PROCEEDINGS OF THE FOURTH INTERNATIONAL WORKSHOP ON BIOLOGICAL CONTROL AND MANAGEMENT OF *CHROMOLAENA ODORATA*

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PREFACE

This volume is an outcome of the papers presented at the **Fourth International Workshop on Biological Control and Management of *Chromolaena odorata*** at Bangalore, India under the auspices of the *Chromolaena* Working Group of the International Organization for Biological Control, *Chromolaena* Network, the Association for Advancement of Pest Management in Horticultural Ecosystems and the Australian Centre for International Agricultural Research.

Articles published in this volume include West Africa in the west to Papua New Guinea and Pohnpei in the east.

One of the major developments in management of *C. odorata* reported in this volume is the introduction and establishment of *Procecidochares connexa* in Indonesia with the support from the Australian Centre for International Agricultural Research.

We thank the Government of India for granting permission to conduct this workshop in Bangalore, India.

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ECOLOGICAL ADAPTATIONS OF *Chromolaena odorata* (L.) KING AND ROBINSON

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ABSTRACT

Chromolaena odorata (L.) King and Robinson is a weed in the tropics causing severe damage to the crops. It inhabits forest areas cleared for developing plantations, forest nurseries and young plantations.

Bright sunlight, higher soil moisture, relative humidity and low temperature favour vigorous growth of *Chromolaena*. It also has allelopathic potentiality. Under natural conditions the phytotoxins are released through the rainwash of the leaves, exudation from the roots and from the decomposing plant residues. In order to understand its success and ecological amplitude, it was thought essential to study the environmental physiology of this weed.

Field trials were conducted in the Malnad areas of Karnataka (Shimoga and Mercara) with heavy infestation of *Chromolaena* to study the ecophysiology of this weed.

C. odorata was found to have very high reproductive capacity - i.e., both by vegetative means and by heavy seed production. Ecotypes were established and in addition, this species was found to carry on associative nitrogen fixation with the help of free living nitrogen fixers both in the root surface and in its rhizosphere soil, enabling it to live luxuriantly in the poor soils and in the thatched roofs and tree trunks devoid of soil and manure. Further, the ecological adaptations of the species is being discussed.

INTRODUCTION

Chromolaena odorata, a widely distributed and dominant species, is a native of South and Central America. It is a successful coloniser in different habits and habitats. It grows luxuriantly on tree trunks, straw roofs of huts with minimum amounts of soil and even in extremely poor soils. It is also allelopathic and the phytotoxins are released through the rainwash of leaves, exudation from roots and from the decomposing plant residues (Ambika and Jayachandra, 1980). In order to understand its success and ecological amplitude it was thought essential to study the environmental physiology of this weed. In the present study the following objectives were tackled:

a) To check for ecotypes in this species - differing in their morphology, physiology and biochemistry.

b) Whether the root surface of the plant and the rhizosphere soil could support good growth of free living nitrogen fixers.

c) To analyse the weed's capacity to propagate vegetatively and to calculate its reproductive capacity.

MATERIALS AND METHODS

Three sites were selected for sampling of *C. odorata* in Karnataka :

a) Ripponpet forests near Shimoga ($25 \pm 5^{\circ}C$, $82 \pm 7.5\%$ R.H. and 1590 mm rainfall).

b) Dubare forests near Kushalnagar (Mercara) ($20 \pm 3^{\circ}C$, $88 \pm 7\%$ R.H and 1834 mm rainfall)

c) Shrubby forests of Kengeri in the outskirts of Bangalore ($24 \pm 6^{\circ}C$, $76 \pm 14\%$ R.H and 460 mm rainfall)

Soil samples for analyses were collected from the above three sites from the rhizosphere of *Chromolaena* stands and at the corresponding depth from a neighbouring area free from the weed.

Experiment 1: Studies on the plant morphology

Chromolaena plants growing in pure stands and in young teak plantations of the first two sampling areas noted above and in stands mixed with other shrubs in Bangalore, were studied in 400 replications. For each replicate the various morphological features listed in Table 1 were recorded. For studies on the number of florets and cypsella, 20 capitula were selected at random from each plant. The seed weight was determined in five sets of 1000 cypsella per plant.

Experiment 2 : Germination of the seed samples

The seed collections from the three sampling sites, stored for 30 weeks (to induce highest germination percent: Ambika and Jayachandra, 1989) were tested for germination in light (50-200 lux) and darkness. During the experimental period the mean maximum and mean minimum temperatures were 30 and 27 ° C respectively, and the relative humidity ranged between 53 and 76%.

Experiment 3: Seed metabolite levels

The proteins were precipitated from aqueous extracts of 50 mg of seeds of Bangalore, Mercara and Shimoga samples and the supernatant was used for determining the phenolic content following A.O.A.C. (1960), free reducing sugars using DNS reagent following Clark (1964) and free amino acids following Moore and Stein (1948). The total alkaloid content was estimated following Clarke (1973). The total proteins of the seed samples were extracted and quantified following Lowry *et al.* (1951).

Experiment 4: Growth performance of the three samples under identical conditions

Chromolaena plants were raised from the seeds of the three samples in six rows of ten plants, each with an inter-row distance of 30 cm and interplant distance of 20 cm, in two square meter blocks in the premises of Botany Department, Bangalore University, Bangalore under identical conditions for 90 days. The light intensity, average rainfall, temperature and relative humidity during the experimental period were 10,000 lux, 114 mm, 34 ± 4°C and 64 to 88% respectively.

Experiment 5: Determination of the Most Probable Number (MPN) of bacteria including nitrogen fixers in the rhizosphere soil and the roots of *C. odorata*

Fresh samples of rhizosphere and non-rhizosphere soils and roots of *Chromolaena* plants aged 2 to 4 years were used for determining the total number of bacteria following the MPN technique of Clarke (1965). Serial dilutions were made from 10 g soil samples, and 0.1 ml aliquots of the dilutions over the range of 10^{-1} to 10^{-8} were inoculated into sucrose, malate and combined media.

Ten gram samples of roots were macerated in a blender with 90 ml water. Serial dilutions and inoculations were made as above. The plates were incubated for one week at 33°C. The numbers of colonies in the rhizosphere, non-rhizosphere and root dilutions incubated in all the three media were counted and the MPN of the bacteria in all the three samples was calculated using the table of Alexander and Clark (1965).

Experiment 6: Acetylene reduction assay

The nitrogenase activity of the cultures obtained from the three extracts in the above experiment (5) was determined using the acetylene reduction technique (Stewart *et al.*, 1967).

Experiment 7: Adventitious root formation from the stem

The internodes of the 45 day-old *Chromolaena* plants raised in the premises of the Department of Botany, Bangalore University, Bangalore were gently bent into a groove of soil and held in position by covering with a layer of soil. Ten replications of the branches treated similarly were kept sufficiently moist and the set was kept under observation to determine the time taken for the formation of adventitious roots.

Experiment 8 : Seed production and reproductive capacity

Five hundred plants each from two categories i.e., about one year old and older in a huge stand of *Chromolaena* at Shimoga were chosen at random to determine the total number of cypsella per plant.

Using the data on the seed germination from Exp. 2, the reproductive capacity was calculated following Salisbury (1942).

The data from all the above tests were analysed using t-test, F-test and two-way analysis of variance following Sokal and Rohlf (1973).

RESULTS

The findings of the studies on the morphology of *Chromolaena* plants collected from the three different places in Karnataka, India showed that these samples differed from each other quite significantly in all the characters (Table 1). The plants of the Shimoga region were found to be the best performers and those of Bangalore were the poorest.

Table 1. Morphological characteristics of *Chromolaena odorata* sampled from three different sites in Karnataka

Place of collection	Plant height	No. of main branches per plant	No. of lateral branches per plant	Leaf dimensions		No. of capitula per plant	No. of capitula	No. of cypsella per head	No. of cypsella per plant	Length of cypsella	1000 cypsella weight (mg)
				length (cm)	breadth (cm)						
Bangalore	1.17 (0.3)	5.1 (2.3)	25.3 (2.4)	5.1 (1.3)	2.8 (0.6)	730.3 (282.6)	34.2 (2.4)	33.2 (2.7)	24246	8.5	188.6 (7.9)
Mercara	1.63 (0.3)	8.7 (2.4)	32.7 (5.7)	4.8 (0.6)	2.6 (0.3)	912.1 (362.2)	33.1 (3.3)	29.9 (2.2)	27272	8.8	227.4 (11.8)
Shimoga	2.03 (0.5)	9.95 (2.3)	58.2 (11.9)	5.3 (0.9)	2.7 (1.0)	1761.2 (939.2)	33.4 (2.7)	29.0 (3.1)	51075	9.9	231.2 (6.6)
CD 5%	1.9	1.3	9.03	0.42	0.07	275.7	0.96	1.2	-	NS	3.8

NS - not significant Figures in parentheses are standard deviations

Table 2. The Most Probable Number (MPN) of bacteria (including N2-fixers) in the root and the rhizosphere soil of *Chromolaena odorata*

	Source of Bacteria		
Nitrogen-free medium	Root	Rhizosphere soil	Non-rhizosphere soil
Sucrose	3.8×10^{-8}	2.6×10^{-7}	1.2×10^{-4}
Malate	1.6×10^{-8}	1.5×10^{-7}	1.4×10^{-3}
Combined	2.2×10^{-8}	9.6×10^{-6}	1.0×10^{-2}

