BIOLOGY AND MANAGEMENT OF *Mimosa invisa* Mart. IN KERALA

By

JAYASREE, P.K.

THESIS

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Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
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DECLARATION

I hereby declare that this thesis entitled **"Biology and management of *Mimosa invisa* Mart. in Kerala"** 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 to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara
21.7.2005

JAYASREE, P.K.

CERTIFICATE

Certified that this thesis, entitled **"Biology and management of *Mimosa invisa* Mart. in Kerala"** is a record of research work done independently by **Mrs. Jayasree, P.K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Dr. C.T. Abraham
Chairman, Advisory Committee
Associate Professor and Head
Department of Agronomy
College of Horticulture
Kerala Agricultural University, Thrissur

Vellanikkara
21.7.2005

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Mrs. Jayasree, P.K.** a candidate for the degree of **Doctor of Philosophy in Agriculture** with major in **Agronomy,** agree that the thesis entitled **"Biology and management of *Mimosa invisa* Mart. in Kerala"** may be submitted by Mrs. Jayasree, P.K. in partial fulfillment of the requirements for the degree.

Dr. C.T. Abraham
(Chairman, Advisory Committee)
Associate Professor and Head
Department of Agronomy
College of Horticulture
Kerala Agricultural University, Thrissur

Dr. C. George Thomas
(Member, Advisory Committee)
Associate Professor
Department of Agronomy
College of Horticulture
Kerala Agricultural University, Thrissur

Dr. Maicykutty P. Mathew
(Member, Advisory Committee)
Associate Professor (Entomology)
Banana Research Station
Kannara

Dr. T.N. Jagadeeshkumar
(Member, Advisory Committee)
Associate Professor
University Livestock Farm &
Fodder Research Station
Mannuthy, Thrissur

Dr. T. Girija
(Member, Advisory Committee)
Assistant Professor
AICRP on Weed Control
College of Horticulture
Vellanikkara, Thrissur

23.12.2005
EXTERNAL EXAMINER
Dr. H.V. Nanjappa

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In loving memory of my father

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Introduction

INTRODUCTION

The silent encroachment of alien weeds is creating threats to the cropping systems and natural vegetation all over India. *Salvinia molesta* Mitch., *Chromolaena odorata* (L.) Kings and Robins., *Lantana camera* L., *Mikania micrantha* H.B.K. and *Parthenium hysterophorous* L. from Central America, and *Eichhornia crassipes* (Mart.) Solms-Laubach and *Saccharum spontaneum* L. from South America are glaring examples of alien invasive weeds which have entered and established in our country. All of them are from the new world tropics (Central and South America). They are not serious weeds in their native habitats, as they are in balance with their natural enemies in their place of origin. However in new areas of their introduction, suitable agroclimatic conditions and freedom from their natural enemies helped them to establish and spread fast, invading new areas and successfully competing out the natural vegetation. These exotic weeds generally infest and cover public waste lands, road sides and other open sites and destroy the biodiversity of the region before reaching cropped fields.

Mimosa invisa Martius ex. Colla, called Giant sensitive plant or Creeping sensitive plant is a native of Tropical America. Outside its native place, *M. invisa* was first recorded in Java, Indonesia in 1900 (Soerjani *et al.*, 1987). Within the past hundred years it has reached all the five inhabited continents viz., Asia (South East Asia and the Pacific), Australia (Queensland), Africa (Nigeria) and Europe (Cuba). Waterhouse (1994) has rated the distribution and importance of *M. invisa* in different parts of the world. Accordingly, in Philippines, the plant is very wide spread and is very important. In Myanmar, Thailand, Laos, Vietnam, Malaysia, Singapore and Indonesia the plant is not very widespread, but it is of great importance as far as its impact on native vegetation is considered.

The earliest reference of *M. invisa* in India is report of introduction to some coffee plantations in South India as cover crop (Coffee Board, 1955). *M. invisa* var. *invisa* Mart. and *M. invisa* var. *inermis* Adelb. are troublesome alien invasive weeds of the tea estates of Assam (Hazarika and Barua, 2003). It is a noxious fast growing

species, and hence is emerging as a new threat to natural forests, forest plantations and agricultural systems throughout India, especially in the North Eastern states of India (Rajkhowa *et al.*, 2003) and Kerala (Sankaran, 2001). The weed has even become a threat to the single horned rhinoceros in the world famous Kaziranga National Park in Assam, now declared a world heritage (Vattakkavan *et al.*, 2004).

In Kerala, *M. invisa* locally called *Anathottavady* or *Padayincha* or *Vishamullu,* was first reported from Perunna near Changanachery (Nair, 1964). Since then it has become naturalized under Kerala conditions over the last 40 years. The reports of infestation of *M. invisa* from Kannuur (Ramachandran and Nair, 1988), Palghat (Vajravelu, 1990) and Pathanamthitta (Anilkumar, 1994) districts, indicate the gradual spread of *M. invisa* since 1964. Sankaran (2001) has reported widespread incidence of the plant in Central and Southern parts of Kerala.

The extent of spread and need for management of *M. invisa* is to be ascertained by conducting a survey of the plant throughout the state. The robust nature of the plant, the presence of recurved spines, high seed production capacity, high viability of the seed and long period of dormancy make *M. invisa* important in the plant community.

Further, a knowledge of the biology of the plant especially the stages of growth, sequence of flowering and seedset, methods of propagation etc. are necessary for devising proper physical or chemical control measures. The presence of any pest or disease which can naturally suppress *M. invisa* population is also of interest. Garcia (1983) and Kuniata and Korrowi (2001) have reported the suitability of exotic pests for the control of the plant in Papua New Guinea, Western Samoa and Queensland. The possibility of introduction of these pests as bioagents is of importance.

Information on the dry matter accumulation pattern in the plant, litter decomposition in soil, nutrient composition of the plant and methods of nutrient enrichment add to the successful utilization of the plant. A detailed study of the problems associated with *M. invisa,* especially the toxicity problems due to mimosine

content (Rajan *et al.* 1986 and Alex *et al.*, 1991), nature of toxicity and methods of lowering the toxicity (Gangadevi and James, 1992) is of great importance. The economic importance of the plant also depends on its possible allelopathic effects and influence on the biodiversity of native flora.

The ability of *M. invisa* to have wide impact on the natural vegetation, cultivated crops and livestock necessitated an investigation on 'Biology and Management of *Mimosa invisa* Mart. in Kerala'. Hence a study was taken up during 2001-2004 with the following objectives.

1) survey the distribution and extent of spread of *Mimosa invisa* in Kerala
2) study the biology of the plant - seed characters, floral biology and reproductive cycle
3) assess the efficiency of different methods of control viz., physical, chemical, and cultural
4) identify any host specific pest or disease and to test their suitability as bioagents
5) examine the utility of the plant as a green manure or cover crop
6) observe the allelopathic effects of the plant on other vegetation and crop plants
7) study the influence on the biodiversity of the native flora of the area of infestation, and
8) examine the extent of toxicity to animals due to presence of mimosine and devise methods to lower the problem.

Review of Literature

2. REVIEW OF LITERATURE

2.1 ORIGIN

The origin of any plant is considered to be the geographical area where a large number of wild varieties, types, species and biotypes of the plant exist. Waterhouse (1994) stated that Tropical America especially Brazil is considered the place of origin of *Mimosa invisa*.

2.2 TAXONOMY

Mimosa invisa belongs to the family Leguminosae. In India, there are 951 different species of plants belonging to Leguminosae and include all types of habits - trees, shrubs, herbs and woody climbers. This family alternately called as Fabaceae includes three important subfamilies - Caesalpinioideae, Mimosoideae and Papilionoideae.

While critically studying the nomenclature of *M. invisa*; Barneby (1987) concluded that the correct name for *M. invisa* C. Martius is *Mimosa diplotricha* C. Wright *ex* Sauvalle . The binominal *M. invisa* was published twice: first in 1834 by Luigi Aloysius Colla, who attributed the name to Martius; and secondly in 1837 by Martius himself. Subsequently, when it became apparent to later taxonomists of *Mimosa* that Colla's proposition had three years' priority, it was very naturally assumed that, that of Martius was merely an inadvertent duplication. However, on comparison of the relevant protologues and types, Barney confirms that they are different species of *Mimosa.* The point to be emphasized is that *M. invisa* C. Martius *ex* Colla and *M. invisa* C. Martius are heterotypic homonyms, based on material of different species. *Mimosa invisa* C. Martius *ex* Colla is the earliest valid name for *Mimosa rodostachya* (Benth). The correct name for *M. invisa* C. Martius is *M. diplotricha* C. Wright *ex* Sauvalle .

However, in most of the literature *M. invisa* is the often used binomial to represent this plant. Hence the name *M. invisa* is used in this study also.

M. invisa, a woody climber, is very aggressive and robust. There are two types of *M. invisa* based on the presence or absence of spines on the stem and other plant parts. They are *M. invisa* var. *invisa,* called spiny or thorny mimosa, which is armed with sharp recurved prickles and *M. invisa* var. *inermis,* called smooth mimosa, which is unarmed or spineless. According to Waterhouse and Norris (1987), a spineless variety, *M. invisa* var. *inermis* has been suggested as a tropical pasture legume, but its tendency to revert to thorny type and its potential toxicity has discouraged its use.

2.3 DISTRIBUTION

2.3.1 World

The genus *Mimosa* is widely distributed all over the world and is now present in all the inhabited continents. Tropical America, the land of origin of *M. invisa,* is harbouring more than 16 important species of *Mimosa.*

Mimosa invisa was first reported in Java, Indonesia in 1900 (Soerjani *et al.*, 1987). Holm *et al.* (1979), in the 'Geographical Atlas of World Weeds', stated that 450-500 species of *Mimosa* are spread all over the world as tropical or subtropical weeds. They also classified them as serious, principal or common weed of the country based on the nature and severity of infestation. Mabberley (1990) also reported the presence of 400 species belonging to family Mimosae all over the world.

Garcia (1982) reported that in South America, *M. invisa* is very common in the Parana basin in Sau Paulo, Brazil. In forest regions, it occurred as thickets among grasses, along roads, river banks and in waste lands.

According to Wills (1988), a few species of *Mimosa* are spread in Africa and Asia and they are mainly herbs or under shrubs. *M. invisa, M. pigra* and *M. pudica* are the three weedy species of *Mimosa* in South East Asia and Australia (Lonsdale, 1992).

M. invisa continues to be a serious weed with more than 85 per cent of villages on the main land of Upolu island of Western Samoa being infested (Wilson and Garcia, 1992).

Waterhouse (1994) recorded the distribution of *M. invisa* from Brazil to Paraguay and tropical North East Argentina and also in low lands of Central America and Columbia. He also stated that *M. invisa* is widely distributed in South East Asia and the Pacific, Queensland, India, Sri Lanka, Taiwan and Nigeria.

Napompeth (1982) reported that another species of *Mimosa*, *M. pigra* is considered as one of Thailand's most serious weeds, together with its close relative *M. invisa*, the creeping sensitive plant. Evans (1999) reported *M. pigra* as an invasive weed of Sri Lanka.

Bebawi *et al.* (2002) prepared the priority list for weed research in wet and dry tropics of north Queensland, Australia, and *M. invisa* was rated third among the 53 weeds found to be of major concern in wet tropics.

Mimosa spp. were reported as weeds in many crop fields also. Caunter and Shibayama (1999) grouped *M. invisa* as an important weed in rice uplands of Philippines, Malaysia, Thailand and Vietnam. Bakar *et al.* (1996) reported that *M. invisa* was widely distributed in open, disturbed and derelict habitats, agricultural areas and ex-mining lands of Malaysia since 1993. In Manila, Philippines, MacLean *et al.* (2003) reported that green manure application in rice uplands with *Glyricidia sepium* and *Cassia spectabilis* favoured emergence of broad leaf weeds including *M. invisa.*

Pornprom *et al.* (2002) reported smooth mimosa, *M. invisa*, as one of the three main weed species in kale leaf crop of Nakhon Pathom area of Thailand.

According to Rajkhowa *et al.* (2003), *Mimosa invisa* var *inermis* appeared as one of the dominant weeds in sugarcane fields of North Eastern hill region of India. Sulaiman *et al.* (2004) reported *M. invisa* as one of the major weeds of corn fields of Malaysia. In Nigeria, *M. invisa* could significantly reduce the growth and yield of tubers in cassava (Alabi *et al.*, 2001).

A list of the different species under the genus *Mimosa* now prevalent in different parts of the world is presented in Appendix-I.

2.3.2 India

The earliest reference of *M. invisa* in India is its report of introduction to some coffee plantations in South India as a cover crop (Coffee Board, 1955). According to Nair (1964), seven species of *Mimosa* were identified in India. These species included *M. rubicaulis, M. angustisiliqua, M. pudica, M. hamata, M. polyancistra, M. prainiana* and *M. invisa*. He also prepared a key to identify these species based on nature of pods, presence of bristles or prickles, stamens, leaves, peduncle, pinnae and pinnules. Santapau and Henry (1973) reported the presence of eight species of *Mimosa* in India. *M. hamata* has been reported from Punjab, Central India and South India. *M. pudica* has naturalized throughout India.

According to Sanjappa (1991), ten species of *Mimosa* have been identified in India as listed below.

Sl. No.	Name of species	Spread
1	*M. angustisiliqua*	Eastern and South Western Ghats
2	*M. barberi*	Andhra Pradesh, North East and Central India
3	*M. diplotricha* var. *inermis*	Kerala
4	*M. hamata*	South India, Delhi, Madhya Pradesh, Punjab, Rajasthan, Uttar Pradesh
5	*M. himalayana*	Jammu & Kashmir to Arunachal Pradesh, Assam, Delhi, Central India
6	*M. invisa*	Karnataka, Kerala, Tamil Nadu
7	*M. polyancistra*	Andhra Pradesh
8	*M. prainiana*	Andhra Pradesh, Gujarat
9	*M. pudica*	throughout India
10	*M. rubicaulis*	throughout India

The species, *M. hamata* was reported from Andhra Pradesh by Lakshmi and Suryanarayana (1997) and from Rajasthan by Rokole (2001). Reddy and Pullaiah

(2000) reported the presence of six species of *Mimosa* in the Eastern Ghats of India, mainly in the states of Orissa, Andhra Pradesh and Tamil Nadu.

Mimosa invisa var. *invisa* Mart. and *M. invisa* var. *inermis* Adelb. are the most troublesome alien invasive weeds of Assam (Hazarika and Barua, 2003). Rajkhowa *et al.* (2003) reported that *Mimosa* spp. have been causing serious threat to native vegetation along the hill slopes and forests of North Eastern India. Serious infestation of spiny biotype of *M. invisa* was reported by Vattakkavan *et al.* (2004) in the world famous Kaziranga National Park, Assam. It is seriously threatening the tall grasses and other local vegetation/food source of herbivores inhabiting the park, especially the endangered single horned rhinoceros.

2.3.3 Kerala

In Kerala, *M. invisa* was first observed in 1964, at Perunna, near Changanacherry in Kottayam district (Nair, 1964). He noticed that the plant grew luxuriantly over large areas, common on field boarders and waste lands, trailing and rambling over bushes, large shrubs and even small trees.

Later, Nayar and Sastry (1987) reported *M. invisa* as a climbing shrub seen as a weed in degraded forests and plains of Kerala. Similar reports were made regarding the presence of *M. invisa* in Kannur district by Ramachandran and Nair (1988), in Palghat district by Vajravelu (1990) and in Pathanamthitta district by Anilkumar (1994).

Muniyappan and Virakthamath (1993) reported invasion of *M. invisa* in vacant lands and cropped fields. According to them, distribution of *M. invisa* in the Western Ghats edwas limited to some patches. The weed was found in Mylampulli and Kalladikode villages of Palghat district as early as 1993 and along the road side from Kumaly to Munnar at Nedumkandam area.

In a survey conducted by Sreenivasan and Sankaran (2000), it was indicated that *M. invisa* infestation had spread to and was severe in Vazhachal and Athirappally areas of Thrissur district, Kalady, Kothamangalam of Ernakulam district

and Punaloor, Anchal and Pathanapuram of Kollam district. Sankaran (2001) reported that *M. invisa* is widespread in Central and Southern parts of the state. According to him out of the 52 sites infested with *M. invisa* in seven districts, more than 50 per cent were heavily infested.

2.4 BIOLOGY

2.4.1 Morphology and botany

Nair (1964) described the plant as a shrub or under shrub with many long trailing or climbing branches. Waterhouse (1994) reported that *M. invisa* is a fast growing, abundantly thorny, biennial or perennial shrub with angular branching stems that become woody with age. Sreenivasan and Sankaran (2000) reported the weed as an annual generally, which will grow as a biennial when water is available throughout the year.

Number of pinnae in the leaves, size of pods and number of seeds per pod, size of prickles and their distribution are the distinguishing features of different *Mimosa* species (Lonsdale, 1992). *Mimosa invisa* folds its pinnate leaves when touched, but is not so sensitive as *M. pudica*. Moreover, the leaves fold at nightfall due to hydronasty (Waterhouse, 1994). Kameyama *et al.* (2000) proposed that the puckering in a ticklish plant of *Mimosa* sp. which is contact sensitive, is controlled by dephosphorylation of an actin-modulating protein.

The main mode of propagation is by seeds (Nair, 1964). Sankaran (2001) stated that the weed can sprout vigorously from the cut base, soon after onset of monsoon.

2.4.2 Floral biology

Nair (1964) described that the inflorescence of *M. invisa* is solitary or in axillary pairs; globose, pink in colour, much shorter than petiole, 1.5 cm long, 11-12 mm in diameter in the open state of flowers. Peduncle up to one cm, clothed with prickles in spiny type. In spineless type, it is clothed with soft hairs.

According to Garcia (1982), *M. invisa* flowers year round in tropical region like Philippines, but in Central and Southern Brazil, it flowers only from the end of January to mid April. Seeds mature from February to end of May and plant start senescence.

Babu (1990) stated that the flowers of *M. invisa* is globose head and pink in colour. The calyx is 3 mm long; petals 4, united at the base; lobes oblong, acute, 1.5 mm long and stamens 8. Waterhouse (1994) reported that the pink or purple globular flowers are borne on a short prickly stalk arising from the leaf axil. Barth and Luz (1998) classified plants under genus *Mimosa* as nectariferous species preferred by honey bees.

Schultz (2000) also reported that the flowers of *Mimosa invisa* are pale pink, very small, round fluffy balls, formed on short stalks at the leaf axils. Sankaran (2001) reported that the inflorescence is a condensed spike (capitate) which is pinkish in colour.

2.4.3 Seed characters

2.4.3.1 Seed production

According to Lonsdale (1992) *M. invisa* has four seeds per pod, *M. pigra* has 12 to 24 seeds per pod and *M. pudica* three to four seeds per pod.

Napompeth (1990) reported that *Mimosa* spp. are bee-pollinated probably self-compatible, possibly wind pollinated as well. They also reported that the typical annual seed production by *M. pigra* is 9000 seeds m^{-2}. Under most ideal conditions, the annual seed production per plant is measured upto 2,20,000 seeds m^{-2} for *M. pigra*. Marambe *et al.* (2001) found that soil seed bank density in the canopy diameter of naturally grown *M. pigra* plants varied from 2336 to 46,410 seeds m^{-2}. According to Baki (2001), each plant of *M. quadrivalvis* var. *leptocarpa* in Malaysia, produced 11,550 seeds per year with 98.23 per cent viability.

The seed production ability of *M. invisa* var. *inermis* ranged from 8000 to 12,000 per square metre and that of *M. prainiana* ranged from 9000 to 20,000 per square metre (Rajkhowa *et al.*, 2003). Vattakkavan *et al.* (2004) reported that the seed production ability of *M. invisa* is prolific (>2000 per square metre).

2.4.3.2 Seed weight

The 1000 seed weight of *M. invisa* ranges from 5.26 g to 6.12 g (KAU, 2003).

2.4.3.3 Seed viability and dormancy

Thadulingam and Venkatanarayana (1932) stated that weeds often produce hard seeds, which enable them to withstand unfavourable conditions and keep viable over a long time even at 80°C and it is an expression of seed dormancy. Chepil (1946) reported that the relative period of seed dormancy is the greatest single factor contributing to the seriousness of a weed. Muniyappan and Virakthamath (1993) suggested that *M. invisa* seeds are hardy and capable of remaining in soil for a long time.

Holm *et al.* (1977) reported that the seeds of sensitive plant (*Mimosa pudica* L.) may remain viable in soil for many years before germination and its seeds stored under laboratory conditions gave two per cent germination even after 19 years. According to Napompeth (1990), the seeds of *M. pigra* can remain dormant for more than 15 years in soil. Ghisi *et al.* (1999) reported that the seeds of 83 accessions of *Mimosa* spp. showed dormancy and required scarification for breaking it.

Roberts (1964) established that there was an exponential decrease in the number of weed seedlings that emerged from year to year from soil seed bank. Roberts and Feast (1973) stated that without exception, the population of viable seeds declined more rapidly in cultivated than in undisturbed soil. Omami *et al.* (1999) suggested that irrespective of placement of weed seeds in soil, all seeds lost viability at an exponential rate over time. According to him decline was most rapid for those placed on the surface, whereas loss in viability decreased with the increased depth of burial.

Sahai (1999) reported that among the seeds of 26 leguminous species tested for seed viability for seven years, refrigeration storage of seeds at 3-5°C temperature, maintained viability over the whole period for nine taxa including *M. pudica* and *Leucaena leucocephala.*

2.4.3.4 Breaking of seed dormancy of Mimosa spp.

i) Pounding

Thadulingam and Venkatanarayana (1932) reported enhancement of seed germination due to mechanical aberration that caused puncturing of the hard seed coat in *Trianthema portulacastrum.* Similar observations were made by Hardcastle (1978) in the case of the weed, scarlet morning glory *(Ipomoea coccinea).* Umarani and Selvaraj (1994) found that mechanical scarification using seed and sand mixture at 1:1 ratio for 45 seconds recorded the highest germination percentage of 53.8 per cent in *T. portulacastrum.* It was even superior to acid scarification and cold water soaking.

Sheded and Hassan (1999) from Egypt obtained 100 per cent germination after penetrating the seeds by mechanical scarification in *M. pigra.* According to Marambe *et al.* (2001), sand scarification of *M. pigra* seeds gave 99 per cent germination in Sri Lanka.

ii) Flaming

Heat treatment of seeds is a method of breaking dormancy. Sampaio *et al.* (1998) showed that, in the growth of wild vegetation after slashing and burning in Brazil, *Mimosa* sp. was favoured in the competition. The germination response of *M. invisa* seeds was studied by Sanchez *et al.* (2003) in Cuba under heat stress conditions (25-35°C and 25-40°C) and was found to be higher at 25-40°C.

Flaming or heat treatment is a method of breaking the dormancy of seeds and hence it will allow more germination and seedling population in each flush. Swamy and Ramakrishnan (1987) noticed that the population size of *Mikania micrantha* was considerably enhanced by fire fallows developing after slash and burn

agriculture in North East India. Seedling recruitment from soil seed bank of weed seeds exhibiting dormancy is related to the micro-environmental changes in the habitat as a consequence of fire (flaming/burning). It has been documented that burning promoted the germination of *Mucuna pruriens* in Nigeria and *Mimosa invisa* in Philippines (Baker and Tery, 1991).

iii) Acid treatment

According to Ribas *et al.* (1996), immersion of *Mimosa bimucronata* seeds in concentrated sulphuric acid for five minutes gave 96.75 per cent germination (untreated seeds gave only 27.75% germination).

Dormancy breaking treatments of immersion in concentrated sulphuric acid for one, three, five, eight and ten minutes were tried for *M. bimucronata* and they were inferior to hot water treatment at 80°C for 18 hrs (Fowler and Carpanezzi, 1998). Sanchez *et al.* (2003) reported that exposition to pre germination, acid scarification could enhance germination of *M. invisa* seeds.

iv) Hot water treatment

Ribas *et al.* (1996) showed that immersion of *M. bimucronata* seeds in water at 80°C followed by natural cooling for 24 hours gave 98.5 per cent germination while immersion in hot water (80°C) for one to five minutes gave 96.75 per cent germination. Fowler and Carpanezzi (1998) reported that out of the dormancy breaking treatments tested for seeds of *M. bimucronata,* immersion in hot water at initial temperatures of 70, 75, 80, 85, 90 and 96°C for over 18 hours, immersion in hot water at an initial temperature of 80°C for 18 hours was the best treatment for breaking seed dormancy.

Pretreatments of seeds of *Mimosa tenuiflora* were done using mechanical scarification, sulphuric acid scarification and fire scarification. Mechanical scarification gave 84-89 per cent germination and sulphuric acid scarification gave 73-91 per cent germination (Camargo and Grether, 1998). Sanchez *et al.* (2003) found that heat scarification (with hot water at 80°C for 2 minutes) with hydration -

dehydration in water (6 and 48 hours respectively) was the best method of breaking dormancy of *M. invisa* seeds.

2.4.3.5 Peak period of germination

According to Roberts and Feast (1973), seedling emergence of weeds did not take place uniformly throughout the year and many weed species exhibited characteristic patterns with peaks of emergence at particular times of the year. Peak period of germination of different weed seeds was related with the receipt of showers. It varied from February month for *Veronica hardenifolia* to June for *Euphorbia helioscopia*. According to Garcia (1982), germination of *M. invisa* seeds occurred when moisture was available, and young plants appeared soon after the first showers of rain.

2.5 CONTROL METHODS

2.5.1 Physical methods

Roberts (1962) showed that when soil containing a naturally occurring population of viable seeds was subjected to frequent cultivation, the numbers surviving decreased exponentially. Roberts and Dawkins (1967) proved that the decrease was more rapid when soil was cultivated, than when allowed to remain undisturbed. Roberts and Feast (1973) also confirmed this observation.

According to Swamy and Ramakrishnan (1987), regeneration of *Mikania micrantha* from the clumps of previous growth left in soil, was reduced in the post burn phase in fallows subjected to flaming.

Schatz (2001) found that cutting plants off at ground level or 15 cm above ground level resulted in resprouting in most plants. Sankaran (2001) has reported that mechanical control of *Mimosa invisa* (spiny) by manual weeding is difficult and labour intensive.

Alabi *et al.* (2004) studied the optimum weeding regime for the control of thorny mimosa (*M. invisa*) in cassava in Nigeria. They found that the vegetative

growth of cassava recovered from thorny mimosa interference, when the first weeding occurred within five weeks after planting (WAP), but interference for more than five weeks reduced the tuber yield. Manual removal of thorny *M. invisa* 4, 7 and 11 WAP consistently gave the highest cassava yield. Allowing thorny mimosa infestation after 11 WAP, had no effect on cassava growth or tuber yield.

Soil solarization

According to Katan (1980), most annual and perennial weeds are effectively controlled by solarization. Yaduraju (1993) reported that the duration of solarization for four to six weeks is sufficient to control the germination of weed seeds from 0 to 10 cm soil depth. Increased reduction in the weed count and dry weight with long period of solarization has also been reported by Ragone and Wilson (1988), Mudalagiriyappa *et al.* (1999) and Chandrakumar *et al.* (2002).

According to Upadhyay and Gogoi (1993), up to 90 per cent control of weeds and 46 per cent kill of weed seeds could be achieved by soil solarization for 31 days. Sainudheen and Abraham (2001) reported that solarization for 60 days resulted in complete suppression of perennial weeds, *Cynodon dactylon* and *Cyperus rotundus*.

According to Hosmani and Meti (1993) soil solarization increased soil temperatures by 8 to 12°C over the corresponding non solarised soil. At 5 cm depth of soil there was an increment of 8.5°C in soil temperature as a result of solarization (Sainudheen and Abraham, 2001). Nimje and Agrawal (2002) reported that 6 to 12°C increase in soil temperature was obtained at 5 cm soil depth in solarised plots than non solarised and was sufficient to kill the weed seeds. According to Chandrakumar *et al.* (2002), greater increase in temperature with longer periods of solarization was due to the cumulative effect of build up of heat inside the solarization sheet. This greater rise in soil temperature reduced weed emergence and weed dry weight to the minimum.

2.5.2 Chemical methods

Attempts to control *M. invisa* using 2,4-D and dinitrobutylphenol (dinoseb) in Brazil were not very successful (Lew, 1993). Muniappan and Virakthamath (1993)

reported that mechanical and chemical control methods are expensive and did not provide a long lasting effect.

Pornprom *et al.* (2002) has reported from Thailand that the herbicides alachlor (3.75 kg ai ha^{-1}), atrazine (3.13 kg ai ha^{-1}) and oxyfluorfen (1.56 kg ai ha^{-1}) were effective against smooth *Mimosa* (*M. invisa*) which was one of the main weed species of kale crop.

Trials in the Kerala Agricultural University showed that, 2,4-D at any stage of application, even at very high dose of 3 kg ha^{-1}, could not control *M. invisa* effectively. Paraquat gave only temporary control and regrowth occurred soon. Glyphosate was the most effective herbicide, which gave 50 per cent control even at 0.2 kg ha^{-1}. Doses of 0.4 kg ha^{-1} glyphosate resulted in very good control of the weed (KAU, 2003).

2.5.3 Biological methods

2.5.3.1 Insects

Garcia (1982) listed 67 insects attacking *M. invisa*. According to Ablin (1992) *Heteropsylla spinulosa,* a Hemipteran psyllid seen in Brazil, is an effective bioagent for the control of *M. invisa*. The adults of *H. spinulosa* could reduce the *M. invisa* plants to masses of bare stems with stunted growing tips, leading to reestablishment of other vegetation. Ablin (1993b) reported that this psyllid reduced seed production on an average by 80 per cent, growing tip elongation by 77 per cent and growth rate of tips by 50 per cent. The pods also contained very few viable seeds. According to Waterhouse (1994), high populations of *H. spinulosa* caused severe stunting and distortion of leaves and growing tips; flowering was reduced or even prevented in *M. invisa*. In extensive host specificity tests, *H. spinulosa* adults and nymphs were unable to live on any plant other than *M. invisa* and its spineless variety *M. invisa* var. *inermis*. In the field, it did not attack *M. pudica* even when growing nearby (Ablin, 1993a). The psyllid is used as bioagent against *M. invisa* in Papua New Guinea (Ablin, 1993b), Pohnpei (Esguerra *et al.*, 1997) and Western Samoa (Wilson and Ablin, 1991).

Psygida walkeri, a lepidopteran moth, seen widespread in Brazil and Columbia is another possible bioagent for control of *M. invisa.* According to Garcia (1983), *P. walkeri,* whose larvae feed voraciously on leaves, flower buds, tender seed pods and tender stems, prevented both flower and seed production. However, the larvae did not attack any other leguminous plant growing near *M. invisa.* Haseler (1984) also reported the host specificity of *P. walkeri.*

The nymphs and adults of the coreid bug, *Scamurius* sp., feed on shoots, causing them to collapse, thereby inhibiting vegetative growth and flowering. According to Garcia (1984) and Wild (1986; 1987), the adults of this bug were found to feed only on species of *Mimosa.* Nymphs were able to develop on *M. invisa, M. pudica* and *M. pigra,* but not on other plants. It was reported that *Scamurius* sp. killed tips of *M. pigra* shoots, but fecundity was very low and the colony died without establishing.

Heteropsylla spinulosa and *Scamurius* sp. were released in Queensland, Fiji, Papua New Guinea, and Western Samoa from 1987 to 1993 and could establish well and give good control of *M. invisa* for many years (Waterhouse, 1994; Kuniata and Korowi, 2001).

Among the other *Mimosa* species, studies on the bioagents for the control was conducted mostly in *Mimosa pigra.* Heard and Forno (1996) studied the laboratory oviposition, feeding and larval development with *Codocephalapion pigrae,* a flower feeding weevil, on *M. pigra* and established its host specificity. Heard *et al.* (1998) identified that adults and larvae of *Chaleodamus persimilis* feed on the seeds of *M. pigra.* However, the host range is too broad to be considered as a biological control agent. Heard *et al.* (1998) reported that *Chaleodamus scaripes* feeding on growing tips, flowers and pods of *M. pigra* will not oviposit or complete its life cycle on any other host other than *M. pigra.*

2.5.3.2 *Fungi*

Corynespora casiicola, a stem spot fungus, is very common in Queensland, Papua New Guinea and Western Samoa and is found to kill *M. invisa* (Haseler, 1984). Wilson and Ablin (1991) reported that *Corynespora casiicola* can be very damaging to *M. invisa* during favourable environment. Ablin (1992) also reported that the fungus caused shedding of the leaflets of *M. invisa* and stems die back as lesions cover the plant. From Venezuela, Evans (1999) reported a fungus *Uredo mimosae-invisae* attacking *M. invisa* plants.

Fusarium pallidoroseum isolated from *Mimosa invisa* in the Philippines provided excellent control of *M. invisa* seedlings when applied as foliar spray of crude culture filtrate, in laboratory and field trials (Mabbayad and Watson, 2000). They suggested that the health risk involved was to be studied and documented before the use of *F. pallidoroseum* for control of *M. invisa*. Waterhouse (1994) reported *Cercospora canescens* as a bioagent for *M. invisa,* for which detailed host specificity studies are to the conducted.

2.6 USES OF *M. invisa*

2.6.1 Reclamation of degraded soils

Mimosa tenuiflora characterized by the good growth capacity in adverse soil conditions, in suited for the rehabilitation of degraded soils (Dias *et al.*, 1995). *Mimosa scabrella* is recommended for improving the soil conditions in Brazil because of the production of high quantity of biomass and nutrient content in above ground biomass (Bertalot *et al.*, 1998).

Liu *et al.* (1999) studied the effect of intercropping Chinese fir with *M. invisa* as a method to control soil erosion, which was decreased by 17.76 to 52.25 per cent compared with controlled burned land. The growing of *M. invisa* also improved soil physical properties and nutrient conditions and enhanced the growth of Chinese fir trees.

Another species of mimosa, *M. caesalpinifolia* when used for rehabilitation treatment of degraded (eroded) area with exposed C horizon, by returning the green matter to the soil, were found to be newly colonized by 20 species of plants with improvement in soil texture, density and organic matter content (Valcarcel and Alterio, 1998). Andrade *et al.* (2001) also reported the significance of *M. caesalpinifolia* in recovering degraded land.

According to Suarez *et al.* (2000) *Mimosa buincifiera* called catclaw could serve as a first colonizer of heavily eroded soils of central high lands of Mexico and be replaced by other vegetation, natural or crops, when fertility is restored by increased microbial biomass, soil organic matter and improved nitrogen mineralisation.

2.6.2 As a green manure crop

Sannamarappa (1987) studied the effect of growing six green manure and cover crops in relation to organic carbon status of soil and arecanut yield. *Mimosa invisa* yielded significantly more green matter and gave best improvement of organic Carbon status.

