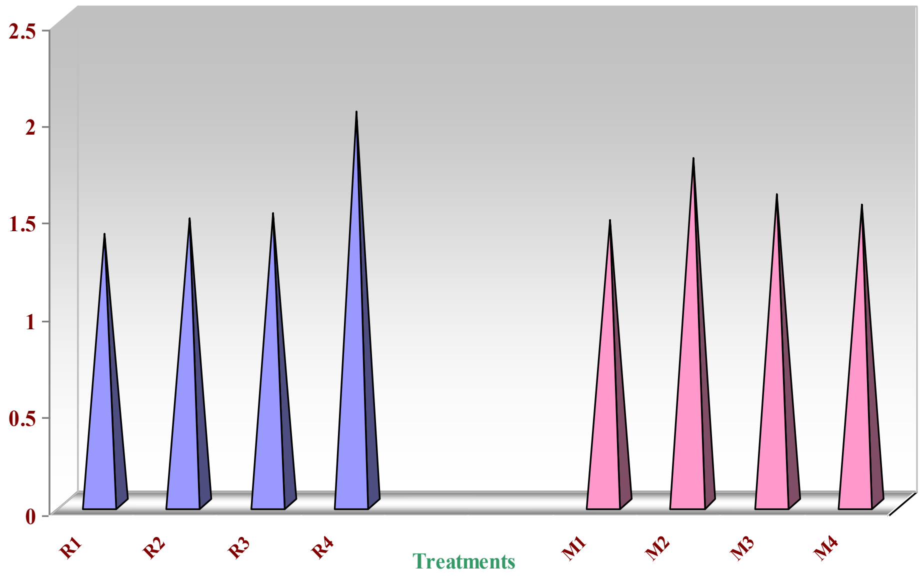


Fig. 9 Effects of root trainer techniques and rooting media on root shootratio

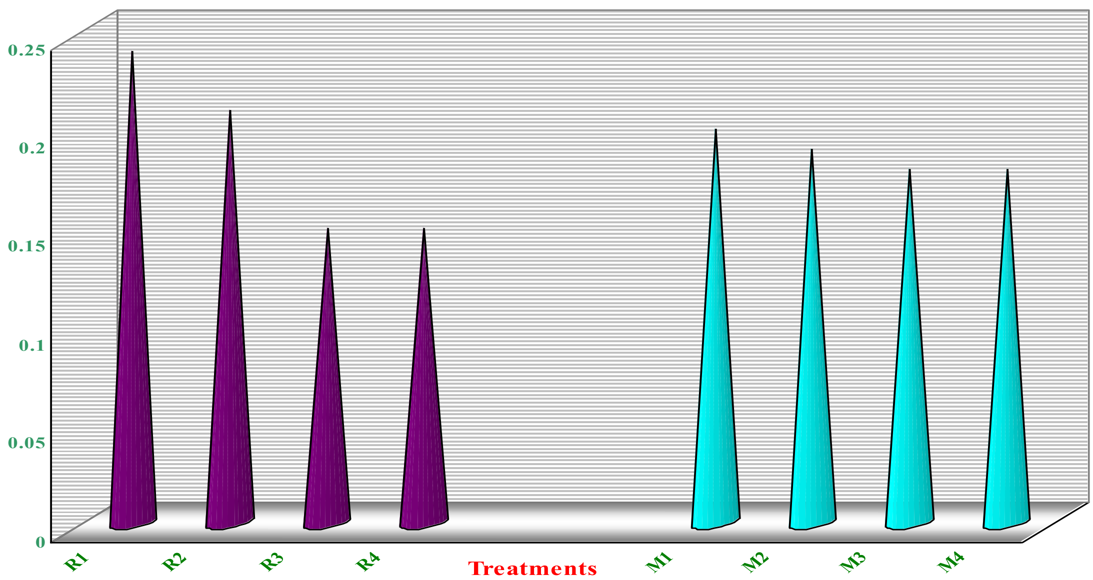


Fig. 10 Effects of root trainer techniques and rooting media on root growth potential

mixture + dual inoculation with Rhizobium and AMF showed favourable effects on root shoot ratio (Fig. 9) and sturdiness quotient (Fig. 11). Potting mixture + dual inoculation with Rhizobium and AMF + rock powder + mixture of vermi compost, FYM and composted coir pith was found to improve seedling growth potential (Fig. 12). Integration of root trainer techniques and rooting media proved the beneficial effect of in improving root shoot ratio and seedling growth potential. Similar results were also reported by Ginwal et al. (2001) in *Acacia niotica* seedlings.

5.1.4 Economics of Planting Material Production

The effect of root trainer techniques in influencing seedling price, gross income, net income and BCR was spectacular and raising seedlings in mud pots showed significant superiority over all other treatments. This was mainly due to the premium price offered by the farmers for the best quality seedlings as indicated by SGP (Table10 and 11).

Among the rooting media, combination of potting mixture + dual inoculation with Rhizobium and AMF + rock powder + mixture of vermi compost, FYM and composted coir pith showed significant superiority with respect to net income (Fig. 13) and BCR (Fig. 14) which were 32.50 and 26.70 % higher compared to potting mixture. This was mainly due to lower cost of production consequent to partial substitution of costly sand with cheap locally available components of rooting media having more desirable characters which facilitated rhizosphere engineering for improvement of SGP, resulting in getting premium price of quality planting stock (Table 11).

The interaction effects indicated wide variation in BCR and ranged from 1.61 to 3.33. Maximum gross income, net income and BCR of Rs. 78.00, Rs. 56.00 and 3.33 were obtained when ashoka seeds were inoculated with

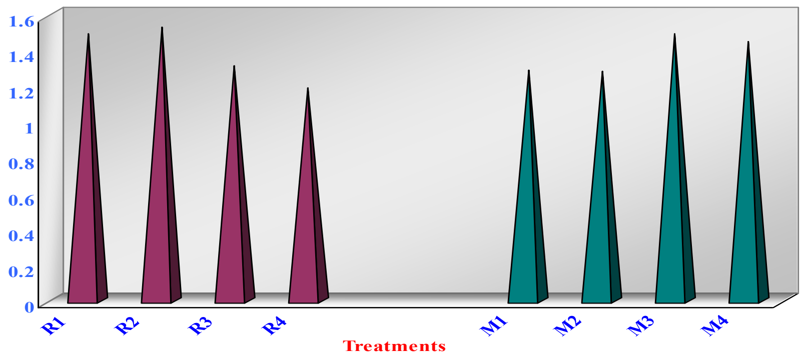


Fig. 11 Effects of root trainer techniques and rooting media on sturdiness quotient

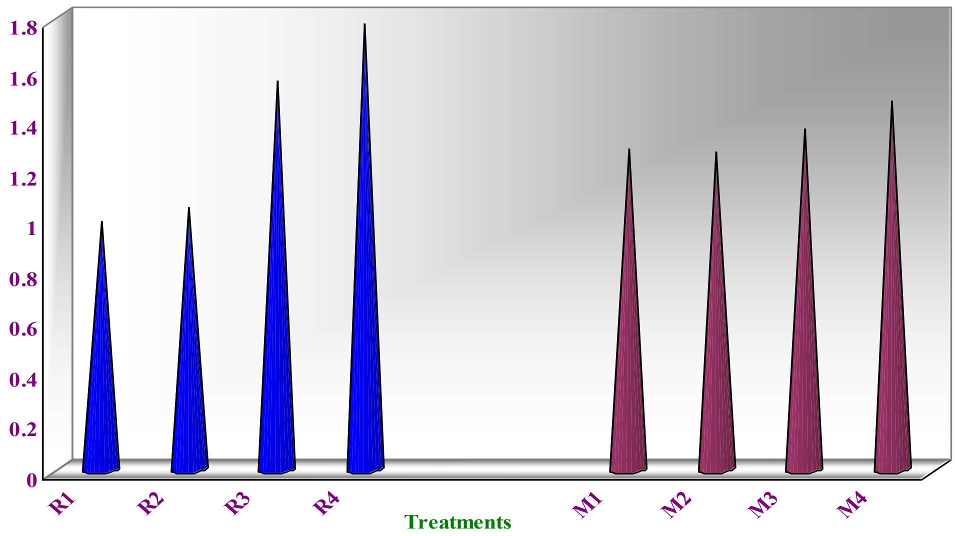


Fig. 12 Effects of root trainer techniques and rooting media on seedling growth potential