Table 3. Ethylene production * by the nitrogen-fixing bacteria from the root and rhizosphere soil of *Chromolaena odorata*

Nitrogen-free media	Malate			Sucrose			Combined		
	A	B	C	A	B	C	A	B	C
10-3	22.1	202.4	13.9	393.4	264.6	157.1	204.9	296.7	169.7
10-4	0	41.6	0	131.3	64.7	194.9	71.0	540.8	35.3
10-5	0	0	0	14.4	10.9	1.0	9.7	13.0	1.2
10-6	0	0	0	0.1	0.3	0	0	0	0
10-7	0	0	0	0.1	0	0	0	0	0
10-8	0	0	0	0	0	0	0	0	0

LSD 5%					
between media	between sources	between dilutions	med x dil	med x source	source x dil
55	55	77	135	95.2	135

*. micromoles of ethylene/bijon/h A, B and C - root, rhizosphere soil and non-rhizosphere soil, respectively

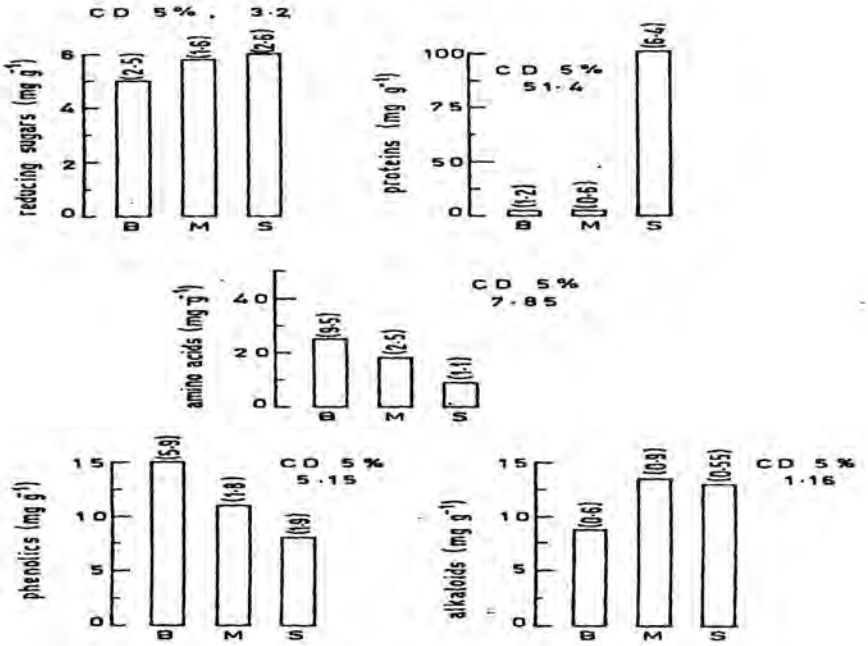
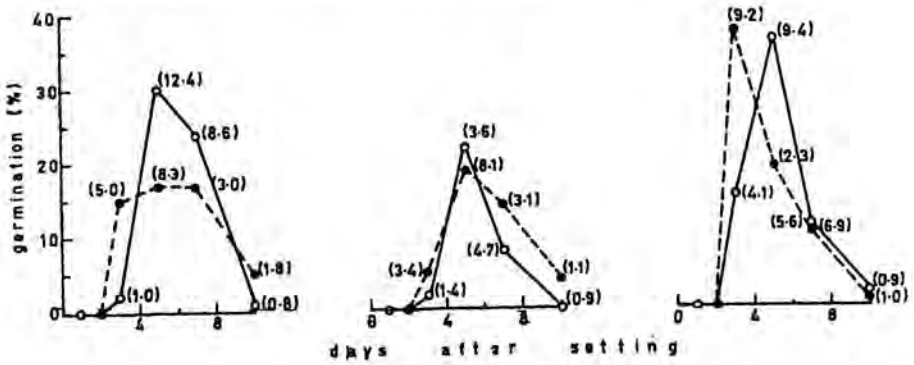


Figure 1. Seed metabolites in three different collections* of *Chromolaena odorata*
*** (B- Bangalore, M-Mercara and S-Shimoga)**
figures in parentheses are standard deviations.



LSD 5%		
between collections	between ht. conditions	inter-action
6·4	7·9	11·1

Figure 2. Seed germination in three different collections* of *Chromolaena odorata*
in light (o ——o) and Darkness (o - - - - o)
*** left to right : Bangalore, Mercara and Shimoga**
figures in parentheses are standard deviations

The seeds from the three regions of Karnataka also differed significantly in the metabolite contents (Fig. 1). The Shimoga plants produced heavier seeds which were richer in proteins and reducing sugars than the plants of the other two regions. Seeds from Shimoga plants also germinated better in light and darkness (Fig. 2).

Further, the plants raised from the three seed samples under identical field conditions in Bangalore retained their differences in the vegetative features (Fig. 3) as shown in their parent generations.

The investigation to determine whether the root system/rhizosphere of the weed supported the activity of free living nitrogen fixers yielded positive results.

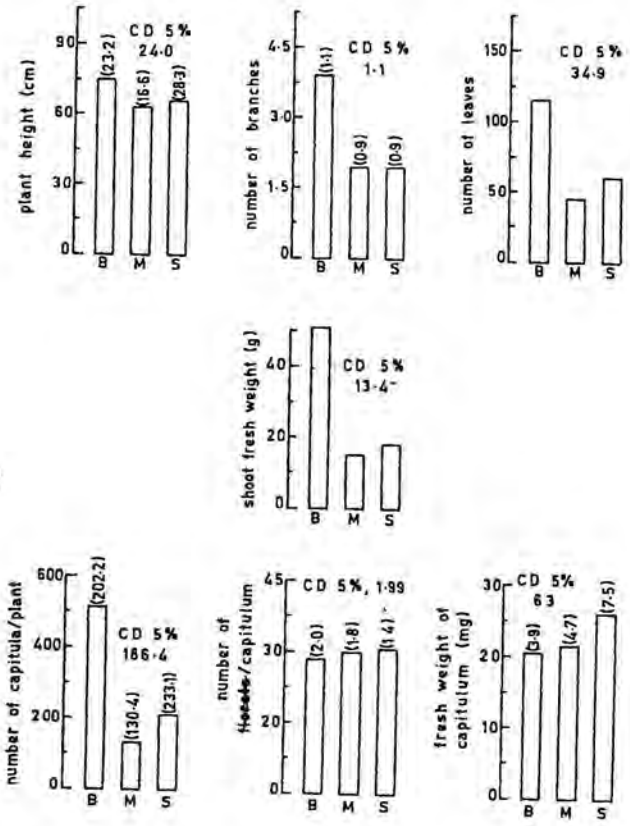


Figure 3. Growth performance of the 90 day-old plants of *Chromlaena odorata* raised from three different collections*, under identical field conditions.
*** B-Bangalore, M-Mercara and S-Shimoga**
figures in parentheses are standard deviations.

Data presented in Table 2 show that the MPN of microbes on the root and in the rhizosphere of *Chromolaena* was quite high, and as these bacteria multiplied well in the nitrogen-free media, it was inferred that there were nitrogen fixers among them. And the ability of bacteria from the extracts of roots and rhizosphere to reduce acetylene (Table 3) testify to their nitrogen fixing ability very convincingly.

The stem cuttings of *Chromolaena* could produce adventitious roots from the internodes within eight days under field conditions. Regarding the reproductive capacity of *C. odorata,* these plants produced a large number of small and light cypsella and their number varied depending on the age of the plants. All the branches of such plants ended with inflorescences producing large numbers of capitula per plant. On an average there were 29 cypsella per capitulum and the reproductive capacity of the species also turned out to be high (Table 4).

Table 4. Seed characteristics, seed output and reproductive capacity of *Chromolaena odorata*

Length of cypsellum (mm)	9.0
1000 cypsella weight (mm)	231.2
Number of cypsella per capitulum	29.0
Total cypsella/plant (one year-old)	739,040
Total cypsella/plant (older)	5,321,120
Germination per cent	80

DISCUSSION

The foregoing account shows that the three samples of *Chromolaena* collected from three regions in Karnataka are distinct intraspecific variants/races adapted to the different conditions prevailing in the places of their sampling. Though the test for their growth performance under identical conditions was

carried out in the rainy season at Bangalore (July-September), the Shimoga and Mercara samples performed very poorly compared to the individuals of the respective samples growing in the places of their collection and also with those of Bangalore. This was obviously because in Bangalore the rainfall and relative humidity are lower and the temperature higher than those prevailing at Shimoga during the corresponding season. As Mercara would be cooler than Shimoga, the Mercara samples suffered more than Shimoga samples under Bangalore conditions.

Though the Bangalore sample showed high seed output and good germinability (Table 1 and Fig. 2), its incidence in Bangalore is very low and even its sparse distribution is confined to areas with good numbers of trees, where the rate of evaporation is low and the soil remains moist. The low rainfall in Bangalore (<460 mm) compared to that in Shimoga (>1590 mm) and Mercara (>1834 mm) must be limiting the spread of the weed in and around the city; the low relative humidity (26-82%) could also be playing its role. Based on studies on lines broadly similar to those of the present study, the occurrence of physiological races in *Tephrosia purpurea* (Rao, 1979), *Striga asiatica* (Bharathalakshmi and Jayachandra, 1979) and *Parthenium hysterophorus* (Asadullah, 1979) has been demonstrated.