Kaufusi and Ashgar (1990) while comparing the effect of incorporating leaves of six leguminous species on *Zea mays* discovered that the growth of maize plant generally increased with amount of plant material incorporated. Growth of maize according to them was stimulated by the legumes and *M. invisa* ranked second. In another study, Tiraa and Ashgar (1990) found that growth increase observed with *Erythrina* sp. as green manure on *Zea mays* was the highest and the effect of *M. invisa* was on par with other four legumes tested.

Mohankumar (1996) reported that *M. invisa* grown as green manure crop in coffee, proved an effective method to improve soil fertility status. Suwanarit *et al.* (1998) in a field experiment in Thailand, allowed several green manure crops intercropped in maize and to continue to grow following maize harvesting and were cut and incorporated into the soil before sowing the next crop. Out of the five intercrops grown, *M. invisa* intercropped maize gave 86 per cent and 190 per cent

yield of that of sole maize in first and second years. According to them maize - *M. invisa* intercropping system was the best for simultaneous production of maize and green manure and to improve soil chemical properties and thereby yield.

Thomas *et al.* (2001) reported that in a study conducted in 30 year old coconut plantation in an acid laterite soil in Kerala (Kasaragod) by growing *M. invisa* as green manure crop in the coconut basin of 1.8 m radius produced 20.5 kg above ground wet biomass and 134.8 g nitrogen per basin when harvested and incorporated at 140 days growth. They also discovered that higher N fixation efficiency was shown by *M. invisa* as evidenced by nodule biomass and acetylene reduction activity of nodulated root system.

2.6.2.1 Litter decomposition

According to De Catanzaro and Kimmins (1985), litter decomposition is one of the most crucial process in the biogeochemical cycle of any natural ecosystem. Prichett and Fisher (1987) reported that studies on litter dynamics of any vegetation is important in the nutrient budgeting of an ecosystem. Panda and Swain (2002) stated that litter decomposition is a complex process by which fresh litter is gradually transferred into refractory soil organic matter.

The pattern and rate of decomposition of litter in any ecosystem is influenced by the nature and quality of the substrate decomposed, microclimate, soil microbial activities etc. as reported by several scientists (Olson, 1963; Singh, 1969 and Hopkins, 1966). The nutrient cycling and litter decomposition studies conducted extensively all over the world, in different natural ecosystems, established the influence of environmental factors on the decomposition rate (Singh and Gupta, 1977; Sankara and Cabale, 1982; Upadhyay *et al.*, 1989; Sreekala, 1997 and Abraham, 1999). According to Toky and Ramakrishnan (1984) and Sugur (1989) the rate of decomposition varied with micro-environmental factors and chemistry of decomposing litter. The significant variation in rate of decomposition between plant species is established from the studies of Kumar and Deepu (1992), Sankaran (1993), Kunhamu *et al.* (1994) and Joshi *et al.* (1999).

2.6.2.2 *Vermicomposting*

Literature available on vermicomposting of *M. invisa* is limited. However, studies conducted on vermicomposting as a means for enrichment and utilization of some of the problem weeds of India are reviewed here.

According to Bhawalker and Bhawalker (1993), earthworms feed on any organic waste, consume 2 to 5 times their body weight and excrete mucus-coated undigested matter as worm casts. The nutrients in worm cast are readily available to plants. Bhaiday (1994) reported that vermicompost is a rich source of macro and micro nutrients, vitamins, enzymes, antibiotics, growth hormones and immobilized microflora.

The earthworm *Eisenia foetida*, a common inhabitant of compost heaps could reduce the composting time very much and homogeneous mass of castings was obtained in 30 days (Haimi and Hutha, 1990). Hand *et al.* (1988) reported that *E. foetida* increased the N content of the substrate used for vemicomposting.

Vermicomposting of lantana and congress grass increased the nutrient contents, except potassium, considerably over the substrate used. The increase in nitrogen content was 2.52 to 2.94 per cent in lantana and 2.04 to 2.38 per cent in congress grass (Sharma *et al.*, 2004). Purakeyastha and Bhatnagar (1997) revealed that all the macro and micro nutrients except Ca and Mg were much higher in vermicompost than in farmyard manure. Composting of rapidly multiplying weeds like *Eicchornia crassipes* and *Salvinia molesta* is a method of utilization of the problem weeds (KAU, 2002).

Rajalekshmi (1996) reported that application of organic manure in the form of vermicompost to the soil recorded higher values for all available nutrients. According to Pushpa (1996) the availability of N, P_2O_5, K_2O, Ca and Mg was improved as a result of vermicomposting and therefore enhanced the growth and yield of crops. Increased availability of nutrients in vermicompost prepared from the organic wastes of ayurvedic preparations was reported by Preetha (2003).

2.6.2.3 Response of crop plants to vermicompost

Kale *et al.* (1987) reported significant influence of vermicompost in enhancing vegetative and flowering characters of crop plants. According to Shuxin *et al.* (1991) 20-25 per cent increase in height and 50 per cent increase in weight of soyabean plants was obtained when vermicompost was applied. Govindan *et al.* (1995) reported higher number of leaves per plant, in treatments receiving 100 per cent vermicompost compared to FYM, in Bhindi.

2.6.3 As a cover crop

Jayasinghe (1991) reported that leguminous cover crops like *M. invisa* improved the biological, chemical and physical properties of soil of rubber plantations and imparted a beneficial effect on plantation soils.

According to Mohankumar (1996) *M. invisa* grown for a year and incorporated into the soil, considerably suppressed weed growth and prevented soil erosion when grown between coffee plants. Coffee plants in the experimental plots with *M. invisa* were greener and supported more branches. Soil erosion problems were also lowered and soil fertility status (especially N) was improved.

2.6.4 Applications of inhibitory effect of mimosine

Lalande (1996) reported that the plant amino acid mimosine, found in *Mimosa* sp. and *Leucaena* sp. reversibly blocks the mammalian cell cycle, which can be used in treatment of cancer or for synchronizing various cell lines. Largo *et al.* (1997) reported that the chloroform extract of air dried leaves of *M. invisa* showed antitumour and anticancer potential.

Mimosine is reported to block the cell cycle progression in the late G_1 stage of interphase. A recent study showed that mimosine might arrest growth by activating the expression of a kinase inhibitor and by inhibiting the activity of cycline E-associated kinases in human breast cancer cells. Thus mimosine can block cell proliferation by multiple mechanisms and is a useful agent for the study of cell cycle

control (Chang *et al.*, 1999). Fulda and Debatkin (2004) also reported that mimosine could act as a cell cycle inhibitor in helping reduce survinin expression and thereby prevent human cancer.

Litherland *et al.* (1999) suggested the use of mimosine in the diet of Angora and Spanish goats as a method to induce fleece shedding. Luo *et al.* (2000) reported that intravenous infusion of mimosine at low doses could induce cashmere (fibre) shedding, suggesting future potential use of mimosine to improve cashmere fibre yield in Spanish goats.

According to Kale and Magar (2000) mimosine at 0.05 per cent exhibited therapeutic use as an anti-tumor agent as well as reversible infertility substance.

2.6.5 Other uses

Sosamma and Jayasree (1999) reported that leaves of *M. invisa* could be effectively used for mass multiplication of nematophagous fungus *Paecilomyces lilacinus*. According to Molina *et al.* (1999) *M. pudica* may pose antidepressant actions in rats. Three alkyl amines isolated from *M. ophthalmacentra* seen in Brazil exhibited hallucinogenic properties in rats. This provides pharmacological use for the plant (Batista *et al.*, 1999).

2.7 HARMFUL EFFECTS OF *M. invisa*

2.7.1 Effect on biodiversity

Vitousek *et al.* (1996) considered biological pollution due to invasion of any alien plant as having greater impact on the world's biota than any other known aspect of global environmental change. They reported the heliophytic nature of *M. invisa* helped it to have an uppermost layer of canopy in any type of vegetation it is competing. This will result in gradual shifting of species composition of plant communities towards a preponderance of the weedy, undesirable species.

The simplest effect of invasive weeds is the displacement of native plant species by simple crowding, by competition for resources or by other mechanisms.

Weeds invading pastures commonly reduce livestock carrying capacity from 35 per cent to 90 per cent (Hiken, 1980 and Harris, 1988). According to Nyvall (1995) very aggressive invaders out compete and forces out native plant species and reduces biodiversity. Kummerow (1992), reported that like human populations, weeds typically increase exponentially beginning slowly, then doubling and redoubling.

Waterhouse (1994) reported rapid smothering effect of *M. invisa* on useful plants and other weeds. Vattakavan *et al.* (2003) reported that the spiny weed *Mimosa rubicaulis* (*M. invisa*) which has badly infested the Kazaringa National Park in Assam is seriously threatening the local vegetation (food source) of several herbivores inhabiting the park, including the endangered single horned rhinoceros. Rajkowa *et al.* (2003) reported serious effect of the weed on crop ecosystems, plantations (tea, coffee, coconut, rubber, pineapple etc.) forest ecosystem, grass land and pastures, parks and sanctuaries. They also reported that *M. invisa* var. *inermis* Adelb. appeared as one of the dominant weeds in sugarcane fields in many areas of Assam, posing serious health hazards to domestic herbivores. According to Vasu (2003), *M. invisa* is a toxic shrub, which impairs the growth of other species especially the grasses and it has been observed that nothing grows in the grass land areas infested by it. He also reported that *M. invisa* contains thorns and spreads vigorously blocking the traditionally used paths and trails by wild animals such as rhinos and elephants.

Basu and Ghosh (2003) also reported that *M. invisa* overpowered the six foot high grasses of more than 120 ha area and made the land unsuitable for any other plant to grow, possibly due to allelopathic effects.

2.7.2 Competition and yield reduction in crops

Tuber yield of cassava was considerably reduced by competition from *M. invisa* at populations higher than 10,000 plants per hectare (Alabi *et al.*, 2001). According to them, the yield reduction increased with increase in population of *M. invisa*, and the highest reduction of 85 per cent occurred in the natural population of 6,30,000 plant ha^{-1}.

Alabi and Makinde (2002) reported that the height of okra (*Abelmoscus esculentus*) plants was significantly affected by thorny mimosa population. According to them, okra growth and yield were not significantly affected by *M. invisa* under adequate rainfall conditions, but the yield was reduced, when the weed population was high and rainfall was inadequate during the fruiting stage.

2.7.3 Allelopathic effects

Allelopathy, according to Rice (1979), is the effect of one plant on another through its metabolic products. Though works on the allelopathic effects *M. invisa* are less, many studies were conducted on *Leucaena leucocephala* (subabul). Avery (1993) focused on mimosine and its degradation product 3-4 dihydroxy pyridine in *Leucaena leucocephala* as the principal N-solute allelopathic to other plant species. John and Narwal (2003) have reviewed the allelopathic effects of leucaena on cereals, pulses, oil seeds, vegetables, fodder crops, weeds and trees. Bioassays with aqueous seed and shoot extracts (10%) identified and characterized the allelopathic effects of *Leucaena leucocephala* on germination and radicle elongation of pasture weeds. The inhibitory effects of seed extracts of leucaena were more pronounced than its shoot extract (Souza *et al.*, 1997).

Kalia *et al.* (1996) reported that aqueous leaf leachates of leucaena inhibited germination and seedling growth of *Ageratum conyzoides* showing its potential in weed management. According to Kamara (1998), plots mulched with prunings from leucaena had a lower weed seed bank than unmulched plots. The aqueous leachates from leucaena also contained mimosine, the toxic amino acid. Chou (1985) reported that leucaena plantations exhibited the unique pattern of weed exclusion beneath its canopy. There were noticeable phytotoxic effects of phenolics and mimosine, released from the plant canopy on the under storey vegetation. Suppression of ground vegetation under leucaena was ascribed to allelopathic effects rather than to physical competition for water and nutrients by Suresh and Rai (1988). The dominant species under leucaena was *L. leucocephala* itself indicating lack of autotoxicity of mimosine. Pires *et al.* (2001) observed that when used as soil mulch,

L. leucocephala could control weeds probably due to the mimosine content, which has allelopathic effects.

Sankar and Rai (1993) attributed the inhibitory effects of the seed leachates of leucaena on germination of vegetable seeds, to the mimosine and dihydroxy pyridine contents. However, Khare and Bisaria (2002) observed that lower concentration of mimosine enhanced the seed germination and seedling growth in *Triticum aestivum*, although inhibitory at higher concentrations.

2.7.4 Mimosine content

Studies on the mimosine content in *M. invisa* is very limited. Several references are available on the mimosine content in subabul- *Leucaena leucocephala*- belonging to family Mimosaceae and ways to manage its toxicity.

Jones (1979) reported that leucaena contained mimosine which is chemically (β-N-3 hydroxy-4-pyridine) - α amino propionic acid. Paterson (1993) reported the presence of toxic amino acid mimosine as an antinutritional factor seen in the foliage of *Mimosa* spp.

2.7.4.1 Variation between plants of Mimosae family

Renz (1936) reported the presence of mimosine in *M. pudica*. Brewbaker and Hylin (1965) on the contrary observed mimosine as a toxic alkaloid apparently unique to leucaena in concentrations ranging from 2-5 per cent, and mimosine surprisingly absent in *M. pudica*.

2.7.4.2 Variation between cultivars of leucaena

Chathurvedi and Jha (1992) and Forrajes *et al.* (2003) reported that there was great difference in mimosine content among different cultivars of leucaena. Kaur *et al.* (2001) reported wide variation in mimosine content among the antiquality factors of eight subabul cultivars used as fodder in Punjab. Chauhan and Hosalli (2003) also reported wide range of variation in mimosine content between 49 different

species/varieties of leucaena. According to La *et al.* (2003), leucaena from Cuba had mimosine content of 4.5 per cent and showed no significant difference between ecotypes.

2.7.4.3 Variation between plant parts

Great variations in the mimosine content between plant parts has been reported in *Leucaena leucocephala*. Hegarthy and Court (1964) reported that the toxic amino acid mimosine is present in large quantities in leucaena seeds. Mimosine content of 1.2 per cent on dry matter basis was reported in the leaves of leucaena by Hamilton *et al.* (1971). According to Megarrity (1978) 1.3 to 4.1 per cent mimosine is present on dry matter basis in leucaena. Leucaena contained mimosine upto 12 per cent in growing tips and 3-5 per cent in young leaves, pods and seeds (Jones, 1979). Tangendjaja *et al.* (1986) reported that mimosine content was the highest in young leaves of *Leucaena leucocephala* at 45 g kg^{-1} dry weight and declined to 2 g kg^{-1} dry weight in 10 week old leaves. According to Chou and Kuo (1986), juvenile leaves of subabul contained higher amounts of mimosine than normal leaves. Prabaharan (1995) reported that average mimosine content of leucaena varied from 3.9 per cent in the tender stems to 12.11 per cent in leaves of immature growing tips. Srinivasulu *et al.* (1997) reported that the mimosine content was 3.42 per cent on dry matter basis in subabul leaf meal. Samantha *et al.* (1998) reported the presence of 4.5 per cent mimosine in leucaena leaf meal.

Bisaria and Khare (2000) reported that mimosine content in leucaena was the highest in the pods and lowest in the leaves. According to Vestena *et al.* (2001) the highest mimosine content in subabul was found in the shoots, and they found that the content could be increased by application of mechanical damage to the shoots. They also suggested that accumulation of mimosine is regulated by ontogenesis and environmental factors. Singh *et al.* (2002) reported that mimosine content in leucaena seeds was 1.1 per cent.

2.7.4.4 Seasonal variation

Gupta *et al.* (1992) studied the seasonal variation in anti quality factors of *Leucaena leucocephala* in India, and discovered that mimosine content increased during the summer rainy season (July-August). Prabaharan (1995) reported that there was significant difference between the different parts of leucaena with respect to mimosine content during different months of the same year.

Ubani *et al.* (2000) reported that mimosine content in leucaena was negatively correlated with rainfall and was the highest in April, the transition month between dry and rainy season. According to Akingbade *et al.* (2001), seasonal variations had no significant effect on the mimosine content of subabul.

2.7.4.5 Harvest interval

Kasthuri and Sadasivam (1991) studied the effect of cutting on the level of mimosine in leucaena. According to them, mimosine content varied from 2.5 to 5.25 per cent in the first cutting to, 2.38 to 4.88 per cent in the second cutting.

2.7.5 Mimosine toxicity

2.7.5.1 Mimosine toxicity in animals

Kingsbury (1964) and Hegarthy *et al.* (1976) described mimosine as a toxic non protein amino acid that causes low weightgains , general poor condition and hair loss in ruminants and non ruminants. Crounse *et al.* (1962) reported the inhibition of growth of hairs in mice due to mimosine toxicity. Toxicity due to feeding of buffaloes on *M. invisa* var. *inermis* was reported by Tungtrakanpoung and Rhienpanish (1992). Li *et al.* (1996) from China reported the case of mimosine toxicity in camels due to feeding on *M. invisa*.

Hegarthy *et al.* (1964) reported that when leucaena seed meal or mimosine itself is included in the feed of sheep, it results in poor wool growth and in extreme cases of toxicity, the animals shed their fleeces and eventually die. Chronic toxicity of leucaena for ruminants is related indirectly to its mimosine content. Mimosine content

as such is not the problem. DHP (3-hydroxy-4-1 (H)-pyridone), the break down product of mimosine in the rumen of animals is a potent goitrogen (Hegarty *et al.*, 1976).

Mimosine, the toxic amino acid has several negative effects on animal cytology and physiology. It can completely inhibit the growth of *Escherichia coli* when present in the growth medium at concentrations > 1.25 mM (Sudha, 1960). Kuo *et al.* (1982) reported that mimosine totally inhibits cell division and synthesis of DNA, RNA and protein in *Paramecium tetraulia* at submillimolar concentrations. According to Tsai (1961) mimosine inhibits several metal-containing enzymes.

Rajan *et al.* (1986) from Kerala, reported the nature of toxicity of *M. invisa* and the biological effects of the toxin, mimosine present in the plant on animal tissues, during their studies in calves. They revealed that the toxic principle in *M. invisa* caused vascular endothelial damage, nephrosis, necrosis of heart and liver and anaemia. They also found that the toxic changes were related to the quantity of the plant consumed by the animal. The possibility of the high mimosine content in fresh subabul reducing the overall digestibility of nutrients in growing goats was reported by Jaikishan *et al.* (1986).

Alex *et al.* (1991) reported a clinical case of mimosine poisoning due to ingestion of *M.invisa* in two year old heifer in Kerala. Clinical signs of mimosine toxicity include alopecia, loss of appetite, excessive salivation, inco-ordination of gait, enlarged thyroid glands, poor breeding performance and finally death (Vohradsky, 1962; Jones *et al.*, 1976; Holmes, 1976; Jones *et al.*, 1978). According to Anderson *et al.* (2001) drought associated mimosine poisoning in cattle, grazing on subabul resulted in profuse salivation, alopecia, weight loss, lethargy and poor body condition.

James and Gangadevi (1990) reported alopecia in rabbits fed with ensiled subabul. Mishra *et al.* (2002) has described the adverse effect and clinical aspects of mimosine poisoning due to overfeeding of sheep on *Leucaena leucocephala.*

Kumar and Sharma (1997) in a study in goats fed with *Leucaena leucocephala,* indicated that 1.6 per cent mimosine in the feed is safe for use in the diets of goats. According to Ubani *et al.* (2000) the toxic non-protein amino acid, mimosine at more than 1 per cent concentration in the feed diet is toxic to livestock. Yami *et al.* (2000) reported that diets containing 0.75% mimosine could be fed to goats without adverse effect on body weight gain and fibre growth. Similar reports were made by Odeyinka (2001) in goats and Singh *et al.* (2003) in calves.

According to Kumar and Sharma (1998) rough coat and alopecia were the clinical symptoms associated with mimosine toxicity in goats. Srivastava and Sharma (1998) reported that Jamnapari goats fed raw subabul revealed signs of colloidal goitre associated with mimosine toxicity.

Sugur *et al.* (2001) reported that feeding rabbits with 10 per cent leucaena in the standard diet resulted in clinical manifestations of mimosine toxicity such as tyrosinuria, alopecia and debility, leading to weakness. Histological examination of muscles revealed severe muscular atrophy.

2.7.5.2 Practices to lower mimosine toxicity

Several practices were used to lower the mimosine content in subabul before feeding animals. The mimosine content in leucaena was lowered by 40 per cent by drying (Jones, 1980). A similar reduction in mimosine content as a result of sun drying was reported by Hossain and Rahman (1990).

According to Chou and Kuo (1986) the harvested leaves exposed to sunlight at noon lost over 50 per cent of total mimosine as compared to air dried leaves. Sun drying and pelletting of leucaena foliage reduced mimosine toxicity (Srivastava and Sharma, 1998).

Chathurvedi and Jha (1992) assessed that leucaena leaves exposed to sunlight lost over 33-42 per cent of total mimosine. Srinivasulu *et al.* (2001) found that wilting had no appreciable effect in lowering mimosine content in subabul leaves, but boiling the leaves for 10 minutes reduced mimosine significantly.

Ubani *et al.* (2000) suggested that leucaena leaves could be harvested during wet seasons and dried and stored for use in dry months as a method of lowering chances of mimosine toxicity.

Lin *et al.* (1985) and Khatta *et al.* (1985; 1987) reported that ensiling is an effective method to reduce mimosine content and thereby its toxicity. James and Gangadevi (1990) found that ensiling is an effective method to reduce the mimosine content in leaves of leucaena without altering the bioavailability of nutrients. They also reported that under the best conditions of fermentation during ensiling the mimosine content dropped even upto 57.2 per cent towards 90th day of ensilment. The decrease in mimosine content was not linear with period of ensilment. Ensiling is also effective in eliminating many toxic factors and other antinutritional factors in animal feed (Gangadevi and James, 1993).

Srinivasulu *et al.* (2001) studied the influence of ensiling on the mimosine content of *Leucaena leucocephala.* The subabul fodder in different proportions with maize and paddy straw ensiled for different periods, showed that the mimosine levels decreased significantly after 15 days in all the proportions of mixture. The reduction in mimosine levels increased with progress in ensiling period. By 60 days the reduction was up to 66.82 per cent.

According to Liu and Wang (1990) mimosine content of fresh shoots of leuceana was reduced from 6.8 per cent to 1.8 per cent as a result of fermentation. Mali *et al.* (1990) reported that dry heating at 100°C for one hour reduced mimosine content of the seeds of subabul by 17 to 19 per cent.

Paul (2000) found that treatment of subabul leaf meal with mimosine binding agents reduced mimosine toxicity significantly in non ruminants. According to Awaya *et al.* (2003) *Rhizobium* sp. strain TAL 1145 can catabolize mimosine, a toxic amino acid of subabul.

Gangadevi and James (1992) revealed through their experiments on rabbits that, animals maintained on ensiled subabul exhibited better growth rate, feed efficiency and nutrient digestibility, compared to rabbits fed fresh subabul. The toxic manifestations were also minimum.

Materials and Methods

3. MATERIALS AND METHODS

Experiments to study the biology and management of *Mimosa invisa* Mart. were conducted at Kerala Agricultural University, Thrissur during the period 2001-2004. The study consisted of four parts:

1. Survey to assess the distribution and spread of *M. invisa* in Kerala
2. Biology and ecology of *M. invisa*
3. Assessment of different methods to control the weed
4. Economic importance of the weed.

The details of materials used and methods employed for the studies are described in this chapter.

3.1 LOCATION OF THE STUDY

Survey on the distribution of *M. invisa* was conducted covering the entire state of Kerala. Experiments to study the biology, ecology and economic importance of the weed and methods to control the weed were conducted at the College of Horticulture, Vellanikkara, University Livestock Farm and Fodder Research Station, Mannuthy and College of Veterinary and Animal Sciences, Mannuthy.

3.2 DISTRIBUTION

A survey was conducted to assess and document the distribution and severity of infestation of *M. invisa* in different parts of Kerala. This was done by travelling along the major roads and rail routes of the state, in 2002 and 2003 during the months of July to September (active vegetative and flowering stages of *M. invisa*). The extent of spread of the weed and intensity of infestation in cropped fields, fallows and non agricultural areas like road sides, waste lands, sides of canals and rivers were observed and recorded. The rating of the intensity of the infestation was done visually and classified as given below:

Intensity of infestation	Description
Severe	The continuous stretch of area is completely occupied by *M. invisa* and >90% of the flora is accounted by the weed.
High	Large patches of *M. invisa* accounting for 50-90% of the flora of the region
Medium	Intermittent small patches of *M. invisa* accounting for 25 to 50% of the flora of the region.
Low	Very small patches of *M. invisa* infestation accounting for <25% of the flora of the region.
Sparse	Isolated very small patches of *M. invisa* seen wide apart.

3.3 BIOLOGY

3.3.1 Morphology

During the survey, the plants growing under different agro ecological situations and in different locations were observed for variation in spiny nature, growth habit, colour of stem, hairiness, trailing nature, flowering behaviour, floral characters and seed characters.

3.3.2 Life cycle

The growth stages of the plant - seedling, vegetative, flowering and seed production of the plant, and seed characters like dormancy, viability, germination and 1000 seed weight were studied under laboratory and field conditions. Details regarding the study are given below.

3.3.3 Normal period of germination

Naturally infested areas of *M. invisa* in identified sites at the University Live Stock Farm and Fodder Research Station, Mannuthy and College of Horticulture, Vellanikkara were observed daily after the onset of summer showers to find the normal period and peak period of germination under normal field conditions.

3.3.4 Growth stages

This was studied by raising ten plants separately in the field, at two locations namely, Mannuthy and Vellanikkara, during 2002 and 2003. These plants were regularly observed for recording the important stages of growth and duration of each stage.

3.3.5 Reproductive cycle

Normal flowering time and period from flowering to seed maturity were noted. The individually raised ten plants were closely observed for the time of first appearance of flower bud in the leaf axil and first opening of flower bud. The newly initiated flower buds were selected and tagged. The tagged buds were observed daily for bloom, anthesis, seed set, seed maturity and dehiscence, and the duration of each stage was noted.

3.4 SEED CHARACTERS

3.4.1 Seed production

The total seed production per plant was estimated from the ten plants raised at Mannuthy and Vellanikkara, during 2002 and 2003. The number of seeds produced per plant was calculated by assessing the number of primary branches per plant, number of secondary branches per primary branch, number of pod clusters per secondary branch, number of pods per cluster and number of seeds per pod. The average seed production of 40 plants raised in the two years was estimated.

3.4.2 Thousand seed weight

Mature seeds collected from the field during first fortnight of December were used for the assessment. Seeds were collected from the two locations of the experiment during 2002, 2003 and 2004. Twenty seed samples were taken from the infested fields of the two locations each year, the weight of 1000 seeds determined, and the average value expressed as thousand seed weight.

3.4.3 Seed viability and germination

The seeds were collected from the field during December to January in 2001, 2002 and 2003 and stored in clean, dry sand in air tight containers. These seeds treated with concentrated sulphuric acid for two minutes, were sown in lots of 100 numbers in plastic trays filled with field soil. They were kept under room conditions, watered regularly and the seedlings germinated were counted.

Seed lots were sown in alternate months to assess the reduction in germination percentage due to fall in seed viability.

3.4.4 Seed dormancy

The mature seeds of current year collected from field during December to January (2002 and 2003) were used for testing the efficiency of different methods for breaking seed dormancy. The methods tested included pounding the seeds with sand, flaming, hot water treatment, acid treatment and Gibberellic acid treatment for different periods of time.

3.4.5 Methods to break dormancy

Five different methods - pounding, flaming, hot water treatment, acid treatment and Gibberellic acid treatment - employed in this study, to break dormancy of *M. invisa* seeds are described below. Each treatment had three replications of 100 seeds each and the experiment was laid out in CRD. The trials were carried out with the seeds collected from the field during 2002 and 2003. The treated seeds were sown separately in plastic trays filled with field soil, kept under room conditions and watered regularly.

3.4.5.1 Pounding

Three hundred seeds were mixed with an equal volume of coarse sand and pounded continuously for five minutes using a mortar and pestle, to crack the hard seed coat and were sown in trays as three replications of 100 seeds.

3.4.5.2 Flaming

Seed lots of 100 numbers each were spread on a very close wire mesh and placed over flame for 15, 30, 45 and 60 seconds respectively. This was replicated thrice and sown.

3.4.5.3 Hot water (60°C and 80°C)

Seven lots of 100 seeds each were soaked for 2, 5, 10 and 15 minutes in hot water at an initial temperature of 60°C and for 2, 5 and 10 minutes in hot water at 80°C. Three replications of each treatment were laid out in CRD and treated seeds were sown.

3.4.5.4 Acid treatment

Nine lots of 100 seeds each were taken in petri dishes, treated with enough concentrated sulphuric acid (1.5 ml/1000 seeds) to smear them , and kept for varying durations from one minute to 35 minutes (1, 2, 5, 10, 15, 20, 25, 30 and 35 minutes). This was replicated thrice and the effect of concentrated sulphuric acid on breaking dormancy of the seeds was observed.

3.4.5.5 Gibberellic Acid

Three lots of 100 seeds each were soaked in 50 ppm GA for 6, 12 and 24 hours before sowing. The trial was laid out in CRD with three replications.

3.4.5.6 Control

Three lots of 100 untreated seeds each were sown to serve as three replications of the control treatment.

3.5 PROPAGATION

3.5.1 Seeds

The effect of depth of sowing was tested by sowing the seeds at different depths. Polythene bags of 15 cm height and six centimetre diameter were filled with field soil. Twenty *M. invisa* seeds treated with concentrated sulphuric acid (1.5 ml/1000 seeds) for two minutes were spread on the surface of the soil in each bag. Fourty eight such bags were prepared. Three bags each were placed in 16 earthern pots and seeds were sown on surface. Soil was filled in the interspaces to keep the bags compact. The thickness/depth of soil filled above the bags was adjusted to get zero, five, 10 and 15 cm depths of sowing. There were twelve replications for each depth of sowing. Observation on number of seeds germinated at different depths was recorded by taking out three bags of each sowing depth at three, six, nine and 12 days after sowing.

3.5.2 Stem cuttings

Three noded stem cuttings from different parts of the stem (base, middle and apex) were taken and planted at different depths, i.e., zero, two, five and 10 cm on ridges during June and replicated five times. The establishment of the cuttings was observed by recording the number of sprouts produced.

3.5.3 Root clumps

The infested areas were ploughed with a power tiller and left as such, just after the onset of first rains to see if sprouting from root clumps occurred. Observations on the number of shoots sprouted were also recorded.

3.6 CONTROL METHODS

The efficiency of different methods for control of *M. invisa* was tested both in field and in pot culture. The field trials were conducted in *M. invisa* infested pasture lands at Mannuthy and in the *M. invisa* infested area adjoining the crop museum of College of Horticulture, Vellanikkara. Areas uniformly infested with

M. invisa at both locations were demarked into experimental plots by sickle weeding 50 cm wide paths, so as to divide the area into plots of size 5 m x 4 m.

3.6.1 Physical methods

The efficiency of different physical methods to control the weed was studied during 2002-2003. The treatments were:

1) Sickle weeding at monthly intervals
2) Sickle weeding at bimonthly intervals
3) Digging and removing the plants when weed growth was one month old
4) Digging and removing the plant twice (June/July and August/September)
5) Flaming in summer
6) Flaming in summer followed by ploughing in June
7) Invaded area left as such (control).

The treatments were laid out in RBD with three replications. Observations on the number of new shoots produced per square metre, as well as dry matter production were taken for one year (May to April) at monthly intervals.

Soil Solarisation

A field experiment was conducted during the summer season (April to May) in 2003 at the College of Horticulture, Vellanikkara to evaluate the effect of solarisation on the germination of *M. invisa* seeds and dry matter production of seedlings.

An area naturally infested by *M. invisa* in the previous year, was selected and levelled by shallow rakings so as to avoid burying the *M. invisa* seeds. They were divided into plots of size 4 m x 1 m by taking channels of 50 cm depth all around. After a light irrigation, the beds were mulched with transparent polythene sheets of 125 gauge thickness, without trapping air. The edges of sheets were sealed with soil to keep the sheets in position and to prevent the movement of air. Soil thermometers were installed at five and 10 cm depths at the centre of the solarized beds. The experiment was laid out in RBD, with four replications.

The treatments included five different periods of solarisation. This was achieved by covering the seed beds with polythene sheets for 0, 10, 20, 30 and 40 days. The polythene sheets were laid on different days such that the lifting of the sheets synchronized.

After lifting the polythene sheets, count of weed seeds germinated was taken using 50 cm x 50 cm iron quadrat. The weed dry matter production was recorded per square metre, separately for *M. invisa* and other weeds one month after lifting the sheets.

3.6.2 Chemical methods

Screening of herbicides for effective control of *M. invisa* was done by testing the different doses of common herbicides, at different stages of growth of the weed. Both pre emergence and post emergence herbicides were evaluated in separate trials.

3.6.2.1 Pre emergence herbicides

The study was conducted by comparing nine common pre emergence herbicides with an unsprayed control as given below.

1. Atrazine @ 1.5 kg ha^{-1}
2. Diuron @ 1.5 kg ha^{-1}
3. Oxyfluorfen @ 0.2 kg ha^{-1}
4. Fluchloralin @ 1.0 kg ha^{-1}
5. Butachlor @ 1.5 kg ha^{-1}
6. Alachlor @ 1.5 kg ha^{-1}
7. Pretilachlor @ 0.5 kg ha^{-1}
8. Metolachlor @ 1.0 kg ha^{-1}
9. Pendimethalin @ 1.5 kg ha^{-1}
10. Control (unsprayed)

The experiment was conducted as a pot culture trial in CRD, with four replications. One hundred seeds of *M. invisa* pretreated with concentrated sulphuric acid for two minutes, were sown in each pot filled with field soil. The pots were sprayed with the herbicides one day after sowing the seeds. Four pots representing four replications were placed within an iron quadrat of 1 m x 1 m. The quantity of each herbicide required for one square metre area was mixed with 150 ml water and the entire quantity was sprayed uniformly inside the quadrat, using a hand sprayer fitted with flood jet nozzle. The pots were watered regularly and the germination of *M. invisa* seeds was observed. Observations on number of seedlings emerged, number of seedlings affected, and symptoms of damage were recorded at seven, 14 and 21 days after spraying. Also the dry matter production of seedlings was recorded at 30 days after spraying.

Details of the pre emergence herbicides used in the trial are presented in Appendix-II.

3.6.2.2 Post emergence herbicides

The experiment was laid out in simple RBD with 19 treatments in three replications.

Treatments

a) Doses of herbicides

1. Glyphosate - 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 kg ha^{-1}
2. Paraquat - 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 kg ha^{-1}
3. 2, 4- D - 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 kg ha^{-1}
4. Control (unsprayed)

b) Stages of application

1. Seedling stage (45 DAG)
2. Active vegetative stage (100 DAG)

The chemicals were sprayed with an Aspee back-pack sprayer fitted with flood jet nozzle using a spray volume of 500 litres per hectare at seedling stage. However, at active vegetative stage 600 litres of water was required for obtaining uniform coverage. The details of the post emergence herbicides used in the trial are given in Appendix-II.