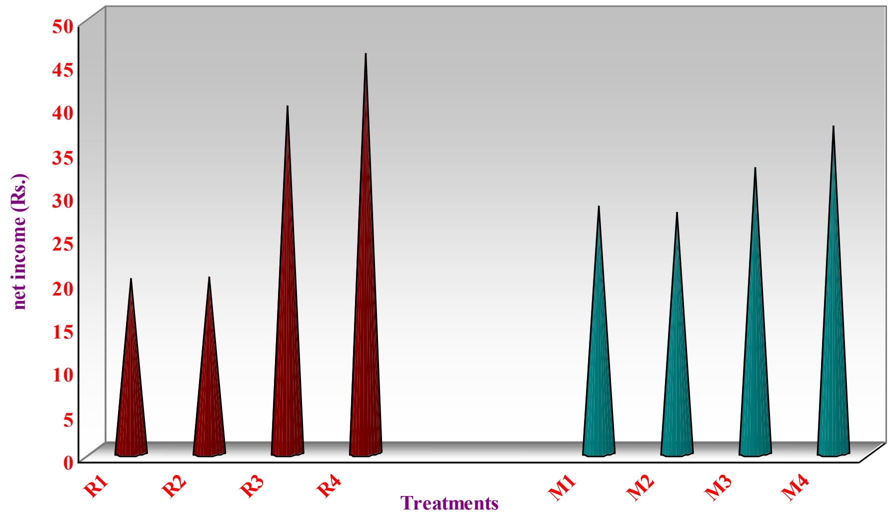


Fig. 13 Effects of root trainer techniques and rooting media on net income (Rs.) per plot

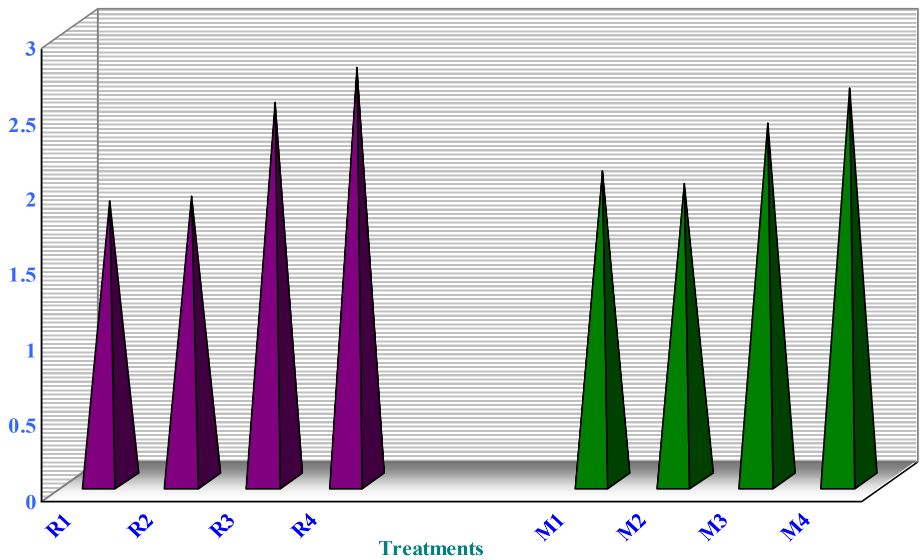


Fig. 14 Effects of root trainer techniques and rooting media on benefit cost ratio

Rhizobium and sown in mud pots filled with potting mixture containing mixture of vermin compost, FYM and composted coir pith.

5.2 MICRO SITE ENRICHMENT TECHNIQUES FOR GROWTH PROMOTION IN THE MAIN FIELD

5.2.1 Crop Growth

Ashoka responded differentially to different micro site enrichment techniques and levels of irrigation. The crop response in relation to biometric characters namely, plant height, functional leaf number, collar girth and number of branches and canopy architecture in terms of bole height, canopy height, canopy spread, canopy width and canopy size varied widely during the initial stages of establishment and could not establish any definite trend in growth pattern. However, after one year of planting, the main and interaction effects of treatments influenced growth characters and canopy attributes almost in a similar manner. In general, after one year of planting, life saving irrigation combined with micro site enrichment + micro catchment + vertical mulching enhanced all growth characters like plant height, functional leaf number, collar girth and number of branches. Canopy characters like bole height, canopy height, canopy width and canopy size were also favourably influenced by the above treatment combination after one year of establishment. In general, among the four micro site enrichment techniques, the impact of micro site enrichment, micro catchment and vertical mulching and their combinations were worth mentioning compared to POP recommendations right from the time of planting in field establishment and early growth of seedlings. Crop response to levels of irrigation varied with stages of growth and moisture sensitive period coincided with early establishment of crop upto 4 months of planting where irrigation scheduled at 50 % depletion of moisture favourably influenced biometric characters and canopy attributes compared to life saving irrigation. This has resulted because ashoka under irrigated condition never faced water stress like rainfed conditions. Water deficit

Plate 5 Biomass accumulation after 1 year of planting
1- Crop performance
2- Root development
3- Stem bark separation

is likely to affect two vital processes namely, cell division and cell enlargement resulting in poor growth under rainfed conditions. The favourable influence of higher moisture regime is likely due to stimulation of metabolic activities resulting in better growth of ashoka. The significance of life saving irrigation at later stages of growth suggests that micro site enrichment treatments were beneficial in *in situ* rain water harvest, conservation and utilization in an effective manner to meet crop water requirements. It also suggests that moisture holding capacity of the rooting medium used for micro site enrichment was sufficient to meet the ET needs of ashoka which was raised under partial shade as an inter crop in a 40 years old coconut garden.

5.2.2 Root Characters

After one year of planting, below ground parts of the plant behaved in a different manner to different micro site enrichment techniques and levels of irrigation. Variations in root parameters namely, number, length, spread, surface area and volume were conspicuous due to treatment effects. Micro site enrichment, micro catchment and vertical mulching and their combinations were effective for promoting root proliferation. The impact of soil moisture regimes on root growth was not consistent. Maintenance of readily available water in the rooting zone increased number (Fig. 15), length and spread of roots. On the other hand, moisture stress in the root zone promoted expansion of root surface and improvement in root volume (Fig. 16). Life saving irrigation combined with micro site enrichment + micro catchment + vertical mulching enhanced root number, whereas irrigation scheduled at 50 % depletion of moisture combined with above micro site enrichment treatments increased the length and spread of roots. Surface area and the volume of root system were found to enhance under life saving irrigation with micro site enrichment and micro catchment. Incorporation of a mixture of enriched vermi compost, enriched coir pith compost and layering mixture enabled vigorous and healthy growth of seedlings for early establishment.