The occurrence of many more races or ecotypes in *C. odorata* as an allohexaploid weed having high ecological amplitude and wide geographical distribution would not be surprising, as the environmental tolerance of a species depends largely on its ability to respond ecotypically (Gregor, 1946) and the wider the ecological range of the species the more numerous are its ecotypes (Daubenmire, 1959).

In addition to these, *Chromolaena* has a tendency to produce adventitious roots from the nodes and internodes, besides having high reproductive capacity (average seed number x germination percentage) ranging from 9,23,800 to 6,651,400 (Table 4). The allied species of *Chromolaena, Eupatorium adenophorum* and *E. riparium* produced 7,700 to 10,080 and 10,000 to 100,000 seeds, respectively annually (Auld, 1970). In comparison with these, the Karnataka population of *C. odorata* produced 60 to 660 times more seeds. Other troublesome weeds like *Eleusine indica* (Zimbabwe's most troublesome weed), *Nicandra physaloides* and *Amaranthus spinosus* are reported to produce approximately 2000 million viable seeds per acre. In *C. odorata,* in the present study, the annual seed output per acre of its stand would range from 110856×10^{5} to 798168×10^{-5}, depending on the age of the stand, which is definitely more than that reported for the above troublesome weeds. Though the cypsella were small and light (Table 1), they were heavier than those of *E. adenophorum* and *E. riparium,* whose fruits weighed from 3.2×10^{-5} to 5.6×10^{-5} and 4.8×10^{-5} to 6.0×10^{-5}g respectively (Auld, 1970). However, the *Chromolaena* weed producing a large number of light cypsella, each with a pappus, should be capable of sending its descendants far and wide and this must have contributed to the spread of the species in different parts of the world. Hence, the high reproductive capacity and the efficient vegetative propagation are other attributes qualifying this species as a successful weed.

Added to the above attributes are the findings as in Tables 2 and 3, which convincingly demonstrate high nitrogen fixing activity on the root surface and to a lesser degree in the rhizosphere of *C. odorata.* This would definitely be one of the factors enabling the weed to thrive in poor soils. Similar non-symbiotic nitrogen fixation on the root surface and the rhizosphere has been reported for a number of crops like rice, maize, sorghum, rye and tomato (Lakshmikumari, 1981; Kavimandan *et al.,* 1978) and several species of grasses and weeds like *Heracleum spondytinum, Rumex acetosa, Convolvulus arvensis* (Subba Rao, 1977). Hence, the activity of free living nitrogen fixers in association with the roots of *Chromolaena* might satisfy to a great extent the nitrogen requirement of the weed and this might be the mechanism behind its capacity to thrive in poor and minimum amounts of soil.

Hence, the above studies clearly point out that the rainfall, relative humidity and temperature influenced the differential adaptation of the *Chromolaena* plants growing in different regions of Karnataka, and this adaptive ability of the species is manifested through intraspecific variations. My studies also make it clear that *Chromolaena* can support the activity of nitrogen fixers in the vicinity of its roots enabling it to extend its horizon to poor soils also. The high seed output and reproductive capacity, coupled with the ability to propagate vegetatively, have obviously contributed to its quick spread and colonisation.

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DISTRIBUTION OF *Chromolaena* IN DIFFERENT PARTS OF KARNATAKA

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ABSTRACT

The survey conducted in several parts of Western Ghat region revealed that *Chromolaena odorata*, first noticed in Karnataka as early as 1960, has infested almost all the forest areas of the region. It has become a serious menace in the lower altitudes of less than 350m above mean sea level, comprising Nilgiri hills in addition to Western Ghat hills. The degree of infestation has been found to be low in thick evergreen forests, wherever light is a limiting factor, indicating the importance of sunlight for establishment of this weed. It has been noticed in various agroclimatic regions, soil types and vegetation, indicating its ability to grow and establish irrespective of the factors enumerated above. It has been found that the infestation is maximum (5914 km^2) in Sagar Division and least in Mysore Division (32 km^2). It is predominantly noticed in forest areas, road-sides, open forest lands and all along the nalas. In addition, it is a serious problem in teak, eucalyptus, dalbergia, bamboo and cashew plantations. It is further interesting to note that the coastal line for about two to three kilometers inland from the sea is devoid of *Chromolaena* infestation, indicating the susceptibility of this weed to saline conditions. If the weed spread is not timely controlled, it may be a threat to the natural growing habitat of the transitional tract.

INTRODUCTION

Chromolaena odorata is widely distributed as an obnoxious perennial weed in tropical countries. Its aggressive, fast growing nature coupled with its capacity to grow efficiently under a wide variety of agroecological conditions and its high regeneration capacity combined with prolific seed production, has led it to invade rapidly to many forest areas, plantations and field crops of tropical countries. After being introduced to India in the early part of the 20th century, *C. odorata* and *Ageratina adenophora*, predominanly have become serious weeds both in lower and higher altitudes of the north-eastern region, western ghats and Nilgiris (Bennett and Rao, 1968).

In order to ascertain the in-depth invasion, quantum spread and its effect on agricultural ecosystems in Karnataka, a questionnaire was first sent to the selected divisional forest headquarters and local organisations and then an intensive survey was conducted in Belgaum, Chikmagalur, Dharwad, Hassan, Shimoga, Uttara Kannada and Dakshina Kannada districts.

Soil and climatic conditions of surveyed area

Karnataka State represents a wide variety of geological, vegetational and climatic features that have influenced soil formation, rainfall pattern and vegetation, covering an area of 191,000 km^2 with coastal line running a length of about 300 km.

Out of 95,000 km^2 surveyed area, *Chromolaena odorata* was spread over in 23,000 km^2 area, where it is totally smothering the growth of other vegetation (Table 1). The weed was found distributed in medium black soils of Dharwad and Belgaum districts, laterite soils of Uttara Kannada and Dakshina Kannada and red loamy to red sandy soils of Shimoga, Chikmagalore, Hassan, Kodagu and Mysore districts. The area receives an average rainfall ranging from 700 mm in plains to 3,000 mm in Western Ghats including Malnad, with temperature variation from 10°C minimum to 35°C maximum and humidity ranges from 30 to 90 per cent. The region enjoys the benefit of two monsoons and hence can well be called the land of the two seasons, because both the south-west and north-east monsoons account for the major part of the rainfall. Malnad merges into the

Table 1. Distribution of *C. odorata* in different parts of Karnataka

Division/District	Year of first notice	Approximate area infested (sq.km.)	Intensity	Predominantly noticed in	Plantation crop in which it is serious	Local method of control
Dharwad / Dharwad	1976	412.00	High	Entire forest area and in open lands	Teak, Eucalyptus and dalbergia, plantations	Hand cutting at ground level
Sagar/Shimoga	NF	5914.14	High	Forest areas, road side and all along the nalas	Teak and soft wood plantations	Cutting and occasionally uprooting
Gajanur/Shimoga	NF	5000.00	Very hign	Forests and open land	Teak and Bamboo	Cutting and burning
Tirthahalli/Chikmagalur	1974	2100.00	Very high	Forests, young plantation and open lands	Teak and eucalyptus	Cutting
Koppa/Chikmagalur	1971	2800.00	Very high	Forests, open lands and road sides	Eucalyptus, bamboo and teak plantations	Cutting
Karwar/Uttara Kannada	1972-73	1312.10	High	Open land, grazing lands, road side forest, etc.	Cashew and other plantations	Cutting and burning
Sirsi/Uttara Kannada	1975	1510.00	Very high	Entire forest except in thick ones and all along road-sides.	Teak and eucalyptus plantations	Hand cutting
Honnavar/Uttara Kannada	1974	1000.21	High	New'v planted area, forest open lands along road side	Teak and cashew plantations	Hand weeding
Yellapur/Uttara Kannada	1970	1280.00	Very high	Open lands, road side, forests	Eucalyptus sisoo and bamboo platations	Hand cutting, burning and uprooting
Haliyal/Uttara Kannada	1967-68	1190.80	Very high	Open land, road side forest	Young teak platations	Uprooting and cutting
Hassan/Hassan	1967-77	91.00	Low	Found scattered all over	Teak platations	Cutting
Mysore/Mysore	1960	32.00	High	Open lands, road-sides	Teak plantations	Cutting
Belgaum/Belgaum	NF	93.20	Low	Open areas	NF	NF

NF : Information not furnished

Western Ghats, reaching a height of 1500 to 1800 m, which receives a large amount of rainfall and is forested and supports one of the largest plantation economies of the country. Unfortunately, *Chromolaena* infastation was noticed in all those areas and is fast encroaching in new areas, indicating its wider adaptability to grow and sustain itself in any adverse climate and soil conditions. However, *Chromolaena* was absent all along the coastal line for about 2 km from the sea water indicating its susceptibility to saline conditions.

Weed distribution and its effect

The weed infestation was noticed as early as 1960 in Mysore division (Boraiah and Gowda, 1981), whereas in Western Ghats, the first incidence was reported in 1970. *Chromolaena* is present practically throughout the Western Ghat of Karnataka and has infested almost all the forest areas of the region. The degree of infestation was low in thick evergreen forests, wherever light is the limiting factor, and profuse growth was noticed in open conditions, indicating the necessity of light for its growth.