The number of new shoots produced per square metre and their dry weight per square metre at 15, 30, 60 and 90 DAS were recorded using iron quadrat of size 1 m x 1 m.

3.6.3 Biological methods

3.6.3.1 Insect pests

Different species of insects found feeding on *M. invisa* in the field during the survey were collected and preserved. The larval and egg stages collected were reared till the adult stage. These were then identified with the help of insect taxonomists.

3.6.3.2 Diseases

During the survey, the plants were closely observed for occurrence of any disease symptoms on leaves, stem, flowers etc. The samples were taken, cultured in the laboratory and identified.

3.7 ECONOMIC IMPORTANCE

3.7.1 Uses

3.7.1.1 As green manure

3.7.1.1.1 Biomass yield

Biomass production of *M. invisa* was assessed under two different conditions:

1) From natural infestation of *M. invisa* in the field
2) From individual plants grown without any competition

i) Dry matter production per square metre

The dry matter production per square metre in a plot uniformly infested with *M. invisa* was assessed by taking observations from five different sites each, in the field at both locations. The random sampling was done using an iron quadrat of 1 m x 1 m size, at three different stages of growth of the plant viz., seedling (45 DAG), active vegetative (100 DAG) and at flowering (150 DAG) stages.

ii) Dry matter production per plant

In order to assess the biomass production capacity of *M. invisa,* individual plants were raised free of competition at two locations, one in the crop museum area of College of Horticulture, Vellanikkara and other at the University Livestock Farm, Mannuthy at an initial spacing of 3 m x 3 m. During June, four seeds of *M. invisa* were sown in each pit, after scarification by concentrated sulphuric acid, and only one healthy plant per pit was retained five days after germination. The space in between was kept free of any plants so as to avoid any competition. One hundred plants were maintained initially at each site. Two plants each from both sites were uprooted at weekly intervals and the dry weight of the plants recorded. This was continued till February (34 weeks) when plants showed symptoms of drying.

3.7.1.1.2 Litter decomposition rate

The rate of decomposition of *M. invisa* in the soil was studied using the litter bag technique (Bocock and Gilbert, 1957; Sreekala, 1997). Nylon bags of 2 mm mesh and 35 cm x 35 cm size were used for the study. The quantity of plant biomass to be taken inside the litter bag was determined based on the average amount of biomass production per unit area in the infested fields at active vegetative stage of the plant. Accordingly, 500 g fresh *M. invisa* at active vegetative stage was filled in each litter bag. This accounted for 220 g dry matter taking into consideration the 56 per cent moisture present in the green matter at active vegetative stage. The mouth of the bag was stitched to prevent loss of filled in litter. These bags were placed in *M. invisa* infested fields in close contact with soil and loosely covered with ground litter.

The study, started in July 2002, was conducted in completely randomised block design with three replications. Forty two litter bags were filled with 500 g each of fresh *M. invisa* and laid at the two sites of infestation (College of Horticulture Campus, Vellanikkara and University Livestock Farm, Mannuthy). Three bags were recovered at monthly intervals for one year. The samples lifted each time, were washed in a fine jet of water over a 100 mesh screen to remove adhering soil and mineral particles, cleaned well and oven dried at 80°C to constant weight. The weight of undecomposed residue left was estimated. Difference between the initial dry weight when laid in the field (220 g) and dry weight of undecomposed residue left while lifting was taken as the quantity decomposed. Percentage decomposition was calculated on dry weight basis.

3.7.1.1.3 Nutrient content

Two common green manure crops, *Sesbania aculeata, Daincha speciosa*, and two cover crops, *Peureria phaseoloides*, *Calapagonium mucunoides* were raised separately and compared with *M. invisa* var. *inermis* and *M. invisa* var. *invisa*. These plants were sampled at the active vegetative stage, just before flower bud appearance. The samples were dried in hot air oven at 70°C, powdered and analysed for major, secondary and micro nutrients.

Total N content of the samples was determined by Kjeldahl digestion and distillation method (Jackson, 1958). For the estimation of total P and K, plant samples (1 g) were digested using diacid mixture (HNO_3 : $HClO_4$ in the ratio 2:1) and the contents were made up to 50 ml. Phosphorus was determined by Vanadomolybdophosphoric yellow colour method (Jackson, 1958) in Spectronic 20 spectrophotometer. Potassium was determined using EEL flame photometer (Jackson, 1958). The same diacid extract was also used for the determination of Ca, Mg, Zn, Cu, Mn and Fe by using Atomic Absorption Spectrophotometer.

i) Vermicomposting

A lot of earthworm castings were seen in the shade under the thick canopy of *M. invisa* plants. The species of these earthworms were identified as *Megascolex mauritiani.* In order to assess the efficiency of *M. mauritiani* for decomposing the *M. invisa* litter in comparison with *Eisenia foetida*, the common earthworm used for making vermicompost, a trial was laid out at the College of Horticulture, Vellanikkara. The treatments included

1. *M. invisa* + *M. mauritiani* (native earthworm)
2. *M. invisa* + *E. foetida*
3. *M. invisa* (50%) and banana pseudostem (50%) + *M. mauritiani*
4. *M. invisa* (50%) and banana pseudostem (50%) + *E. foetida*
5. *M. invisa* alone (no earthworms)

The experiment was laid out in CRD with four replications. Twenty earthern pots of 30 cm diameter, 35 cm height and provided with lids having holes for aeration, were used for the experiment. *M. mauritiani* was collected from the *M. invisa* infested fields and *E. foetida* from Agricultural Technology Information Centre at College of Horticulture, Vellanikkara.

Freshly collected *M.invisa* plants were chopped into pieces and kept in a sealed polythene bag for two days to allow partial wilting, which would help to tide over the thermophilic stage of decomposition and improve the speed of composting. Rice straw was used as a bedding material (lowermost layer). Above this layer partially decomposed cowdung (about 2-3 cm thick layer) was spread. Over this, five kilograms each of the material for composting was filled in the pots. For the first two treatments five kg of *M. invisa* alone were taken. For the second and third treatments a mixture of 2.5 kg mimosa and 2.5 kg chopped banana pseudostem was taken. One litre cowdung slurry was sprinkled in each pot and thoroughly mixed. The pots were kept closed for five days.

On the sixth day, 20 earthworms were released into each of the pots, wetted with 500 ml cowdung slurry and kept closed. Subsequently the material was wetted by sprinkling 500 ml cowdung slurry once in a week for all the treatments. Composting was completed in 90 days. The count of earthworms as well as the quantity and quality of the compost obtained were observed on the last day. Chemical analysis of the compost was done to find the contents of N, P, K, Ca, Mg and S.

ii) Crop response to the vermicompost

A pot culture study was conducted to assess the response of amaranthus, a short duration leafy vegetable, to the four types of composts prepared from *M. invisa*. The recommendations as per Package of Practices of Kerala Agricultural University (KAU, 2000) for the amaranthus crop (FYM 50 tons ha^{-1} + NPK @ 50:50:50 kg ha^{-1}) was the control treatment. In the other treatments, instead of FYM, different types of vermicompost prepared using *M.invisa* (50 t ha^{-1}) were used as detailed below.

1. *M. invisa* composted by *M. mauritiani* + 50:50:50 kg NPK ha^{-1}
2. *M. invisa* composted by *E. foetida* + 50:50:50 kg NPK ha^{-1}
3. *M. invisa* 50% and banana pseudostem 50% composted by *M. mauritiani* + 50:50:50 kg NPK ha^{-1}
4. *M. invisa* 50% and banana pseudostem 50% composted by *E. foetida* + 50:50:50 kg NPK ha^{-1}
5. FYM + 50:50:50 kg NPK ha^{-1}

The experiment was laid out as Completely Randomised Design with seven replications. Thirty five earthern pots of 30 cm diameter and 35 cm height were used for the trial. In each pot, 5 kg field soil was mixed with 125 g vermicompost/FYM and 50:50:50 kg NPK ha^{-1} as 0.3 g urea, 0.8 g super phosphate and 0.2 g MOP as per treatments listed above. Fourteen day old seedlings were transplanted to the earthern pots @ 2 seedlings per pot. The pots were kept in an open area and irrigated daily. Top dressing of N (0.3 g urea) was given at 15 DAP, after the first harvest.

Observations on height of plant and number of leaves per plant were recorded just before first and second harvests at 15 and 30 days after planting. The yield of amaranthus (fresh weight) was also recorded at both harvests.

3.7.2 Harmful effects

3.7.2.1 Effect on biodiversity

Competition of *M. invisa* with native flora was studied by comparing the flora in a newly infested area with an adjacent area free of *M. invisa* and another area containing only *M. invisa* and no other weeds. The experiment was laid out in RBD with three replications in plots of size 6m x 6m and observations were taken on weed count from five sampling sites for each plot. Weed count (number of active vegetative shoots per square metre) of different groups of weeds such as grasses, sedges, *M. invisa* and other broad leaved weeds was taken during May. Subsequently the number of active vegetative shoots per square metre was counted in July and September. At the onset of flowering, the plants were cut and dry weight per square metre was noted. The same area was observed for three consecutive years (2002, 2003 and 2004) from May to September.

Based on the dry matter production by native flora in the infested and uninfested fields, smothering efficiency of *M. invisa* was calculated using the following equation:

$$SE = \frac{(X - Y)}{X} \times 100$$

where SE = Smothering efficiency of *M. invisa*

X = Dry matter production of native flora in *M. invisa* free plot

Y = Dry matter production of native flora in *M. invisa* infested plot

3.7.2.2 Allelopathic effects

Pot culture experiments were conducted with rice and cowpea as indicator plants, to determine whether *M. invisa* and its extracts could produce any inhibitory or toxic (allelopathic) effects on germination and growth of the seedlings. Seeds of rice variety 'Jyothi' and cowpea variety 'Kanakamany' were used for sowing.

Earthern pots of 50 cm diameter and 20 cm height filled with 5 kg soil from paddy field, were used for study on rice. For cowpea, the pots were filled with 5 kg upland soil. Twelve seeds per pot for paddy and 5 seeds per pot for cowpea were sown on the day of application of *M. invisa*. The treatments included three methods of application viz., incorporation and mulching using fresh *M. invisa* @ 0, 2, 4, 6, 8 and 10 t ha^{-1} (dry weight) and application as 0, 2, 4, 6, 8 and 10 per cent water extracts. Considering the 42 per cent dry matter present, the quantity of fresh, chopped *M. invisa* required for each pot (0.2 m^2) was calculated and applied.

The experiment was laid out in CRD with four replications. The germination count was recorded at 4, 6 and 8 days after sowing. The plants were thinned to three per pot for paddy, and one per pot for cowpea at 9 DAS. The height of plant, number of tillers/branches and number of leaves per plant at 30 days growth were recorded.

i) Incorporation

Fresh *M. invisa* was incorporated in soil @ 0, 2, 4, 6, 8 and 10 tons per ha on oven dry weight basis. These rates of application were achieved by incorporating 0, 95, 190, 285, 380 and 475 g respectively of fresh chopped *M. invisa* in the soil per pot before sowing the seeds.

ii) Mulching

Fresh *M. invisa* was applied as mulch @ 0, 2, 4, 6, 8 and 10 tons per ha on oven dry weight basis. These rates of application were achieved by mulching with 0, 95, 190, 285, 380 and 475 g of fresh *M. invisa* over the soil, after sowing the seeds.

iii) Water extracts

Water extracts of different concentrations were prepared by soaking appropriate quantities of crushed green material of one month old *M. invisa* seedlings along with roots, for 18 hrs in water, followed by squeezing and filtering through muslin cloth. Concentrations of 0, 2, 4, 6, 8 and 10 per cent were prepared depending on the number of grams of dry material soaked in 100 ml water. Thus 0, 4.8, 9.5, 14.3, 19.1 and 23.8 g of fresh, chopped *M. invisa* were soaked in 100 ml water to prepare the above concentrations. These extracts were applied @ 250 ml per pot at four days interval from the date of sowing seeds till 21 days after sowing.

3.7.2.3 Mimosine content

Mimosine content was estimated using the method described by Brewbaker and Kaye (1981). One gram of air dried, ground plant sample was weighed out into a 100 ml volumetric flask, and the volume was made up with 0.1 N HCl and then macerated in a homogenizer. Ten ml aliquot of the macerate and 15 ml of 0.1 N HCl containing charcoal was taken in a test tube and heated in a boiling water bath for 15 minutes. It was then filtered through Whatman No. 2 filter paper. To two ml of the above filtrate, five ml of EDTA solution (1 g Na_2 EDTA. 2 H_2O in four litres of distilled water) and one ml of ferric chloride reagent (4 g $FeCl_3.6H_2O$ in 500 ml of 0.1 N HCl) were added. The blank and standards containing 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75 and 2 ml of pure mimosine (0.25 mg/ml) were prepared similarly. They were kept in dark for 15 minutes. The absorbance was determined at 535 nm in a Spectronic 20 - spectrophotometer. The mimosine contents of the samples were found out from the standard curve. The details of toxic plant aminoacid, mimosine are given in Appendix-III.

The mimosine content in the plant was analysed at different growth stages, in different parts and in comparison with common mimosaceous plants as detailed below.

i) Growth stages of M. invisa

The mimosine content of the plant was analysed at different stages of growth of plant viz., 5, 15, 30 and 45 days after germination (seedling), 100 DAG (active vegetative stage) and 120 DAG (flowering stage).

ii) Parts of M. invisa

The immature leaves, mature leaves, stem (apex), stem (basal), flower buds and seeds of *M. invisa* at flower bud initiation stage were analysed separately for mimosine content.

iii) Common mimosaceous plants

The mimosine content in different parts of common plants belonging to family Mimosae was analysed. The samples from immature leaves, leaves and stem, flowers and seeds of *M. invisa*, *M. pudica* and *Leucaena leucocephala* were analysed.

3.7.2.4 Effect of ensiling on mimosine

The effect of ensiling on the degradation of toxic mimosine in *M. invisa* was studied. Also the safe level of admixture of pasture grass with *M. invisa*, if the pasture grass along with *M. invisa* was cut and ensiled for feeding was also studied. The fodder grass, Hybrid Napier (variety CO-6) and *M. invisa* were mixed in different proportions and ensiled for 60 days as follows:

1) 90% Hybrid Napier + 10% *M. invisa*
2) 75% Hybrid Napier + 25% *M. invisa*
3) 50% Hybrid Napier + 50% *M. invisa*
4) 25% Hybrid Napier + 75% *M. invisa*
5) 10% Hybrid Napier + 90% *M. invisa*

Thirty plastic buckets with lid having capacity to hold four kg green matter were used for ensiling. Drainage hole was provided at the bottom and in the polythene bag used as lining inside the buckets. Hybrid Napier and *M. invisa* were cut and

chopped separately and wilted in shade for one day. These materials were weighed separately, added 50 ml of molasses per treatment and mixed so as to get the required proportions of Hybrid Napier: *M. invisa* as per treatments. The quantity for each bucket was packed without trapping air space in the polythene bag kept inside the bucket, and polythene bag was tied airtight. The space in the bucket above the polythene bag was mud plastered and covered with the lid so as to provide the anaerobic condition required for ensiling. The buckets were kept as such for 60 days so as to complete the ensiling (Plate 1).

After 60 days, the buckets were opened and samples were drawn for analysis of mimosine. The analysis was done by the method proposed by Brewbaker and Kaye (1981) and read colorimetrically in Spectronic-20 spectrophotometer. Mimosine content of sun dried powdered *M. invisa* and extract of fresh *M. invisa* were also analysed.

3.7.2.5 Mimosine toxicity

To understand the mimosine toxicity to animals fed with *M. invisa* in different forms (fresh, dried or ensiled), a study was conducted at the College of Veterinary and Animal Sciences, Mannuthy during November-December, 2003. The study was conducted at the Rabbitary of the college with rabbits as test animals. The trial consisted of six treatments as detailed below.

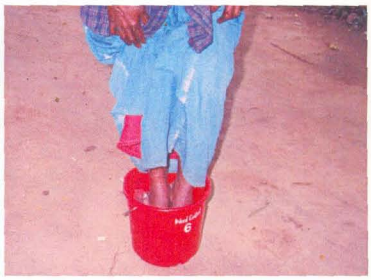
Sl. No.	Type of feed	Quantity fed/day
1	Silage of *M. invisa* and fodder grass in 25:75 ratio	150 g
2	Silage of *M. invisa* and fodder grass in 50:50 ratio	150 g
3	Silage of *M. invisa* and fodder grass in 75:25 ratio	150 g
4	Dried, powdered *M. invisa*	150 g
5	Fresh juice of *M. invisa*	5 ml
6	Routine diet-green grass (control)	250 g

Plate 1. Procedure for ensiling *M. invisa* : fodder mixture

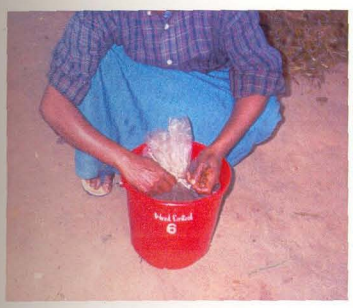
① Filling chopped *M. invisa* & fodder in layers

② Adding molasses

③ Compacting after adding each layer



④ Stamping with feet to expel air



⑤ Tying the bag

⑥ Mud plastering

Eighteen rabbits belonging to age group of 2-3 months and weighing about 400 g were selected for the trial. All animals received a daily common ration of concentrate mixture (100 g) and soaked Bengal gram (100 g), irrespective of the treatments. They were kept under standard management for a week and dewormed. The animals were individually housed and three animals constituting one replication received one treatment. The feeding was continued for 30 days. All the animals were thoroughly examined daily for appearance of any symptoms of toxicity.

Animals which died during the course of treatments were subjected to detailed post-mortem examination and the gross lesions were observed. Tissues showing lesions were collected and preserved in 10 per cent neutral formalin. Tissues after fixation were sliced, processed and paraffin blocks were made. Sections cut at 4μ thickness were stained with routine hematoxylin and eosin as per standard methods. Those animals which survived were sacrificed by exsanguination on the last day of the experiment and the examination was made as above. The histopathological slides were examined microscopically.

3.8 STATISTICAL ANALYSIS

The data collected were subjected to statistical analysis using the analysis of variance technique as described by Panse and Sukhatme (1985). Data on shoot count, germination count and dry matter production which showed wide variation were subjected to square root transformation and the data on proportionate value were subjected to arc sine transformation, to make analysis of variance valid as suggested by Bartlett (1947). The results have been discussed at the probability level of 95 per cent.

Results

4. RESULTS

4.1 DISTRIBUTION IN KERALA

The distribution of *M. invisa* in Kerala is listed in Table 1 and illustrated in Fig. 1.

During the survey, it was observed that the weed had spread to all the 14 districts of Kerala, with intensity ranging from sporadic to severe (Fig.1). Infestation of the weed was very severe in Kottayam, Pathanamthitta, Ernakulam, Thrissur and Palghat districts. In Idukki and Waynad districts, which are at higher altitudes (3500 to 4000 m above MSL), the infestation was sparse to medium, except in Thodupuzha where it was severe. It was not observed at very high altitudes like Munnar (4000 m above MSL).

Trivandrum district had only sparse to medium infestation while Kollam district had severe infestation in Ochira and Edappallykotta areas. The Sabarimala route from Ranni to Pampa in Pathanamthitta district, presented low to medium incidence. Banks of the river Pampa were severely infested. In Thottappally area of Alleppy district, the infestation of *M. invisa* was severe in raised bunds whereas medium incidence is seen in Haripad and Mavelikara.

Severe infestation was noticed Kottayam and Ernakulam districts. Trichur district presented wide spread infestation of *M. invisa*. Chalakkudy, Kodakara and Mannuthy areas of Thrissur district were severely affected by the weed. Valappad and Thriprayar areas of the district showed medium infestation. It is slowly spreading in Peechi, Kodungalloor and Amballoor. In Palghat district, it had spread severely in areas like Koyalmannam, Mannarghat, Palghat, Kallidikode etc.

The infestation of *M. invisa* is fast spreading in Malappuram, Kozhikode, Kannur and Kasargod districts, where sparse to medium infestations were observed during the survey.

Table 1. Distribution of *Mimosa invisa* in Kerala

District	Places of infestation	Intensity of infestation
Thiruvananthapuram	Palode	Medium
	Aruvikkara	Low
	Perumgulam	Low
	Neyyar	Sparse
	Attingal	Sparse
Kollam	Ochira	Severe
	Edappallykotta	Severe
	Chavara	Medium
	Pathanapuram	Medium
	Karuvatta	Low
	Vallikkavu	Sparse
	Kilikollur	Sparse
Pathanamthitta	Pampa	Severe
	Konni	Severe
	Erumallur	Severe
	Thiruvalla	Medium
	Sabarimala	Medium
	Pandalam	Low
Alappuzha	Thottappally	Severe
	Haripad	Medium
	Mavelikara	Medium
	Moncompu	Low
	Cherthala	Low
	Kareelamkulangara	Sparse
Kottayam	Changanacherry	Severe
	Ponkunnam	Severe
	Pampadi	Severe
	Ettumanoor	Low
	Kanjirappally	Low
	Mundakayam	Sparse
	Erattupetta	Low
	Thalayolaparambu	Low
Ernakulam	Panangad	Severe
	Angamaly	Severe
	Aluva	Severe
	Vyttila	Severe
	Perumbavoor	Medium
	Kalady	Medium
	Thripunithura	Low
	Njarakkal	Sparse
	Muvattupuzha	Sparse
Idukki	Thodupuzha	Medium
	Thekkady	Medium
	Painavu	Medium
	Kumily	Low

Contd.

Table 1. continued

District	Places of infestation	Intensity of infestation
Thrissur	Vellanikkara	Severe
	Mannuthy	Severe
	Kodakara	Severe
	Chalakudy	Severe
	Koratty	Severe
	Kanimangalam	Severe
	Irinjalakuda	Medium
	Triprayar	Medium
	Valappadu	Medium
	Peechi	Low
	Kodungallur	Low
	Kunnamkulam	Low
	Amballur	Low
Palakkad	Koyalmannam	Severe
	Alathur	Severe
	Yakkara	Severe
	Mannarkkad	Medium
	Panthalampadam	Medium
	Pattambi	Medium
	Ottappalam	Low
	Malamalamukku	Low
Malappuram	Thirur	Severe
	Parappanangadi	Medium
	Kottakkal	Medium
	Valancheri	Low
	Kondotti	Low
Kozhikode	Kunnamangalam	Medium
	Quilandi	Low
	Kuttiyadi	Low
	Elathur	Low
	Vadakara	Low
	Naduvannur	Sparse
Wayanad	Mananthavady	Low
	Vaithiri	Low
	Kalpetta	Sparse
Kannur	Karimbam	Medium
	Chittariparambu	Medium
	Edakkad	Low
	Thalassery	Low
	Thaliparamba	Low
	Peringome	Low
	Valappattanam	Low
Kasargod	Muttathody	Medium
	Trikaripur	Medium
	Mogralputhur	Medium
	Mangalppady	Low
	Panathady	Low
	Belur	Low
	Eleri	Sparse
	Cheemeni	Sparse

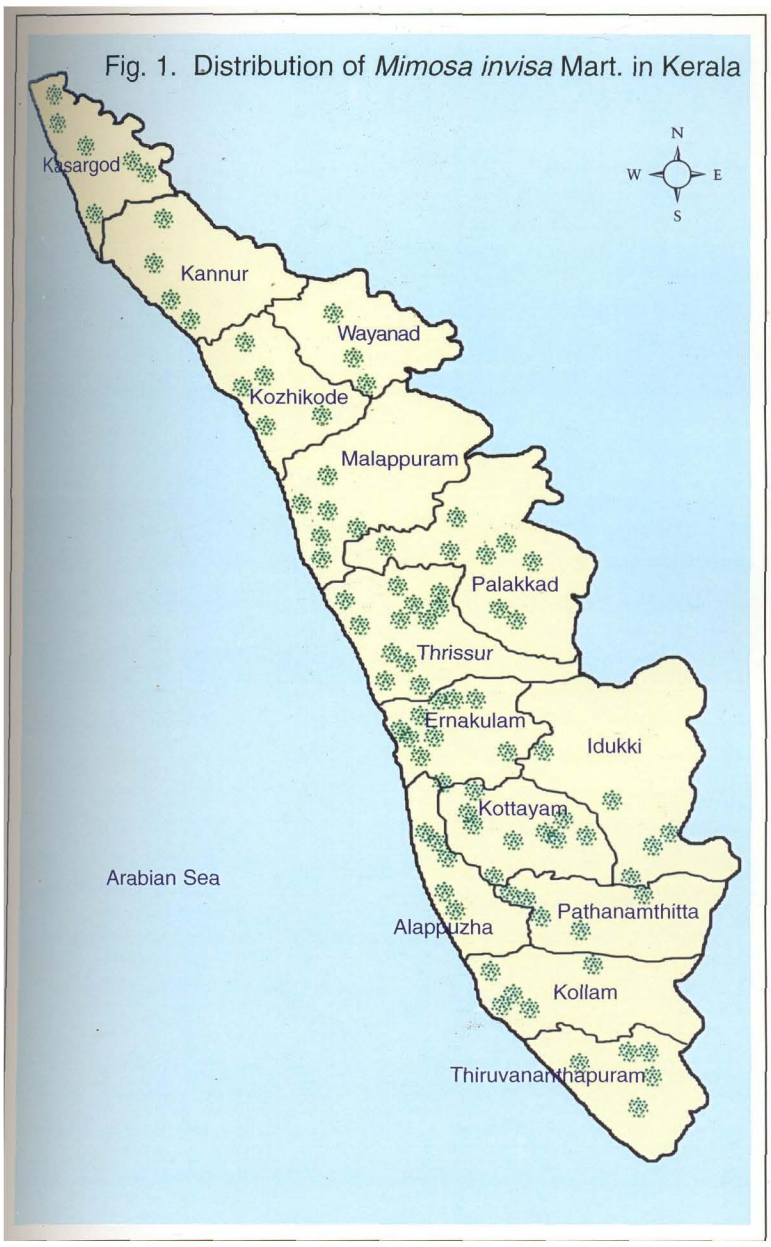


Fig. 1. Distribution of *Mimosa invisa* Mart. in Kerala
N
W
E
S
Kasargod
Kannur
Wayanad
Kozhikode
Malappuram
Palakkad
Thrissur
Ernakulam
Idukki
Kottayam
Arabian Sea
Pathanamthitta
Alappuzha
Kollam
Thiruvananthapuram

In all these infested areas, *M. invisa* was found in open spaces like roadsides, sides of railway tracks, and along the banks of irrigation and drainage channels. In severely infested roadsides, *M. invisa* was found climbing on trees, stay wires, advertisement and location boards (Plate 2). The plant was found to grow smothering all the native vegetation, trying to occupy the upper most layer of canopy. It was not seen in shaded areas. It also climbed on banana plants, tapioca plants, jack trees, mango trees, polyalthia, coconut trees etc. (Plate 3). It was even found infesting the upland paddy fields of Palghat in Pattambi and Malamalamukku.

4.2 BIOLOGY

Mimosa invisa is a trailing or climbing undershrub, fast-growing and scrambling on any support, live or dead. The stem becomes semi woody as it matures. The plant is usually an annual, but on sides of irrigation and drainage channels and other irrigation sources where moisture is available throughout the year, the plant behaves like a biennial.

4.2.1 Morphology

Two varieties/types of *M. invisa* were identified in the field during the survey. (1) Spined or thorny and (2) Spineless or thornless. The spined variety is *Mimosa invisa* var. *invisa* Mart. and spineless variety *Mimosa invisa* var. *inermis* Adelb. The spined variety was found to have spread in more areas than spineless variety. The morphological features other than spiny nature were same for both types. The stem of spined type was armed with downwardly pointed prickles with broad bases arranged in three to four rows. In spineless type the prickles were absent on the stem and instead, the stem was covered with smooth soft pubescent hairs (Fig. 2 and Plate 4).

The leaves were paripinnate or bipinnate, alternate and compound with 5-15 cm length. Rachis, pilose and prickly; petiole 5-10 cm long; pinnae 5-6 pairs with a bristle between the pinnae; pinnules 18-20 pairs about 5 mm long; inflorescence solitary or in axillary pairs; globose head, pink in colour, 1.5 cm long and 11 to 12 mm

Plate 2. Habitats of infestation of *Mimosa invisa*

Irrigation canal

Neglected building

Electric post and stay wire

Compound wall

Open area

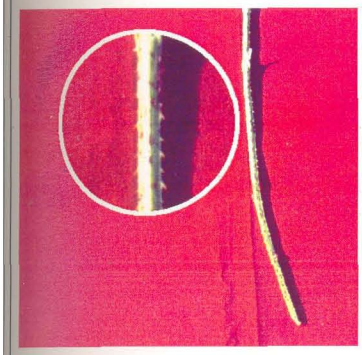
Road side

Plate 8.Defoliated branches of *Mimosa invisa*

Initial stage

Later stage

Plate 9. Infection of Alternaria sp. on *Mimosa invisa*



Alternaria sp.

Culture

Plate 3. Competition of *Mimosa invisa* with other plants

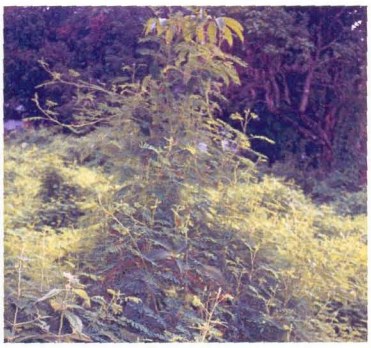
Banana

Tapioca

Polyalthia

Jack tree

Calapagonium



Wild shrub

in diameter, when the flower was fully opened. Calyx minute, upto 0.3 mm long. Corolla upto 2 mm long. Petals united at the base and stamens eight. Pods subfalcate and occur in clusters of 7 to 12. Each pod had 4 to 5 locules (segments) with one seed in each locule. The pods were 2.3 to 2.5 cm long and 4-6 mm broad with spiny margins.

In both spined and spineless types most of the plants had green stem. But in a few plants red/purple coloured stem were also seen. Some plants had stem with red or purple colour at the base and green towards the tip (Plate 4).

The plant is found to be strongly heliophytic with its shoots penetrating through any thick canopy to gain an upperhand and become the top most canopy.

The leaves of both spined and spineless types showed the tendency to fold on touching, though the speed of folding was not as fast as in *Mimosa pudica.*

4.2.2 Life cycle

4.2.2.1 Normal period of germination

The seeds of *M. invisa* were found to germinate within three days after receipt of a good shower during the second fortnight of April. When these seedlings were uprooted and removed, new flush was found to germinate from the soil seed bank, though with lesser density. Maximum germination was obtained in the first flush.

4.2.2.2 Growth stages

The important stages of growth of the plant are seedling, active vegetative, flowering, seed set and seed dehiscence, drying and death of plant (Table 2).

4.2.2.3 Reproductive cycle

The first flower bud appeared approximately 120 days after germination, by second fortnight of August. 10 to 15 days after emergence of buds, flower opening (blooming) took place. Pollination took place on the day of flower opening itself. The

Fig. 2. Botany of *Mimosa invisa*

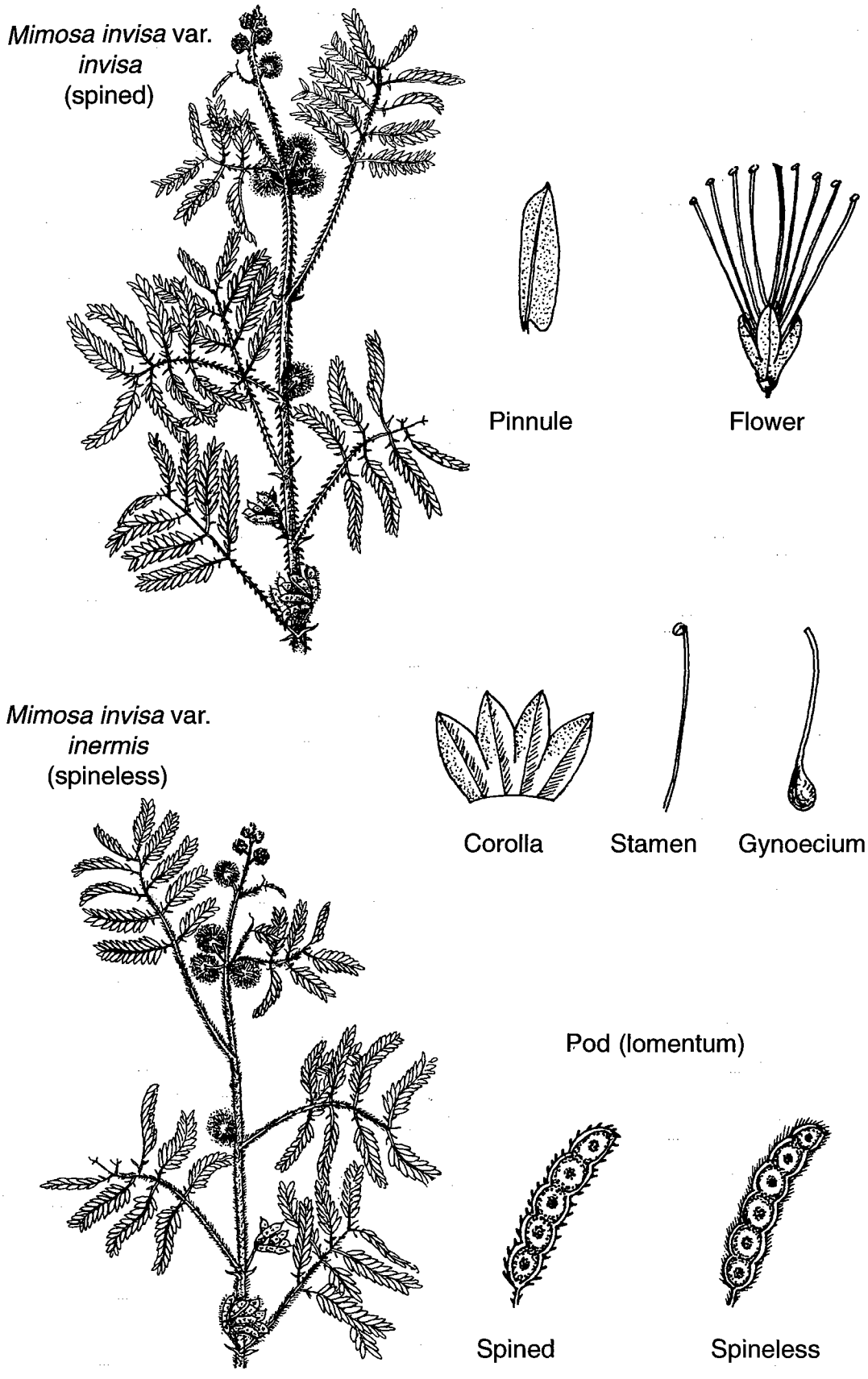


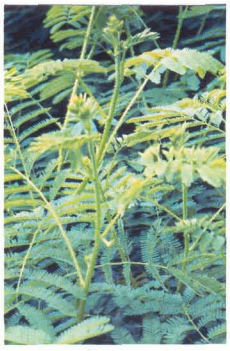
Plate 4. Types of *Mimosa invisa*

Mimosa invisa var. *invisa* (spined)

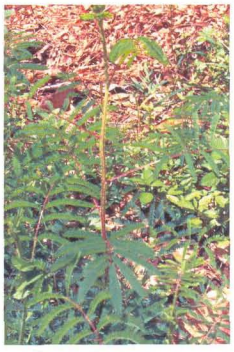
Mimosa invisa var. *inermis* (spineless)

Variations in colour of the stem

Red



Green



Red at the base

Table 2. Growth stages and phenology of *Mimosa invisa*

Sl. No.	Stage of growth	Period
1	Seedling stage	April-May
2	Active vegetative phase	June-July-August
3	Peak flowering	September-October-November
4	Seed set and seed dehiscence	September-February
5	Drying of the plant	February-March
	Sequence	**Approximate time**
1	First appearance of flower buds	Second fortnight of August
2	Bud to flower	10 to 15 days after appearance of flower bud
3	Withering of flowers and seed set	Day next to flower opening
4	Flowering to pod maturity (browning)	30 days
5	Pod maturity to dehiscence	15 to 20 days

Table 3. Seed production potential and thousand seed weight

Characters	Maximum value	Minimum value	Mean	SD±
No. of primary branches/plant	10	5	7.38	1.359
No. of secondary branches/ pr. branch	15	9	11.52	1.537
No. of pod clusters/ sec. branch	25	16	19.57	2.638
No. of pods/ cluster	12	7	9.05	1.564
No. of seeds/ pod	6	4	4.95	0.669
Total no. of seeds/plant	127620	46200	72651.4	19595.5
1000 seed weight (g)	7.22	6.44	6.88	0.2073

next day, withering of corolla and stamens occurred. The pod maturity or browning of seeds took place 30-35 days later. The dehiscence of pods took place within two to three weeks after maturity (Table 2).