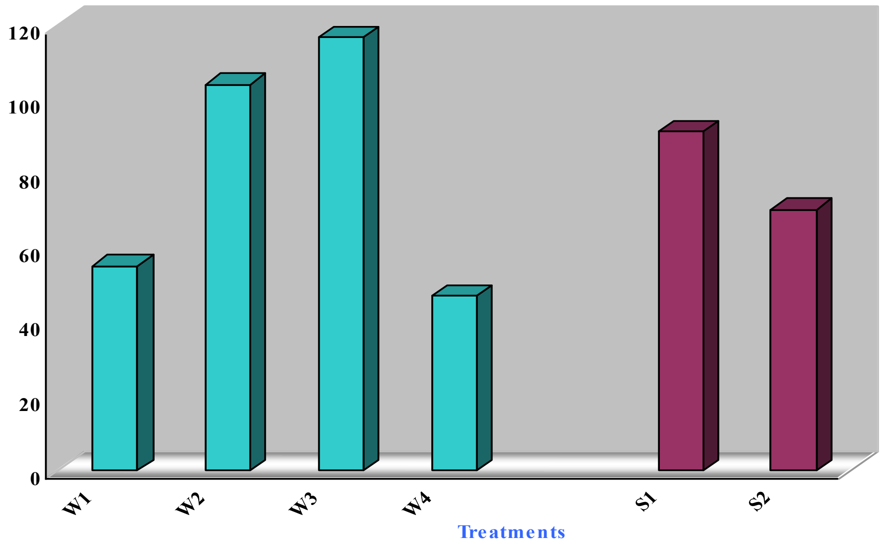


Fig. 15 Effects *of in situ* rain water harvesting techniques and levels of irrigation on total number of roots

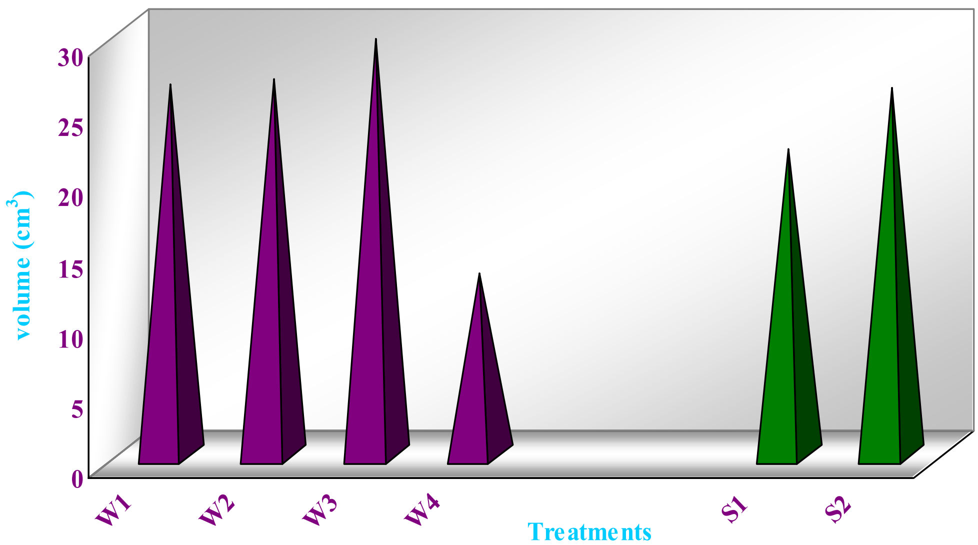


Fig. 16 Effects of *in situ* rain water harvesting techniques and levels of irrigation on volume of roots (cm^3)

The rooting medium physically supports the growing medium and supplies water, nutrients and air to the root system. The better the medium, the better will be the development of healthy fibrous root system and better establishment and development. A proper blend of organic manures constituted an excellent medium for efficient root growth. The characteristics of the different components of the enriched biomanure mix are worth mentioning in this context. It has several advantages for root development. It contains significant quantities of available nutrients, beneficial micro organisms and biologically active metabolites particularly gibberellins, auxins, cytokinins 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 for rain water conservation (Joseph, 1995, Gopinathan, 1996, Salam et al, 2004 and Venkitaswamy and Khan, 2004).

In all the micro site enrichment techniques, a layer of coconut husk mulched at the pit bottom restricted downward growth of tap roots beyond the active root zone to a certain extent. Vertical mulching with coconut husk also restricted and confined root growth within the rooting medium. As the natural habit of the root is disturbed by manipulation of the habitat (planting site), the root growth form seemed to be 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 (Table 18). Total root length is a better measure of fibrosity over absorptive surface. Plants possessing large root system comprising high per cent of fibrous roots have large surface area for absorption of water and nutrients.

5.2.3 Growth Indices

Leaf area index is an important parameter determining crop productivity

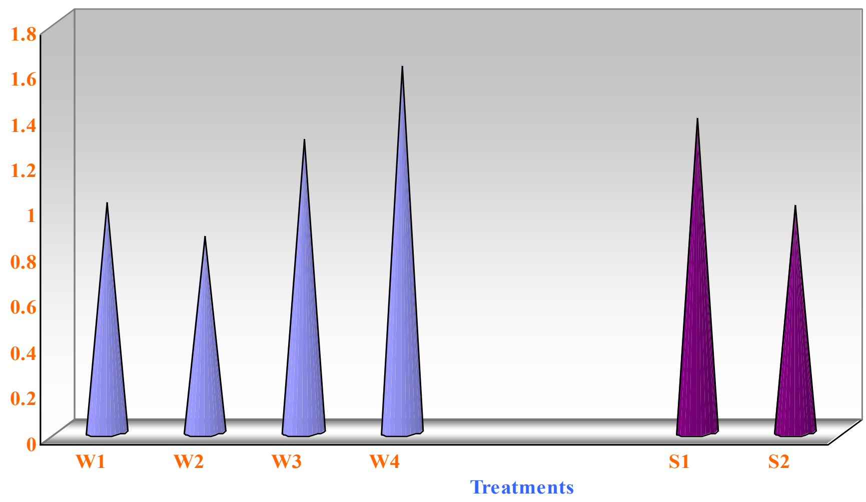


Fig. 17 Effects of *in situ* rain water harvesting techniques and levels of irrigation on root shoot ratio

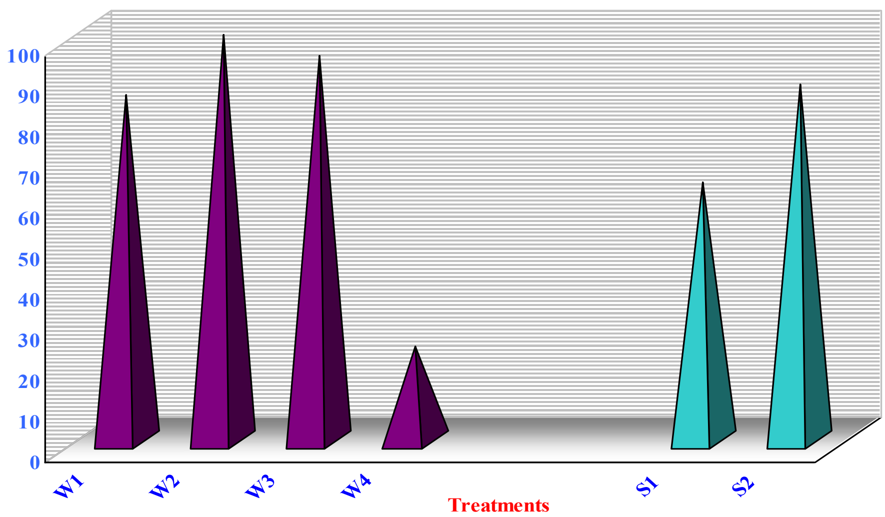


Fig. 18 Effects of *in situ* rain water harvesting techniques and levels of irrigation on crop growth potential

and efforts should be directed towards increasing leaf area index. Though there was no definite trend with respect to micro site enrichment techniques on leaf area index at different growth stages, micro site enrichment + micro catchment was beneficial for increasing leaf area index at most of the growth stages. In general, maintenance of readily available water in the rooting zone by scheduling irrigation at 50 % depletion of moisture favoured leaf area index compared to moisture stress situation arisen consequent to life saving irrigation. Variations in leaf area index is due to changes in leaf number or leaf size. Leaf number depends on shoot length (Table 12) and rate of leaf production (Table 13) (Gupta, 1975).

Effect of soil moisture on rate of leaf production is remarkable. Maintenance of readily available moisture by bringing rooting medium to field capacity more frequently resulted in favourable soil moisture regime for better development. 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 is to reduce the transpirational surface area which helps the plants to reduce the heat load on leaves (Nath,1993). After one year of planting, maximization of leaf area index was possible in ashoka by scheduling irrigation at 50 % depletion of moisture with micro site enrichment + micro catchment. Increase in leaf number as evident from Table 13 has resulted in maximization of leaf area index.