The area of infestation was maximum, about 6,200 km^2, in Sagar division of Shimoga district and the direction of spread is from wet deciduous forests to evergreen forests. In most of the several districts, the direction of spread is from west to east. *Chromolaena* was also noticed in the transitional zone of Dharwad and Belgaum, where it is popularly known as Gandhi Gulabi, Communist Weed and Bundar. It is spreading alarmingly in open areas, all along irrigation channels, arable land, dry deciduous forest and interior shrub jungles, where it does not allow the growth of grasses and other flora. This creates an acute problem for fodder and fuel, and as a result local people hack bamboo and other fodder species for feeding their cattle and thus destroy the natural forests.

Increase in the *Chromolaena* infested area year by year in these areas is mainly attributed to the wider popularity of local method of weed control. Hand cutting or burning of the weed is the common method usually followed throughout the area, which has indirectly helped the weed to develop with profused branching and vigorous growth after the onset of rains. Above all, because of its airborne seeds, unabated deforestation and lack of extension activities by the local organisations towards educating the farming community to control this weed, *Chromolaena* is encroaching over more and more areas within a short period of time.

From the present survey, it was clearly evident that because of the aerial spreading of *Chromolaena odorata* seeds from the area surrounding the controlled field, the very purpose of chemical control of the weed becomes nullified. Hence, it is most advisable and wise to avoid control of the weed by chemical pesticides, but instead to opt for any of the ecologically feasible biological control agents as seen with many of the obnoxious weeds like *Lantana camera*, *Parthenium hysterophorus*, etc. Hence, biological control agents suitable against *Chromolaena* should be explored.

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INFLUENCE OF GROWTH CONDITIONS AND THE EFFICACY OF HERBICIDES ON GROWTH AND DEVELOPMENT OF *Chromolaena**

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ABSTRACT

In an attempt to find out the effect of growth conditions on growth and development of *Chromolaena adorata* and the efficacy of different herbicides, a pot experiment was conducted. Two sets of pots were planted with *Chromolaena* seedlings. One set was exposed to natural sunlight of 1500 to 1800 $\mu E\ m^{2}s^{-1}$ and the other was kept under a thatched roof which received irradiance of 200 to 400 $\mu E\ m^{2}s^{-1}$. After acclimatisation for two months, plants were sprayed with 2,4-D, paraquat and glyphosate each at concentrations of 2000, 3000 and 4000 ppm. Observations on morphological, anatomical and physicochemical parameters were recorded at 2, 4, 6 and 8 days after the herbicidal spray.

It was observed that the irradiance had marked influence on morphology, growth and development of *Chromolaena*. Shade grown plants had dark green leaves with tender, erect and tall stems in contrast to the light grown plants which had pale green leaves, woody, branched and short stems. Light grown plants had leaves with thicker epidermis and a greater number of stomates and hairs per unit area and larger petioles compared to shaded plants. The total chlorophyll content was more in shaded plants. The apical bud and the subtending leaves of light grown plants appeared brown and flowered during the usual month of November in contrast to the shaded plants that continued vegetative growth. The electrical conductivity (EC) of leaf leachates increased continuously from 2 to 8 days after herbicidal spray and the rate of increase was more in light as compared to shade condition. Among the herbicides, paraquat recorded maximum EC values indicating more disintegration of tissue membranes.

INTRODUCTION

The infestation of *Chromolaena odorata (Eupatorium odoratum)* in forests and plantations, particularly in the Western Ghat and north eastern regions of the country, has become a serious concern not only for the survival of precious forest species, but also due to its rapid spread to the plains (Borthakur and Gosh, 1975). It has been adapted in the evolutionary process to grow, multiply and perpetuate effectively under low light intensity areas (forests) apart from its existence in open lands (Malhotra and Jain, 1978). Leaves are the primary sites of herbicide application and the impact of applied herbicides depends not only on the type and concentration of herbicide but also on the environmental conditions in which plants grow (George, 1968). Therefore, an experiment was conducted to find out the effect of light and shade conditions on the anatomy, morphology and growth of *Chromolaena* and the efficacy of different herbicides under these conditions.

MATERIALS AND METHODS

Naturally grown fresh seedlings of *Chromolaena* of uniform height (25-30 cm) were transplanted to earthen pots. Five pots were maintained for each treatment, replicated thrice, in randomised block design. The experiment was conducted at College of Agriculture, Dharwad during July-December, 1991. Two sets of pots were made, one of which was exposed to natural sunlight of 1500 to 1800 $\mu E\ m^{2}s^{-1}$ and the other was kept under a thatched roof which received an irradiance of 200 to 400 $\mu E\ m^{2}s^{-1}$. Plants were allowed to grow and acclimate for these conditions for two months with regular watering. Plants were sprayed with 2,4-D, paraquat

* *Part of the Ph.d. thesis submitted by the senior author to the University of Agricultural Sciences, Dharwad*

and glyphosate each at concentrations of 2000, 3000 and 4000 ppm. Control plants were sprayed with water. Observations on morphological, anatomical and physico-chemical parameters were recorded at 2, 4, 6 and 8 days after treatment. Data on leaf anatomical parameters were recorded following standard microtomy technique. Leaf chlorophyll was estimated as per the method of Arnon (1949), leaf relative water content according to Barrs and Weatherly (1968) and electrical conductivity of leaf leachates by using an electrical conductivity (EC) bridge. Transpiration rate and stomatal resistance were measured by using a steady state porometer (LICOR LI 1600 USA Model).

RESULTS AND DISCUSSION

The irradiance level was found to have a marked influence on the anatomy, morphology and growth of *Chromolaena*. Shade grown plants had dark green leaves with tender and erect tall stems in contrast to the light grown plants which had leaves with thicker epidermis and a greater number of stomates and hairs per unit leaf area and larger petioles (Table 1). It appears that plants in shaded conditions developed thin, slender and tall stems because of the competition for light, and the cells elongate and the internodal length extends. Leaves in shade conditions develop compact cells with less spongy palisade compared to light grown leaves with thicker epidermis, more spongy polisade region resulting in thick leaves. Similar leaf modifications were reported in light and shade grown desert shrub *Hyptis emoryi* (Nobel, 1976) and in itchgrass (Paul and Paterson, 1980).

Table 1. Effect of light and shade conditions on anatomical characters in *Chromolaena*

Leaf characters	Light	Shade
Stomatal number per mm^2 leaf area	320.000	242.000
Leaf thickness (mm)	0.184	0.109
Petiole diameter (mm)	2.130	1.490
Thickness of epidermis (mμ)		
abaxial	35.400	26.800
adaxial	24.600	19.300
Number of hairs per mm^2 leaf area		
abaxial	436.000	349.000
adaxial	51.000	36.000
Mesophyll thickness (mm)	0.091	0.072
No. of mesophyll cells per mm^2	62.700	48.300

Note : Observations are the means of five readings.

It was interesting to note that in light grown plants the apical bud and the subtending leaves appeared brown and flowered during the usual month of November, in contrast to the shade plants that continued vegetative growth. This difference could be attributed to the photoperiodic response of this weed.

Herbicidal effect on leaf anatomy in both light and shade conditions when observed with respect to leaf thickness (Table 2) and petiole diameter (Table 3) indicated significant differences in control after the sixth day of treatment. Glyphosate and 2,4-D at all the concentrations reduced leaf thickness and petiole diameter to the maximum extent with delay in time after spraying. The effect was more in the light conditions than in the shaded. Shade grown plants had more leaf chlorophyll compared to light grown plants when estimated on area basis (Table 4). The chlorophyll content decreased significantly at all the days and at all the concentrations of herbicides. However, the extent of reduction with lapse of time was more in light conditions than shade. Among the herbicides paraquat caused maximum reduction in leaf chlorophyll. Similarly relative water content (RWC) decreased with an increase in the concentration of herbicides under both open light and shaded conditions, and the maximum decrease was noticed in paraquat as compared to other herbicides at all the concentrations (Table 5). The extent of decrease in RWC was more under open light as compared to shaded conditions, which could be mainly attributed to the active transport of herbicides under open light. It was also noted that there was a decrease in RWC with an increase in the days after spray (DAS) inuicating the persistence of desiccation due to herbicides and this desiccation was more in paraquat as compared to other herbicides. Leaf tissue injury by herbicides has been measured in terms of electrical conductivity (EC) of leaf leachate. EC was maximum in paraquat compared to other herbicides in both light and shade conditions and it increased continuously with time (Table 6). In general EC was more under open light than in shade. It implies that herbicides are more effective in light than shade, and this could be because stomates keep open in light and help to better absorb the applied herbicides.

The effect of different herbicides on biophysical characters indicated that there was a significant reduction in stomatal conductance (Table 7) and transpiration rate (Table 8). The decrease in TR and SC was maximum with paraquat, since paraquat is a contact herbicide which causes rapid desiccation of the leaves. Due to fast desiccation and loss of turgidity, as has been evidenced by a decrease in

Table 2. Effect of herbicides on leaf thickness (mm x 10^{-3}) in *Chromolaena* grown in open light and shade conditions.