4.2.3 Seed characters

4.2.3.1 Seed production potential

Single plant produced 7-8 primary branches and 11-12 secondary branches per primary branch. There were 19-20 pod clusters per secondary branch and 9 to 10 pods per cluster. Each pod contained 4-5 seeds. Thus, the seed production potential was estimated to range from 46,200 to 1,27,620 with an average of 72,650 seeds per plant (Table 3).

4.2.3.2 Thousand seed weight

Average weight of 1000 seeds was 6.880 g with a range of 6.44 to 7.22 g (Table 3).

4.2.3.3 Seed viability and germination

Fresh seeds collected in September gave 90 per cent germination. The germination percentage gradually decreased with storage and the seeds retained 45.72 per cent germination even after 36 months (Table 4 and Fig. 3). The fall in germination percentage was slow in the beginning, showing only a 10 per cent decrease after the first eight months. But, by the end of 36 months, the germination percentage was only 45 per cent, causing a 50 per cent reduction in germination.

4.2.3.4 Dormancy of seeds

The untreated seeds (sown in moist soil) gave only 10.34 per cent germination. Various treatments for breaking the dormancy resulted in considerable increase in the germination percentage of the seeds of *M. invisa*.

Table 4. Seed viability as influenced by duration of storage

Duration of storage (months)	Germination %
0	90.11
2	88.56
4	85.78
6	84.67
8	83.11
10	81.83
12	81.44
14	79.50
16	79.17
18	79.00
20	74.17
22	68.84
24	68.00
26	66.00
28	62.33
30	54.67
32	53.33
34	49.67
36	45.72

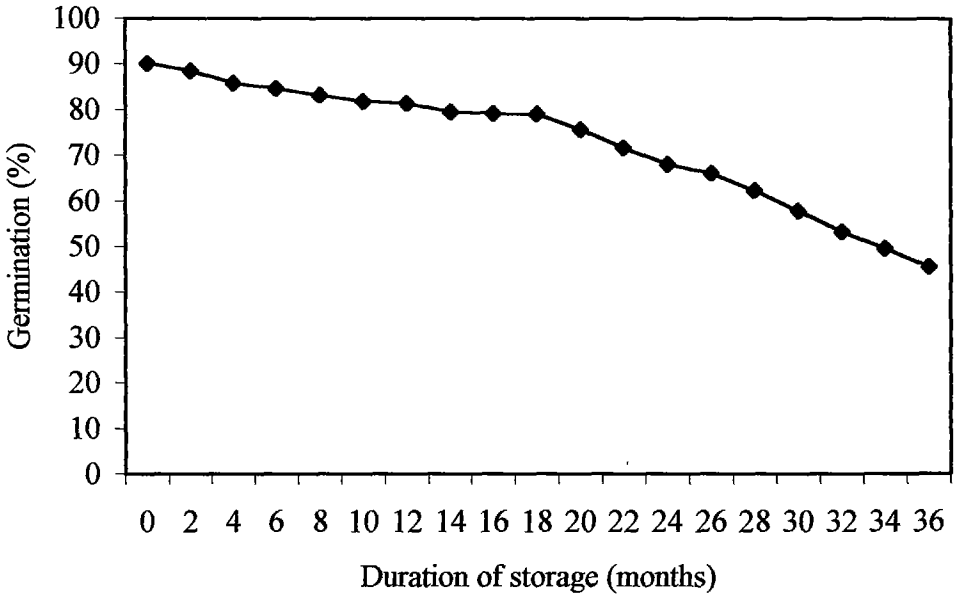


Fig. 3. Seed viability of *Mimosa invisa* as influenced by duration of storage

4.2.3.5 Methods to break dormancy

The efficiency of various treatments for breaking dormancy of *M. invisa* seeds was tested by sowing the treated seeds in soil and finding germination per cent. The data are given in Table 5 and illustrated in Figure 12.

i) Pounding

Pounding the seed with coarse sand for five minutes could give a germination percentage of 17.5 per cent. Though it was statistically superior to the control (10.34%), it was inferior to all other treatments.

ii) Flaming

Among the different flaming treatments, flaming for 30 seconds gave the highest germination of 71.83 per cent, which was significantly higher than flaming for 15 seconds and 45 seconds.

iii) Hot water (60°C)

Immersing the seeds in hot water at 60°C for two minutes and five minutes gave 83.5 per cent and 89.17 per cent germination which were on par. Further increase in duration to 10 or 15 minutes declined the germination.

iv) Hot water (80°C)

Treating the seeds in hot water at 80°C for two and five minutes were on par and gave 88.32 per cent and 85.54 per cent germination, respectively. Increase in duration to 10 minutes had a negative effect.

v) Acid treatment

Treating the seeds with concentrated sulphuric acid for two minutes gave the highest germination of 85.67 per cent. This was found to be statistically on par with the different periods of treatment ranging from one minute to 15 minutes. When the time of treatment exceeded 15 minutes, the germination per cent rapidly fell below 50 per cent giving 41.67, 24.67 and 8.00 per cent germination for 20, 25 and

Table 5. Effect of different treatments on breaking the seed dormancy

Treatment	Germination %	
	2002	2003
A. Pounding		
5 minutes	0.448 (19.00)	0.410 (16.00)
B. Flaming		
15 seconds	0.629 (34.67)	0.657 (37.33)
30 seconds	0.987 (69.33)	1.044 (74.33)
45 seconds	0.455 (21.00)	0.476 (21.00)
60 seconds	0.00	0.00
CD (0.05)	0.138	0.138
C. Hot water treatment (60°C)		
2 minutes	1.187 (85.67)	1.128 (81.33)
5 minutes	1.254 (90.00)	1.228 (88.33)
10 minutes	1.113 (80.33)	1.095 (79.00)
15 minutes	1.025 (73.00)	0.984 (69.33)
CD (0.05)	0.130	0.130
D. Hot water treatment (80°C)		
2 minutes	1.241 (89.23)	1.213 (87.40)
5 minutes	1.198 (86.67)	1.169 (84.40)
10 minutes	1.025 (73.33)	1.025 (73.00)
CD (0.05)	0.069	0.138
E. Acid treatment		
1 minute	1.141 (82.33)	1.116 (80.67)
2 minutes	1.186 (85.67)	1.157 (83.67)
5 minutes	1.126 (81.00)	1.178 (85.00)
10 minutes	1.128 (81.33)	1.083 (78.00)
15 minutes	1.117 (80.67)	1.072 (77.00)
20 minutes	0.701 (41.67)	0.651 (37.00)
25 minutes	0.516 (24.67)	0.475 (21.00)
30 minutes	0.255 (8.00)	0.270 (7.33)
35 minutes	0.00	0.00
CD (0.05)	0.15	0.12
F. Gibberellic Acid (50 ppm)		
6 hours	0.455 (19.33)	0.438 (18.00)
12 hours	0.438 (18.00)	0.378 (13.67)
24 hours	0.382 (14.00)	0.355 (12.33)
CD (0.05)	0.104	0.104
G. Control (untreated)	0.316 (9.67)	0.337 (11.00)
CD (0.05)*	0.114	0.114

* CD for comparing treatments irrespective of the method of seed treatment
Arcsine transformed values are given. Values in parenthesis are in original scale

30 minutes treatments, respectively. The seeds were burnt/charred, when the duration of acid treatment was extended to 35 minutes.

vi) Gibberellic acid (50 ppm)

The treatments with GA for 6, 12 and 24 hours could enhance the germination to some extent. However, the germination in these treatments were much lesser than that in other methods. It was also observed that the germination percentage decreased when the period of soaking was increased from 6 to 24 hours.

vii) Control

The untreated seeds gave an average germination percentage of 10.34 only.

Comparing the best treatments under each type of seed treatment, it could be seen that all the best treatments viz., treating with concentrated sulphuric acid for two minutes (84.67%), hot water treatment at 60°C for five minutes (89.17%), hot water treatment at 80°C for two minutes (88.32%) were on par.

4.2.4 Propagation

The effectiveness of propagation through seeds, stem cuttings and root clumps were tested.

4.2.4.1 Seeds

Seeds were found to be the most important method of propagation in *M. invisa*. The seeds were observed to have high viability as well as a very long dormancy period due to the presence of hard seed coat.

The effect of depth of burial of seeds on the germination percentage was tested and found that most of the seeds (75%) germinated by the third day, even though the germination continued upto 9 DAS, when sown on the soil surface (Table 6). Out of the total seeds germinated, 88.24 per cent germinated by third day itself (0 cm depth) and 87.81 per cent (5 cm depth). The seeds on the soil surface

produced 85 per cent germination at nine days after sowing. It was reduced to 68.33 per cent when the depth of burial was 5 cm. The seeds did not germinate when the depth of sowing was beyond 5 cm.

Table 6. Germination of *Mimosa invisa* seeds as influenced by depth of sowing

Depth of sowing (cm)	Germination (%)			
	3 DAS	6 DAS	9 DAS	12 DAS
0	75	81.67	85	85
5	60	63.35	68.33	68.33
10	0	0	0	0
15	0	0	0	0

DAS - Days after sowing

4.2.4.2 Stem cuttings

Three nodded cuttings, taken from base, middle and apex of stem and planted on ridges at different depths such as 0, 2, 5 and 10 cm did not sprout. All the cuttings gradually dried up, even though it was the rainy season.

4.2.4.3 Root clumps

The survival of root clumps, by producing new sprouts from the base, on receipt of rains was tested by giving shallow (6 cm) and deep (12 cm) diggings and turning the root clump upside down, partially or fully. In partially upturned cases by simple digging with spade, the clumps were found to survive the summer months, only if moisture was available from some perennial source. Fully upturned clumps did not survive the summer months.

4.3 CONTROL METHODS

4.3.1 Physical methods

4.3.1.1 At vegetative stage

During the vegetative stage of plant from May to August, the digging and removing the plant once or twice a year and flaming followed by ploughing in

June/July were effective in reducing the number of shoot regrowths and dry matter production. The shoot and dry matter production was significantly higher for all other treatments during May to August (Tables 7, 8 and Figs. 4, 5).

During the vegetative stage of the plant (May to August), the number of shoots and dry matter production per square metre were on par or even higher in fields flamed in summer, compared to the unweeded control.

In general, sickle weeding at monthly interval was the best treatment as far as the number of new shoots produced and dry matter production of the regrowth are concerned, during the early stages.

ii) ***At flowering and seed setting stage***

Sickle weeding at monthly interval gave significantly lower values of number of shoots and dry matter production during the five months from September to January (Tables 7, 8 and Figs. 4, 5). Sickle weeding bimonthly, was the second best treatment in which both count and dry matter production was on par with other treatments. Digging and removing *M. invisa* twice was superior to digging and removing once a year (Plate 5).

The profuse germination of seedlings in the flamed plot compared to others is evident from the Table 7 and Plate 5. Flaming in summer enhanced the germination of seeds and dry matter production. Flaming in summer followed by ploughing in June, was statistically superior to flaming in summer alone, during the flowering and reproductive stages of *M. invisa* with respect to new shoots and dry matter production.

iii) ***At seed dehiscence and drying stage***

During February to April, when the plant was in the last stages of growth, it could be seen that sickle weeding at monthly interval maintained superiority over other treatments, with only 7.33 g dry matter and 33.33 new shoots per square metre (Tables 7 and 8). The second best treatment, sickle weeding bimonthly was found to

Plate 5. Effect of physical methods of control on *Mimosa invisa*

Burning

Burning in progress

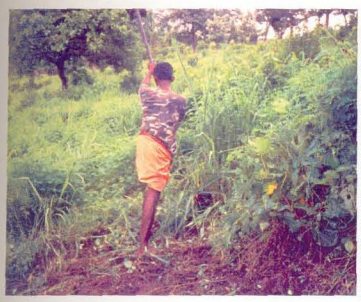
Profuse germination after burning

Sickle weeding

Sickle weeding is laborious

Regrowth after sickle weeding

Digging and removing



Digging the infested field

Regrowth after digging

Table 7. Effect of physical methods of control on the new shoots produced (no. m^{-2})

Treatments	Vegetative stage					Flowering and seed set				Seed dehiscence and drying		
	May	June	July	August	September	October	November	December	January	February	March	April
Sickle weeding at monthly interval	54.00	30.67	34.80	36.67	34.67	27.33	35.33	32.00	35.33	20.00	16.33	7.33
Sickle weeding at bimonthly interval	41.67	86.33	116.00	102.33	104.67	100.00	74.67	50.33	33.67	20.67	20.00	10.33
Digging and removing once	50.67	82.67	32.00	88.00	119.67	104.00	105.33	90.00	80.00	53.33	37.67	26.67
Digging and removing twice	43.00	52.67	14.67	44.00	16.33	45.00	80.67	88.00	58.67	41.33	35.67	25.33
Flaming in summer	112.00	161.33	191.67	179.00	193.67	175.00	109.33	111.67	107.00	97.33	89.67	75.33
Flaming in summer fb. ploughing	108.00	30.00	57.33	111.67	113.67	101.00	87.00	81.67	63.33	50.33	30.33	24.67
Control (unweeded)	66.33	197.33	223.00	259.67	272.33	246.00	181.33	141.33	134.00	121.33	100.67	87.00
CD (0.05)	15.72	24.98	51.92	30.75	22.39	23.48	19.24	22.54	24.86	17.92	12.28	8.93
SEm±	5.103	8.106	16.850	9.979	7.266	7.619	6.244	7.316	8.070	5.814	3.986	2.897

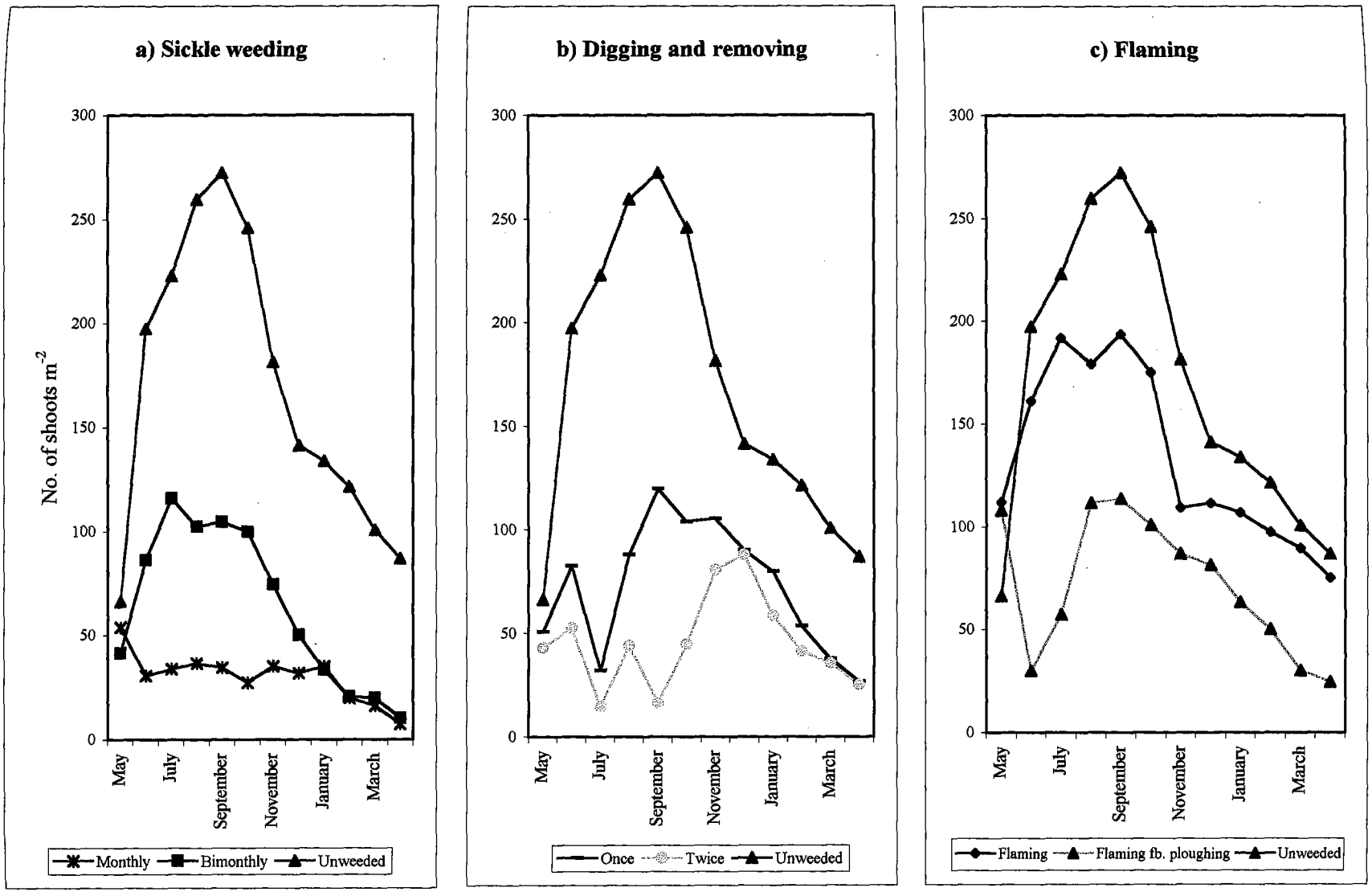


Fig. 4. Effect of physical methods of control on the production of new shoots in *Mimosa invisa*

Table 8. Effect of physical methods on dry matter production (g m^{-2})

Treatments	Vegetative stage					Flowering stage				Seed dehiscence and drying		
	May	June	July	August	September	October	November	December	January	February	March	April
Sickle weeding at monthly interval	237.01	155.54	325.87	266.64	377.72	133.32	381.44	96.29	129.62	81.47	44.44	33.33
Sickle weeding at bimonthly interval	307.38	551.8	525.89	614.75	281.45	562.91	237.01	266.64	199.98	203.68	99.99	51.85
Digging and removing once	344.41	407.37	140.73	533.28	629.57	736.96	644.38	559.2	429.59	296.27	207.39	166.65
Digging and removing twice	348.11	422.18	111.1	162.95	96.29	240.72	377.74	333.3	292.56	192.57	140.73	81.47
Flaming in summer	562.91	814.73	925.13	1025.82	1192.47	1196.18	985.09	799.92	592.53	477.73	314.78	248.12
Flaming in summer fb. ploughing	659.19	870.28	148.13	314.78	474.03	533.28	440.7	377.74	288.86	211.09	177.76	159.24
Control (unweeded)	362.93	892.5	1033.2	1270.24	1559.1	1433.19	1325.79	1129.52	981.38	785.11	711.04	559.19
CD (0.05)	93.65	148.09	117.90	156.83	194.65	290.54	280.81	267.02	165.20	245.49	138.09	119.15
SEm±	30.39	48.06	38.26	50.90	63.17	94.30	91.14	86.66	53.61	79.68	44.82	38.67

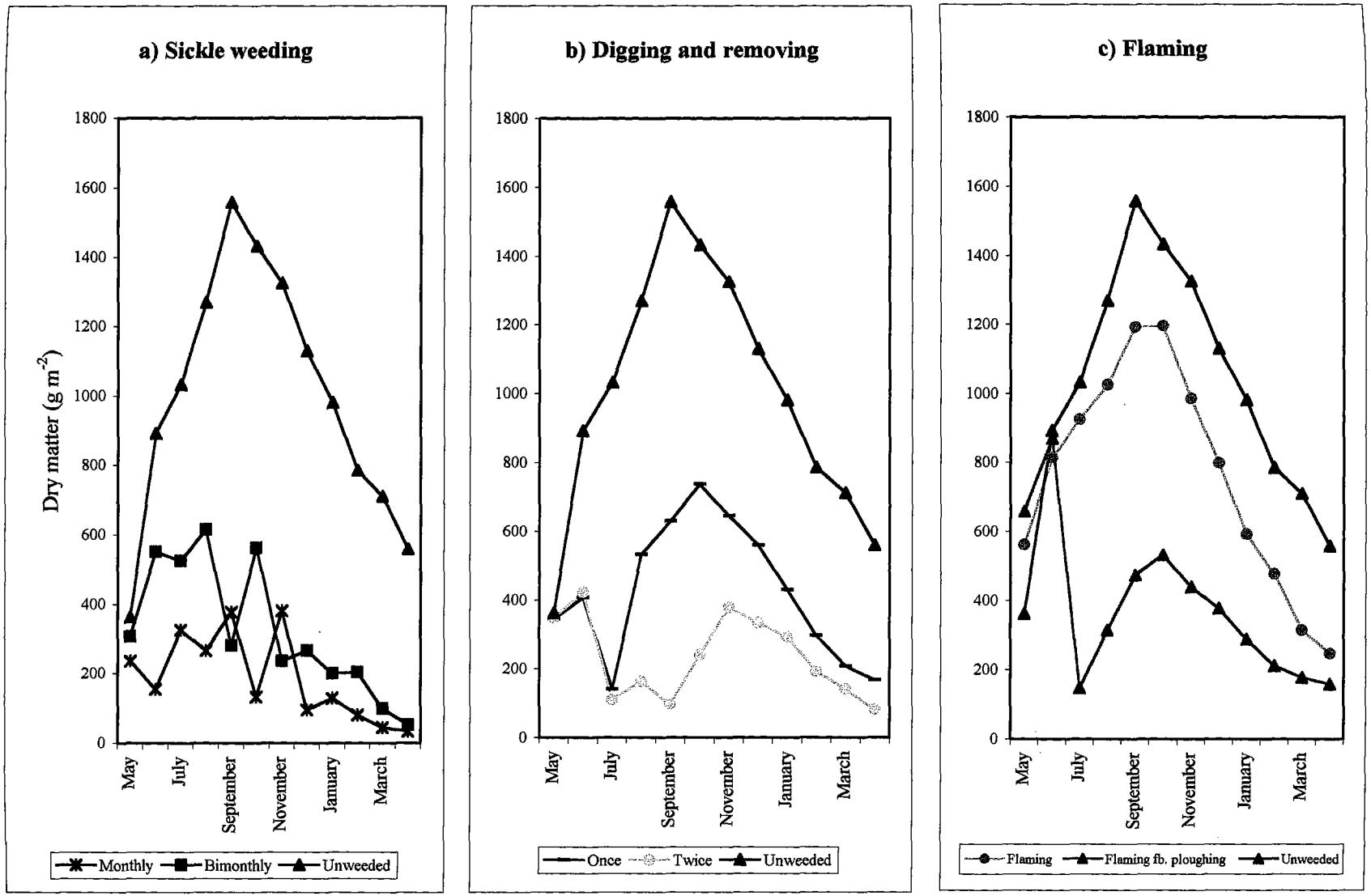


Fig. 5. Effect of physical methods of control on dry matter production of *Mimosa invisa*

be on par with sickle weeding at monthly interval from December to April, with regard to new shoots and dry matter produced. Digging and removing the weed twice a year was statistically superior to digging and removing once a year at seed dehiscence stage. All the physical methods tried, except flaming in summer, were superior to unweeded control at this stage.

4.3.1.2 Soil solarisation

The soil solarisation studies showed that 30 days solarisation could significantly reduce the germination of *M. invisa* seeds in soil and that for 40 days prevented germination. Statistical analysis of data showed that these two treatments were on par (Table 9).

Germination of other broad leaved weed seeds was significantly reduced by solarisation for 40 days, which gave the lowest weed count, and was significantly lower than the germination for 10, 20 and 30 days solarisation. Solarisation for 10 days was on par with no solarization (control), but 20 and 30 day solarisation were significantly superior. Solarisation for even 40 days, could not significantly reduce the grass and sedge germination. The total weed dry matter production 30 days after lifting the polythene sheets, was the least (58.20 g m^{-2}) for solarisation for 40 days. Solarisation for 10, 20 and 30 days were on par, and were significantly superior to control (286.92 g m^{-2}), even though they were inferior to solarisation for 40 days.

4.3.2 Chemical methods

4.3.2.1 Pre emergence herbicides

Among the herbicides tried Atrazine, Diuron, Fluochloralin, Metolachlor and Pendimethalin were very effective in controlling *M. invisa* germination (Table 10 and Figs. 13, 14). Oxyfluorfen, Butachlor, Alachlor and Pretilachlor could not control the weed.

When the control treatment (no herbicide) gave 81.75 per cent germination, the effective herbicides gave germination per cent varying from 36.75 to 58.5 per cent

Table 9. Effect of soil solarisation on germination and dry matter production

Duration of solarisation (days)	Weed count (no. m^{-2})				Total weed dry matter (g m^{-2})
	M. invisa	Other broad leaved weeds	Grasses	Sedges	
0	7.28* (53.33)	10.59 (112.00)	11.88 (145.33)	10.99 (130.67)	16.91 (286.92)
10	6.81 (46.67)	10.31 (106.67)	11.75 (141.33)	10.14 (104.00)	12.82 (164.23)
20	6.14 (38.67)	8.48 (74.67)	10.52 (113.33)	8.13 (66.67)	12.28 (151.33)
30	1.44 (2.67)	8.06 (65.33)	10.25 (106.67)	8.07 (65.33)	11.46 (131.95)
40	0.71 (0.00)	5.64 (33.33)	10.11 (104.00)	6.86 (50.67)	7.65 (58.20)
CD (0.05)	1.948	1.964	3.828	4.376	2.154
SEm±	0.598	0.603	1.174	1.315	0.661

* $\sqrt{x} + 0.5$ transformed values

Original values are given in parentheses

Table 10. Effect of pre emergence herbicides on germination of seeds and dry matter production of seedlings

Sl. No.	Treatments	Germination (%)*			Dry matter production at 30 DAS (g/pot)**
		7 DAS	14 DAS	21 DAS	
1	Atrazine	3.49 (58.50)	0	0	0
2	Diuron	2.60 (36.75)	0	0	0
3	Oxyfluorfen	3.22 (52.00)	3.17 (50.75)	3.17 (50.75)	29.32 (859.25)
4	Fluchloralin	3.31 (54.25)	0	0	0
5	Butachlor	4.21 (75.25)	4.14 (73.75)	4.14 (73.75)	29.71 (882.50)
6	Alachlor	2.55 (35.50)	3.24 (52.50)	3.24 (52.50)	30.43 (927.00)
7	Pretilachlor	2.73 (40.00)	3.02 (47.00)	3.02 (47.00)	28.23 (802.50)
8	Metolachlor	2.89 (44.00)	1.77 (18.50)	1.77 (18.50)	0
9	Pendimethalin	3.27 (53.25)	0	0	0
10	Control (unsprayed)	3.95 (69.50)	4.52 (81.75)	4.52 (81.75)	39.32 (1546.25)
CD (0.05)		0.116	0.089	0.089	2.350
SEm±		0.04	0.03	0.03	0.78

* Arc sine transformed values
** $\sqrt{x} + 0.5$ transformed values
Original values are given in parentheses
Zero values are not included in statistical analysis
DAS - Days after spraying

only. None of the nine herbicides tested prevented germination of the weed, though there was less number of seedlings in Diuron and Alachlor at 7 DAS. In some treatments, the seedlings were destroyed subsequently due to drying or damping off.

In Atrazine, Diuron, Fluchloralin and Pendimethalin the seedlings dried up within two weeks and in Metolachlor all the seedlings dried by three weeks. Lanky seedlings were seen in Atrazine, Diuron, Alachlor, Pretilachlor, Metolachlor and Butachlor. In the case of Pendimethalin, Fluchloralin and Oxyfluorfen the seedlings were short and stout.

By 14 days after spraying, the seedlings in plots treated with Oxyfluorfen, Butachlor, Alachlor and Pretilachlor seemed to recover and regain growth. However control of the weed was significant in Atrazine, Diuron, Fluchloralin and Pendimethalin sprayed plots (Fig.13, 14).

In Atrazine, Diuron and Metolachlor treated soils, the seedlings showed yellowing, gradually wilted and dried up. In Pendimethalin and Fluchloralin, the seedlings damped off at collar region within 14 days after spraying.

4.3.2.2 Post emergence herbicides

i) Production of new shoots

Among the post emergence herbicides applied at seedling stage (45 days after germination), Glyphosate at all doses from 0.2 to 1.2 kg ha^{-1} could significantly lower the number of regrowing shoots, at 15 days after spraying (Table 11). At 30 days after spraying (DAS) the lower doses 0.2 to 0.6 kg ha^{-1} were on par and were significantly inferior compared to higher doses. The doses 0.8 to 1.2 kg ha^{-1} were on par and superior to all the lower doses. But, by 60 and 90 DAS the number of shoot regrowth for glyphosate (1.2 kg ha^{-1}) only was statistically superior for controlling *M. invisa.*

Application at active vegetative stage (90 days after germination), gave more effective control of *M. invisa* with lower shoot regrowths at 15, 30, 60 and

Table 11. Effect of post emergence herbicides on new shoots produced (no. m^{-2})

Treatments	Application at seedling stage (45 DAG)				Application at active vegetative stage (100 DAG)			
	15 DAS	30 DAS	60 DAS	90 DAS	15 DAS	30 DAS	60 DAS	90 DAS
Glyphosate								
0.2 kg ha^{-1}	0.707* (0.00)	7.682 (60.00)	9.648 (93.33)	10.911 (120.00)	1.650 (2.67)	2.179 (5.33)	4.197 (17.33)	5.451 (29.33)
0.4 kg ha^{-1}	1.179 (1.33)	7.6 37 (58.67)	9.40 (89.33)	10.714 (114.67)	1.179 (1.33)	2.179 (5.33)	4.042 (16.00)	4.904 (24.00)
0.6 kg ha^{-1}	0.707 (0.00)	6.908 (48.00)	9.122 (84.00)	10.633 (113.33)	0.707 (0.00)	1.179 (1.33)	2.651 (6.67)	4.217 (17.33)
0.8 kg ha^{-1}	0.707 (0.00)	6.850 (46.67)	9.075 (82.67)	10.259 (105.33)	1.179 (1.33)	0.707 (0.00)	0.707 (0.00)	3.329 (10.67)
1.0 kg ha^{-1}	0.707 (0.00)	6.420 (41.33)	8.632 (74.67)	10.149 (102.67)	1.179 (1.33)	0.707 (0.00)	1.179 (1.33)	2.179 (5.33)
1.2 kg ha^{-1}	1.179 (1.33)	6.124 (37.33)	7.552 (57.33)	8.719 (76.00)	0.707 (0.00)	0.707 (0.00)	0.707 (0.00)	1.443 (2.67)
Paraquat								
0.2 kg ha^{-1}	7.830 (61. 33)	9.662 (93.33)	11.265 (126.67)	12.102 (146.67)	0.707 (0.00)	5.059 (25.33)	8.150 (66.67)	13.615 (185.33)
0.4 kg ha^{-1}	7.588 (58.67)	7.843 (62.67)	10.441 (109.67)	11.896 (141.33)	1.179 (1.33)	4.668 (21.33)	8.173 (68.00)	13.616 (185.34)
0.6 kg ha^{-1}	6.778 (46.67)	7.739 (60.33)	10.347 (106.67)	10.729 (114.67)	1.179 (1.33)	3.504 (12.00)	7.083 (50.67)	10.469 (109.33)
0.8 kg ha^{-1}	6.629 (44.00)	7.732 (60.00)	9.863 (97.33)	10.250 (105.33)	0.707 (0.00)	3.298 (10.67)	6.236 (38.67)	8.732 (76.00)
1.0 kg ha^{-1}	5.325 (29.33)	7.542 (57.33)	9.548 (92.00)	10.401 (108.00)	0.707 (0.00)	2.857 (8.00)	5.672 (32.00)	9.171 (84.00)
1.2 kg ha^{-1}	4.602 (22.67)	6.814 (46.67)	9.314 (86.67)	9.801 (96.00)	0.707 (0.00)	2.386 (5.33)	5.807 (33.33)	8.098 (65.33)
2, 4-D								
0.5 kg ha^{-1}	8.301 (69.33)	9.998 (100.00)	10.589 (112.00)	11.789 (138.67)	6.359 (40.00)	6.841 (46.67)	7.818 (81.37)	10.845 (117.33)
1.0 kg ha^{-1}	7.891 (62.67)	9.781 (96.00)	10.592 (112.33)	11.789 (138.67)	6.122 (37.33)	6.699 (45.33)	7.465 (56.00)	10.330 (106.67)
2.0 kg ha^{-1}	7.552 (57.33)	9.264 (88.00)	10.412 (109.33)	11.089 (122.67)	6.035 (36.00)	6.343 (40.00)	6.938 (48.00)	10.322 (106.67)
3.0 kg ha^{-1}	6.343 (40.00)	8.506 (72.00)	9.725 (94.67)	10.536 (110.67)	5.731 (33.33)	6.017 (36.01)	6.699 (45.33)	9.103 (82.67)
4.0 kg ha^{-1}	6.3 43 (40.00)	8.373 (70.67)	9.462 (87.33)	10.547 (106.67)	5.915 (34.67)	6.001 (36.00)	6.437 (41.33)	9.401 (88.00)
5.0 kg ha^{-1}	6.343 (40.00)	7.837 (61.33)	9.673 (93.33)	10.007 (100.00)	5.872 (34.67)	5.672 (32.00)	6.122 (37.33)	9.393 (88.00)
Unweeded (control)	8.960 (80.00)	10.469 (109.33)	10.589 (112.00)	11.902 (141.33)	17.702 (246.67)	17.787 (316.00)	18.627 (346.67)	19.843 (393.33)

DAS - Days after spraying; DAG - Days after germination

CD (0.05) Application at seedling stage - 0.739

Application at active vegetative stage - 0.568

*$\sqrt{x + 0.5}$ transformed values are given

Original values are given in parenthesis

90 days after spraying compared to unweeded control as well as all other treatments (Table 11,12 and Figs. 15,16). Among the different doses of glyphosate, 0.6 kg ha^{-1} to 1.2 kg ha^{-1} gave the best control of *M. invisa* at this stage.