Root shoot ratio is an indication of the ability of the plant to survive even under nutrient - moisture stress situations by strengthening its root system without proportionate development of shoot. It is evident that nutrients and moisture present in the root zone decide the ratio. Potting mixture which contains lesser quantities of plant nutrients compared to the other three micro site enrichment treatments increased root shoot ratio (Fig. 17). The moisture holding capacity of potting mixture is less compared to the other three micro site enrichment treatments which warranted regular irrigation at 50 % depletion of moisture for enhancing root shoot ratio. Incorporation of potting mixture along with scheduling irrigation at 50 % depletion of moisture is beneficial for increasing root shoot ratio. Per cent dry matter production at 12 MAP furnished in Table 23 suggests the reasons for higher root shoot ratio for the above treatment combination. Application of potting mixture and scheduling irrigation at 50 % depletion of moisture resulted in partitioning of dry matter in favour of root compared to shoot in other treatment combinations.

Root growth potential after one year of planting was maximum when potting mixture was used as the rooting media along with life saving irrigation. Root growth potential is the ability of a tree seedling to initiate and elongate roots when placed into an environment favourable for root growth. Root growth potential is often affected by soil temperature, soil moisture and other factors. High root growth potential 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 viscinity, 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 occurs. The condition of the seedling shoot and foliage is also important for root growth potential. Since leaves of many tree species export an essential rooting co-factor, removal of, or damage to the foliage can impede root growth. Root growth potential represents only a potential to grow roots and its expression depends on many factors, viz., soil moisture, soil fertility, soil temperature, etc.

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. Appropriate blend of biomanures namely, enriched vermi compost, enriched coir pith compost and enriched layering mixture integrated with life saving irrigation provided appropriate micro climate to attain accelerated growth of primary roots and subsequent secondary and tertiary roots. Higher root length and lesser number of roots resulted in improvement of root growth potential which is evident from Table 18.

Seedling's sturdiness to withstand even in strong wind is indicated by sturdiness quotient. Micro site enrichment + micro catchments + vertical mulching combined with irrigation scheduling at 50 % depletion of moisture produced better quality planting material in relation to sturdiness quotient, capable of withstanding environmental stress on field planting. Plant height and girth measurements decide sturdiness quotient and the effect of above treatment combination on the above two parameters were favouring sturdiness quotient as evident from Tables 12 and 14.

Crop growth potential estimated after one year of planting indicated the superiority of treatment combinations, micro site enrichment + micro catchment and micro site enrichment + micro catchment + vertical mulching combined with life saving irrigation (Fig. 18). Crop growth potential is influenced by total dry matter production, sturdiness quotient and shoot root ratio. The above treatment combination favoured all the above three parameters including crop growth potential as evident from Tables 19 and 22.

5.2.4 Physiological Parameters

Osmotic potential is an indication of the concentration of solutes which reflects the accumulation of biochemical constituents in the officinal parts of medicinal plants. Nutrient and moisture stress situation improved osmotic potential. Combination of potting mixture and life saving irrigation enhanced osmotic potential compared to other treatment combinations. This indicates that life saving irrigation is beneficial for promoting the accumulation of biochemical constituents in the officinal part of ashoka compared to irrigation scheduling at 50 % depletion of moisture. Effect of soil moisture stress on the accumulation of biochemical constituents especially proline has been reported in other medicinal trees and it is well established that accumulation of biochemical principles takes place at a faster rate under moisture stress environments. Hence it is advisable to resort to life saving irrigation for improving the quality of stem bark of ashoka.

Relative leaf water content is an alternative measure of plant water status (Elamathi and Singh, 2001). Impact of soil moisture was evident on relative leaf water content and canopy temperature measured 24 and 48 hours after irrigation. Relative leaf water content was maximum when micro site enrichment was adopted and irrigation scheduled at 50 % depletion of moisture. Combination of micro site enrichment + micro catchment + vertical mulching and irrigation scheduling at 50 % depletion of moisture facilitated maintenance of readily available moisture in the rooting zone for lowering of canopy temperature both 24 and 48 hours after irrigation.

5.2.5 Biochemical Parameters

Chlorophyll a, chlorophyll b and total chlorophyll ranged from 0.35 to

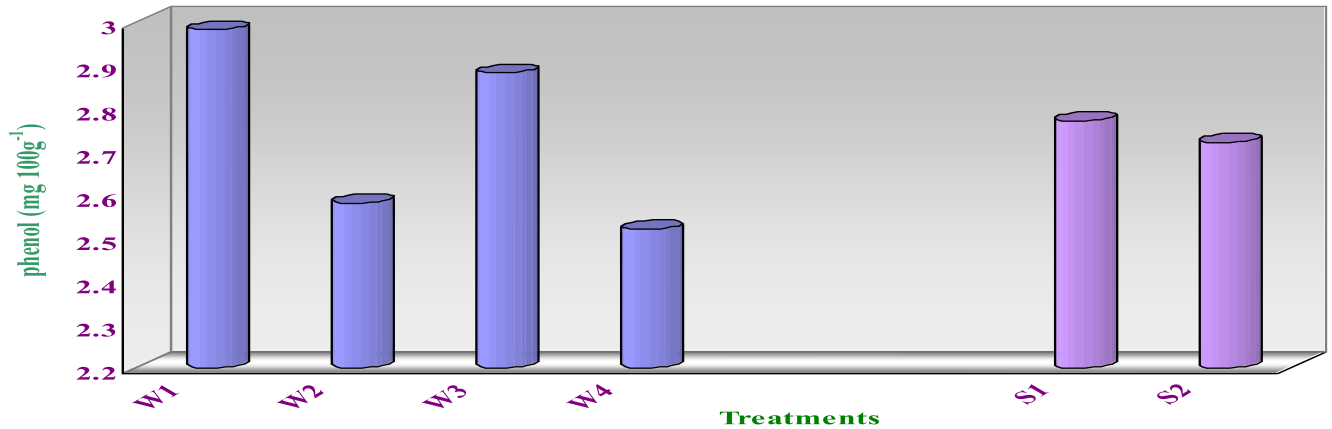


Fig. 19 Effects of in situ rain water harvesting techniques and levels of irrigation on phenol content of stem bar

0.53, 0.12 to 0.20 and 0.47 to 0.73 mg g^{-1} respectively. The treatment combination, POP recommendations and life saving irrigation recorded maximum values for the above biochemical constituents which indicates that disintegration of chlorophyll is also sensitive to variations in nutrients and soil moisture.

Integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation enhanced tannin production both in the stem bark and leaves. Tannin content ranged from 0.27 to 0.31 mg 100 g^{-1} in the stem bark and 0.50 to 0.62 mg 100 g^{-1} in the leaves and the per cent increase over control were 6.89 and 24.00 respectively for stem bark and leaves.

Total phenol content of stem bark (Fig. 19) and leaves ranged from 2.47 to 3.00 and 6.77 to 7.87 mg 100 g^{-1} respectively . Integration of micro site enrichment and irrigation scheduling at 50 % depletion of moisture was effective in enhancing total phenol production both in the stem bark and leaves which were 21.46 and 16.25 per cent higher over control (Fig. 20).

5.2.6 Biomass Production

The effect of micro site enrichment techniques on total biomass production and its partitioning into root (Fig. 23), stem (Fig. 21), stem bark (Fig. 22) and leaves (Fig. 24) was remarkable after one year of planting (Plate 5). Incorporation of potting mixture was insignificant in biomass production and its partitioning compared to other three micro site enrichment techniques. In general, impact of micro site enrichment, micro catchment and vertical mulching and their combinations was positive on biomass productivity. Maximum biomass production resulted when micro site enrichment + micro catchment + vertical mulching were combined. After one year of planting, life saving irrigation was sufficient to meet crop water need as moisture holding capacity of the rooting