Treatments	Concentration (ppm)	Growth conditions							
		Open light				Shade			
		2	4	6	8	2	4	6	8
		Days after spray							
Control	-	168.0	172.3	174.1	183.6	118.5	120.1	123.4	124.9
2, 4-D	2000	110.5	107.5	104.0	100.6	116.3	114.8	111.0	108.7
2, 4-D	3000	97.3	94.1	89.0	86.9	111.6	108.3	104.2	103.2
2, 4-D	4000	92.0	88.3	82.7	80.6	105.8	100.7	96.5	95.1
Paraquat	2000	132.0	129.1	126.5	124.2	116.9	115.0	113.4	111.3
Paraquat	3000	128.3	124.5	119.4	115.3	113.8	110.5	107.6	105.7
Paraquat	4000	125.0	120.4	114.3	109.0	109.4	104.1	99.8	97.2
Glyphosate	2000	98.0	94.1	91.7	90.2	115.2	113.5	110.7	106.4
Glyphosate	3000	92.6	87.4	83.0	81.5	108.4	105.8	100.3	98.2
Glyphosate	4000	85.3	79.2	74.3	71.4	98.4	93.4	88.5	82.5
S. Emt		2.1	2.4	3.3	4.5	3.4	4.4	6.3	5.1
C.D at 5%		5.9	6.8	9.6	12.3	9.9	12.8	18.2	14.3

Table 3. Effect of herbicides on petiole diameter (mm) in *Chromolaena* grown in open light and shade conditions.

Treatments	Concentration (ppm)	Growth conditions							
		Open light				Shade			
		2	4	6	8	2	4	6	8
		Days after spray							
Control	—	1.98	2.04	2.10	2.13	1.49	1.53	1.50	1.51
2, 4-D	2000	1.71	1.68	1.64	1.61	1.41	1.38	1.34	1.29
2, 4-D	3000	1.69	1.54	1.47	1.36	1.37	1.34	1.26	1.22
2, 4-D	4000	1.64	1.43	1.31	1.13	1.33	1.29	1.21	1.16
Paraquat	2000	1.84	1.81	1.76	1.73	1.45	1.43	1.40	1.37
Paraquat	3000	1.79	1.67	1.61	1.59	1.41	1.39	1.36	1.32
Paraquat	4000	1.72	1.58	1.49	1.36	1.37	1.32	1.29	1.23
Glyphosate	2000	1.36	1.32	1.28	1.23	1.38	1.35	1.29	1.22
Glyphosate	3000	1.26	1.21	1.15	1.08	1.34	1.30	1.23	1.15
Glyphosate	4000	1.18	1.06	0.98	0.85	1.30	1.24	1.16	1.06

Table 4. Effect of herbicides on total chlorophyll (mg dm^{-2} leaf area) in *Chromolaena* grown in open light and shade conditions.

Treatments	Concentration (ppm)	Growth conditions					
		Open light			Shade		
		2	4	6	2	4	6
		Days after spray					
Control	—	34.7	36.2	36.7	50.8	51.5	52.7
2, 4-D	2000	24.4	21.5	16.2	44.7	42.8	39.5
2, 4-D	3000	22.2	15.4	15.6	43.2	41.0	37.8
2, 4-D	4000	20.3	16.1	13.8	41.6	38.6	36.2
Paraquat	2000	14.3	12.5	9.6	49.7	45.4	43.2
Paraquat	3000	11.5	10.6	8.0	49.2	40.2	41.1
Paraquat	4000	9.4	5.3	6.4	48.5	40.2	39.6
Glyphosate	2000	20.6	17.8	14.2	46.3	40.3	37.4
Glyphosate	3000	18.2	15.7	12.8	45.2	38.6	35.3
Glyphosate	4000	16.4	13.6	11.5	43.4	36.6	34.5

Table 5. Effect of herbicides on leaf relative water content (RWC %) in *Chromolaena* grown in open light and shade conditions

Treatments	Concentration (ppm)	Growth conditions							
		Open light				Shade			
		2	4	6	8	2	4	6	8
		Days after spray							
Control	—	83.2	84.6	83.9	84.1	86.3	85.9	85.5	84.5
2, 4-D	2000	76.1	70.4	61.8	50.2	83.7	82.6	72.4	68.3
2, 4-D	3000	73.8	67.3	58.1	46.4	82.4	81.3	68.6	64.6
2, 4-D	4000	72.4	65.5	55.4	43.3	80.5	80.2	63.4	59.1
Paraquat	2000	74.5	53.6	48.6	44.5	82.6	78.4	69.6	65.9
Paraquat	3000	72.8	50.3	46.3	44.1	81.2	75.1	66.7	62.2
Paraquat	4000	71.6	49.4	40.2	35.7	80.3	72.8	60.3	57.5
Glyphosate	2000	75.3	69.1	60.9	49.4	82.7	83.2	76.3	69.8
Glyphosate	3000	72.9	65.6	56.1	44.5	83.5	82.3	74.5	66.3
Glyphosate	4000	71.2	63.3	51.5	39.1	81.2	78.6	70.8	61.6
S. Em±		0.8	0.7	0.7	0.8	1.1	0.9	1.0	0.9
C.D at 5%		2.3	2.1	2.2	2.4	3.4	2.6	2.9	2.7

Table 6. Effect of herbicides on electrical conductivity (ds/m/dm^2 leaf area) of leaf leachater in *Chromolaena* grown in open light and shade conditions

Treatments	Concentration (ppm)	Growth conditions							
		Open light				Shade			
		2	4	6	8	2	4	6	8
		Days after spray							
Control	-	0.51	0.49	0.54	0.59	0.42	0.43	0.42	0.50
2, 4-D	2000	0.54	0.57	0.62	0.68	0.40	0.42	0.46	0.50
2, 4-D	3000	0.58	0.64	0.69	0.75	0.44	0.47	0.53	0.58
2, 4-D	4000	0.63	0.67	0.76	0.83	0.48	0.56	0.61	0.65
Paraquat	2000	0.77	0.86	0.95	1.15	0.56	0.61	0.67	0.71
Paraquat	3000	0.82	0.90	1.04	1.19	0.63	0.68	0.72	0.79
Paraquat	4000	0.88	0.97	1.13	1.25	0.74	0.79	0.84	0.88
Glyphosate	2000	0.56	0.59	0.65	0.71	0.46	0.49	0.53	0.57
Glyphosate	3000	0.61	0.67	0.73	0.79	0.50	0.52	0.56	0.61
Glyphosate	4000	0.65	0.69	0.76	0.88	0.52	0.55	0.60	0.68
S.Em±		0.16	0.02	0.01	0.09	0.14	0.04	0.01	0.03
C.D. at 5%		NS	0.05	0.03	0.24	NS	0.11	0.03	0.09

RWC, there is a partial or complete closure of stomates leading to an enormous increase in stomatal resistance which is indicated by a decrease in stomatal conductance. Under shaded condition, the TR and SC were greater, mainly because of increase in RWC over open light and better maintenance of turgidity. The decrease in transpiration rate or stomatal conductance with paraquat could be attributed to the fast action of this contact herbicide. Putnam (1976) has also reported that transpiration is rapidly affected by glyphosate.

Sunlight is one of the most important environmental factors that determine the efficacy of most of the herbicides. Light also changes the anatomy, morphology and growth of the plants, as well as causing the stomates to keep open in light, thus serving as the major route of tissue penetration of foliar applied herbicides. Hence, it may be concluded that to increase the efficacy of herbicides in plants grown in shade (limited light) conditions, some carriers need to be used to enable the absorption and translocation of herbicides.

Table 7. Effect of herbicides on leaf stomatal conductance (cm s^{-1}) in *Chromolaena* grown in open light and shade conditions

Treatments	Concentration (ppm)	Growth Conditions			
		Open light		Shade	
		5	10	5	10
		Days After Spray			
Control	—	2.44	3.03	1.38	2.38
2, 4-D	2000	1.92	2.13	1.37	1.15
2, 4-D	3000	1.89	1.56	0.99	0.80
2, 4-D	4000	1.03	1.31	0.62	0.60
Paraquat	2000	0.87	0.42	1.12	0.87
Paraquat	3000	0.54	0.91	1.09	0.78
Paraquat	4000	0.43	0.17	0.76	0.45
Glyphosate	2000	0.76	0.63	1.01	0.86
Glyphosate	3000	0.64	0.61	0.97	0.64
Glyphosate	4000	0.42	0.58	0.52	0.41
S. Em±		0.37	0.48	0.43	0.54
C D at 5%		1.16	1.17	1.34	1.61

Table 8. Effect of herbicides spray on transpiration rate (µmol H_2O $m^{-2}s^{-1}$)in *Chromolaena* grown in open light and shade conditions

Treatments	Concentration (ppm)	Growth Conditions			
		Open light		Shade	
		5	10	5	10
		Days After Spray			
Control	—	31.4	57.5	26.3	43.6
2, 4-D	2000	30.5	26.3	25.8	24.9
2, 4-D	3000	20.8	16.7	15.0	14.3
2, 4-D	4000	10.9	9.8	8.6	8.0
Paraquat	2000	9.9	5.3	18.7	10.7
Paraquat	3000	7.3	3.3	11.5	8.6
Paraquat	4000	4.5	1.5	9.3	6.5
Glyphosate	2000	19.8	16.1	11.5	9.8
Glyphosate	3000	15.2	10.6	9.9	8.3
Glyphosate	4000	13.4	5.7	6.8	6.2
S. Em±		1.9	2.7	2.0	2.5
C D at 5%		5.3	7.8	5.9	7.2

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SEED DISPERSAL OF *Chromolaena odorata* RECONSIDERED

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ABSTRACT

The rapid spread of *Chromolaena odorata* since introduction in KwaZulu-Natal (South Africa), and the failure of this species, until recently, to invade conservation and other *C. odorata* free areas, has necessitated the reconsideration of primary dispersal mechanism of this species. The study of *C. odorata* seed movement in the southern region of the Greater St Lucia Wetland Park indicated that (a) seed rain occurred from August to November, (b) airborne seeds were unlikely to travel distances greater than 80 m from the source and (c) off-road vehicles transported a significantly higher number of seed over greater distances than were carried as seed rain. This evidence suggests (1) that the atmosphere does not act as a large reservoir within which *C. odorata* seeds are carried great distances, and (2) that mechanical transport of *C. odorata* seed is the most likely reason for the rapid spread of this species. The importance of these observations in terms of conserved and other *C. odorata* free areas are discussed.