None of the doses of paraquat from 0.2 to 1.0 kg ha^{-1} gave effective control at 15, 30, 60 and 90 DAS. The highest dose, 1.2 kg ha^{-1} produced lowest number of shoot regrowth per m^2 at 90 DAS.

Application of 2,4-D at all doses (1 to 5 kg ha^{-1}), at seedling stage was effective in reducing the short regrowths upto 15 DAS. But by 90 DAS, for the lower doses of 2,4-D (0.5 to 1 kg ha^{-1}), the regrowth became on par with unweeded control (Table 12 and Fig 17).

All the herbicides tested were more effective at 15, 30, 60 and 90 DAS, when applied at active vegetative stage, compared to application at seedling stage. Comparing between chemicals, it can be seen that glyphosate, 0.2 to 1.2 kg ha^{-1} was the most effective in reducing the number of new shoots. Eventhough all other treatments were superior to unweeded control, they were inferior to the glyphosate treatments. The yellowing of growing tips and subsequent drying of the plants due to glyphosate application, are depicted in Plate 6.

ii) Dry matter production

Glyphosate at all doses (0.2 to 1.2 kg ha^{-1}) when applied at seedling stage was more effective in reducing the regrowth of *M. invisa* to very low levels, compared to all other treatments (Table 12 and Fig. 17).

Paraquat at doses from 0.2 to 1.2 kg ha^{-1} were not significant statistically, compared to glyphosate doses. The drymatter of regrowth (Plate 6) rapidly increased from 30 to 90 days after spraying indicating that the chemical was not effective in keeping *M. invisa* under control, when applied at seedling stage.

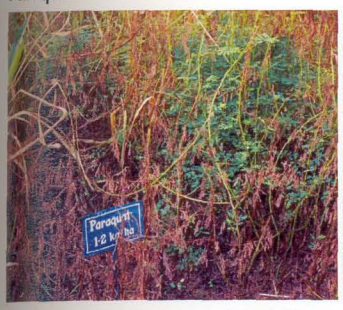
Plate 6. Effect of post emergence herbicideson *Mimosa invisa*

Glyphosate

Yellowing of the growing tips

Dried plants

Paraquat



Lower canopies escape herbicide

Regrowth after application

2,4-D

Epinasty symptoms

Recovery from epinasty

Table 12. Effect of post emergence herbicides on dry matter production (g m^{-2}) of *Mimosa invisa*

Treatments	Application at seedling stage (45 DAG)			Application at active vegetative stage (100 DAG)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Glyphosate						
0.2 kg ha^{-1}	6.514 (42.00)	13.489 (182.00)	11.782 (138.33)	0.707 (0.00)	7.84 (61.33)	11.45 (130.67)
0.4 kg ha^{-1}	5.072 (25.33)	11.792 (126.00)	11.709 (136.67)	0.707 (0.00)	7.68 (58.67)	9.93 (98.67)
0.6 kg ha^{-1}	5.033 (25.00)	10.910 (118.67)	11.701 (136.60)	0.00 (0.707)	5.20 (26.67)	6.34 (40.00)
0.8 kg ha^{-1}	4.829 (23.00)	10.542 (110.67)	11.638 (135.00)	0.707 (0.00)	1.66 (2.67)	6.23 (38.43)
1.0 kg ha^{-1}	4.527 (20.33)	9.957 (98.67)	11.321 (127.67)	0.707 (0.00)	0.707 (0.00)	5.56 (30.67)
1.2 kg ha^{-1}	3.571 (12.33)	9.760 (95.00)	11.198 (125.00)	0.707 (0.00)	0.707 (0.00)	5.40 (28.67)
Paraquat						
0.2 kg ha^{-1}	10.052 (100.67)	14.414 (207.67)	19.777 (390.67)	0.707) (0.00)	7.68 (58.67)	11.49 (132.00)
0.4 kg ha^{-1}	9.611 (92.00)	13.053 (170.00)	16.792 (281.67)	0.707 (0.00)	8.02 (64.01)	10.85 (117.33)
0.6 kg ha^{-1}	9.041 (81.33)	12.856 (165.00)	17.102 (293.33)	0.707 (0.00)	6.61 (44.00)	9.17 (84.00)
0.8 kg ha^{-1}	8.295 (68.33)	10.792 (116.67)	15.399 (236.67)	0.707 (0.00)	6.09 (37.33)	8.35 (69.33)
1.0 kg ha^{-1}	7.242 (52.00)	10.698 (114.00)	14.459 (208.67)	0.707 (0.00)	6.95 (40.00)	8.43 (72.00)
1.2 kg ha^{-1}	7.167 (51.00)	10.541 (110.67)	13.655 (186.00)	0.707 (0.00)	5.06 (25.33)	8.46 (72.06)
2,4-D						
0.5 kg ha^{-1}	24.089 (580.00)	28.267 (798.67)	30.786 (947.67)	19.64 (385.33)	25.66 (658.67)	26.85 (720.67)
1.0 kg ha^{-1}	20.813 (433.33)	23.484 (551.33)	28.82 (846.00)	17.86 (318.67)	24.21 (586.66)	25.05 (627.33)
2.0 kg ha^{-1}	15.001 (225.00)	20.060 (402.00)	28.09 (830.67)	16.59 (274.67)	20.01 (400.00)	21.12 (446.00)
3.0 kg ha^{-1}	16.080 (258.33)	20.035 (401.00)	27.616 (762.33)	17.02 (289.33)	21.19 (450.67)	22.75 (517.60)
4.0 kg ha^{-1}	13.097 (171.67)	13.567 (184.00)	20.843 (434.00)	17.93 (321.33)	20.74 (432.00)	24.24 (587.60)
5.0 kg ha^{-1}	10.727 (114.67)	13.599 (185.00)	22.474 (504.67)	18.30 (334.67)	20.92 (440.00)	22.40 (502.00)
Unweeded (Control)	24.562 (603.33)	30.580 (936.00)	32.632 (1065.00)	61.36 (3766.67)	64.05 (4106.67)	61.26 (3752.00)

CD (0.05) Application at seedling stage : 0.473
Application at active vegetative stage : 0.863
$\sqrt{x+0.5}$ transformed values are given. Original values are given in parentheses

Application of 2,4-D was not effective in controlling *M. invisa* at 0.5 kg ha^{-1} and was on par with unweeded control. Eventhough increase in dose from 0.5 to 5 kg ha^{-1} lowered drymatter production of *M. invisa* to low values compared to unweeded control, the treatments were less effective than the glyphosate treatments. Severe epinasty symptoms typical of 2,4-D were produced, but the *M. invisa* shoots were seen to recover from the symptoms even when doses of 2,4-D as high as 4 to 5 kg ha^{-1} was applied (Plate 6).

Application at active vegetative stage (100 DAG) with glyphosate @ 0.2 to 1.2 kg ha^{-1} could give very effective control of *M. invisa*, when drymatter production of new shoots produced per square metre was considered (Table 12 and Fig.18). The observation was same at 30, 60 and 90 days after spraying, giving statistically superior control over paraquat and 2,4-D applications.

4.3.3 Biological methods

4.3.3.1 Insect pests

Six species of insects belonging to five different families of the order Lepidoptera were identified as pests of *M. invisa* (Table 13 and Plate 7). These were mainly flower bud or leaf feeders. The type of damage caused by them are given in Table 13. The defoliated branches are depicted in Plate 8.

4.3.3.2 Pathogens

The only disease noticed in *M. invisa* was small circular spots on the stem, mainly on mature parts, seen during heavy monsoon period. The diseased samples were taken to the laboratory and slides were prepared from the infected portion. Large number of spores of *Alternaria* sp. were observed under the microscope. The pathogenicity of the organism was proved by inoculating the pathogen on the healthy *M. invisa* under aseptic conditions.

Plate 7. Insect pests of *Mimosa invisa*

Flower bud feeders

Rapala sp.

Euproctis scintillans Wlk.

Defoliators

Ericeia optature Wlk.

Porthesia sp.

Adoxophyes moderanata Wlk.

Family - Pyraloidea

Table 13. Nature and extent of damage by insect pests

Insect pests	Family	Nature of damage	Extent of damage
A. Flower bud feeders			
1. *Euproctis scintillans* Wlk.	Lymantriidae	The larvae feed on flowers and flower buds. They feed in groups and prevent seed set	Moderate
2. *Rapala* sp.	Lycaenidae	The larvae feed on flowers and flower buds. They resemble the flower buds of *M. invisa* with characteristic body markings	Negligible
B. Defoliators			
1. *Porthesia* sp.	Lymantriidae	The larvae feed on the leaves in batches during early morning hours, leaving behind the midrib of compound leaf.	Moderate
2. *Ericeia optature* Wlk.	Noctuiidae	The larvae feed on the leaves and pupate in the soil.	Negligible
3. *Adoxophyes moderanata*	Tortricidae	Larvae feed on the leaves.	Negligible
4. Unidentified species	Pyraloidea	Larvae feed on the leaves.	Negligible

The pathogen was isolated on Potato Dextrose Agar medium which yielded dark coloured concentric mycelial growths (Plate 9). However, no sporulation was observed in the culture.

4.4 ECONOMIC IMPORTANCE

4.4.1 Utility of *M. invisa*

4.4.1.1 Green manure / cover crop

4.4.1.1.1 Biomass production

The dry matter production by spined and spineless types of *M. invisa* were assessed per square metre and per plant, at three growth stages and the data are presented in Table 14.

Table 14. Dry matter production of *Mimosa invisa*

Growth stages	*M. invisa* var. *invisa* (spined)		*M. invisa* var. *inermis* (spineless)	
	g plant^{-1}	g m^{-2}	g plant^{-1}	g m^{-2}
Seedling stage (45 DAG)	405.35	720.66	398.33	695.48
Active vegetative stage (100 DAG)	1847.33	1850.50	1815.50	1749.50
Flower bud appearance (150 DAG)	3625.00	2005.40	3595.00	1989.86

The dry matter production did not show any significant variation between spined and spineless types of *M. invisa* for both methods of assessment. The maximum dry matter production at flower bud appearance (150 DAG) was 3.625 kg plant^{-1} in spined and 3.595 kg plant^{-1} in spineless types. When estimated on unit area basis it came to 2.01 kg m^{-2} for spined and 1.99 kg m^{-2} for spineless types.

4.4.1.1.2 Dry matter accumulation potential

The dry weight accumulation by individual plants of *M. invisa* was estimated at weekly intervals, starting from germination of seeds to drying of the plant

Table 15. Dry matter accumulation in *Mimosa invisa*

Weeks after germination	Dry weight (g/plant)
1	3.60
2	7.20
3	18.67
4	52.67
5	116.00
6	232.33
7	398.33
8	609.33
9	811.67
10	1121.00
11	1427.67
12	1586.00
13	1747.33
14	1978.67
15	2145.00
16	2464.00
17	2634.00
18	2870.00
19	3122.33
20	3291.67
21	3436.67
22	3625.00
23	3520.00
24	3482.00
25	3198.00
26	2950.00
27	2908.00
28	2820.00
29	2538.00
30	2460.00
31	2280.00
32	2050.00
33	1850.00
34	1700.00

and presented in Table 15 and Fig. 19. The data and graph clearly indicates the slow growth during the initial four weeks, with only 50 g increase in dry weight per plant. During 5th to 22nd week, there was a rapid and constant increase in dry weight (from 116 g to 3625 g). The maximum dry weight recorded was 3625 g per plant in the 22nd week. This coincided with first appearance of flower buds in *M. invisa*. Thereafter, there was a rapid fall in the dry matter accumulation in the plant upto 37th week of growth, by which time the plant completely dried up.

4.4.1.1.3 Litter decomposition

The rate of decomposition was highest in the first fortnight, during which 59.8 per cent of the biomass was degraded (Table 16 and Fig.20). Subsequently, the rate of decomposition was slower with 35.06 per cent of the material getting decomposed in the next 106 days. Afterwards, biodegradation in soil was very slow and it took 240 days more for the remaining 4.76 per cent of the material to get decomposed. However, the decomposition was completed (99.65%) within one year.

4.4.1.1.4 Nutrient composition

The data on the average content of N, P, K, Ca, Mg, S, Fe, Mn, Zn and Cu in the spined and spineless types of *M. invisa*, in comparison with the common green manure and cover crops are furnished in Table 17.

The two types of *M. invisa* viz., *M. invisa* var. *inermis* (spineless) and *M. invisa* var. *invisa* (spined) recorded comparatively higher values for N (3.8 and 3.9% respectively) than the other legumes except *Peuraria phaseoloides*, which recorded the highest N content (4.2%).

The content of P, K, Ca, Mg, S, Fe and Mn were lower in both types of *M. invisa* than the other legumes.

However, *M. invisa* recorded distinctly higher Zn content of 90 ppm and 100 ppm for spineless and spined types respectively, while the other legumes had Zn content in the range of 10 to30 ppm only.

Table 16. Litter decomposition in *Mimosa invisa*

Days after laying	Quantity decomposed (g)	% decomposition
7	51.58	23.45
14	131.57	59.80
30	160.49	75.20
60	192.97	87.71
90	202.89	92.22
120	208.70	94.86
150	209.71	95.36
180	211.87	96.30
210	214.19	97.36
240	216.04	98.20
270	216.92	98.60
300	217.81	99.14
330	218.27	99.21
360	219.23	99.65

Quantity kept for decomposition - 220 g dry weight (500 g fresh weight)

Table 17. Nutrient composition of *M. invisa* and other common green manure/cover crops

Crop	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Mimosa invisa var. *inermis*	3.8	0.25	2.3	1.55	1.48	0.32	170	100	90	5
Mimosa invisa var. *invisa*	3.9	0.29	2.3	1.56	1.60	0.28	160	120	100	5
Sesbania aculeata	3.6	0.39	3.3	1.86	2.58	0.36	210	400	30	5
Daincha speciosa	3.5	0.30	3.0	2.41	2.02	0.42	140	110	15	5
Peureria phaseoloides	4.2	0.36	2.4	1.82	1.94	0.45	420	180	25	10
Calopagonium mucunoides	3.8	0.31	3.1	2.42	1.02	0.40	230	40	10	5
CD (0.05)	0.346	0.031	0.392	0.266	0.130	0.041	19.32	15.103	10.527	0.000
SEm±	0.112	0.010	0.127	0.086	0.043	0.014	6.412	5.012	3.493	0.000

4.4.1.1.5 Nutrient enrichment through vermi composting

i) Earth worm count

Native earth worms (*Megascolex mauritiani*) could not survive or multiply in the substrate which contained *M. invisa*. Their count after 90 days of composting was very poor both in substrate with *M. invisa* alone and in combination with banana pseudostem. The mean count of native earthworms were significantly lower (2.0 and 2.5 respectively), compared to that in the case of *Eisenia foetida* with same substrates (25 and 38.75 respectively).

For *E. foetida*, the commonly used species of earthworm for vermicomposting, the population was highest (38.75 per pot) at harvest, in *M. invisa* + banana pseudostem (1:1) media. The *M. invisa* alone media contained less earthworms (25.00 per pot) than that of the pseudostem mixed media (38.75 per pot) at maturity of compost (Table 19).

ii) Yield of vermicompost

a) Quantity

The highest quantity of compost was obtained when no earth worms were used, but the nutrient content was poor. The quantity of compost obtained was the lowest (1.575 kg pot^{-1}) in treatment where *M. invisa* : banana pseudostem (1:1) mixture was composted by *E. foetida*, which was on par with the mixture of *M. invisa* and banana pseudostem treated with *M. mauritiani* (Table 19).

b) Physical quality

Among the different types of compost prepared from *M. invisa*, the best quality of compost was obtained for *M. invisa* : banana pseudostem composted by *E. foetida* and second best quality was for *M. invisa* alone composted by *E. foetida.*

At maturity, the best quality compost was black in colour, granular, slightly moist, soft, light weight, non-sticky and humus rich. The physical qualities of different types of vermicompost prepared are given in Table 18.

Table 18. Physical qualities of vermicomposts from *M. invisa*

Types of compost	Physical qualities
M. invisa 100% composted by *M. mauritiani*	Partially composted, fibrous, poor texture, sticky and brownish black in colour.
M. invisa 100% composted by *E. foetida*	Fully composted, slightly fibrous, good texture (granular), non sticky and black in colour.
M. invisa 50% + banana pseudostem 50% composted by *M. mauritiani*	Partially composted, less fibrous, poor texture, sticky and brownish black in colour.
M. invisa 50% + banana pseudostem 50% composted by *E. foetida*	Fully composted, non fibrous, good texture (granular), soft, free flowing, non sticky and black in colour.
M. invisa 100% composted (no earthworms)	Partially decomposed, highly fibrous, very poor texture, sticky and brown in colour.

4.4.1.1.6 Nutrient content of the vermicompost

The N, P, K, Ca, Mg and S contents of the different vermi composts produced were analysed in the laboratory and the data are presented in Table 19. The N content was highest in *M. invisa* : banana pseudostem (1:1) compost (4.15%) which was on par with *M. invisa* alone composted with *E. foetida*. This was 7.80 per cent higher than the N content of raw mimosa (3.85% N). Also, there was a 100 per cent increase in P content from 0.27 per cent P in raw mimosa to 0.54 per cent in best quality vermi compost (Table 19). The contents of K, Ca and Mg in the vermicompost increased by 13.33, 10.89 and 14.29 per cent respectively, over that of fresh *M. invisa*.

4.4.1.1.7 Response of amaranthus to the vermicompost

The response of crops to different types of vermicompost prepared from *M. invisa* was tested using short duration leafy vegetable, amaranthus as test crop.

Table 19. Effect of vermi composting of *Mimosa invisa* on nutrient composition and yield of compost

Treatment	Earthworm count (No.)	Yield of compost (kg)	Nutrient composition					
			N%	P%	K%	Ca%	Mg%	S%
M. invisa + *M. mauritiani*	2	3.08	3.43	0.278	1.805	1.515	1.552	0.32
M. invisa + *E. foetida*	25	2.69	3.90	0.399	1.990	1.300	1.490	0.36
M. invisa + Banana pseudostem (1:1) + *M. mauritiani*	2.5	1.79	3.73	0.311	1.790	1.510	1.523	0.29
M. invisa + Banana pseudostem (1:1) + *E. foetida*	38.75	1.58	4.15	0.542	2.545	1.727	1.760	0.34
M. invisa alone (no earthworms)	0	3.16	3.73	0.282	2.045	1.417	1.450	0.29
CD (0.05)		0.422	0.301	0.030	0.151	0.121	0.090	0.14
SEm±		0.14	0.10	0.01	0.05	0.04	0.03	0.04

Table 20. Response of Amaranthus to vermicompost of *Mimosa invisa*

Treatments	15 days after planting (1st harvest)			30 days after planting (2nd harvest)		
	Height of Plant (cm)	No. of leaves/ plant	Fresh weight/ plant (g)	Height of Plant (cm)	No. of leaves/ plant	Fresh weight/ plant (g)
M. invisa + *M. mauritiani*	25.14	12.00	30.57	27.14	12.43	26.86
M. invisa + *E. foetida*	33.00	12.80	30.00	31.07	13.00	30.00
M. invisa + Banana pseudostem (1:1) + *M. mauritiani*	24.86	12.29	25.07	25.50	12.29	29.57
M. invisa + Banana pseudostem (1:1) + *E. foetida*	40.57	14.00	34.36	38.07	13.57	31.71
FYM + 50:50:50 kg NPK ha^{-1}	29.14	11.57	29.50	27.21	11.57	29.14
CD (0.05)	3.292	1.299	3.666	3.782	0.982	1.819
SEm±	1.14	0.45	1.27	1.31	0.34	0.63

The height of plant, number of leaves per plant and fresh weight of plant were measured at the two stages of harvest, 15 and 30 days after planting. The data are presented in Table 20.

All the three parameters observed were significantly influenced by the *M. invisa* : banana pseudostem (1:1) substrate, composted by *E. foetida* at both stages of harvest (15 and 30 days after planting). Maximum values were obtained for height of the plant (40.7cm), number of leaves per plant (14.0) and fresh weight of the plant (34.36 g) during first harvest, i.e., 15 days after planting (Table 20). Similar improvement in the above parameters was observed during the second harvest, at 30 days after planting also. The manure obtained by composting *M. invisa* alone with *E. foetida* was second best treatment and gave significantly superior values for height, number of leaves and fresh weight of amaranthus, compared to other three treatments.

4.4.2 Harmful effects of *M. invisa*

4.4.2.1 Biodiversity of native flora

M. invisa has shown great influence on the biodiversity of the native flora. (Table 21 and Fig. 6). The data recorded for three consecutive years (2002, 2003 and 2004) showed that infestation of *M. invisa* in an area could considerably reduce the population of other native flora (mostly weeds).

The proportion of *M. invisa* in the flora of a newly infested area increased from six per cent during May 2002 to 22 per cent by May 2004. At the same time, the invasion of *M. invisa* brought down the proportion of all other components of the weed population viz., other broad leaved weeds and grasses by 5 per cent, and sedges by 6 per cent, during the same period (Fig. 6).

The adjacent *M. invisa* free field showed that the proportion of the population between other broad leaved weeds, grasses and sedges was maintained in the ratio 1:1:1 at germination and during initial stages of growth in all the three years. In the absence of *M. invisa*, a balance between the population of component flora was thus achieved and the ratio was stabilized over the years. In the presence of *M. invisa*,

Table 21. Progressive changes in the biodiversity of native flora (no. m^{-2}) due to infestation of *Mimosa invisa*

	M. invisa only					*M. invisa* + other weeds					Other weeds only				
	M	OBLW	G	S	Total	M	OBLW	G	S	Total	M	OBLW	G	S	Total
2002															
May	114.86	0	0	0	114.86	31.43	194.88	118.86	146.29	491.46	0	312.57	285.71	244.00	842.28
July	214.29	0	0	0	214.29	52.57	188.60	160.00	154.86	556.03	0	297.71	265.41	193.71	756.83
Sept.	297.14	0	0	0	297.14	96.57	142.86	104.00	44.57	388.00	0	229.14	250.29	48.57	528.00
2003															
May	217.71	0	0	0	217.70	64.57	177.70	90.86	127.40	460.53	0	297.70	242.29	241.71	781.7
July	268.57	0	0	0	348.60	77.14	172.00	124.6	152.00	525.74	0	244.57	230.29	213.71	688.57
Sept.	350.29	0	0	0	368.70	116.00	115.14	82.29	40.00	353.43	0	204.57	215.43	35.77	455.77
2004															
May	237.71	0	0	0	287.70	98.00	157.61	85.19	107.60	448.40	0	286.29	227.43	237.71	751.43
July	348.57	0	0	0	268.60	138.8	145.2	128.57	129.40	541.97	0	251.43	212.57	224.57	688.57
Sept.	368.71	0	0	0	350.30	152.00	98.86	72.00	51.43	374.29	0	237.71	200.00	51.43	489.14

M - *M. invisa*; OBLW - Other broad leaved weeds; G - Grasses; S - Sedges

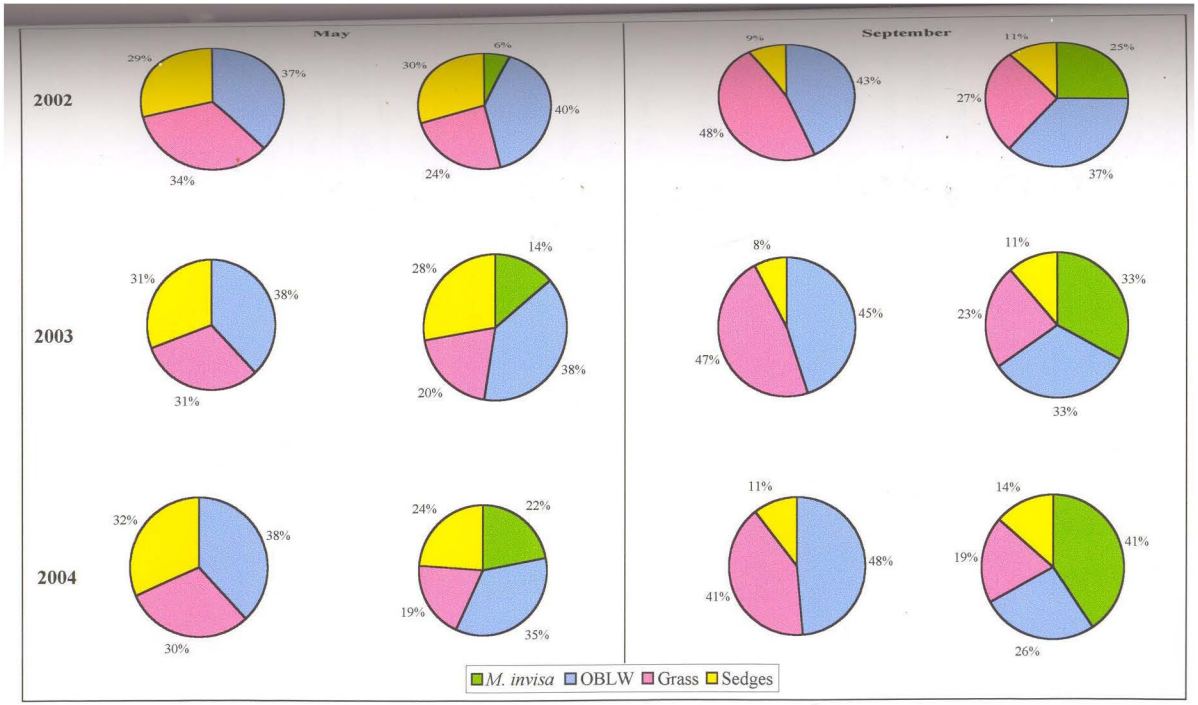


Fig. 6. Progressive changes in the biodiversity of native flora (no. m^{-2}) due to infestation of *Mimosa invisa* over a period of three years

the proportion of grasses was suppressed by an average of 10.67 per cent in the month of May, 7.33 per cent in July and 22.33 per cent in the month of September during the three years of the study. The proportion of other broad leaved weeds was not influenced much in the first month of observation (May). But later, in September an average decline of 13.3 per cent was observed over the three years (Table 21 and Fig. 21).

The proportion of other broad leaved weeds was not influenced much in the first month of observation (May), but by September, an average decline of 13.3 per cent was observed during the three years. However, the analysis of the flora in *M. invisa* infested field, during the month of September showed that by flowering stage, the proportion of *M. invisa* improved by 16 per cent (from 25% to 41%) over the three years of observation. The proportion of other broad leaved weeds dropped from 37 per cent in 2002 to 26 per cent in 2004, and that of grasses from 27 per cent in 2002 to 19 per cent in 2004. The proportion of sedges did not vary significantly.

Based on the dry matter production by *M. invisa* and other weeds in the three treatments at active vegetative stage of *M. invisa*, smothering efficiency of the weed was calculated for the three consecutive years of investigation from 2002 to 2004 and is presented in Table 22.

Table 22. Progressive changes in the smothering efficiency of *Mimosa invisa*

Year	Dry weight (g m^{-2})				
	Mimosa free plot		Mimosa infested plot		Smothering efficiency (%)
	Native flora	*M. invisa*	Native flora	*M. invisa*	
2002	1079	0	927	640	14.08
2003	1401	0	1087	674	22.41
2004	1829	0	1124	727	38.55

The efficiency of *M. invisa* to smother the native vegetation increased progressively from 14.08 per cent during first year of infestation, to 22.41 per cent during second year, and to 38.55 per cent in the third year, when *M. invisa* infested areas were left unweeded.

4.4.2.2 Allelopathic effects

Mulching and incorporation of *M. invisa* at 2 to 10 t ha^{-1} as well as water extract application at 2 to 10 percent concentrations, produced progressive allelopathic effects on the germination of rice and cow pea seeds and also on the growth parameters of their seedlings .These effects are presented below.

4.4.2.2.1 Germination of seeds

a) Rice

The germination percentage of rice seeds, decreased with increase in the rate of application of *M. invisa* from 2 to 10 t ha^{-1}, when applied as incorporation or mulching. A similar effect was obtained when the concentration of water extract of *M. invisa* was increased from 2 to 10 per cent (Table 23). But the inhibitory effect on germination was more pronounced with increase in rate of application as water extract, compared to the other two methods. (Fig.7). Also mulching had a more significant negative effect on germination of rice seeds than incorporation at the same rates.

Incorporation of *M. invisa* at 8 to 10 t ha^{-1} had significant negative effect, giving only 37.5 and 31.25 per cent germination respectively, compared to 56.25 per cent for control, at 4 DAS. At this stage, incorporation at 2 to 4 t ha^{-1} produced favourable effects on germination compared to control (Table 23). But by 8 DAS, incorporation at the lowest rate (2 t ha^{-1}) also could inhibit germination significantly. At this stage 95.8 per cent germination was obtained for control. There was a progressive decrease in germination with increase in the rate of incorporation of *M. invisa*, giving a 30 per cent decrease in germination at 8 DAS for 10 t ha^{-1}, compared to control.

Table 23. Allelopathic effect of different methods of application of *Mimosa invisa* on germination of rice

Rate of appln.of *M. invisa*	Incorporation (t ha^{-1})			Mulching (t ha^{-1})			Water extract (%)		
	Germination of rice								
	4 DAS	6 DAS	8 DAS	4 DAS	6 DAS	8 DAS	4 DAS	6 DAS	8 DAS
0 (Control)	0.848* (56.25)**	1.188 (85.42)	1.424 (95.83)	0.898 (56.25)	1.188 (85.42)	1.424 (95.83)	0.848 (56.25)	1.188 (85.42)	1.424 (95.83)
2	1.001 (70.83)	1.099 (79.17)	1.287 (89.58)	0.614 (33.33)	1.156 (83.33)	1.319 (91.67)	0.220 (6.25)	0.521 (25.00)	0.593 (31.25)
4	0.957 (66.67)	1.073 (77.08)	1.124 (81.25)	0.593 (31.25)	1.124 (81.25)	1.214 (87.50)	0.146 (4.17)	0.325 (10.42)	0.570 (29.17)
6	0.744 (45.83)	0.806 (52.08)	1.099 (79.17)	0.521 (25.00)	1.027 (72.92)	1.099 (79.17)	0.146 (4.17)	0.325 (10.42)	0.498 (22.92)
8	0.659 (37.50)	0.764 (47.92)	1.099 (79.17)	0.472 (20.83)	0.785 (50.00)	1.024 (72.92)	0.073 (2.08)	0.146 (4.17)	0.498 (22.92)
10	0.593 (31.25)	0.723 (43.75)	0.934 (64.58)	0.446 (18.75)	0.521 (25.00)	0.614 (33.33)	0.000 (0.00)	0.220 (6.25)	0.220 (6.25)
CD	0.116			0.126			0.067		
SEm±	0.017			0.018			0.024		

* Arc sine transformed values are given.

** Percentage values are given in brackets

Mulching *M. invisa* gave more significant allelopathic effect, than incorporation at the same rates. At 4 DAS, mulching at 2 t ha^{-1} could inhibit germination by about 23 per cent, which was significant. But at 6 DAS, mulching at higher rates (6 to 10 t ha^{-1}) only could impart the negative effect, resulting in a 60 per cent reduction in germination. By the time germination is completed (8 DAS), the allelopathic effect was significant for mulching at 4 to 10 t ha^{-1}, giving about 8 per cent to 62 per cent reduction in germination compared to control.

Water extract of *M. invisa* applied at all concentrations from 2 per cent to 10 per cent gave significant allelopathic effects, at all stages of observation. At 4 DAS, 2 per cent water extract gave only 6.25 per cent germination and 10 per cent water extract, completely inhibited germination. At 6 DAS also a similar trend was noticed. When germination was completed by 8 DAS, 10 per cent concentration of water extract gave the least germination (6.25%) as against 95.8 per cent germination in control (Table23).

b) Cowpea

The germination of cowpea seeds was significantly reduced at all rates of application of *M. invisa* as incorporation, mulching or water extract compared to control (Table 24 and Fig. 7). Also the decrease in germination percentage was progressive with increase in the rate of application for all three methods.

The germination of cowpea seeds was significantly reduced at 8 DAS, when *M. invisa* was incorporated at 10 t ha^{-1} giving only 5 per cent germination as against 80 per cent germination in control.

Similar effect was obtained when mulching of *M. invisa* was done at the same rates. The allelopathic effects increased with increase in the rate of application, and significantly low germination (5%) was obtained at 8 DAS, when mulched at 10 t ha^{-1}.

Water extract application at 2 per cent to 10 per cent concentrations gave more pronounced negative effects, compared to incorporation and mulching. For

Table 24. Allelopathic effect of different methods of application of *Mimosa invisa* on germination of cowpea

Rate of appln.of *M. invisa*	Incorporation (t ha^{-1})			Mulching (t ha^{-1})			Water extract (%)		
	Germination of cowpea								
	4 DAS	6 DAS	8 DAS	4 DAS	6 DAS	8 DAS	4 DAS	6 DAS	8 DAS
0 (Control)	0.735* (45.00)**	0.891 (60.00)	1.168 (80.00)	0.735 (45.00)	0.891 (60.00)	1.168 (80.00)	0.735 (45.00)	0.891 (60.00)	1.168 (80.00)
2	0.464 (20.00)	0.574 (30.00)	0.629 (35.00)	0.348 (15.00)	0.629 (35.00)	0.730 (45.00)	0.464 (20.00)	0.574 (30.00)	0.629 (35.00)
4	0.464 (20.00)	0.519 (25.00)	0.464 (20.00)	0.464 (20.00)	0.574 (30.00)	0.629 (35.00)	0.232 (10.00)	0.403 (20.00)	0.519 (25.00)
6	0.232 (10.00)	0.464 (20.00)	0.464 (20.00)	0.232 (10.00)	0.464 (20.00)	0.574 (30.00)	0.116 (5.00)	0.232 (10.00)	0.464 (20.00)
8	0.116 (5.00)	0.232 (10.00)	0.232 (10.00)	0.116 (5.00)	0.232 (10.00)	0.232 (10.00)	0.000 (0.00)	0.116 (5.00)	0.232 (10.00)
10	0.000 (0.00)	0.000 (0.00)	0.116 (5.00)	0.00 (0.00)	0.000 (0.00)	0.116 (5.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
CD	0.95			0.106			0.103		
SEm±	0.034			0.037			0.036		

* Arc sine transformed values are given.