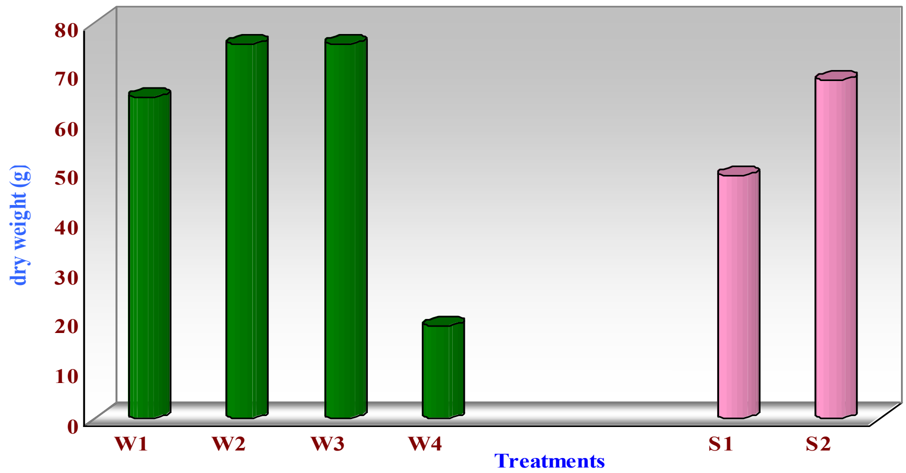


Fig. 20 Effects of *in situ* rain water harvesting techniques and levels of irrigation on stem dry matter production (g)

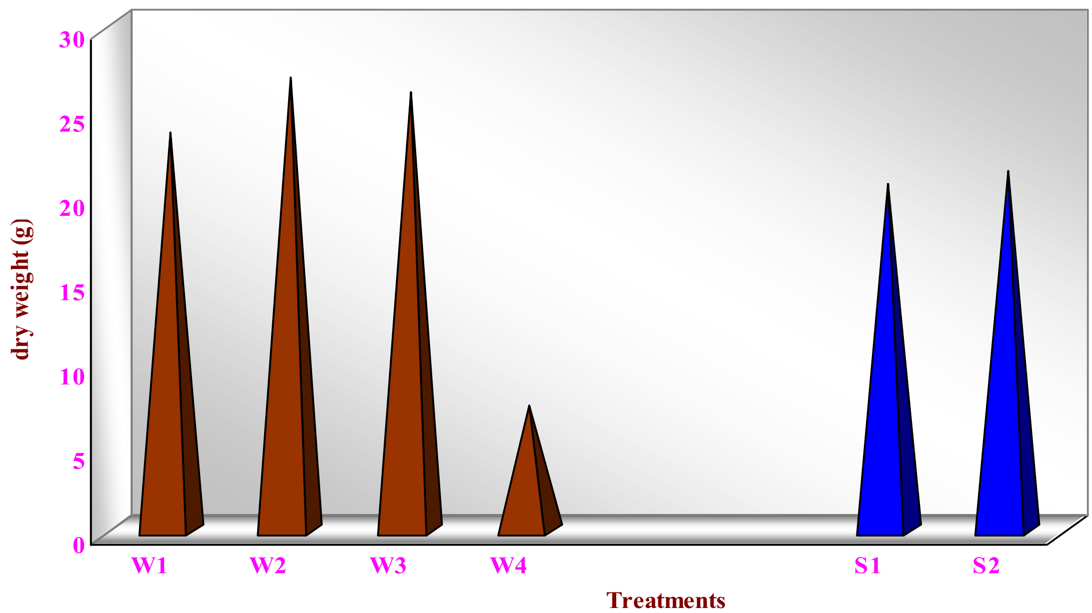


Fig. 21 Effects of *in situ* rain water harvesting techniques and levels of irrigation on stem bark dry matter production (g)

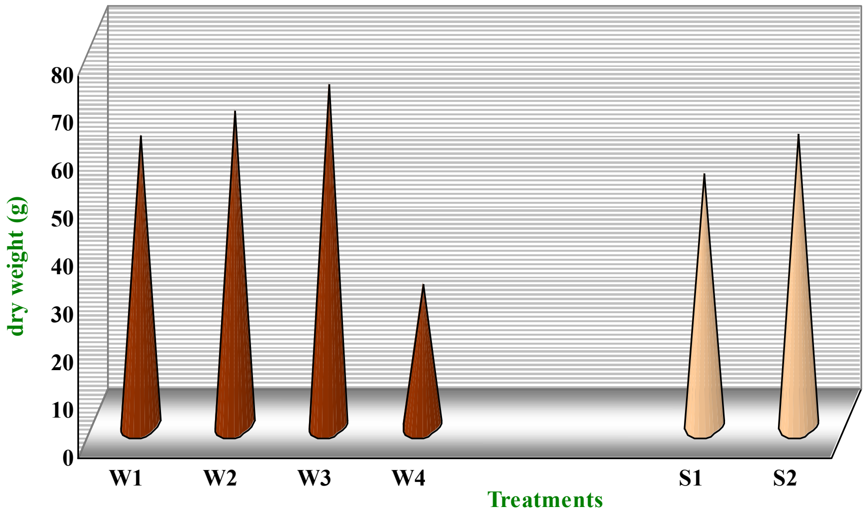


Fig. 22 Effects of *in situ* rain water harvesting techniques and levels of irrigation on root dry matter production (g)

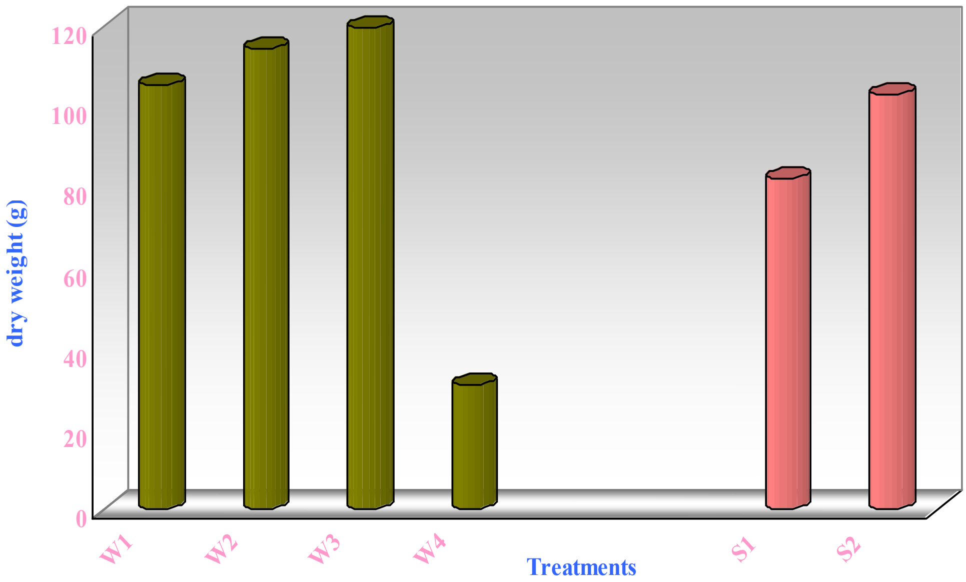


Fig. 23 Effects of *in situ* rain water harvesting techniques and levels of irrigation on leaf dry matter production (g)

medium and root activity were in favour. Integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation was found favourable for improving total biomass production and its partitioning. The above treatment combination was found worth popularising for improving the productivity of the officinal part of ashoka, i.e stem bark to the tune of 425.18 % over control.

The growth of a plant is influenced by the metabolic activities which require adequate amount of nutrients and moisture. Growth characters and canopy attributes reveal that ashoka crop responded very well to combined imposition of micro site enrichment, micro catchment and vertical mulching. Nutrient and moisture supplying power of potting mixture is less compared to components of the rooting medium used for microsite enrichment which resulted in lesser growth.

5.2.7 Soil Moisture Studies

Maximum moisture per cent was observed when micro site enrichment + micro catchment + vertical mulching was practiced compared to POP recommendations which indicates the intrinsic capacity of micro site enrichment treatments in holding moisture even for longer periods after irrigation or rainfall. Mere presence of organic matter alone is not sufficient to enhance the available moisture content of soil as increase in field capacity of organic matter is associated with corresponding increase in PWP values. Adoption of POP recommendations registered the minimum moisture content as cow dung incorporated was not as efficient as manure mix of micro site enrichment treatments in absorption and retention as detailed in section 2.3.1. As 50 % of available water was present in the soil while scheduling irrigation at 50 % depletion of moisture compared to zero availability of available water at life saving irrigation, the former registered maximum moisture content before irrigation (Fig. 25).