INTRODUCTION

Chromolaena odorata (L.) King and Robinson is considered to be the most aggressive invader of indigenous sub-tropical areas (Liggitt, 1983; Macdonald and Jarman, 1985; McFadyen, 1991; Wilson, 1995). *C. odorata* is capable of producing vast quantities of seed, with estimates ranging from 93,000 (Weerakoon, 1972) to 1,600,000 (Wilson, 1995) per plant. It is believed that the rapid spread of this species is directly related to the extensive seed production and wind dispersal architecture of the seeds (Erasmus, 1985; Liggitt, 1983; Macdonald and Frame, 1988). The rapid spread of *C. odorata* has prompted a number of studies on its distribution (Gautier, 1992; Liggitt, 1982), biological control (Ambika, 1990; Archibold, 1979; Joy *et al.*, 1993; Kluge, 1990; Kluge and Caldwell, 1992; Lyla and Joy, 1992; Viraktamath and Muniappan, 1992) and biology (Erasmus, 1985; Wilson, 1995). However, there are few, if any, published studies testing whether seed rain is the principal mode for seed dispersal and whether the spread of this species is as a direct consequence of seed rain. Since the apparent accidental (Pickworth, 1976) or horticultural (Gautier, 1992) introduction of *C. odorata* into KwaZulu-Natal (South Africa) during the Second World War (Liggitt, 1983), the maximum rate of spread recorded was in the region of 2000% for the period 1975 to 1980 (Liggitt, 1983). Until recently, the Greater St Lucia Wetland Park (Figure 1) has been relatively free of *C. odorata*. However, invasion of the Park is now occurring at an alarming rate (Unpublished NPB data). The rapid spread and consequent high densities of *C. odorata* on the periphery (Erasmus, 1985) and the delayed invasion of the interior of the park raises questions regarding our understanding of the dispersal mechanisms of *C. odorata*.

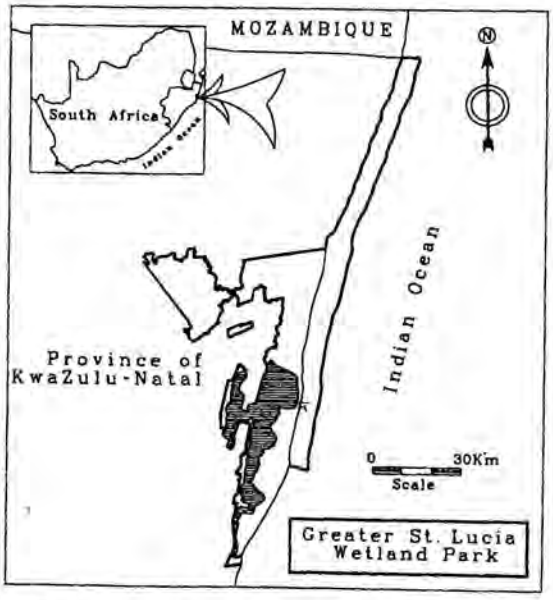

Figure 1. Location of study area, the Greater St Lucia Wetland Park

The light weight, parachutal structure of *C. odorata* seeds is perceived to enable them to become easily airborne and hence easily dispersed as 'seed rain' (Burrows, 1973). Two hypotheses describe the potential wind dispersal of airborne seeds. The first assumes that the atmosphere acts as a large reservoir within which *C. odorata* seeds are carried great distances (Figure 2a). If this hypothesis holds, then

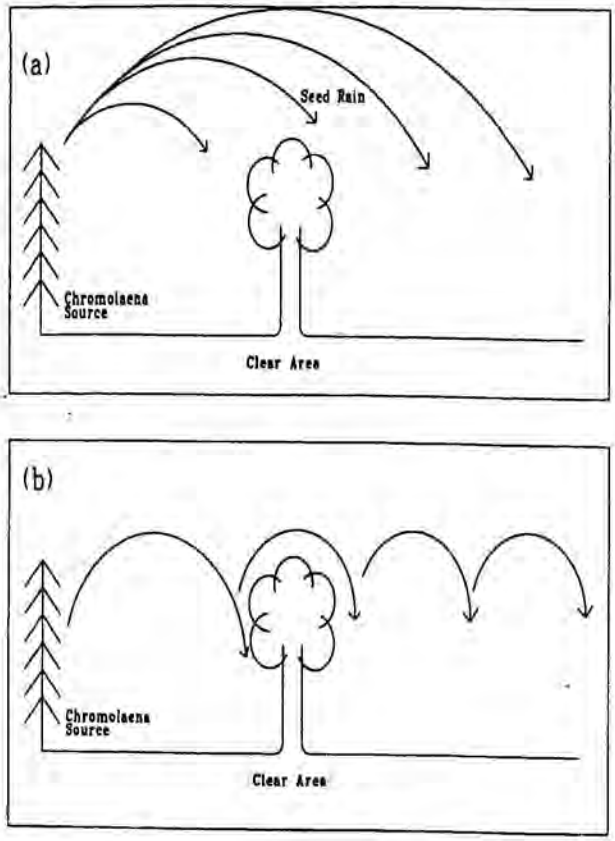

Figure 2. Two hypotheses explaining the potential spread of *Chromolaena odorata*. The first (a) assumes that *C.odarata* seed are blown large distances, whereas the second (b) assumes that the bulk of *C.odorata* seed are blown short distances before re-establishement (see text for details)

large numbers of *C. odorata* seeds, that originate on the periphery, may conceivably be transported deep into the park. Prevention of *C. odorata* seed rain into the park would, therefore, necessitate the eradication of *C. odorata* within an extremely wide belt around the park. Failing this, conservation managers would be forced to continually re-clear areas within the park. Under this scenario, costs of eradication programmes would remain, at best, constant at an elevated rate over time.

The second hypothesis (Figure 2b) argues that the bulk of the *C. odorata* seed is dispersed over short distances. After establishment and flowering, the seeds are again dispersed short distances. In so doing *C. odorata* effectively 'leap frogs' into *C. odorata* free areas. If an area is cleared and maintained as such, then eradication programmes would require a decreasing amount of effort, and hence cost, dedicated to reclearing.

The objective of this study is to (1) determine which hypothesis best describes the wind dispersal of *C. odorata* and (2) evaluate the role that off-road vehicles may play in the transport of *C. odorata* seed from areas invaded by this species. In so doing, particular reference is made to the dependence of the conserved areas on its surrounds for the preservation of its ecological and aesthetic integrity.

STUDY AREA

The location of the Greater St Lucia Wetland Park (Figure 1), in KwaZulu-Natal, is at the interface between tropical and subtropical climates and hence is highly sensitive to invasion of *C. odorata* (Blackmore, 1991; Henderson, 1989; Macdonald and Jarman, 1985). The landscape of the park is generally of low relief, with coastal barrier dunes in the east and the Lebombo Mountains in the west. These two prominent features are separated by a complex mosaic of lowland wetlands, grasslands and forests. Annual rainfall ranges from 1330 mm in St Lucia town to 1120 mm at Charters Creek in the south west, and 1045 mm at Sodwana Bay in the north east to 650 mm at Mkuze Game Reserve in the north west (unpublished CCWR data). Soils of the park are generally sandy and of marine origin, increasing significantly in age, and hence nutrient status, from east to west. The predominant wind directions are north east and south west in nature, although easterly and westerly winds are common (Taylor, 1980).

The study area, the southern region of the park, is divided into three sections currently known as the Western Shores, Eastern Shores and Mapelane Island. The Western Shores is a narrow 1.5 km strip along the western edge of the estuary and St Lucia Lake system. A large proportion of the western boundary of the Western Shores has been afforested with *Pinus elliottii*. The habit of the South African Forestry Company Limited (SAFCOL - formally the

Department of Forestry) of plowing or rotovating fire breaks on the periphery of the plantations has facilitated the spread of *C. odorata* along the western boundary of the park (Anon, 1993; Blackmore 1991). The Western Shores is predominately grassland, however, clumps of woody vegetation pruned by biennial fires are common. The distribution of *C. odorata* within the 1.5 km strip has been limited to the woody clumps and estuary edge (Blackmore, 1991). The Eastern Shores exhibits significantly lower densities of *C. odorata* than that recorded on the Western Shores and Mapelane Island. The small isolated patches of *C. odorata* that occur on the Eastern Shores are limited to the timber plantations and are substantial distances away from the study areas. All of the patches of *C. odorata* within the 1.5 km strip and along the estuary were cleared prior to the study. The Mapelane Island is highly disturbed and is almost solely covered with *Casuarina equisetifolia* and *C. odorata*. Isolated patches of *C. odorata* within a radius of 2 km from the study area on the St Lucia township side of the estuary (to the north of the Mapelane Island) were cleared prior to initiating this study. This was the only available site allowing exclusive investigation of seed movement on a north south axis.