** Percentage values are given in brackets

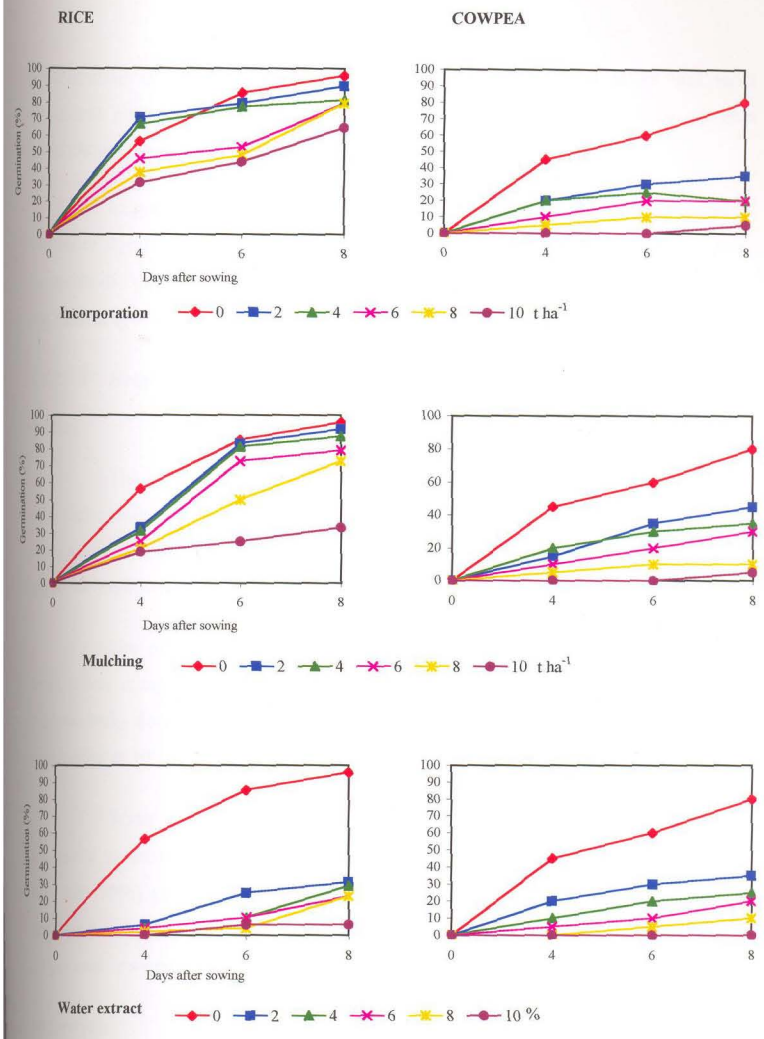


Fig. 7. Allelopathic effect of different methods of application of *Mimosa invisa* on germination of rice and cowpea

concentration of water extracts above 6 per cent, the negative effect was most significant giving less than 20 per cent germination. Concentration of 10 per cent water extract, completely inhibited germination of cowpea seeds at 8 DAS.

In general between the crops tested, the allelopathic effects of *M. invisa* was more significant on cowpea than on rice, for any method of application. Among the methods, the water extract application was more allelopathic than incorporation and mulching at the same doses, for both rice and cowpea (Tables 23, 24 and Fig. 7).

4.4.2.2.2 Height of plants

a) Rice

The height of rice plants at 30 days growth presented an increasing trend, with increase in the rate of incorporation of *M. invisa* in soil (Table 25). The rate of application at 4, 6, 8, and 10 t ha^{-1} gave significantly higher values for heights (30.8 cm to 32.8 cm) which is 50 per cent more than control (21.7 cm).

The effect of mulching *M. invisa* on height of rice showed an opposite trend when compared to incorporation at the same rates. The height of the plant progressively decreased from 27.8 cm for application at 2 t ha^{-1} to 21.3 cm for application at 10 t ha^{-1} effecting a two per cent reduction in height (Fig. 8).

Water extract application gave very low values for height of the plants, compared to incorporation and mulching. The high concentrations of water extract (8% and 10%) gave significantly lower values for height (17.8 cm and 12.2 cm) compared to control (21.7 cm). The maximum reduction in height (43.8%) was for 10 per cent concentration of water extract (Fig 8).

b) Cowpea

All the three methods of application gave significant negative effect on the height of cowpea plants, compared to control (Table 26 and Fig. 8).

Table 25. Allelopathic effect of different methods of application of *Mimosa invisa* on growth parameters of rice

Rate of appln.of *M. invisa*	Height (cm)			Number of tillers			Number of leaves		
	Incorporation (t ha^{-1})	Mulching (t ha^{-1})	Water extract (%)	Incorporation (t ha^{-1})	Mulching (t ha^{-1})	Water extract (%)	Incorporation (t ha^{-1})	Mulching (t ha^{-1})	Water extract (%)
2	22.5	27.8	24.3	2.8	2.0	1.0	7.3	6.3	5.3
4	30.8	27.7	24.0	2.8	1.5	1.0	8.5	5.0	5.3
6	31.0	27.4	19.5	2.3	1.3	0.5	9.0	5.3	4.5
8	31.8	22.5	17.8	3.0	1.3	0.0	9.5	4.3	3.5
10	32.8	21.3	12.2	2.8	1.0	0.0	9.3	3.8	3.3
Control	21.7			2.7			7.5		
CD	1.69			0.74			1.27		
SEm±	0.512			0.223			0.383		

Table 26. Allelopathic effect of different methods of application of *Mimosa invisa* on growth parameters of cowpea

Rate of appln.of *M. invisa*	Height (cm)			Number of branches			Number of leaves		
	Incorporation (t ha^{-1})	Mulching (t ha^{-1})	Water extract (%)	Incorporation (t ha^{-1})	Mulching (t ha^{-1})	Water extract (%)	Incorporation (t ha^{-1})	Mulching (t ha^{-1})	Water extract (%)
2	22.0	16.5	15.9	2.5	1.5	1.3	9.3	7.0	5.8
4	19.0	14.0	14.9	2.3	1.3	1.3	8.5	6.3	5.5
6	19.0	12.0	13.0	2.3	1.3	0.8	8.8	5.5	5.3
8	14.5	10.3	12.3	2.0	1.0	0.5	8.0	5.0	4.5
10	0.5	0.0	0.0	0.5	0.00	0.0	0.5	0.0	0.0
Control	23.6			2.8			9.0		
CD	1.49			0.84			1.12		
SEm±	0.451			0.255			0.337		

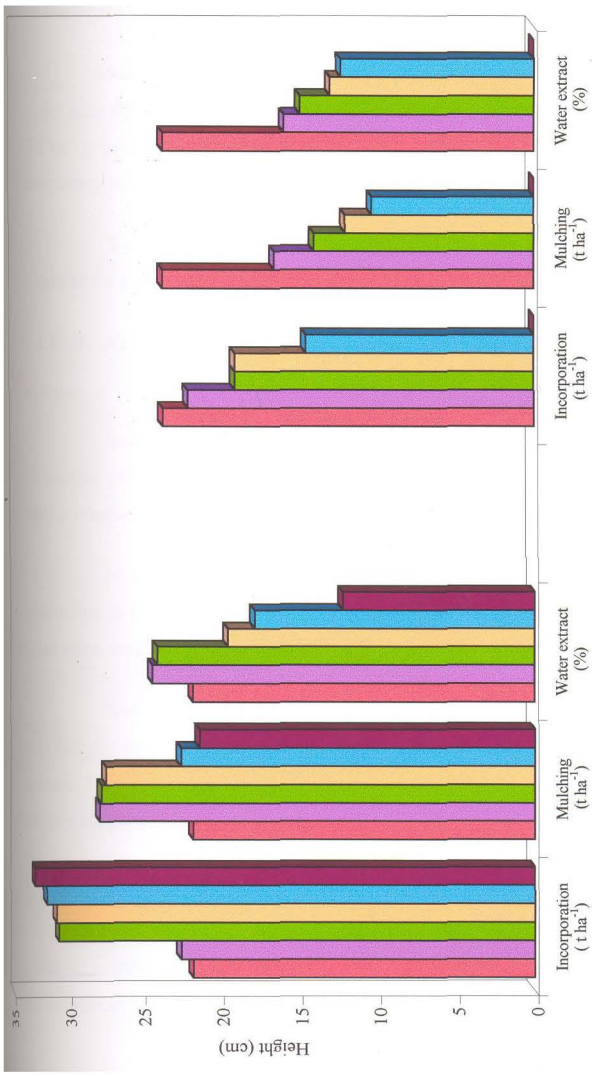


Fig. 8. Allelopathic effect of different methods of application of *Mimosa invisa* on height of rice and cowpea

The inhibitory effect on height of cowpea due to incorporation of *M. invisa* was significant even at 2 t ha^{-1} giving 6.8 per cent reduction in height. Incorporation at 10 t ha^{-1} gave 97.9 per cent reduction in height compared to control.

Mulching gave more significant negative effects compared to incorporation at the same rates. Application at 2 t ha^{-1} produced 30 per cent reduction in height and 8 t ha^{-1} produced 50 per cent reduction compared to control. Mulching at 10 t ha^{-1} completely inhibited the growth of the plant (Table 26).

Water extract application had strong allelopathy giving very low values for height of the plant (0 to 15.9 cm) at all concentrations compared to control (23.6 cm).

4.4.2.2.3 Number of tillers / branches per plant

a) Rice

Incorporation of *M. invisa* at any rate had no significant allelopathic effect on number of tillers in rice. The rates of application from 2 to 10 t ha^{-1} increased the tiller production, eventhough the increase was not significant (Table 25 and Fig. 9).

Mulching at 2 t ha^{-1} had no significant allelopathic effects on the tiller production in rice. But there was a progressive reduction in the number of tillers per plant when mulched at 4 t ha^{-1} to 10 t ha^{-1}.

Water extract application at 2 per cent to 10 per cent concentration significantly lowered the number of tillers produced (0 to 1 per plant) compared to control (2.7 per plant). For application at 8 per cent and 10 per cent concentrations, no tillers were produced.

b) Cowpea

Incorporation of *M. invisa* at 2 to 8 t ha^{-1} had no significant allelopathic effect on number of branches in cowpea. Application at 10 t ha^{-1} drastically reduced the number of branches produced (Table 26 and Fig. 9).

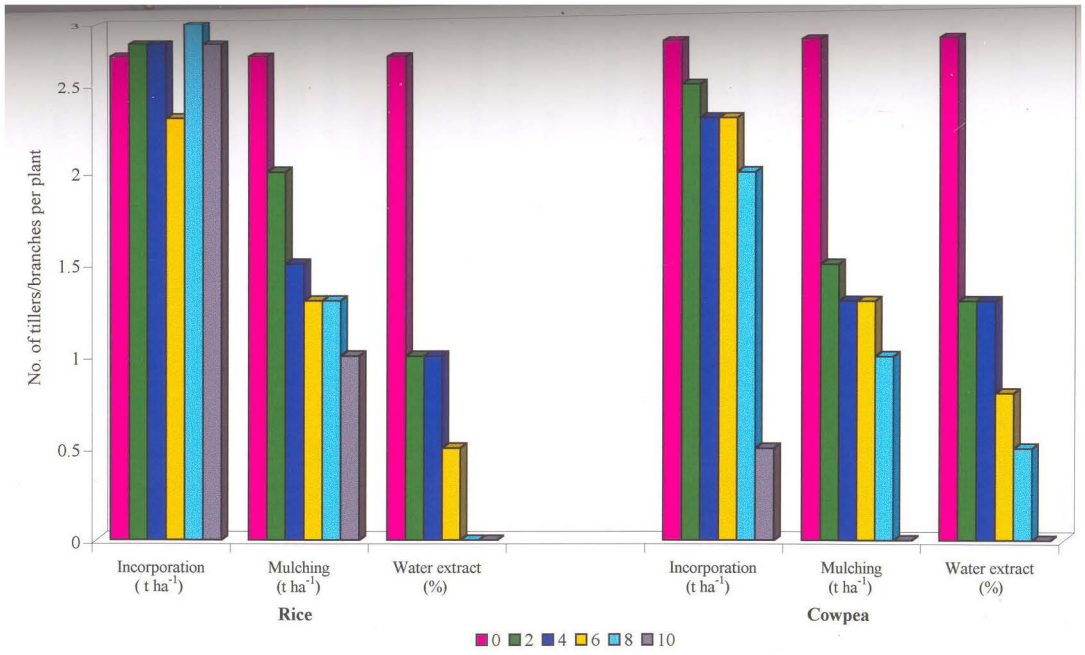


Fig. 9. Allelopathic effect of different methods of application of *Mimosa invisa* on number of tillers/branches of rice and cowpea

Mulching and water extract application significantly reduced the number of branches of cowpea (0 to 1.5 per plant) compared to control (2.8 per plant).

Water extract application at 2 per cent significantly reduced the number of branches and at 10 per cent completely inhibited the growth of branches.

4.4.2.2.4 Number of leaves per plant

a) Rice

Production of leaves by rice seedlings was not adversely affected by incorporation of *M. invisa*. The number of leaves per plant improved significantly for application at 6, 8 and 10 t ha^{-1} (from 9 to 9.5 leaves per plant) compared to control (7.5 leaves per plant).

Production of leaves showed a decreasing trend, with increase in the rate of application when *M. invisa* was applied as mulch (Table 25 and Fig. 10). The decrease was significant for applications above 2 t ha^{-1}.

Water extract application at 2 per cent to 10 per cent caused significant reduction in the number of leaves (from 5.3 to 3.3 leaves per plant) with increase in concentration of water extracts compared to control (7.5 leaves per plant) (Table 25).

b) Cowpea

Production of leaves by cowpea was not adversely affected by incorporation of *M. invisa* upto 8 t ha^{-1}. Incorporation at 10 t ha^{-1} inhibited the growth and significantly lowered leaf production (Table 26 and Fig. 10).

Mulching at 2 to 8 t ha^{-1} had significant allelopathic effects on number of leaves produced. Mulching at 10 t ha^{-1} completely inhibited the production of leaves.

Water extract at 2 per cent to 10 per cent concentration gave strong allelopathic effects with significantly reduced the number of leaves (from 5.8 to 4.5 leaves per plant) compared to control (9.0 per plant).

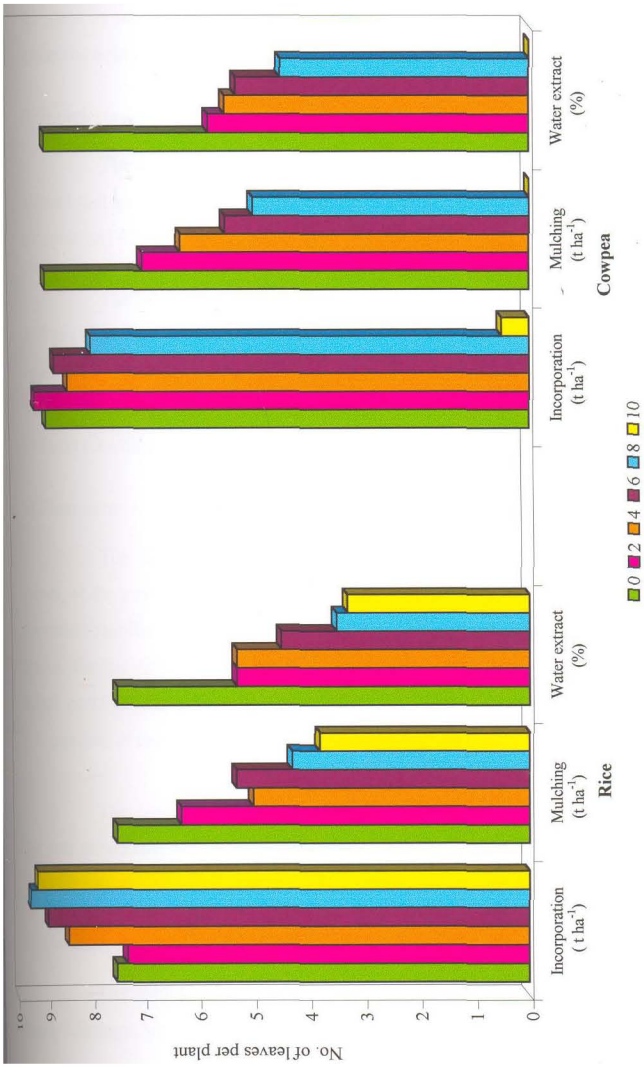


Fig. 10. Allelopathic effect of different methods of application of *Mimosa invisa* on number of leaves of rice and cowpea

4.4.2.3 Mimosine content

The mimosine content in *M. invisa* at different growth stages and parts of the plant, as well as in different mimosaceous plants were analysed and the results are presented below.

i) Growth stages

The analysis of mimosine content in *M. invisa* at different growth stages showed that the content was highest (9.22%) at active vegetative stage (90 days after germination) of the plant (Table 27 and Fig. 22).

The mimosine content increased gradually from 2.55 per cent at 5 DAG, to 4.89 per cent at 45 DAG. Thereafter, it rapidly rose to 9.22 per cent at 90 DAG (active vegetative stage) and later dropped to 5.10 per cent at 120 DAG (flowering stage). There was no significant difference between the mimosine contents at 5 DAG and 15 DAG (seedling stages) and at 120 DAG (flowering stage).

ii) Plant parts

The highest content (10.42 %) of mimosine was present in immature leaves, at the growing tips of the plant (Table 28 and Fig. 23). The mimosine content decreased significantly with maturity of leaves and reached 9.53 per cent in matured leaves. Similar difference in the mimosine content was noticed between the basal and apical parts of the stem also. It varied between 6.30 per cent at apical region to 5.31 per cent at the basal region (Table 28 and Fig. 23).

The seeds contained the lowest mimosine (3.07%). Flower buds had 5.10 per cent mimosine, which was significantly higher than that in seeds, but lower than that in the stem.

iii) Common mimosaceous plants

The content of mimosine in different parts of common plants belonging to family Mimosae were compared and the values are furnished in Table 29 and depicted

Table 27. Mimosine content in *Mimosa invisa* at different growth stages

Stage of growth	Mimosine (%)
A. Seedling stage	
5 DAG	2.55
15 DAG	3.07
30 DAG	4.64
45 DAG	4.89
B. Active vegetative stage	
90 DAG	9.22
C. Flowering stage	
120 DAG	5.10
CD (0.05)	0.524
SEm±	0.17

DAG - Days after germination

Table 28. Mimosine content in different parts of *Mimosa invisa*

Parts of the plant	Mimosine (%)
Immature leaves	10.42
Mature leaves	9.53
Stem apex	6.30
Stem basal	5.31
Flower buds	5.10
Seeds	3.07
CD (0.05)	0.77
SEm ±	0.25

Table 29. Mimosine content in different parts of common mimosaceous plants

Plant part	Mimosine (%)		
	M. invisa	*M. pudica*	*Leucaena leucocephala*
Immature leaves	9.88	2.85	10.71
Leaf and stem	6.32	1.83	5.76
Flowers	5.01	1.24	3.11
Seeds	3.30	0.89	12.23
CD (0.05)	1.109	0.462	1.210
SEm±	0.360	0.150	0.390

Table 30. Mimosine content in fresh and ensiled *Mimosa invisa*

M. invisa: Fodder	Quantity of mimosine		Reduction in mimosine (%)
	Fresh mixture (g)	Ensiled mixture (g)	
10:90	0.92	0.62	32.51
25:75	2.30	1.49	35.43
50:50	4.61	2.76	40.11
75:25	6.91	3.75	45.76
90:10	8.30	4.47	46.13
CD (0.05)	0.479		-
SEm±	0.166		-

in Fig. 24. Both *M. invisa* and *M. pudica* had the highest concentration of mimosine in immature leaves (9.88 and 2.85% respectively), which was significantly different from other parts of the plant (Table 29 and Fig. 24).

Subabul, the common fodder plant of mimosae family, had the highest mimosine content of 12.23 per cent in the seeds, significantly higher than all other parts. Moreover, the content in immature leaves (10.71%) in subabul, was also higher than that in *M. invisa* and *M. pudica*.

iv) Effect of ensiling on mimosine content

Mixtures of *M. invisa* and Hybrid Napier grass in different proportions were ensiled under anaerobic conditions for 60 days and the mimosine content in the silage samples were analysed.

The results show that ensiling could effectively lower the mimosine content (Table 30 and Fig. 25). However, there was no proportionate increase in mimosine content in the silage, with increase in the *M. invisa* in the mixture. This is because a higher reduction in the mimosine content was obtained when the proportion of *M. invisa* was more in the mixture. The decrease in mimosine content was 32.5 per cent when the proportion of *M. invisa* was only 10 per cent in the mixture, against 46.13 per cent when the proportion was 90 per cent.

4.4.2.4 Mimosine toxicity

The results of the trial to study the mimosine toxicity in animals, with rabbit as the test animal are presented in Table 31 and Fig. 11. Initially the rabbits were reluctant to consume the ensiled material. However they started feeding on subsequent days. The affected animals developed alopecia (hair fall) and moderate diarrhoea during the course of experiment. The animals appeared weak day by day and some died during the course of the study. The sequence of developments in different treatments as observed in the gross observations and histopathological studies are detailed in Table 32.

Table 31. Effect of feeding different forms of *M. invisa* on the weight of rabbits

Type of feed	Weight at different days after feeding (g)					
	0	**5**	**10**	**15**	**20**	**25**
M. invisa:fodder 25:75 (ensiled)	100 (325)	102.2 (332)	107.7 (350)	112.3 (365)	116.9 (380)	123.1 (400)
M. invisa:fodder 50:50 (ensiled)	100 (425)	102.4 (435)	100.00 (425)	102.4 (435)	108.2 (460)	109.4 (465)
M. invisa:fodder 75:25 (ensiled)	100 (350)	102.9 (360)	105.7 (370)	104.3 (365)	105.7 (370)	107.2 (375)
Dried, powdered *M. invisa*	100 (400)	97.5 (390)	93.8 (375)	103.7 (415)	107.5 (430)	112.6 (450)
Raw juice (from 150 g *M. invisa*)	100 (330)	100.6 (332)	100.6 (332)	94.6 (312)	92.42 (305)	84.9 (281)
Control	100 (439)	107.1 (470)	114.6 (503)	131.2 (576)	145.8 (636)	154.5 (678)

The values in table are the weight as per cent, equating the weight at start of the trial as 100.
The values in parenthesis are the actual weights.

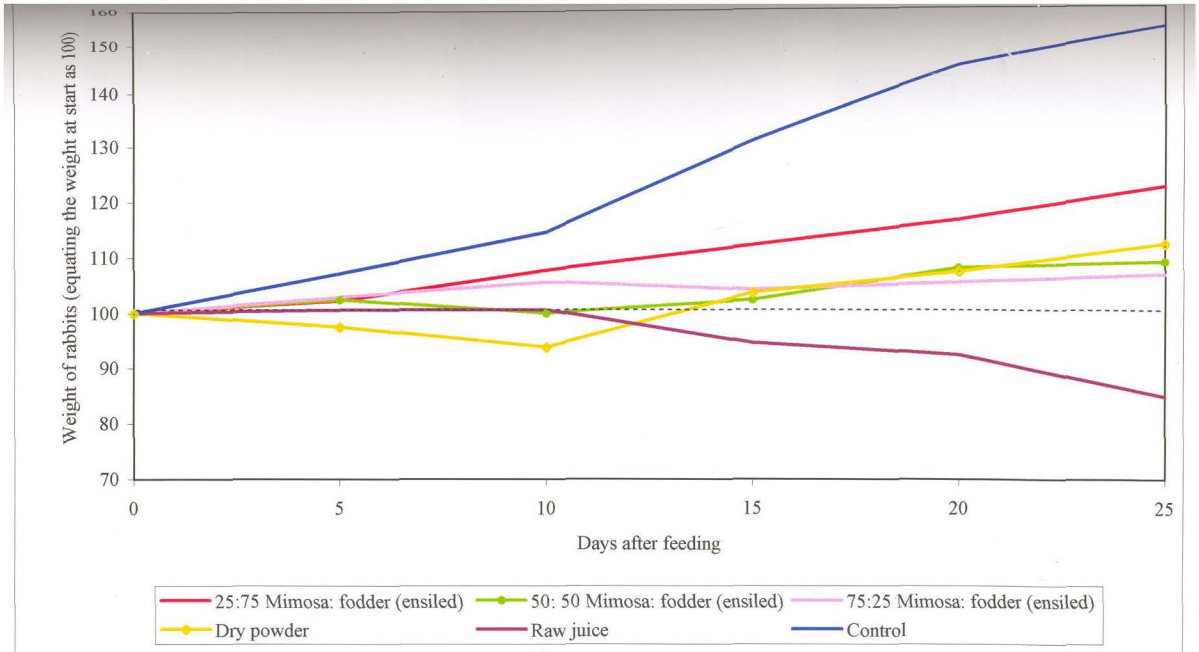


Fig. 11. Effect of feeding different forms of *Mimosa invisa* on weight of rabbits

Plate 10. Mimosine toxicity in rabbits

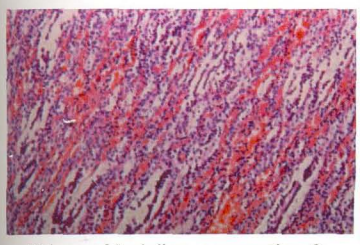
Layout of the experiment

Alopecia

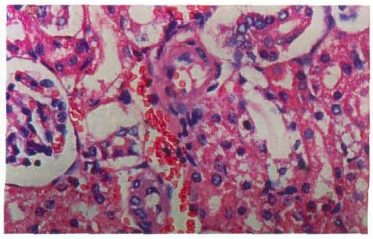
Death

Postmortem examination in progress

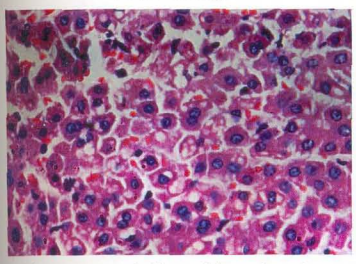
Plate 11. Histopathology of rabbit affected by mimosine toxicity



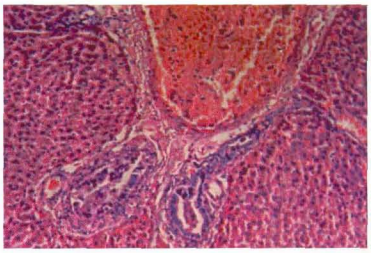
Kidney - Medullary congestion & heamorrhage



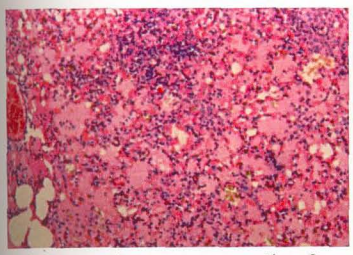
Kidney - Cystic dialation of tubules & necrosis



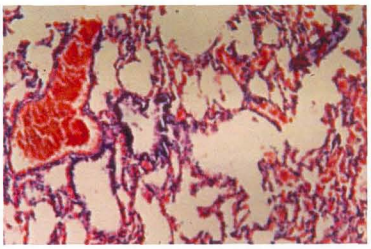
Liver - vacuolation of hepatocytes



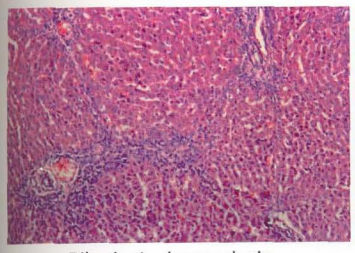
Liver - hepatocyte degeneration



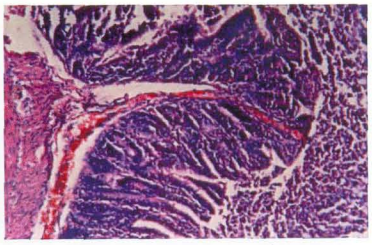
Lungs - pulmonary congestion & oedema



Lungs - congestion & emphysema



Bile duct - hyperplasia



Intestine - heamorrhage of mucosa

Table 32. Mimosine toxicity in rabbits fed with *Mimosa invisa* in different forms and doses

Sl. No.	Treatments	Toxic manifestations	Gross lesions in internal organs	Histopathology (see Plate 11)
1	Control (normal diet)	1. All animals remained healthy throughout the experimental period (25 days). 2. An average weight gain of 54.5% was obtained during the period	No gross lesions	No microscopic lesions observed in the internal organs
2	Silage (*M. invisa* 25% + Hybrid Napier 75%)	1. No toxic manifestations. 2. Animals were weak. 3. Average weight gain was only 23% during the period	1. No characteristic lesions in kidney, liver, spleen and other organs 2. Mild catarrh and congestion of the mucosa of the intestine 3. Oocysts of coccidia in the intestinal contents	No microscopic lesions
3	Silage (*M. invisa* 50% + Hybrid Napier 50%)	1. No visible abnormalities 2. General weakness more pronounced 3. Diarrhoea and slight alopecia noted towards the third week 4. Only 9.4% average weight gain by the animals	1. No gross lesions in kidney, liver, spleen and other organs 2. Mild catarrh 3. Oocysts of coccidia in the intestinal contents	No microscopic lesions
4	Silage (*M. invisa* 75% + Hybrid Napier 25%)	1. Animals were very weak 2. Weight gain was only 7.2% 3. Alopecia developed towards third week	1. Mild gross lesions in kidney, lungs and intestine 2. Oocysts of coccidia more in the intestinal contents	**1. Kidney** Medullary congestion **2. Intestine** Desquamation of the epithelium **3. Lungs** Emphysema

Contd.

Table 32. continued

Sl. No.	Treatments	Toxic manifestations	Gross lesions in internal organs	Histopathology (see Plate 11)
5	Dried, powdered *M. invisa*, substituted for green fodder	1. No visible abnormalities 2. General weakness observed 3. Coccidial oocysts in the feacal samples 4. Weight gain of 12.6% by the animals	1. Pulmunory congestion, hepatosis and congestion of kidney with diffuse greyish areas 2. Catarrhal enteritis	**1. Kidney** Medullary congestion, heamorrhage and tubular degeneration **2. Liver** Hepatocyte degeneration **3. Lungs** Congestion, haemorrhage and emphysema
6	Raw juice from 150 g fresh *M. invisa*	1. Dullness, depression and sluggishness of animals 2. Progressive weakness and weight loss 3. One animal each died on third and seventh day of trial 4. A weight loss of 16% in 25 days in the survived animal 5. Alopecia increased after third week	1. Gross lesions observed in kidney and liver 2. Greyish white streaks of necrosis in kidney 3. Hepatosis of the liver and pale modularity in the parenchyma 4. Gastritis and catarrhal intensity	**1. Kidney** Renal tubular degeneration, necrosis and cystic dialation of tubules. Cystic dialation of tubules, glomerular congestion and necrosis **2. Lungs** Pulmonary congestion, haemorrhage and oedema **3. Intestine** Congestion and haemorrhage in mucosa and submucosa, with necrosis. Desquamation of epithelial cells **4. Liver** Vacuolation of hepatocytes ensinusoidal congestion Bile duct hyper plasia

The feeding experiments using rabbit as test animal, and *M. invisa* ensiled with Hybrid Napier in different proportions as substitute for fresh grass, caused weight reduction at varying rates in animals. The expression of toxicity symptoms in the animal also depended on the proportion of *M. invisa* and fodder in the silage. The mimosine content of *M.invisa* was proved to be hepatotoxic and nephrotoxic (Plate 11)

The increase in the proportion of *M. invisa* in the fodder led to progressive increase in the rate of reduction of weight of animals in general, which is an indication of adverse effect of the feed (Table 31 and Fig.11). *M. invisa* : fodder in 25:75 ratio showed about 33 per cent reduction in weight over the control at 25 days after feeding. But the animals were not expressing any toxicity symptoms and were active. However, 50:50 and 75:25 proportions of *M. invisa* : Hybrid Napier caused over 50 per cent reduction in weight gain at 25 days after feeding.

The dry powder form of *M. invisa* substituting 50 per cent of fresh grass showed an initial reduction in weight in the first 10 days, followed by a gain in weight thereafter. The expression of toxicity symptoms was also the least. The results indicate that sun drying can be suggested as a method to lower the toxicity due to *M. invisa* in animals. When raw juice of *M. invisa* foliage was fed, the weight of the animals dropped at a rapid rate with about 15 per cent reduction from the initial weight.

The toxicity symptoms developed in the internal organs are described in Table 32 and are illustrated in Plates 10 and 11.

Discussion

5. DISCUSSION

Mimosa invisa Mart. an alien weed from South America, is spreading fast in Kerala causing problems to agricultural and non agricultural areas, affecting the biodiversity of the flora of the state, as well as causing toxicity problems to animals feeding it. Therefore studies were taken up to understand the spread, biology, control, toxicity to animals and utilization of the plant for other purposes. Results obtained are discussed in this chapter.

Distribution

Most of the alien weeds that have spread as problem weeds in Kerala are natives of South and Central America, which lie in the tropical region as our country. The agro climatic conditions of Kerala are ideally suited for *M. invisa*, a native of the humid tropics of the new world. Once introduced to Kerala, free of its natural enemies, the plant finds it easy to multiply and spread quickly all over the state.

M. invisa was first reported in Kerala from Changanachery (Kottayam District) in 1964 (Nair, 1964). Since then the plant has spread to the neighbouring districts and is locally called *Anathottavady*, *Vishamullu* or *Padayincha*. It is now severe in Pathanamthitta, Ernakulam, Alappuzha and Thrissur districts (Table1 and Fig.1). Locations of severe infestation were maximum in Central Kerala, in the districts adjoining Kottayam and is now spreading to the northern districts, Kannur and Kasaragod also. This rapid spread clearly points to the noxious nature of the plant. The heliophytic adaptation of the plant might be the reason for its luxuriant growth in unshaded open places, waste lands and road sides. This character of the plant was reported earlier by Waterhouse and Norris (1987), Muniyappan and Virakthamath (1993) and Sankaran (2001). Heliophytic nature, combined with the smothering efficiency of the plant helps it to prevail in the upper most level in the canopy of any mixed vegetation. Thus, *M. invisa* could adversely affect the biodiversity of the flora of an area and cause habitat degradation. The ability of the plant to continue its vegetative growth and flowering beyond the summer season, in areas of moisture

availability, and behave as a perennial also adds to its competitive nature. This indirectly points to the fact that if this plant is left unmanaged, it can become a menace, toppling the equilibrium of the vegetation of the area. This inference is supported by the observations of Muniyappan and Virakthamath (1993) and Sreenivasan and Sankaran (2000).

The varied habitats of occurrence of *M. invisa,* like waste lands, roadsides, fallows, banks of irrigation and drainage canals etc., and the ability to climb on any support, dead or alive (electric posts and stay wires, crop plants, trees, sign boards etc.) indicates the aggressiveness and wide adaptability of the plant. These observations corroborates with the reports of Garcia (1982).