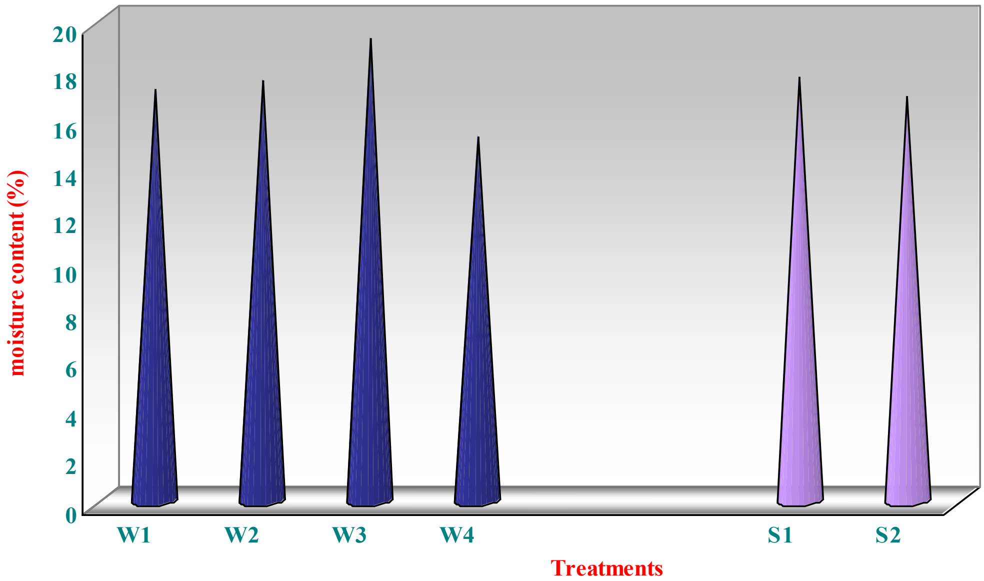


Fig. 24 Effects of *in situ* rain water harvesting techniques and levels of irrigation on soil moisture content (%) before irrigation

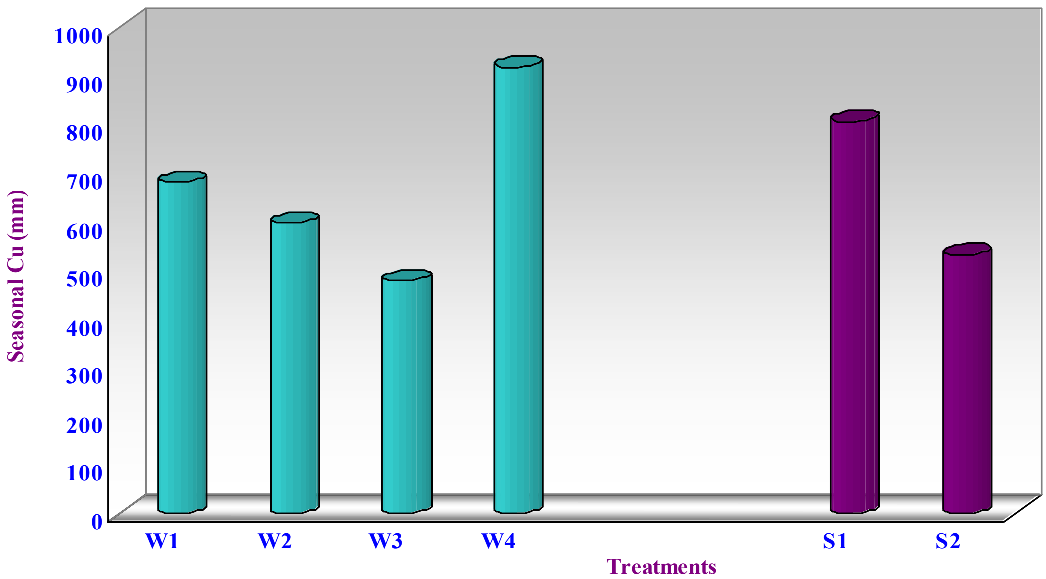


Fig. 25 Effects of *in situ* rain water harvesting techniques and levels of irrigation on seasonal consumptive use (mm)

The main and interaction effects indicated the influence of micro site enrichment treatments and levels of irrigation in altering consumptive use and kc values. Due to the interaction effect of treatments, seasonal consumptive use, daily consumptive use and kc values ranged from 380.59 to 969.47 mm, 1.06 to 2.69 mm and 0.30 to 0.76 respectively. The maximum values were recorded when POP recommendations were practiced along with irrigation scheduled at 50 % depletion of moisture. The consumptive use increased with increased levels of irrigation (Fig. 26). The total number of irrigations given for the treatment POP recommendation was maximum (Table 6) as its moisture holding capacity was minimum compared to other micro site enrichment treatments. K_c is influenced by several parameters of which number of leaves and leaf area are significant. The above treatments registered maximum leaf number during the early stages of establishment, leading to maximum absorption of water to meet the ET needs. Frequent moisture supply created more favourable conditions for higher ET as canopy temperature was minimised due to transpirational cooling as evident from Table 20. Similar reports were put forth by Jacob (1986) and Desai and Patil (1984). The above treatment combination also recorded the highest K_c value (Fig. 27) because consumptive use of the seedling relating to this treatment combination was also maximum. Frequent irrigation recorded the highest value and there was a decrease in K_c value with a decrease in degree of wetness of soil. The higher K_c values with increase in soil wetness was due to the enhanced consumptive use with increase in the frequency of irrigation. Vertical and surface mulching with coconut husk increased the value as more moisture was available for meeting the ET requirement of crop consequent to reduced rate of soil evaporation, percolation and seepage coupled with higher retention of moisture in the rooting medium.

The results indicated the superior performance of treatment combination micro site enrichment + micro catchment + vertical mulching combined with life saving irrigation with respect to crop water use efficiency, field water use

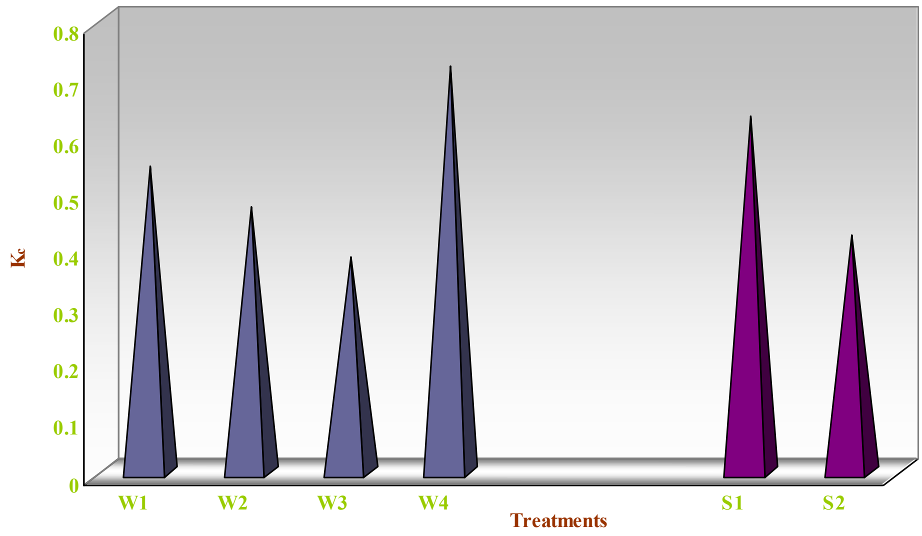


Fig. 26 Effects of *in situ* rain water harvesting techniquesand levels of irrigation on crop coefficient, K_c