METHODS

The distribution and density of *C. odorata* was determined in the St Lucia region prior to the initiation of the study, and mapped at a 1: 20,000 scale. The seed traps were located near the highest infestations of *C. odorata*. The movement of seed was determined by trapping airborne seeds on a 0.5 m x 0.5 m board smeared with petroleum jelly. Six trapping transects were located within the 1.5 km strip of the Western Shores. These traps were spaced at 0 m, 10 m, 20 m, 30 m, 50 m, 80 m and 100 m from the afforested boundary. Two transects (three traps each) were located between the St Lucia estuary and the Mapelane Island at 0 m, 20 m (southern estuary bank) and 200 m (northern estuary bank).

The 0 m traps were placed within the *C. odorata* infestations with the smeared board located at the average height of the lowest flowering buds. The remainder of the traps were set at 1 m above the ground. Trapped seeds were enumerated approximately every two days, and the petroleum jelly was renewed. Seed trapping was initiated prior to seed set and was terminated two months after the last seed was trapped.

An index of seed release was determined by marking 5 stems consisting of approximately 20 florets (each arising from different plants) within 5 m of each 0 m trap. Each floret was inspected, at two daily intervals, for rupture. The numbers of unruptured florets were counted. Many immature buds were marked, and monitoring of these was initiated once it became evident that they would not be aborted and hence would contribute to *C. odorata* seed rain.

In order to determine the potential transport of *C. odorata* seed by vehicles, a four wheel-drive light delivery vehicle was driven through a *C. odorata* infested area for approximately 20 minutes on 15 occasions. At the end of the first five replicates, the vehicle was cleaned throughout and the trapped seeds enumerated. For the remaining 10 replicates, the vehicle was driven 4 km and 15 km (five replicates each), in an uninfested area, before being cleaned and the seeds enumerated.

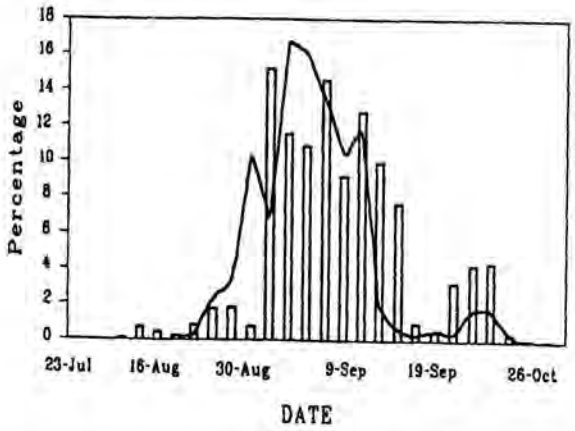

Figure 3. Percentage of the numbers seed trapped (□) and florets ruptured (-) during the study period

RESULTS

Seed rain season

Two seed release events were prevalent (Figure 3). The first and most extensive occurred from August to mid September. The second, made up entirely of the florets that had been flowering during the latter part of this seed release event, occurred from late September to the end of October. The pattern of seed trapped was similar to that of the index of seed release and no significant lag between the two was noted.

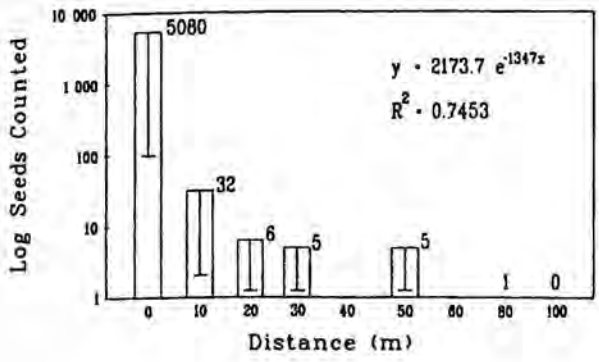

Figure 4. Average number of seed trapped along western boundary transects (non-logged standard deviation values are presented)

Effective distance of seed rain

It was noted that over 99% of *C. odorata* seed rain occurred immediately below the plant (Figure 4). Movement of seed further than 80 m from the afforested boundary on the Western Shores was not noted to occur. Likewise, no seed rain was observed to have occurred on the northern side of the estuary to the south of the St. Lucia township. Release rates and timing of seed rain occurring on the estuary traps were similar to that of the Western Shores.

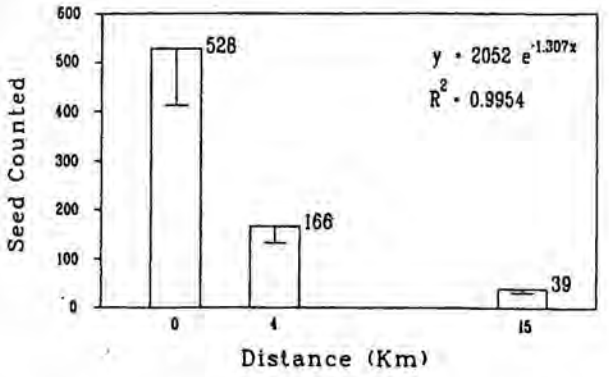

Figure 5. Average number of seed trapped and transported by a four wheel-drive light delivery vehicle

Vehicle transport of *C. odorata* seed

A large number of seeds were collected by the vehicle moving through a *C. odorata* infested area (Figure 5). The number of seeds counted dropped exponentially over the distances travelled. Although there were a large number of loose seeds collected after 4 km and 15 km, the majority collected were mature seeds still contained within the floret. Many of the florets were lodged in joints and grooves within the vehicles body-work.

DISCUSSION

Given that alien plant eradication programmes are a significant proportion of conservation budgets (Erasmus, 1985), a thorough understanding of the fundamental concepts of alien plant seed dispersal is paramount to derive a cost effective control and eradication strategy. In the 20 years between 1960 and 1980, the densities of *C. odorata*, in the Charters Creek area, increased from absent to a very heavily infested state, in places forming monospecific stands along the afforested boundary (Blackmore, 1991; Erasmus, 1985; Liggitt, 1983). Yet in that time, the Eastern Shores remained relatively free of *C. odorata* with a few infestations occurring along the estuary (Anon., 1993). If *C. odorata* seed was spread by seed rain where the atmosphere acts as a large reservoir in which seed are transported great distances (Figure 2a), the invasion of the Eastern Shores by this species would have followed a similar pattern to that documented outside of the park. This inference is supported by this study in that *C. odorata* seed was not observed to be transported further than 80 m from its source (Figure 4). It is conceivable, therefore, that the infestations along the estuary and within woody patches on the Western Shores were as a result of *C. odorata* being dispersed consecutive short distances from the afforested boundary (Figure 2b).

In order to maintain the densities of *C. odorata* to that of pre-1980, the annual NPB alien plant eradication budget had to be increased 10 fold (early 1990) and again by eight fold in 1995 (Anon., 1996). The timings of the needs for budget increases lag behind, but coincide with, the clearfelling of the *P. elliottii* plantations within the park. Other than the patches of *C. odorata* along the estuary, *C. odorata* occurs along tracks within, and along rotovated firebreaks surrounding, the plantations (personal observation) on the Eastern and Western Shores. The distribution of *C. odorata* and timing of budget increases, support the notion that the recent invasion of the Greater St Lucia Wetland Park, and in particular the Eastern Shores section, has been significantly assisted by activities of the timber industry, and not primarily by seed being blown in from the periphery in the form of seed rain. It is, therefore, conceivable that the rapid spread of this species throughout KwaZulu-Natal, and beyond, may

be as a direct result of vehicles ferrying seed large distances. Thus, the movement of airborne seed would contribute little to the 'provincial invasion', but would facilitate establishment of the monospecific stands in the vicinity of the newly established propagule.

This reasoning has two profound implications for conserved and other *C. odorata* free areas. The first, by maintaining a *C. odorata* free belt on the periphery of the park, seed rain encroachment of the park may easily be avoided. The second, by allowing off-road and heavy duty vehicles that have operated in *C. odorata* infested areas into the park unchecked, may have profound consequences for maintaining *C. odorata* free areas.

CONCLUSIONS

C. odorata is one of a number of alien plants that are currently threatening the ecological integrity of the conserved areas in KwaZulu-Natal. Despite the parachutal architecture of the seed, wind distribution of seed is significantly less than that carried by off-road vehicles. It is unlikely that large amounts *C. odorata* seed would be transported great distances as seed rain. It has been observed that the bulk of *C. odorata* seed are transported only short distances in the form of seed rain. Invasion of virgin areas by this species is, therefore, a progressive stepwise process. The clearing of a strip of greater than 80 m around the periphery of the park, would significantly reduce the amount of seed being blown into the protected area.

A single flowering plant within a *C. odorata* free area presents itself as a greater threat to the integrity of the system than incoming seed derived from seed rain. Likewise, vehicles moving through a *C. odorata* infested area transport significantly more seed, and over further distances, than does seed rain.