In the high ranges, sporadic incidence of the plant was seen associated with the plantation crops. This indicates the possibility of the seeds of *M. invisa,* being transported by the farmers (settlers) from Central Kerala, along with the planting materials. The spread of *Mikania micrantha* by similar means was reported by Abraham (1999).

In areas where sporadic incidence was noted, the infestations were either on roadsides or near railway lines, indicating the importance of traffic in the quick spread of the plant. Sparse infestation is now noticed even in higher altitudes area like Kalpetta and Mananthavady. This indicates the ability of the plant to tolerate low temperatures also.

The spread of this weed to cropped fields is creating more alarm. During the survey, *M. invisa* was observed even in upland paddy fields of Malamalamukku and Pattambi in Palghat district. Problems due to infestation of. *M. invisa* in the rice uplands, in Philippines, Malaysia, Thailand and Vietnam are already reported (Bakar *et al.*, 1996; Caunter and Shibayama, 2000). It was also noticed that *M. invisa* could compete with and cause yield reduction, in crops like tapioca and banana. Negative impact of the weed on crop growth was reported by Waterhouse and Norris (1987) in early stages of coconut, tea and rubber plantations, and in sugarcane and

pineapple. Reports on lowering crop yields due to competition from *M. invisa* was also reported in tapioca and okra from Nigeria (Alabi *et al.*, 2001; Alabi and Makinde, 2002).

Biology

Two types of *M. invisa,* spined and spineless, were identified in Kerala during the survey. Variations in stem colour of the plant was also noticed in both types. During the survey, red / purple and green colour of the stem, as well as a type with red colour at the base of the stem and green towards the tip were noticed (Plate 4). The presence of the spineless type, *M. invisa* var. *inermis*, was suggested by Waterhouse and Norris (1987). They have also reported the tendency of the spineless type to revert to spiny type. It was observed that the population of spined type was distinctly more than that of spineless type. This suggest the more competitive nature of the spined type. Also the presence of spines makes the plant less manageable. Waterhouse (1994) reported that the spines lacerated the hands of labourers, and that it was very difficult for even animals to penetrate the dense spiny thickets of *M. invisa.* Similar reports on formation of dense thickets by the plant were made by Sreenivasan and Sankaran (2000) in Thrissur and Ernakulam districts.

Seed characters

In a field previously infested with *M. invisa,* the seeds germinated from the soil seed bank in flushes. It is probably an adaptation of the weed to replace the casuality of seedlings, if drought occurs after first rains. It is the variable dormancy and long viability of the seeds that helps it to survive in the seed bank for years and produce a sequence of flushes at intervals.

In this study, the estimated average seed production capacity of a single plant of *M. invisa* is 72,650 (Table 3). The prolonged period of flowering (August to February) is due to the indeterminate growth of the branches. This is one of the factors contributing to the high seed production potential of the plant. A very wide range in seed production by *M. invisa* was noticed by several scientists, ranging from >2000

seeds per square metre (Rajkhowa *et al.,* 2003) to 12,000 seeds per square metre (Vattakkavan *et al.*, 2004).

The wide range in seed production per unit area can be attributed to the variation in plant population and number of shoots per unit area, which is influenced by the soil and climatic conditions. A more reasonable estimation of the production of seeds by invasive plants is the seed production potential per plant, since it gives a correct estimate of the number of seedlings that can be produced from a single plant. Thus high multiplication rate of the plant, along with seed dormancy and viability can be an index of the aggressiveness of *M. invisa*. Great variations in the seed production capacity of other mimosaceous plants have been reported by many workers. Marambe *et al.* (2001) found that the seed production of *M. pigra* per square metre varied from 2,335 to 46,140 seeds.

The spiny nature of the pods and peduncle help in short distance dispersal by sticking to clothes of people moving about and to the skin of grazing animals. Similar observations were made for *M. pudica* and *M. pigra* by Waterhouse (1994). The plant produced 4 to 6 seeds per pod. This is in accordance with observations of Lonsdale (1992). The seeds are small in size with a thousand seed weight of 6.88 g (Table 3). The pods were found to burst open after maturity and drying, to disperse the seeds. The locules of the seeds break at the joints and the seeds are scattered. After seed dispersal, the rim of the pods remain in cluster at the leaf axils.

Studies on seed dormancy showed that, even after remaining buried in soil for three years, the seeds of *M. invisa* are highly viable, giving more than 45 per cent germination (Table 4 and Fig. 3). This tendency to retain viability of seeds was observed in other members of mimosae family also. Nascimento *et al* (1999) reported that *M. pigra* retained viability for 15 years. Seeds of *M. pigra* buried deeper in the soil lay dormant for at least 23 years and seeds of *M. pudica* remained viable even after 19 years and gave two per cent germination (Waterhouse, 1994). All these reports conclusively point to the long viability of seeds of *Mimosa* spp. and the ability to retain germination capacity for long periods in soil. This helps the seeds to tide over

the adverse climatic conditions, contributing to the highly competitive and aggressive nature of *Mimosa* spp.

Studies on the methods to break the seed dormancy, showed that pounding of seeds with coarse sand for five minutes, improved the germination only by 7.5 per cent (Table 5 and Fig. 12). This can be attributed to the acute hardness of the seed coat. It is an adaptation to overcome the temperature and moisture stress in soil. The presence of hard seed coat was observed in the seeds of many weeds as a natural adaptation for dormancy and retention of viability. Such reports were made by Thadulingam and Venkatanarayana (1932) in *Trianthema portulacastrum*, Hardcastle (1978) in *Ipomoea coccinea*, Sheded and Hassan (1999) and Marambe *et al.* (2001) in *Mimosa pigra.*

Flaming the seeds for 15 seconds could enhance the germination considerably in *M. invisa* (Table 5). The effectiveness of flaming in breaking dormancy was also reported by Swamy and Ramakrishnan (1987) in *Mikania micrantha* and by Baker and Tery (1991) in *Mucuna pruriens*. Effect of heat on breaking dormancy of seeds is also proved by the profuse germination obtained in *M. invisa* infested fields, after slashing and burning. This method can be utilized for controlling *M. invisa* in small and compact areas like nurseries. Here burning the stubbles can initiate profuse germination from soil seed bank, which can be destroyed manually or chemically. Efficacy of slashing and burning as a method for weed control is supported by the reports of Swamy and Ramakrishnan (1987) on *Mikania micrantha* in North East India and Sampaio *et al.* (1998) on *Mimosa* spp. in Brazil. Flaming of *M. invisa* seeds for more than 30 seconds reduced the germination drastically, probably due to damage to the embryo.

Treating the *M. invisa* seeds with concentrated sulphuric acid for two minutes could enhance the germination by 76 per cent (Table 5). Similar observations have been made with concentrated sulphuric acid (5-10 minutes) in the case of *M. bimucronata* by Ribas *et al.* (1996) and in *M. caesalpinifolia* seeds (Nascimento *et al.*, 1999). It was also found that the seeds of *M. invisa* could tolerate

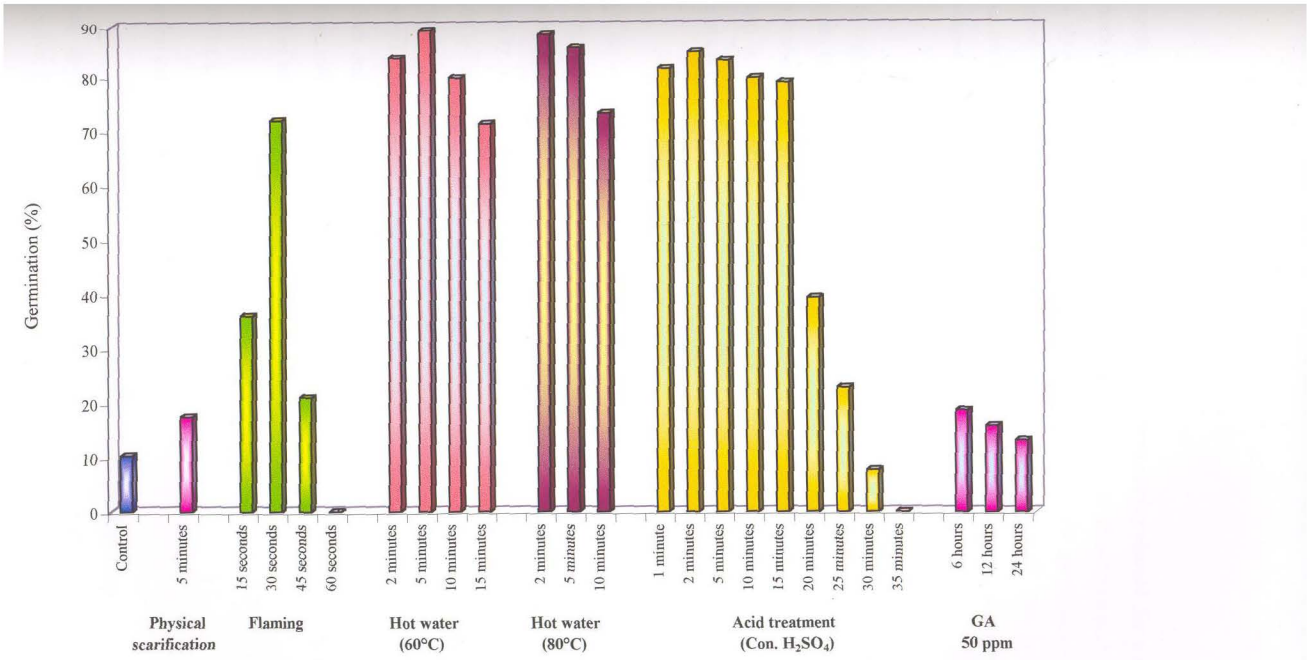


Fig. 12. Effect of different treatments on breaking seed dormancy in *Mimosa invisa*

concentrated sulphuric acid for over 25 minutes without getting charred. Even after 25 minutes of treatment with sulphuric acid, the seeds could give 25 per cent germination. But, upon increasing the period of treatment to 30 minutes, the germination rapidly dropped to 8 per cent and at 35 minutes it was completely charred. This proves the acute hardness of the seed coat which may be one of the major factors contributing to the high dormancy of the seeds.

Hot water treatment at 60°C for five minutes and at 80°C for two minutes gave high germinations on par with concentrated sulphuric acid treatment for two minutes (89.17% and 88.32% respectively) (Table 5). Similar results of improving germination by hot water treatment of seeds were observed by Fowler and Carpanezzi (1998) in *M. bimucronata*, Nascimento *et al.* (1999) in *M. caesalpinifolia* and Sanchez *et al.* (2003) in *M. invisa*.

Seeds are the main propagule of *M. invisa*. In the studies on germination of seeds buried at different depths, germination did not take place when the depth of sowing was more than 5 cm (Table 6). This result indicated that, deep ploughing leading to burial of seeds to deeper soil layers, helped the seeds to extend their longevity, and re-infest the field consequent to deep ploughing at a later stage. The report of Roberts (1964) that deep ploughing decreased seed density in the upper soil layers, lowering germination and increasing density of seeds in the deeper layers, also confirms this observation. This view is supported by reports of Chepil (1946) and Roberts and Feast (1973) that the rate of seed decline on ploughed plots was not uniform with depth of burial, when there is annual soil inversion adjusting the relative depths of seed reserve in soil.

CONTROL METHODS

Physical control

The spiny nature of the weed and the dense thickets made by the plant during its growth makes physical methods of control difficult, laborious and expensive. During the weeding operations, the scratches and lacerations made on the

arms and legs of labourers, caused oedema in some persons. Similar reports were made by Waterhouse and Norris (1987) stating that crops infested with *M. invisa* were difficult to harvest because the thorns punctured and lacerated the legs and hands of workers.

The high efficiency of sickle weeding monthly was overruled by the high cost of labour charges. The labour intensive nature of manual weeding in *M. invisa* was reported by Sankaran (2001) also. Digging and removing once in June/July helped to impart some control; but if the rainy season is prolonged, new flushes germinated lowering the efficiency of the control. It is the variable dormancy and long viability of the buried seeds which came to the soil surface on digging that helped to produce new flushes.

Flaming in summer enhanced germination of seeds probably due to the breaking of dormancy of the seeds in the soil. This is supported by the similar results obtained for germination, when the seeds were subjected to flaming, during the studies on dormancy in *M.invisa* seeds (Table 5 and Fig. 12). Flaming the field also had poor weed control efficiency since the increased germination of seeds lead to greater dry matter production also. Flaming followed by ploughing was effective in controlling *M. invisa* towards the later stages of the plant and was on par with digging and removing twice.

The inability of the stem cuttings to germinate even during the rainy season suggests the efficiency of sickle weeding as a method of control of *M. invisa*. The survival of root clumps through the summer season occurred only when soil moisture was available and when they were not fully upturned during ploughing. Sreenivasan and Sankaran (2000) also reported that *M. invisa* could sprout vigorously from the cut base soon after the onset of monsoon. Similar report was made by Schatz (2001) in *M. pigra*, where physical control methods which cut or broke the plant off at ground level or above, such as slashing or chaining did not kill a high proportion of plants. This indicates the possibility of efficient weed control through deep digging or

ploughing the infested field. Even if some root clumps escaped, two or three years of continuous digging or ploughing may control the infestation of *M. invisa*.

Soil solarisation

The positive effect of solarisation for forty days in controlling *M. invisa* might be because of the very high rise in soil temperature (8 to 10°C) within the five centimeter depth of soil (Table 9). As has been observed in the studies on depth of sowing, most of the germination of *M. invisa* in occurred from the first five centimeter depth of soil. It was also observed from the seed treatment studies to break dormancy, that the seeds of *M. invisa* could tolerate temperature as high as 80°C and also the temperature at flaming. The seeds of *M. invisa* might have germinated under the conditions of high temperature and humidity in solarised soil. After germination, the high temperature and humidity beneath the solarization sheet might have destroyed them before emerging above the soil, when the duration of solarisation was too long, as in 40 day treatment. Similar reports regarding effective control of weeds by solarisation were given by Hosmani and Meti (1993), Kattan and Devay (1995) and Nimje and Agrawal (2002).

M. invisa is a weed inhabiting vast areas like waste lands, roadsides, public places and pastures, where plenty of direct sunlight is available. It is not practically possible to solarise these areas. However, solarisation can be made useful to control germination of *M. invisa* seeds in small compact areas, nursery sites, seed beds or for soils collected from *M. invisa* infested fields.

Chemical control

Pre emergence herbicides

The efficiency of Atrazine @ 3.13 kg ha^{-1} in controlling *M. invisa* was reported by Pornprom *et al.* (2002). However, in this study, it is observed that only 1.5 kg ha^{-1} is required for controlling the germination (Table 10 and Fig. 13,14). Alachlor and Oxyfluorfen were effective in controlling the weed in Thailand

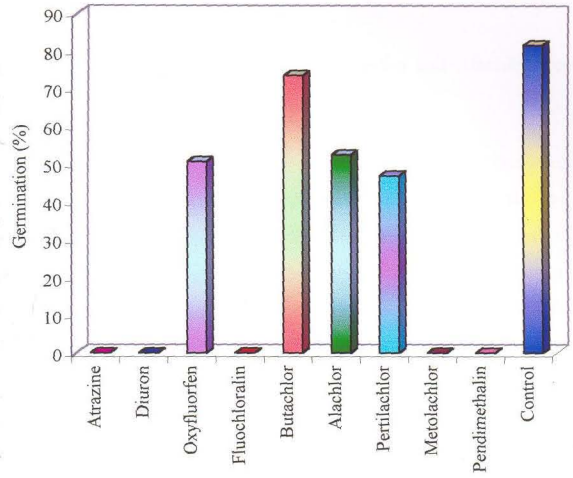


Fig. 13. Effect of pre emergence herbicides on germination and survival of *Mimosa invisa* seedlings (21 DAS)

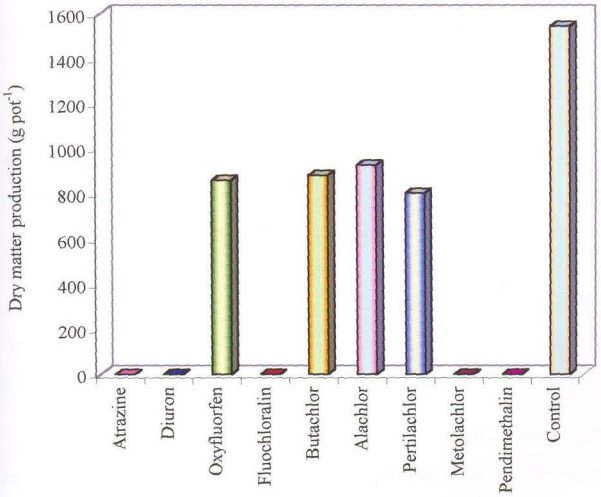


Fig. 14. Effect of pre emergence herbicides on dry matter production of *Mimosa invisa* seedlings (30 DAS)

(Pornprom *et al.*, 2002). But in this study Oxyfluorfen and Alachlor were not very effective in controlling germination of *M. invisa* seeds.

However, in the *M. invisa* infested areas, pre-emergence herbicides may not be very effective because of the variable dormancy of seeds in the soil seed bank and ability of the seeds to germinate in flushes depending on availability of rains. Hence the application of pre-emergence herbicides will have to be repeated many times, to achieve complete control. Moreover, the uneven land surface and the presence of stubbles and plant residues on the soil surface under natural field conditions, reduce the effectiveness of pre emergence herbicides by obstructing the spray fluid from coming in contact with the germinating seeds of *M. invisa.*

Post emergence herbicides

The field experiments conducted to study the efficient post emergence herbicide and its effective dose, proved that glyphosate @ 0.6 kg ha^{-1} is the best. Paraquat and 2,4-D were not effective in controlling *M. invisa* (Table 11 and 12).

The application of glyphosate, a systemic herbicide, at seedling stage (45 days after germination) coincided with the month of July, when monsoon was very active. At this time eventhough the application of glyphosate at low dose (0.2 kg ha^{-1}) could effectively defoliate and dry *M. invisa*, new flushes emerged from the soil seed bank quickly, utilizing the soil moisture availability. As a result, repeated applications of the herbicide, to destroy all the emerging new flushes or till the seed bank is exhausted, is necessary. However, the repeated application of chemicals is not a healthy practice, from the point of view of ecological and environmental safety. The optimum dose of glyphosate for application at seedling stage is 0.6 kg ha^{-1}.

The application of glyphosate at active vegetative stage (100 DAG), @ 0.6 kg ha^{-1} effectively killed the *M. invisa* vegetation within a fortnight (Figs. 15 and 16). This time of application coincided with the retreat of monsoon, and the germination and establishment of new flushes were very poor, due to low availability of moisture in the soil.

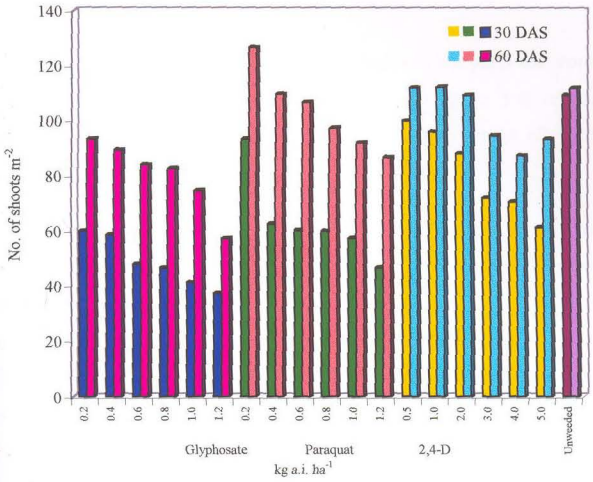


Fig. 15. Effect of post emergence herbicides on the production of new shoots in *Mimosa invisa* at seedling stage

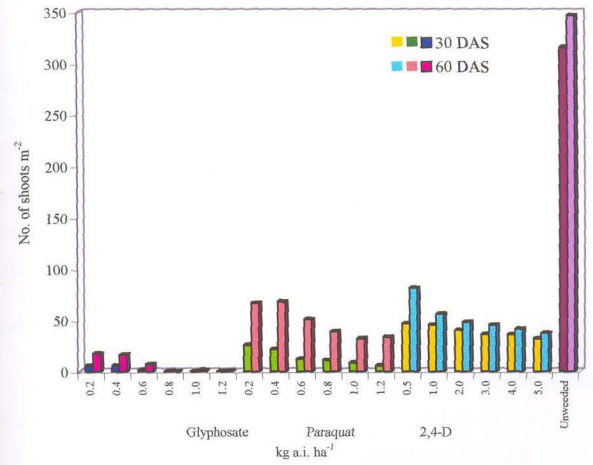


Fig. 16. Effect of post emergence herbicides on the production of new shoots in *Mimosa invisa* at active vegetative stage

Paraquat, being a contact herbicide, killed only the parts that contacted the herbicide. For application at lower doses (0.2 kg to 0.6 kg ha^{-1}) at seedling stage, regrowth from the unaffected portions occurred within two weeks after defoliation. But at higher doses (1 to 1.2 kg ha^{-1}), this regrowth was delayed.

Application of paraquat at active vegetative stage was also ineffective (Fig. 16). The tangled thicket of lush green canopy of *M. invisa* made penetration of chemicals to the lower layers difficult. So a single application of paraquat left green patches of *M. invisa* vegetation below, unsprayed. These patches which escaped the herbicide, put forth regrowth to cover the area quickly (Plate 6). Hence, repeated application of paraquat was necessary. Application of paraquat at high concentration (1 to 1.2 kg ha-^{1}), could effectively control the weed when sprayed with large volume of water enough to penetrate to the lower canopies. This necessitated use of more labour for the spraying (Plate 6). However, such a heavy dose is not advised due to economic and environmental considerations.

Application of 2,4-D was ineffective even at very high dose (4 to 5 kg ha^{-1}), both at seedling and active vegetative stages (Figs. 17 and 18). This result confirms the earlier reports from this university (KAU, 2000). The ineffectiveness of 2,4-D to control *M. invisa* was reported from Brazil also (Lew, 1993). 2,4-D generally used to control broad leaved leaves might be detoxified in *M. invisa* due to some special mechanism. This might have helped the growing tips to recover from the epinasty symptoms and resume growth (Plate 6).

Biological control

All the insect pests listed in Table 13 and depicted in Plate 7 found to feed on *M. invisa* under field conditions, are to be subjected to detailed study to find whether they are polyphagous in nature. The caterpillars of *Euproctis scintillans*, a flower bud feeder of *M. invisa* is reported to be polyphagous, feeding gregariously on kharif pulses, green gram, black gram, red gram and cowpea and also on the oil seed

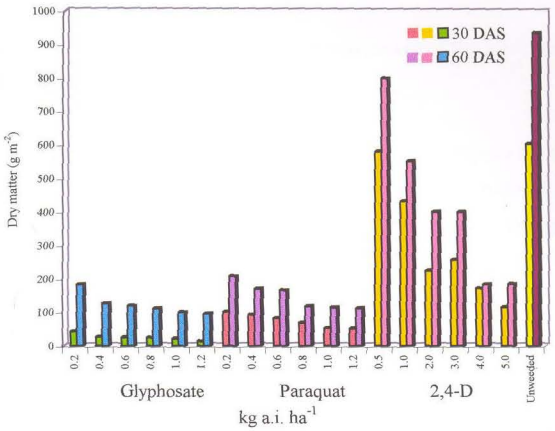


Fig. 17. Effect of post emergence herbicides on the dry matter of *Mimosa invisa* at seedling stage

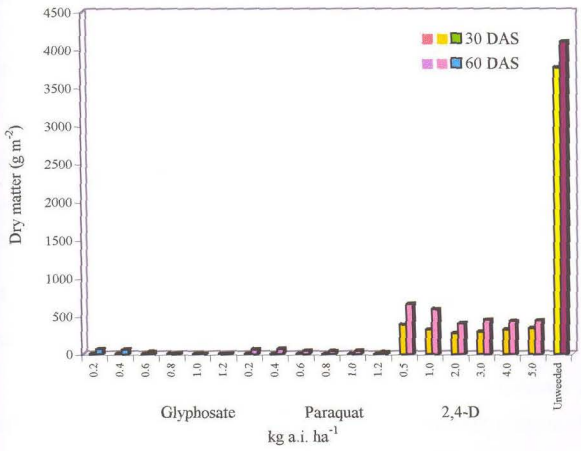


Fig. 18. Effect of post emergence herbicides on the dry matter of *Mimosa invisa* at active vegetative stage

crop, linseed (Nayar *et al.*, 1980). The polyphagous nature of the insect over rules its use as a biocontrol agent.

The host specificity of the newly identified pests *Rapala* sp. (flower bud feeder), *Porthesia* sp. and *Ericeia optature* (defoliators) are to be studied in detail. The larvae of *Porthesia* sp. showed gregarious feeding of the leaves of the plant leaving behind only the midrib of pinnately compound leaves (Table 13 and Plate 8). This pest has significance as a bioagent against *M. invisa*, if its host specificity is proved. The species of family Pyreloidea and *Adoxophyes moderatana* are to be subjected to detailed study.

The bioagents, *Heteropsylla spinulosa*, a psyllid, *Psygida walkeri*, a lepidopteran moth and *Scamurius* sp., a coreid bug, were found very effective against *M. invisa* in Papua New Guinea, Western Samoa, Brazil, Columbia, Queensland, Fiji etc. (Garcia, 1983; Kuniata and Korrowi, 2001). These exotic insects have to be tested for the host specificity, feeding nature, fecundity etc. on *M. invisa* in Kerala before introduction as bioagents for the control of the weed.

The only pathogen identified is an *Alternaria* sp., producing spots on the mature stem (Plate 9). Study should be conducted to identify the species of the pathogen, its host specificity and use as bioagent. Also a detailed survey is to be conducted for identification of other pathogens if any, for the weed.

Utility of *M. invisa*

Green manure crop

The high rate of dry matter accumulation, increased biomass production per unit area, rapid rate of litter decomposition and high nutrient content of the plant, combined with nitrogen fixing capacity, provides ample scope for utilising *M. invisa* as a green manure crop.

The biomass production per plant (3.6 kg plant^{-1}) and per unit area (1.80 kg m^{-2}) reported for *M. invisa* are high values, compared to other green manure

crops (Table 14). *Mimosa tenuiflora, M. scabrella* and *M. caesalpinifolia* and other members of family mimosaceae also are reported to have high biomass production (Dias *et al.*, 1995; Bertalot *et al.*, 1998; Liu *et al.*, 1999; Andrade *et al.*, 2001).

The significantly high green matter production by *M. invisa* compared to other leguminous cover crops is supported by reports of Sannamarappa (1987); Kaufusi and Ashgar (1990) and Tiraa and Ashgar (1990). The utility of *M. invisa* as an efficient green manure plants, due to the high biomass production and nitrogen fixing capacity, are reported by Suwanarit *et al.* (1998) in maize, Mohankumar (1996) in coffee and Thomas *et al.* (2001) in coconut. Thomas and Santharam (1984) supported the ability of *M. invisa* to produce high quantity of green manure (1.67 kg m^{-2}) in coconut basins on par with *Peuraria phaseoloides* (1.91 kg m^{-2}).

The dry matter accumulation and growth pattern of *M. invisa* followed a growth curve almost similar to sigmoid curve (Table 15 and Fig. 19). The first four weeks of growth typically represented the lag phase of the sigmoid curve with only about 50 g accumulation of dry matter per plant. Thereafter upto 22^{nd} week there was a constant and rapid increase in dry matter production by the plant, accumulating about 3.625 kg $plant^{-1}$. This log phase of growth ends when the plant completes its active vegetative growth phase. At this stage, flower bud initiation might have started and the plant prepares to enter the reproductive phase. Translocation of dry matter for the production of reproductive structures like flowers pods and seeds lead to a fall in cumulative dry matter of the plant. Marambe *et al.* (2001) has also reported that the relative growth rate increased until the onset of flowers and then decreased for *M. pigra*, a member of family Mimosaceae. The flowering coincided with the onset in of summer season, and scarcity of water in soil caused reduction in growth, and drying of plant.

The rate of decomposition of the litter (fresh matter) in soil was very rapid in the first fortnight accounting to 59.8 per cent of the material getting decomposed (Table 16 and Fig. 20). This rapid rate of decomposition (within three months, 90 per cent of the litter and within one year 99.65 per cent of material was decomposed),

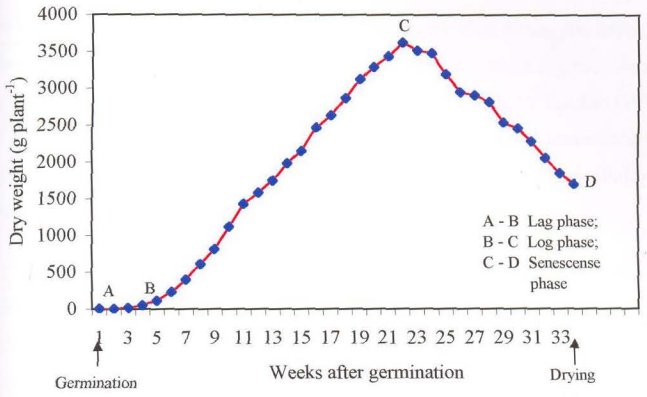


Fig. 19. Dry matter accumulation in *Mimosa invisa*

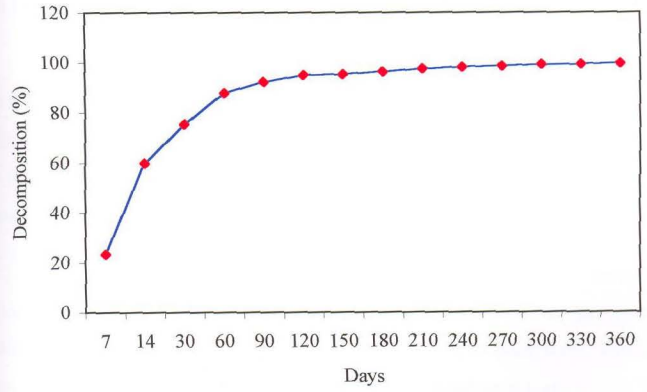


Fig. 20. Cumulative decomposition of the litter of *Mimosa invisa*

makes it an ideal green manure crop. The rapid decomposition during the initial stages (14 days) is attributed to the favourable moisture and temperature regimes during the period when litter bags were kept for decomposition. According to Tandon (1994) the water soluble fraction in the plant material decomposes rapidly, immediately after incorporation and the remaining portion containing cellulose, hemicellulose and lignin, the most resistant fraction, decomposes slowly over a longer period.

After 180 days, the decomposition rate was very slow. By the end of the year, 99.65 per cent of the material decomposed. Similar decomposition patterns with initial rapid phase followed by slower phase, and then a very slow phase was obtained for *Acacia aculiformis,* where 90 per cent of litter disappeared in six months and residual mass remained for 16 months (Kunhamu *et al.*, 1994). Abraham (1999) also reported similar trend in litter decomposition of *Mikania micrantha.* The rapid rate of decomposition of litter and speedy addition of nutrients to the soil makes *M. invisa* useful as a soil-enricher, in the recovery of degraded soils. The use of *M. caesalpinifolia,* a shrub, for the recovery of degraded land has been reported from Brazil by Andrade *et al.* (2001).

The nutrient composition of both spined and spineless types of *M. invisa* showed high Nitrogen content and moderate to low contents of P, Ca, Mg, S, Fe, Mn and Cu. The very high Zn content in both types in the range 90 to 100 ppm, which is about 9 to 10 times higher than the Zn content of ordinary green manure crops, is a striking feature of *M. invisa* (Table 17).

The low content of most nutrients other than N makes *M. invisa* a low depletor of soil nutrients compared to other commonly used cover crops. Hence it is suited as a good green manure or cover crop for nitrogen poor soils. The high N content of the plant and the N fixing capacity of the plant as a legume, are the two favourable aspects for considering *M. invisa* as a good green manure. The nutrient contents of the plant obtained in the study are similar to those reported for *M. invisa* by Thomas (1995).

The very high number of earthworm castings observed beneath the *M. invisa* canopy could be attributed to the cool and moist, microclimate beneath the lush green growth. This observation is similar to that observed by Watanabe (1975) in megascoloid earthworms. The earthworms extracted from the site were identified as *Megascolex mauritiani.* These earth worms were found to burrow deep into the soil (hypogaeic) and feed on organic matter in the soil only. They did not directly feed on the organic matter supplied for decomposition. Hence in the trial, the worms tried to escape through the drainage hole of the earthern pot used for composting. When this hole was sealed most of the worms died, instead of multiplying and only very few remained.

Composting of *M. invisa*, alone and with banana pseudostem, using *M. mauritiani* was not successful and the quality of compost was very poor (Table 18 and 19). *E. foetida* produced good quality compost from *M. invisa* alone and with *M. invisa* + Banana pseudostem (1:1) mixture. Thus, from this study it can be concluded that the high population of *M. mauritiani* seen in the soil of *M. invisa* infested field had no influence on the decomposition of its litter. The congenial conditions of moisture availability created in the media for composting, due to the presence of banana pseudostem, which is a succulent substrate, could be the reason for the rapid multiplication of the earthworms. This also lead to the rapid and perfect grinding of the substrate, producing improved quality vermicompost with desirable physical and nutritional qualities. The enhancement of nutrient quality through vermicomposting was reported earlier by Hand *et al.* (1988), Rajalekshmi (1996), Pushpa (1996) and Sharma *et al.* (2004).

The vermicompost containing *M. invisa* and banana pseudostem in the ratio 1:1 composted by *Eisenia foetida* gave good response by the test crop Amaranthus, with regard to height, number of leaves and fresh weight of plant (Table 20). This is because of the improvement in the total nutrient content as well as increased availability of nutrients due to composting. The positive response by amaranthus to the application of *M. invisa* vermicompost is supported by the response of different crops to vermicompost application. Supporting results were obtained in

soyabean (Shuxin *et al.*, 1991), paddy (Janaki and Hari, 1997), cowpea and gardenpea (Reddy *et al.*, 1998), brinjal (Karmachandran, 2003), chilli (Yadav and Vijayakumari, 2003) and amaranthus (Preetha, 2003).

Harmful effects of *M. invisa*

Biodiversity of native flora

Mimosa invisa has a smothering effect on the native flora of the infested area and a progressive influence in reducing the biodiversity of the area over the years of infestation. The smothering efficiency of *M. invisa* increased from 14.08 per cent in the first year of infestation to 38.55 per cent in the third year (Table 22). This is because of the ability of *M. invisa* to compete with native flora and gradually reduce the biodiversity. This will lead to take over of the area by *M. invisa*, if the infestation is left uninterrupted. The smothering effect of *M. invisa* in teak plantations was reported by Sankaran (2001). He also reported that *M. invisa* is found to over grow and exceed *Mikania micrantha* in forest plantations.