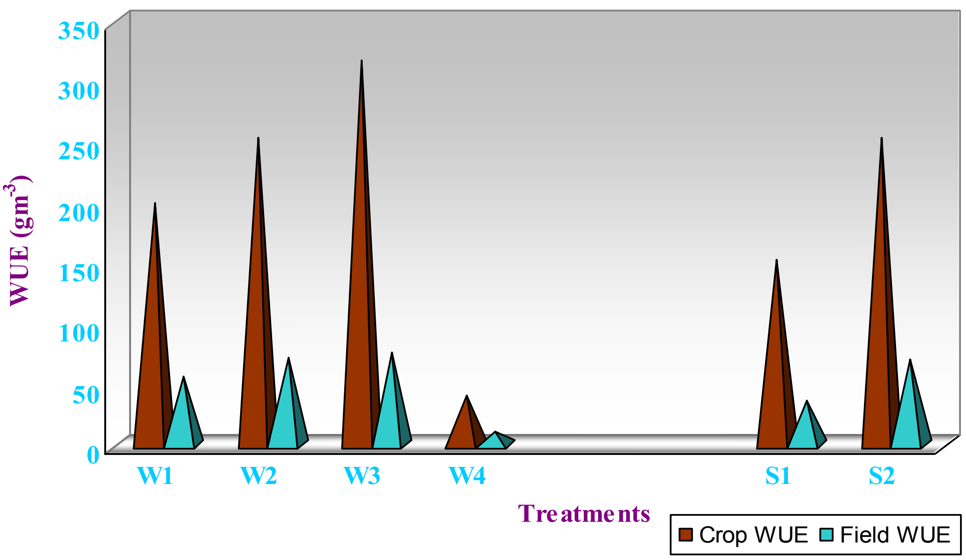


Fig. 27 Effects of *in situ* rain water harvesting techniques and levels irrigation on crop and field water use efficiencies (gm^{-3})

efficiency and water productivity. This was mainly due to increase in yield and total biomass production compared to other treatment combinations. The water use efficiency and water productivity decreased with increase in the levels of irrigation. Water use efficiency is likely to increase with decrease in moisture supply (Fig. 28) until it reaches the maximum critical level because plants may actively try to economise water use in the range from minimum critical to optimum moisture level. Water above the optimum level may be lost in the form of excessive evaporation, transpiration or even as deep percolation. The above three losses were contained in the above treatment combination which recorded maximum crop water use efficiency, field water use efficiency and water productivity.

5.3 BARK REGENERATION

Thickness of regenerated bark ranged from 0.87 to 1.30 cm and application of kinetin resulted in increasing bark thickness to the tune of 30.00 % over control. Yield of bark ranged from 115.00 to 221.67 g $tree^{-1}$ and the highest yield was recorded by kinetin .

Quality parameters of bark namely, tannin and total phenol content ranged from 0.39 to 0.40 mg 100 g^{-1} and 2.73 to 3.03 mg 100 g^{-1} respectively. Combination of NAA + kinetin resulted in increasing tannin and phenol content of bark by 2.56 and 10.99 % respectively over control.

According to Hathway (2008), tannin accumulates in young plants during active photosynthesis and the enhanced level is maintained for a considerable period of time. However, proportionate increase in tannin level is not reported with increase in age of trees. Mathew et al. (2007) reported that ashoka leaves had more tannin content than stem bark and age of the tree didn't significantly influence these biochemical constituents.

Summary

6. SUMMARY

Three separate experiments were carried out at the Instructional Farm attached to the College of Agriculture, Vellayani to develop agro techniques for growth promotion and increasing bark yield in ashoka. The nursery trial was conducted to standardize root trainer techniques for improving seedling growth potential of ashoka seedlings during the period from 15.6.2009 to 15.12.2009. Two field experiments were also carried out to develop sustainable rain water harvesting and conservation measures to extend the period of stored moisture availability for establishment and early growth and to evolve techniques for rapid stem bark regeneration using plant growth substances from 21.3.2009 to 9.4.2010 and 2.7.2009 to 10.4.2010 respectively.

Sowing seeds inoculated with Rhizobium and AMF in mud pots filled with enriched rooting medium containing potting mixture, rock powder and mixture of vermicompost, FYM and composted coirpith was found beneficial for the production of taller seedlings. Combined inoculation of seeds with Rhizobium and AMF and sowing in mudpots filled with potting mixture resulted in better collar girth at the time of transplanting. Sowing seeds in mud pots filled with potting mixture was found to improve leaf production. Filling of mud pots with rooting medium consisting of a consortium of bioinoculants and biomanures sprinkled with rock powder recorded maximum leaf area at 135 DAS.

Integration of root trainer techniques and rooting media indicated the superiority of treatment combination, root trainer filled with rooting medium consisting of a consortium of bioinoculants and biomanures sprinkled with rock powder in increasing the length of tap root. Treatment combinations of root trainers (tubes and blocks) and all the four rooting media didn't coil at all. Mud pots filled with potting mixture enhanced root let production which in turn resulted in maximum root number.

Dual inoculation of seeds with Rhizobium and AMF and sowing in mud pots containing enriched rooting media containing potting mixture, rock powder and mixture of vermicompost, FYM and composted coirpith was found to be beneficial for improving biomass accumulation in ashoka seedlings.

Root trainer registered the maximum value for sturdiness quotient and root growth potential and it was significantly different from all other treatments. M_3 and M_4 were on par and significantly different from M_1 and M_2. Among the different combinations, higher values of sturdiness quotient were shown by R_2M_3 followed by R_1M_4.

Root trainer techniques showed remarkable influence on seedling growth potential and mud pots registered maximum potential and it was significantly different from all other treatments. Rooting media did not influence seedling growth potential. Though not significant, M_4 recorded maximum seedling growth potential. Though interaction effects of root trainer techniques and rooting media were insignificant with respect to seedling growth potential, mud pots filled with rooting medium consisting of a consortium of bioinoculants and biomanures sprinkled with rock powder registered higher values.

Maximum seedling price of Rs. 9.75, gross income of Rs. 78.00, net income of Rs. 56.00 and BCR of 3.33 were estimated when ashoka seeds were inoculated with Rhizobium and AMF and sown in mud pots filled with potting mixture containing a mixture of vermin compost, FYM and composted coir pith.

After transplanting, integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation resulted in taller plants. Though the interaction effects didn't significantly influence the production of functional leaves, micro site enrichment + micro catchment + vertical mulching and life saving irrigation enhanced the leaf production. Micro site enrichment + micro catchment + vertical mulching and life saving irrigation favoured collar girth and micro site enrichment and life saving irrigation improved leaf area index. Though the main and interaction effects of treatments didn't significantly affect the production of branches, micro site enrichment + micro catchment + vertical mulching and life saving irrigation recorded maximum number of branches.

Among the different treatment combinations, integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation registered maximum bole height. Main effects and the interaction didn't significantly influence the canopy height and significant influence of micro site enrichment + micro catchment + vertical mulching registered maximum canopy spread. Interaction effects indicated the superior performance of micro site enrichment + micro catchment + vertical mulching and life saving irrigation in increasing canopy height. Similar to canopy width, maximum canopy size was also recorded by the treatment combination, micro site enrichment + micro catchment + vertical mulching and life saving irrigation.

Significant effect of micro site enrichment technique, micro site enrichment + micro catchment + vertical mulching on length and number of roots was observed. Significant influence of micro site enrichment + micro catchment + vertical mulching was observed on root volume. The influence of micro site enrichment techniques on root surface area was similar to that of root length.

The effect of micro site enrichment techniques on root shoot ratio was significant and POP recommendations registered the maximum value. POP recommendations registered maximum root growth potential and sturdiness quotient. The minimum sturdiness quotient value was recorded by the treatment combination, micro site enrichment + micro catchment + vertical mulching and irrigation scheduled at 50 % depletion of moisture. Micro site enrichment + micro catchment recorded maximum crop growth potential. Though the effect of levels of irrigation on crop growth potential was insignificant, life saving irrigation was found beneficial. Among the treatment combinations, micro site enrichment + micro catchment and life saving irrigation enhanced crop growth potential.

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Maximum osmotic potential was registered when POP recommendations was combined with life saving irrigation. Significant influence of micro site enrichment on relative leaf water content was observed. Canopy temperatures recorded at 24 and 48 hours after irrigation were not all influenced by micro site enrichment techniques. Minimum temperature variation was recorded by micro site enrichment and irrigation at 50 % depletion of moisture.

Chlorophyll a, chlorophyll b and total chlorophyll content were not at all significantly influenced by micro site enrichment techniques. In all cases, POP recommendations registered maximum values. The treatment combination, POP recommendations and life saving irrigation registered maximum values for all these parameters. With respect to tannin content of stem bark and leaves, micro site enrichment + micro catchment + vertical mulching recorded maximum values. Integration of micro site enrichment + micro catchment + vertical mulching and life saving irrigation enhanced the tannin production both in the bark and leaves. Micro site enrichment techniques significantly influenced the total phenol production of stem bark and micro site enrichment and micro site enrichment + micro catchment + vertical mulching enhanced total phenol production respectively for stem bark and leaves.

Micro site enrichment techniques significantly influenced the root and stem biomass production. Micro site enrichment + micro catchment + vertical mulching produced maximum root and stem biomass both fresh and dry. Among the treatment combinations, micro site enrichment + micro catchment recorded maximum root biomass both fresh and dry. The combined effect of micro site enrichment + micro catchment + vertical mulching and life saving irrigation was found favourable for enhancing stem biomass production both fresh and dry.

Significant variation in stem bark and leaf biomass production was observed due to the main effects of micro site enrichment techniques. Micro site enrichment + micro catchment produced maximum bark yield both fresh and dry. Micro site enrichment + micro catchment + vertical mulching registered maximum fresh and dry leaf yield. The treatment combination, micro site enrichment + micro catchment + vertical mulching combined with life saving irrigation was found favourable for improving both fresh and dry yield of stem bark and leaves.

Total biomass production was significantly influenced by micro site enrichment techniques. Micro site enrichment + micro catchment + vertical mulching recorded maximum production. Life saving irrigation improved total biomass production. Maximum total fresh and dry biomass production were observed when micro site enrichment + micro catchment + vertical mulching was combined with life saving irrigation.

POP recommendations enhanced biomass partitioning in favour of roots and it was significantly different from all other treatments. No significant variation was observed with respect to partitioning of dry matter into stem, stem bark and leaves.

The effect of micro site enrichment was significant before irrigation and maximum moisture content was observed in micro site enrichment + micro catchment + vertical mulching. Interaction effects showed the superiority of micro site enrichment + micro catchment + vertical mulching combined with irrigation scheduled at 50 % depletion of moisture with respect to moisture content both before and after irrigation.

The peak consumptive use was recorded by the treatment, POP recommendation, which was significantly different from other treatments. Scheduling irrigation at 50 % depletion of moisture significantly enhanced seasonal consumptive use. The trend was similar with respect to mean daily consumptive use as well. Combinations of the above two treatments, i.e POP recommendation and scheduling irrigation at 50 % depletion of moisture recorded maximum peak seasonal consumptive use and mean daily consumptive use. The main and interaction effects of treatments on crop coefficient were exactly similar to their effects on consumptive use.

Significant variations on crop water use efficiency, field water use efficiency and water productivity were observed due to main effects of treatments. In all cases, the trend was exactly similar. Micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment + micro catchment and micro site enrichment but significantly different from POP recommendations improved crop water use efficiency, field water use efficiency and water productivity. Similarly, the effect of life saving irrigation was conspicuous and it enhanced all the above three parameters considerably. Interaction effects indicated the significance of treatment combination micro site enrichment + micro catchment + vertical mulching and life saving irrigation in enhancing crop water use efficiency, field water use efficiency and water productivity. However, the least efficiency and productivity values were registered by POP recommendations with life saving irrigation or 50 % depletion of moisture.

Application of kinetin resulted in increasing bark thickness and yield. Combination of NAA + kinetin resulted in increasing tannin and phenol content of bark.

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* original not seen

Appendix

Appendix I

Weather data during the experimental period

Period	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)	Relative Humidity (%)	Evaporation (mm)
March	33.3	25.8	12.6	89.0	4.2
April	33.0	26.8	39.9	88.2	4.1
May	32.9	25.8	305.6	89.1	3.9
June	31.0	24.0	174.0	85.7	2.9
July	30.1	24.0	190.6	87.1	2.8
August	30.2	24.1	74.9	84.6	3.3
September	29.6	24.2	114.2	88.0	3.5
October	30.4	24.2	100.9	87.3	3.5
November	29.5	23.8	485.7	87.0	2.9
December	30.7	23.7	5.6	88.1	3.3
January	31.2	23.5	119.2	89.7	4.4
February	32.2	24.0	8.8	89.9	0

AGRO TECHNIQUES FOR GROWTH PROMOTION AND INCREASING BARK YIELD IN ASHOKA (*Saraca asoca* Roxb.)

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Abstract of the
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ABSTRACT

Ashoka is an important medicinal tree gaining economic significance in recent years. As the domestic production of the officinal parts of ashoka is quite insufficient to meet the demand of ayurvedic medicine manufacturing units there is an urgent need for developing appropriate technologies for growth promotion and increasing bark yield in ashoka.

Three separate experiments were carried out at the Instructional Farm attached to the College of Agriculture, Vellayani to develop agro techniques for growth promotion and increasing bark yield in ashoka during 2009-10. The nursery trial on 'Techniques for quality planting material production' consisting of combinations of four root trainer techniques, *viz*, root trainer (individual tubes – R1), root trainer (blocks – R2), poly bags (R3) and mud pots (R4) and four rooting media, *viz*, potting mixture (M1), potting mixture +dual inoculation with Rhizobium and AMF (M2), potting mixture + dual inoculation with Rhizobium and AMF + Rock powder (M3) and potting mixture +dual inoculation with Rhizobium and AMF + Rock powder + mixture of vermicompost, FYM and composted coir pith (M4) was conducted in CRD with four replications. The field experiment on 'Micro site enrichment techniques for growth promotion' consisting of combinations of four *in situ* rain water harvests, viz, micro site enrichment, micro site enrichment + micro catchments, micro site enrichment + micro catchments + vertical mulching and POP recommendations and two levels of irrigation, *viz*, irrigation at 50 % depletion of moisture and life saving irrigation was carried out in FRBD with three replications. The third trial on 'Techniques for increasing bark yield' comprising four treatments, *viz*, NAA 50 mg l^{-1}, Kinetin 50 mg l^{-1} , Combination of NAA 50 mg l^{-1} and Kinetin 50 mg l^{-1} and control was conducted in CRD with three replications.

In the nursery trial, dual inoculation of seeds with Rhizobium and AMF and sowing in mud pots containing enriched rooting media consisting of potting mixture, rock powder and mixture of vermicompost, FYM and composted coir pith was found beneficial for improving biomass accumulation in ashoka seedlings. The quality of the planting stock was evaluated based on three growth indices, *viz*, sturdiness quotient (SQ), root growth potential (RGP) and seedling growth potential (SGP). Among the different

treatment combinations, higher values of SQ were shown by R_2M_3 followed by R_1M_4. Mud pots filled with rooting medium consisting of a consortium of bioinoculants and biomanures sprinkled with rock powder registered higher root growth and seedling growth potential. Besides, economic analysis of the system also proved its contribution in relation to gross income, net income and BCR.

The combined effect of micro site enrichment + micro catchment + vertical mulching and life saving irrigation was found favourable for enhancing total biomass production including stem bark, stem and leaf. The above treatment combination also proved its superiority in terms of accumulation of biochemical constituents in the officinal parts of ashoka, *viz*, total phenol and tannin in both stem bark and leaves.

Seasonal consumptive use, mean daily consumptive use and crop coefficient were maximum when POP recommendation was combined with irrigation scheduling at 50 % depletion of moisture. Significant variations on crop water use efficiency, field water use efficiency and water productivity were observed due to main effects of treatments. In all cases, the trend was exactly similar. Micro site enrichment + micro catchment + vertical mulching which was on par with micro site enrichment + micro catchment and micro site enrichment but significantly different from POP recommendations improved crop water use efficiency, field water use efficiency and water productivity. Similarly, the effect of life saving irrigation was conspicuous and it enhanced all the above three parameters considerably. Interaction effects indicated the significance of treatment combination, micro site enrichment + micro catchment + vertical mulching and life saving irrigation in enhancing crop water use efficiency, field water use efficiency and water productivity. However, the least efficiency and productivity values were registered by POP recommendation with life saving irrigation or 50 % depletion of moisture.

Investigations on bark regeneration indicated the importance of application of kinetin in increasing bark thickness and yield. However, quality constituents like, tannin and phenol content of bark increased with combined application of NAA + kinetin.