The smothering effect of *M. invisa* was more severe on the grasses which are heliophytic, but are not tall enough to compete with *M. invisa*. The proportion of grasses reduced by over 21 per cent during the three years of *M. invisa* infestation (Table 21 and Fig. 6, 21). Such suppression of grass weeds due to *M. invisa* encroachment is reported by Vasu (2003) in Kaziranga National Park, Assam, threatening the availability of forage for single horned rhinoceros.

Allelopathic effects

Results of the studies on the effect of *M. invisa* applied as mulch or incorporation in soil or as water extract, on the germination of rice and cowpea seeds indicate that in all the three methods of application the negative effect on seed germination was more on cowpea than on rice (Tables 23, 24 and Fig. 7). The delay in the germination was pronounced in rice. In all the three methods and for both crops in

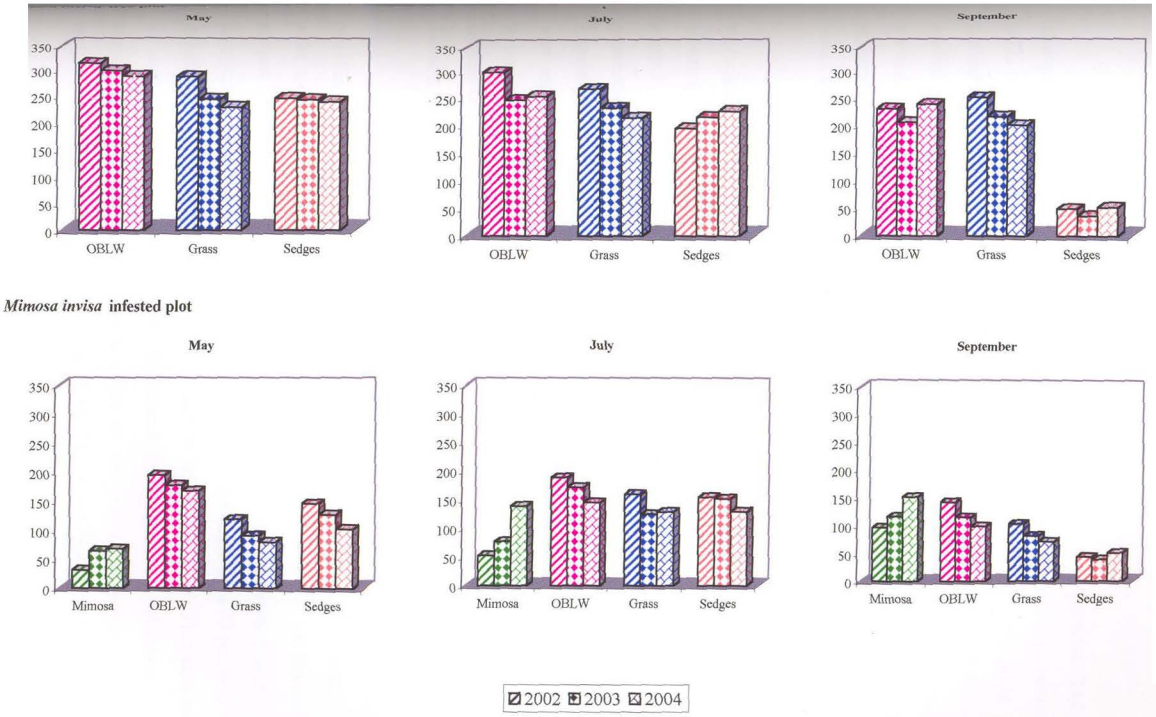


Fig. 21. Effect of infestation of *Mimosa invisa* on the population of other weeds of the area over three years

general, the allelopathic effect increased with increase in the rate of application of *M. invisa.*

Among the methods of application of *M. invisa,* incorporation had lesser allelopathic effects compared to mulching and water extracts. This may be because the seeds of rice and cowpea came in contact with only a limited quantity of *M. invisa* applied in the upper soil layers. But in mulching, the entire quantity of *M. invisa* was applied on the soil surface whose leachates, containing the allelochemicals, probably washed down through the soil delaying or inhibiting the germination. Similar report of inhibition of germination of rice seeds due to application of 5 tons ha^{-1} of subabul leaves in paddy fields was made by Prathiban and Kathiresan (2002).

When the water extract was applied to the soil, availability of allelochemicals directly to the seeds, inhibited or delayed the germination. The effective inhibition of germination by the water extracts containing allelochemicals of subabul was reported by John and Narwal (2003). Also the inhibitory effect on germination of rice and cowpea seeds was found to increase with increase in the concentration of water extracts from 2 per cent to 10 per cent. Similar observations were made by Qasem and Irmaileh (1985) in wheat using the extracts of *Salvia syriaca,* by Hoque *et al.* (2003) in bengal gram and green gram using *Chromolaena odorata* extracts and by Gupta and Vimala (2003) in *Tagetes erectus* using extracts of *Lantana camara.*

The height of the plant, number of leaves per plant and number of tillers or branches per plant were adversely affected by *M. invisa* application as mulch or as water extract. On the contrary, incorporation had a positive effect on the rice and cowpea growth, may be because of its favourable effect as a green manure when incorporated. As observed in litter decomposition studies more than 75 per cent of the material incorporated was decomposed within the first three weeks. This accounts for the positive effect of incorporated *M. invisa* as a green manure. Application as water extract had more significant negative effect on all growth parameters of rice and cowpea seedlings compared to mulching (Table 25, 26 and Figs. 8, 9, 10).

According to John and Narwal (2003), mimosine, an allelochemical in subabul, may be attributed as the reason for the negative effect on germination and growth parameters of plants. The same allelochemical (mimosine) present in *M. invisa* can be attributed as the cause for the allelopathic effects of the plant.

Mimosine content

The mimosine content was highest (9.22%) at 90 days after germination (active vegetative stage) of *M. invisa* (Table 27 and Fig. 22). This is very high compared to the 3.0 per cent mimosine content in subabul at active vegetative stage as reported by Prabaharan (1995). The mimosine content gradually increased from germination upto active vegetative stage and dropped at flowering. The highest mimosine content (10.4%) was found in the growing tips of the plant at active vegetative stage. The goats and cattle grazing on pastures infested with *M. invisa* are tempted to feed on the lush green growing tips. If they feed in large quantities, the mimosine toxicity may lead to death of the animal.

The *M. pudica* plants were found to contain 2.85 per cent mimosine (Table 29), which is in contrast to the earlier reports of Brewbaker and Hylin (1965) stating the absence of mimosine in *M. pudica*. Since *M. pudica* is relished by goats and fed upon by them, without developing any toxicity symptom, it may be assumed that mimosine content in *M. pudica* is below the toxic level. Immature leaves and seeds of leucaena is found to contain 10 to 12 per cent mimosine which is toxic to cattle, as reported earlier by Jones (1979).

Ensiling has been found to be an effective method for reducing the mimosine content and thereby lowering the toxicity problems due to *M. invisa*. It is found that the green pastures which receive bright sunlight are the areas of rapid infestation of the heliophyte, *M. invisa,* as is observed in the grass lands of Kazaringa National Park, which is famous as 'world heritage site of one-horned rhino' (Vattakavan *et al.*, 2004). From the present study it is evident that the *M. invisa* infested areas of the pastures need not be discarded, if the percentage of infestation by *M. invisa* is less than 50 per cent. It is evident that a 40 per cent reduction in mimosine content could be obtained by ensiling for 60 days (Table 30 and Fig. 25).

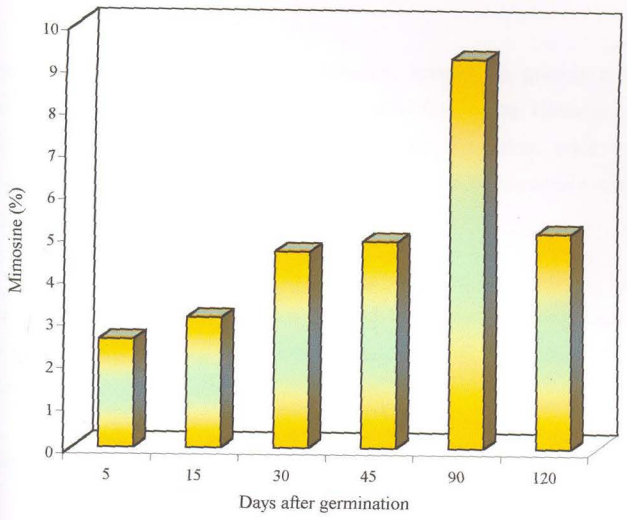


Fig. 22. Mimosine content in *Mimosa invisa* at different growth stages

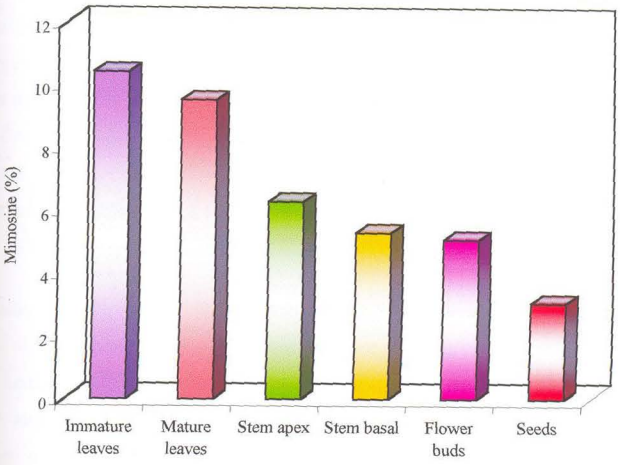


Fig. 23. Mimosine content in *Mimosa invisa* in different plant parts

Therefore during the early stages of infestation, eventhough grazing cannot be allowed, the admixed fodder can be ensiled and used for feeding. However, suitable control measures should be adopted to contain the infestation, since a higher proportion of admixture of *M. invisa* may render the fodder unsuitable, even after ensiling.

A reduction in mimosine content in *Leuceana leucocephala* by about 57.2 per cent due to ensiling has been reported by James and Gangadevi (1990). Similar reports of ensiling has been made by Lin *et al.* (1985), Khatta *et al.*, (1987) and Srinivasulu *et al.* (2001) also.

Mimosine toxicity in animals

An experiment was conducted in rabbits to evaluate the nature of toxicity of *M. invisa* in animals, and to assess whether ensiling and powdering after drying, would reduce the toxic effects of mimosine on animals (Plate 10). The observations made in this experiment, and the histopathological studies undoubtedly proved that the toxic principle present in the plant is both nephrotoxic and hepatotoxic (Plate11). Reports of mimosine toxicity were made in different animals by several scientists. In calves the toxicity due to *M. invisa* was reported by Rajan *et al.* (1986), in heifer by Alex *et al.* (1991), in camels by Li *et al.* (1996), in cattle by Anderson *et al.* (2001) and in sheep by Mishra *et al.* (2002).

It is observed that the process of ensiling caused a 40 to 46 per cent detoxification (Table 30 and Fig. 25), and the animals which were fed with the ensiled material did not develop any gross or microscopical lesions in any of the organs. So it can be assumed that the process of ensiling caused a considerable reduction in the toxicity, and at a lower concentration, it would be well tolerated by the animals. It has also been observed that the dried and powdered plant, though initially lowered the weight and produced mild changes in the kidney and liver of rabbits, the animals recovered later. This suggests the suitability of drying *M. invisa* as a method to lower mimosine toxicity.

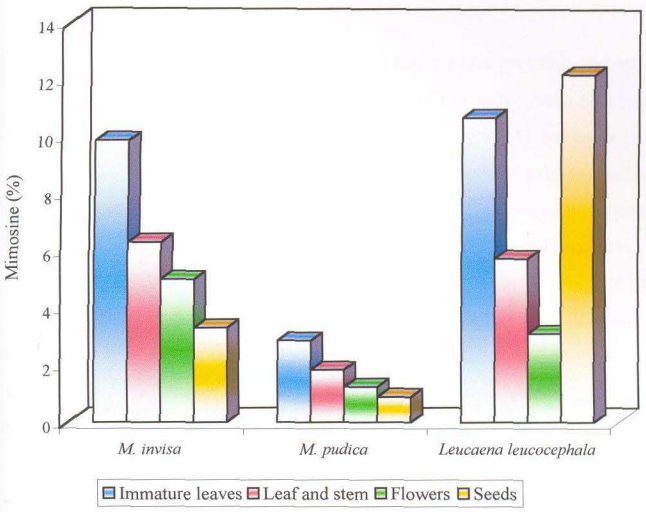


Fig. 24. Mimosine content in common mimosaceous plants

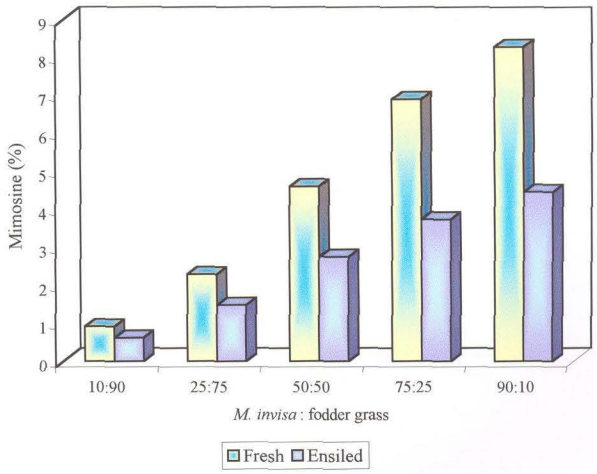


Fig. 25. Mimosine content in fresh and ensiled *Mimosa invisa*

Results of this experiment suggest that this rapidly growing and spreading plant, which has become a problem in the fields, could be effectively utilized as an adjunct to green fodder in animal nutrition, if the admixture of *M. invisa* is less than 50 per cent. However, the toxicity is to be removed by way of proper ensiling and drying processes as has been observed in this experiment .Many earlier experiments on subabul (Lin *et al.*, 1985; Khatta *et al.,* 1987; James and Gangadevi, 1990; Srinivasulu *et al.*, 2000) also confirm this observation. It is therefore essential to carry out planned and controlled experiments, under standard conditions in large and small ruminants, to see whether the effects are the same as in rabbits (non ruminant) and to prove the suitability of the processed plant as an adjunct to green fodder in their nutrition.

The study has clearly shown that *M. invisa* is a fast spreading introduced weed which is highly competitive with the native plants, having allelopathic effects on other plants and capable of effecting the biodiversity of the areas where it infests. It is toxic to the animals feeding on it, due to the presence of a toxic alkaloid mimosine, and so ways to tackle the problem are also discussed. The results of the study has brought out effective strategies for managing the weed, including the possibility of utilizing the natural enemies of the weed. The weed offers scope for utilization as a good plant for restoring soil fertility by way of using as green manure and vermi compost.

Summary

SUMMARY

Mimosa invisa Martius *ex.* Colla, a native of new world tropics was introduced to Kerala in 1964. It is now a problem weed of both agricultural and non agricultural/ waste lands. Being a comparatively new introduction, no systematic and comprehensive work has been undertaken to study the problems associated with the weed and strategies to manage it. Hence, the project entitled "Biology and management of *Mimosa invisa* Mart in Kerala" was taken up at the College of Horticulture, Vellanikkara during 2001-2004 with the intention of studying the following aspects:

1. Distribution and severity of infestation of *M. invisa* in Kerala
2. Biology and ecology of the plant
3. Efficiency of different control methods
4. Utility of the plant and
5. Harmful effects of *M. invisa*

The study was conducted in five parts as briefed below:

Distribution

A survey was conducted by travelling along the major terrestrial routes to study the extent of spread and intensity of *M. invisa* in different parts of Kerala. The severity of infestation of the weed in agricultural and non agricultural areas was noted and intensity recorded. After its first introduction in Changanachery in 1964, it has spread to the neighbouring districts causing problem. The infestation was severe along the coastal areas of Kerala with medium to severe infestation in the coastal districts like Kollam, Kottayam, Ernakulam, Alappuzha, Thrissur and Kozhikode. It had also spread to high altitudes of Pathanamthitta, Idukki, Palghat and Malappuram, where sporadic to medium infestations were noted.

During the survey based on morphological characters, two types of *M. invisa*, spined and spineless, were noticed. But the spined type was found to be predominant and more invasive compared to the spineless type in all the areas

observed. Also, based on stem colour three types - red or purple stemmed, green stemmed and a type with red colouration at the basal part and green towards the tip, were noticed.

M. invisa was strongly heliophytic and could climb on any support available - dead (stay wire, electric posts, sign boards, walls etc.) or alive (tapioca, banana, polyalthia, jack tree etc.). The infestation was severe in open sites like road sides, banks of irrigation cum drainage channels, and in neglected areas.

Biology and Ecology

Life cycle from germination to drying of the plant was studied by observing time periods for the seedling, active vegetative, flowering, seed set, seed dehiscence and drying stages of the plant in the natural field condition. Also, the phenology of the plant was studied by raising individual plants during the same period. The phenological observations revealed that November to January is the seed set and dehiscence period for naturally growing *M. invisa.* It took 65 to 70 days from first appearance of flower buds to seed dehiscence. The plant usually grew as a thick bush, but if a support was available it could climb on it.

The mean seed production potential of individually raised plants was more than 72,500 seeds per plant, with an average thousand seed weight of 6.88 g. The seeds of *M. invisa* could retain 45 per cent germination capacity even after a period of 36 months when stored in dry sand. Only about 10 per cent loss of germination was observed in the first year of storage, 13 per cent during the second year and 23 per cent during the third year.

The effect of different treatments on breaking the dormancy of *M. invisa* seeds was studied using acid, flame, hot water, GA and physical methods. Hot water treatment at 60°C for five minutes and at 80°C for two minutes gave the highest germination (89%). Smearing the seeds of *M. invisa* with concentrated H_2SO_4 for two minutes resulted in a high germination of 84.67 per cent. The hard seed coat could tolerate concentrated sulphuric acid for upto 30 minutes without getting charred.

Flaming the seeds for 30 seconds could enhance the germination by over 50 per cent which explains the increased emergence of *M. invisa* seedlings observed after the first monsoon showers in the infested areas burned in the preceding summer. Gibberellic acid treatment and physical scarification were not effective in breaking dormancy.

The most important propagation material is the seed. Rooted clumps rarely put forth new growth under moist situations. The seeds placed at more that five centi metre depth in soil could not germinate, indicating that deep ploughing would only help to bury the seeds of *M. invisa* in the soil. The normal time of emergence of seedlings above the soil was within four to five days after receipt of a soaking monsoon shower. The maximum number of seedlings germinated in the first flush, and this is considered the peak period of germination. There was progressive decrease in the number of seedlings emerging in the subsequent flushes. Stem cuttings could not produce any sprouts. The rooted clumps could survive the hot summer and produce sprouts if a moist condition was available in the soil throughout the summer.

Control methods

The efficiency of different physical methods of control of *M. invisa* was evaluated for one year in trials at two locations from May 2002. Screening of pre emergence herbicides for controlling germination of seeds was done in pots and that of post emergence herbicides was conducted in the field at two sites. The effect of soil solarisation on the germination and growth of *M. invisa* was also studied under field conditions.

All the six different physical methods of control tested significantly reduced the production of new shoots as well as dry matter production per unit area compared to the unweeded control. At vegetative stage of the plant (May to August) sickle weeding at monthly intervals was the best, and was on par with digging and removing the plant twice, with regard to number of new shoots and dry matter produced per square metre. But both methods were not cost effective. Towards the flowering and seed setting stage, monthly and bimonthly sickle weeding were the best methods of control.

Among the pre emergence herbicides tested, Atrazine, Diuron, Fluchloralin, Metolachlor and Pendimethalin were very effective in destroying the *M. invisa* seedlings within seven days after germination. Alachlor, Oxyfluorfen, Butachlor and Pretilachlor were not effective in controlling the weed.

Three popular post emergence herbicides, Glyphosate, Paraquat and 2,4-D were evaluated at different doses, during seedling stage and active vegetative stage of *M. invisa*. Glyphosate, a systemic herbicide, applied at 0.6 kg ha^{-1} during active vegetative stage (90 to 100 days after germination) could effectively and economically control *M. invisa*. Paraquat, a contact herbicide, could defoliate the existing growth but re-growth occurred easily from the lower portions which escaped the herbicide. 2,4-D was ineffective for controlling *M. invisa*, even at a very high dose of 5 kg ha^{-1}. Growing tips of *M. invisa* were able to recover quickly from the epinasty symptoms induced by 2,4-D. Spraying at seedling stage of *M. invisa* allowed germination of new flushes since the monsoon rains were available in June-July (45 days after germination). At active vegetative stage, i.e., in the month of August, the application could control the existing vegetation. At the same time germination of further flushes did not occur due to retreat of the monsoon and less availability of moisture in the upper soil layers.

During the survey, two flower bud and flower feeders and four defoliators belonging to the order Lepidoptera were identified. Also a pathogen belonging to genus *Alternaria* was identified. The host specificity of these pests is to be studied in detail for utilization as biocontrol agents.

Soil solarisation for 30 to 40 days could drastically reduce the viability of the *M. invisa* seeds upto a depth of 5 cm in soil, thereby preventing germination. This method of control is suited for small compact areas such as nursery beds.

Uses

Utilisation of the plant as a green manure or cover crop has been substantiated by the high rate of biomass production and dry matter accumulation both

on unit area basis (1.80 kg m^{-2}) and per plant basis (1.83 kg $plant^{-1}$) at active vegetative stage, which is the most appropriate stage for incorporation and decomposition in soil.

The rate of decomposition of the litter (fresh matter) in soil was very rapid in the first fortnight, accounting for 59.8 per cent. This rapid rate of decomposition combined with the fact that within three months, 90 per cent of the litter and within one year, 99.65 per cent of material decomposed makes its use as a green manure crop acceptable. It is a rich source of all major and minor nutrients and is an efficient nitrogen fixing legume. The content of Zinc (90-100 ppm) was found to be higher than common green manure crops. The green material of *M. invisa* is a good substrate for vermicomposting when mixed with banana pseudostem in 1:1 ratio and *Eisenia foetida* used as the agent for vermicomposting. This vermicompost gave significant positive effects on the growth parameters (height of the plant and number of leaves per plant) and yield of amaranthus.

Harmful effects

The infestation and spread of *M. invisa* in new areas proved to affect the biodiversity adversely. The plant had a smothering effect on the native flora, with about 19 per cent increase in its population each year. Over the three years of observation, smothering efficiency of *M. invisa* increased from 14.08 per cent in first year of infestation to 38.55 per cent by the third year. This proves that the *M. invisa* plant infestation if left uninterrupted, can smother all types of vegetation (broad leaved, grasses or sedges) in a few years.

Application of *M. invisa* as mulch or water extract had noticeable allelopathic effects on the germination of rice (cereal) and cowpea (legume), than incorporation. The plant when used for incorporation, delayed germination initially in rice and cowpea by two to four days compared to control. The allelopathic effect of the plant was more severe, on both germination and growth parameters of cowpea than rice. The inhibitory effect of water extract was pronounced on growth in both cowpea and rice at all concentrations from 2 per cent to 10 per cent when compared to control.

The toxic non protein plant amino acid mimosine, in the plant was very high (9.22%) compared to 2.85 per cent in *M. pudica*. The immature growing tips of *M. invisa* contained highest mimosine (10.4%) with lowest in seeds (3.1%). The reports of death of cattle and goat, feeding on fresh green *M. invisa* may be due to the toxic principle present in it. Ensiling is an effective method for reducing the mimosine content, thereby lowering the toxicity problems associated with the plant. When there is less than 50 per cent admixture of *M. invisa* in the fodder grass, it can be cut and ensiled as such for 60 days. This could effectively lower the mimosine content by 40 per cent to 46 per cent.

Studies conducted with rabbit as test animal, showed that feeding *M. invisa* ensiled with fodder in different proportions for 60 days influenced the expression of toxicity symptoms. Rapid reduction in weight, sluggishness, alopecia, diarrhoea, damage to internal organs, mainly liver and kidney were the main manifestations of toxicity. It was observed that admixture of less than 50 per cent with *M. invisa* in pasture grass was not toxic to animals, if fed after cutting and ensiling for 60 days. The histopathological studies revealed and established that the mimosine is hepatotoxic and nephrotoxic.

Future line of work

In this investigation, six insects were found to feed on *M. invisa* and a fungus was found to cause infection (spots) on the plant. Further detailed survey would help to identify more number of insects/disease organisms. The scope for releasing some of the pests as biological agents for the control of *M. invisa* has to be considered. For this, studies on host specificity and damage potential of the insect pests and pathogens are to be taken up. From the literature, it can be seen that liberation of exotic organisms like *Heteropsylla spinulosa* and *Scamurius* sp. from Brazil was successful as bioagents against *M. invisa* in Queensland, Papua New Guinea, Pohnpei and Western Samoa. Attempts should be made to evaluate the scope for their use as bioagents in our country also in suppressing *M. invisa*.

Studies on toxicity of mimosine in animals were conducted with rabbit, a non-ruminant, as the test animal. Further studies are to be conducted with ruminants like cattle, goat, etc., as these are the animals more likely to feed on *M. invisa* growing as admixture with fodder grass.

The present study has given some indication on reducing the mimosine content by ensiling, drying, etc. Further detailed studies on reducing the mimosine toxicity in *M. invisa* contaminated fodder are also necessary.

M. invisa is a leguminous plant having the capacity for high dry matter production as well as effective nitrogen fixation. Utility of *M. invisa*, in comparison with other cover crops, for conserving and building up degraded and eroded lands, is also worth studying.

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* Originals not seen

Appendices

APPENDIX-I

List of species under the genus *Mimosa* and their distribution

Sl. No.	Mimosa species	Countries
1)	*Mimosa caesalpinifolia*	Brazil, USA
2)	*M. dalnoides*	Brazil
3)	*M. aceiba*	Brazil
4)	*M. tenuiflora*	Latin America (Costarica), Mexico
5)	*M. scrabrella*	Brazil
6)	*M. bimucronata*	Brazil
7)	*M. sensibilis*	Brazil
8)	*M. procurrens*	Brazil
9)	*M. invisa*	Philippines, Mexico, Central America, China, Thailand, Australia, Malaysia, India
10)	*M. pigra*	Australia, Argentina, Mexico, Egypt, Sweden, Brazil, Malaysia
11)	*M. flocculosa*	Brazil
12)	*M. pudica*	India, China, Taiwan, Brazil, USA, Java, Ghana, Malaysia
13)	*M. affinis*	Mexico
14)	*M. hamata*	Brazil, India, Pakistan
15)	*M. ophthalmecentra*	Brazil
16)	*M. pilulifora*	Brazil
17)	*M. speciosa*	Italy, USA, Indonesia
18)	*M. hostilia*	Brazil
19)	*M. arenosa*	Brazil
20)	*M. laxiflora*	Brazil
21)	*M. naguirei*	Mexico

Source: CAB Abstr. 1996/07 - 2004/07

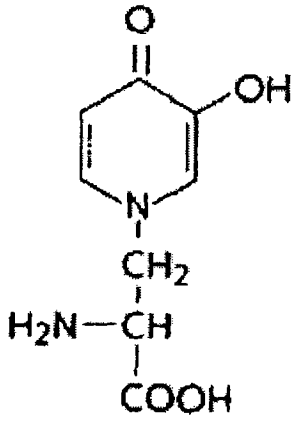
APPENDIX-II

Details of herbicides used for the trials

Common name	Trade name	Formulation	Manufacturing company
Pre emergence herbicides			
Atrazine	Atrataf	50% WP	Rallis India Ltd.
Diuron	Klass	80% WP	Aventis Crop Science India Ltd.
Oxyflourfen	Oxygold	23.5% EC	Indofill Chemicals Company
Fluochloralin	Basalin	45% EC	BASF India Ltd.
Butachlor	Machete	50% EC	Monsanto Chemicals India Ltd.
Alachlor	Lasso	50% EC	Monsanto Chemicals India Ltd.
Pretilachlor	Rifit	50% EC	Hindustan Ciba Giegy Ltd.
Metolachlor	Dual	50% EC	Hindustan Ciba Giegy Ltd.
Pendimethalin	Stomp	30% EC	Cynamid Agro Ltd.
Post emergence herbicides			
2,4-D sodium salt	Kem-D	80% WSP	Suvo Chem Industries Pvt. Ltd.
Paraquat	Gramoxone	24% SL	Syngenta Crop Protection Pvt. Ltd.
Glyphosate	Roundup	41% WSL	Monsanto Chemicals India Ltd.

APPENDIX-III

Details of the toxic, non protein plant amino acid, mimosine present in *Mimosa invisa*

Molecular formula	:	$C_8H_{10}N_2O_4$
Molecular weight	:	198.18
Appearance in pure form	:	Brownish crystalline powder
Melting point	:	225 to 228°C
IUPAC name	:	(β - N - 3 hydroxy - 4 - pyridine) - α amino propionic acid
Structural formula		

Source: Jones, R.J. 1979. *World Anim. Rev.* 31: 13-23

BIOLOGY AND MANAGEMENT OF *Mimosa invisa* Mart. IN KERALA

By

JAYASREE, P.K.

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
K.A.U. P.O., THRISSUR 680 656
KERALA, INDIA

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ABSTRACT

Mimosa invisa Mart. *ex*. Colla, called giant sensitive plant (Anathottavodi or Padayincha in Malayalam), a native of Tropical America, introduced in Kerala in 1964, is now a problem to both cultivated and wastelands. Being a comparatively new introduction, no systematic and comprehensive work has been undertaken to study the problems associated with the weed and strategies to manage it. Hence, the project entitled "Biology and management of *Mimosa invisa* Mart in Kerala" was taken up at the College of Horticulture, Vellanikkara during 2001-2004 with the intention to study the distribution and severity of infestation and biology of the plant, the efficiency of different control methods, utility of the plant and its harmful effects.

A survey revealed medium to severe infestation in Kollam, Kottayam, Ernakulam, Alappuzha, Thrissur and Kozhikode districts. It had also spread to high altitude regions in Pathanamthitta, Idukki, Palghat and Malappuram where sporadic to medium infestations were noted.

During the survey, based on morphological characters, two types of *M. invisa*, spined and spineless, were noticed. The spined type was found to be predominant and more invasive compared to the spineless type in all the areas observed. *M. invisa* is strongly heliophytic and could climb on any support available - dead (stay wire, electric posts, sign boards, walls etc.) or alive (tapioca, banana, polyalthia, jack tree etc.). The infestation was severe in open sites like road sides, banks of irrigation cum drainage channels, and in neglected areas.

The important growth stages of the plant included seedling, active vegetative, flowering, seed set and dehiscence stages. The duration from flower bud appearance to pod dehiscence was 50-60 days. The seed production potential of a single plant was 72,650 seeds. The germination percentage decreased with time. Still the seeds could retain more than 45 per cent germination even after three years. High dormancy was exhibited by the seed. Hot water treatment at 60°C for five minutes, 80°C for two minutes or scarification with concentrated sulphuric acid for upto

15 minutes gave good germination above 85 per cent. Flaming for 30 seconds was also equally efficient.

Seeds are the main propagule for *M. invisa*. It is not propagated by stem cuttings. Root clumps could survive the summer months if soil moisture was available.

Sickle weeding at monthly interval gave the best control, followed by digging and removing the plant twice, and sickle weeding bimonthly, which were on par. Although production of new shoots and dry matter per square metre were effectively controlled by these treatments, they were not cost effective.

In nursery beds and small compact areas where high value crops are raised, or for soils collected from *M. invisa* infested fields, the solarisation for 40 days could effectively prevent the establishment of *M. invisa* seedlings.

Among the pre emergence herbicides, Atrazine, Diuron, Fluocloralin, Metolaclor and Pendimethalin gave almost 100 per cent control. These herbicides did not prevent the emergence of seedlings, but killed them within few days after emergence.

Glyphosate was the most effective post emergence herbicide against *M. invisa* and the optimum dose was found to be 0.6 kg ha^{-1}. 2,4-D was not at all effective even at high dose of 5 kg ha^{-1}. The growing tips of *M. invisa* were found to recover from epinasty caused by 2,4-D within a few days. Paraquat could completely defoliate the plants, but the lower canopies of the thick growth of the weed escaped the herbicide and regrowth was observed within weeks. Application of post emergence herbicides at active vegetative stage (100 days after germination) was more effective compared to the application at seedling stage (45 days after germination).

The survey on insect pests and diseases of *M. invisa* lead to the identification of two flower bud feeders, four defoliaters and a pathogen. Detailed studies are to be conducted on *Porthesia* sp. and *Ericeia optature* (defoliaters), to

ascertain the host specificity and intensity of feeding of these insects, before using them as bioagents.

The utility of *M. invisa* as a green manure crop was assessed based on dry matter production potential, nutrient content and litter decomposition pattern of the plant in the soil. The very high dry matter accumulation of upto 3.63 kg plant^{-1} and the ability to decompose 60 per cent of the litter within the first fortnight of incorporation in soil upholds its use as green manure crop. The high content of nitrogen (3.85%) and exceptionally high content of Zinc (90-100 ppm) combined with the nitrogen fixing capacity of the legume add to its utility as green manure.

The earthworm species, *Eisenia foetida* could effectively compost *M. invisa* and banana pseudostem (1:1) within 60 days, thus enriching the content of primary and secondary nutrients in the substrate. The positive response of the growth parameters of amaranthus confirmed the quality of the compost.

The harmful effects of the *M. invisa* included its negative effects on biodiversity of native flora, allelopathic effects and the toxicity problems to animals due to the mimosine. The smothering efficiency of *M. invisa* gradually increased to above 38 per cent within three years of infestation of a new area, destroying the biodiversity of the native flora.

Application of the plant as mulch or water extract had noticeable allelopathic effects on the germination of rice (cereal) and cowpea (legume). Application at 10 tons ha^{-1} as mulch or as ten per cent water extract almost completely inhibited germination of cowpea and negatively effected the growth parameters. But in rice, the application at 10 tons ha^{-1} as incorporation, eventhough severely reduced germination initially, the positive effect on growth parameters was more significant towards 30 days growth. This can be attributed to the green manurial effect of the plant when incorporated.

Presence of mimosine, a toxic non protein plant amino acid, is the reason for the animal toxicity of *M. invisa*. The content of mimosine was highest (9.22%) at

90 days growth, which is very high, compared to the 3.0 per cent in subabul, at active vegetative stage. The mimosine content dropped at flowering stage. Among the plant parts highest content was in the growing tips at active vegetative stage (10.42%), which is generally grazed by live stock.

Intake of mimosine through *M. invisa* caused nephrotoxic and hepatotoxic symptoms in animals. Ensiling of fodder containing *M. invisa* under anerobic conditions is the best method for reducing mimosine toxicity. Ensiling *M. invisa* for 60 days could reduce the mimosine content by 40 percent to 46 percent. Drying and powdering of the plant could also reduce the mimosine content. Feeding trials in rabbits using ensiled *M. invisa* and fodder in different proportions, demonstrated the reduction in toxicity due to ensiling. It is possible that pastures infested upto 50 percent with *M. invisa* could be cut, ensiled and used for feeding animals after reducing the mimosine content significantly.