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MAJOR INDIAN WEEDS OF NEOTROPICAL ORIGIN AND THE POSSIBILITIES FOR COLLABORATIVE BIOCONTROL PROJECTS

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ABSTRACT

This paper discusses the use of biocontrol as a management strategy for a range of major Indian weeds of conservation and agricultural importance, with particular reference to *Chromolaena odorata*. Several recently initiated projects, involving the weeds *Parthenium hysterophorus* and *Mikania micrantha* and the evaluation of neotropical fungal pathogens as biocontrol agents, are outlined, with emphasis being on international collaboration between scientists in India, Brazil, Mexico and the U.K. It is concluded that the successful implementation of these projects will lay the groundwork and establish the protocol for the importation and release of fungal biocontrol agents in India and, thereby, stimulate similar projects for weeds of critical conservation importance, notably *Chromolaena odorata*. Emphasis is placed on a multidisciplinary, holistic approach, since the successful control of one exotic weed (such as *C. odorata*) may only result in the upsurge of another (for example, *Lantana camara*).

INTRODUCTION

Biological control of weeds through the use of fungal pathogens is still a relatively new weapon in the weed management armoury. Despite early and outstanding success with this approach, notably in Australia and Hawaii (Evans and Ellison, 1990), it is still viewed with scepticism. Part of the problem is due to "Pathophobia", or a fear of pathogenic micro-organisms, both on the part of quarantine authorities and the public in general. Evans (1995a) discussed the issues involved and concluded that the requirements for release of a fungal pathogen are significantly more stringent than those for an arthropod biocontrol agent. This is referring, of course, only to classical biological control, in which coevolved natural enemies from the centre of origin of the target pest are imported and released into the problem area where the weed is an alien species (Evans and Ellison, 1990; Watson, 1991). A less emotive approach is the use of indigenous pathogens - that have jumped or adapted to the exotic weed species - as mycoherbicides, in which the fungus is mass-produced, formulated and applied inundatively like a conventional herbicide (Charudattan, 1991). Both approaches can be considered for any particular weed target, however, in natural ecosystems and low input agricultural systems, such as rangeland, the use of mycoherbicides is not an economically viable option.

Relatively few exotic biocontrol agents have been introduced into India as a weed management strategy; significantly, all have been arthropods. This paper discusses some actual and potential biocontrol projects targeted against major Indian weeds of neotropical origin with particular reference to fungal pathogens and to the protocol or code of conduct which has to be followed in order to effect their release. As befits the theme of the present Workshop, the main emphasis is on the biological control and management of *Chromolaena odorata*.

THE WEEDS AND THEIR COEVOLVED PATHOGENS

Parthenium hysterophorus L.

Parthenium weed, or "Congress grass", is a relatively recent immigrant into India. It was not included in the review of alien weeds by Biswas (1934), but it has certainly followed the predicted trend he so accurately observed: "The American plants seem to have particular liking for the Indian soil, so that once they set foot on any part of India they spread like wild fire in no time". Since the arrival of *P. hysterophorus* from

the New World in the 1950's (Rao, 1956), it has spread throughout most of the Indian subcontinent (Aneja *et al.*, 1991), and is now considered to be the principal terrestrial weed in India (Dhawan *et al.*, 1993). As well as being a highly aggressive weed in a range of crops and urban situations (Tripathi *et al.*, 1991), *P. hysterophorus* is toxic to livestock and causes allergenic responses, such as respiratory malfunctions and dermatitis, in susceptible humans (Towers *et al.*, 1977). It has been calculated that over 40% of the population in Bangalore has been sensitised to parthenium pollen (Towers and Subba Rao, 1992).

IIBC (formerly CIBC) was involved in the search for and evaluation of arthropod natural enemies in Mexico, and subsequently, in the release of several agents into Australia in the 1980's (McClay *et al.*, 1995). At least one of these insect species was introduced later into India, and the chrysomelid beetle, *Zygogramma bicolorata* Pallister, is proving to be an effective control agent in certain regions and within particular climatic parameters (Jayanth and Ganga Visalakshy, 1994). In order to increase the biocontrol options, coevolved fungal pathogens have also been assessed (Evans, 1987a), and the rust fungus, *Puccinia abrupta* Diet. and Holw. var *partheniicola* (Jackson) Parmelee, from semi-arid upland regions in Mexico, was released in Queensland in the early 1990's (Parker *et al.*, 1994).

As with the insect agents, local climatic factors have proved to be critical and the spread and build-up of the pathogen have been slow due to the narrow optimum temperature range for spore germination and subsequent host infection. Thus, the search has now been extended to other areas of the natural range of *P. hysterophorus* (from Texas to the Chaco region of Argentina), in order to identify and collect pathogens with less restrictive temperature requirements. Amongst the fungi being screened is a microcylic rust, *Puccinia melampodii* Diet. and Holw., which is giving promising results in the greenhouse screening studies being undertaken both in Mexico and at IIBC (U.K.) using Australian funding. A collaborative project with four Indian institutions, in different geographic regions, has been initiated recently which aims to assess not only these classical biocontrol agents for possible introduction into India, but also the mycoherbicide potential of any endemic pathogens which may have adapted to this exotic host within India.

Mikania micrantha H. B. K.

This fast growing, perennial vine is native to Central and South America where it is a ruderal weed of only minor importance (Cock, 1982; Barreto and Evans, 1995). However, in its palaeotropic, exotic range, *M. micrantha* has become a major invader and suppressive weed of forestry and plantation crops, particularly in south-east Asia (Waterhouse, 1994). In India, attention was first drawn to this weed by Choudhury (1972) who reported it as a threat to forestry and agriculture in the north-east region, especially in Assam, and later in Bengal (Palit, 1981). It has since spread to other regions and is now a serious threat to both plantation and natural forests in the Western Ghats (Nair, 1988). A number of insect natural enemies have been identified in the neotropics. Cock (1982) and Waterhouse (1994) concluded that, despite the failure of one of these potential biocontrol agents in Malaysia, *M. micrantha* is an ideal target for classical biological control.

A provisional evaluation of neotropical fungal pathogens has since been undertaken (Evans, 1987b; Barreto and Evans, 1995), and, on the basis of these studies, a more intensive investigation will shortly be underway with collaborating scientists from India (Kerala Forestry Research Institute), Brazil (Viçosa University, Minas Gerais), Mexico (Instituto de Ecologia, Veracruz) and IIBC (U.K. and Trinidad stations), in order to assess both the classical and inundative approaches. A leaf spot fungus, *Cercospora mikaniacola* F. Stevens, has already been identified on *M. micrantha* in India and Malaysia (Evans, 1987b; Barreto and Evans, 1995), but the economics of developing and applying a mycoherbicide against such a weed, in such situations (both commercial plantations and natural forests) makes the inundative approach a highly debatable option, and the best long-term solution seems to lie with the introduction and release of coevolved natural enemies.

Lantana camara L.

Along with *Chromolaena odorata*, Biswas (1934) reflected on the rapidly growing menace of this prickly, verbenaceous, neotropical shrub in India, particularly in the forests of the eastern and north-western Himalayas, as evidenced by the questions being asked by local legislative councils on its control and eradication. In fact, Lantana weed had

been introduced much earlier into India at the beginning of the 19th century as an ornamental, and had been noted as a dangerous, invasive weed since the turn of the century (Singh, 1976). The historical aspects relating to the search for insect biocontrol agents, and their introduction and subsequent performance in India, which began as long ago as 1921, have been thoroughly documented by Thakur *et al.* (1992). They concluded that: "Notwithstanding all the research efforts to contain the spread and encroachment of new areas [in India] by lantana during the last nine decades, the weed has defied man and continues to be one of the most challenging problems of the 20th century the world over". An overstatement, perhaps, but it does reflect the concern afforded to this weed and the considerable efforts over the years to contain it.

Until recently, only arthropods had been evaluated as biocontrol agents of *L. camara*, however, several promising fungal pathogens have now been identified in Brazil (Barreto *et al.*, 1995). The latter authors compared the mycofloras associated with *L. camara* in both the New and Old Worlds and concluded that the palaeotropic fungi constitute an assemblage of non-specific, opportunistic pathogens unlike those from the neotropics which are represented by more specific or obligate, coevolved species. They further concluded that there is considerable potential for classical biological control, perhaps in combination with arthropod natural enemies, and with more traditional control methods. This integrated strategy for management of *L. camara* in India has been stressed previously by Thakur *et al.* (1992), although predictably, perhaps, pathogens were not considered. They proposed the establishment of a "lantana eradication" programme involving an integrated, multidisciplinary, collaborative approach. With the assistance of both weed and biocontrol specialists in the affected regions of India, as well as those from neotropical countries where *L. camara* is native and non-problematic, the time may be ripe to develop such an ambitious management programme.

Chromolaena odorata (L.) R. M. King and H. Robinson

In contrast to the weeds listed above, efforts to curtail and control the spread of *C. odorata* have had a more international impetus which has resulted in a well-co-ordinated exchange of information, as well as of biocontrol agents, resulting in the establishment of the Chromolaena Working Group and the *Chromolaena odorata* Newsletter and, of course, the current series of International Workshops devoted to the biological control and management of *C. odorata*.

There is considerable disparity of views as to when this neotropical herbaceous perennial shrub was introduced to India. Ambika and Jayachandra (1990) quoted a reference from 1920 as the first reported occurrence. However, Biswas (1934) implied that it was deliberately introduced much earlier from Jamaica, presumably as an ornamental into the Royal Botanic Gardens in Calcutta, and noted that Sir Joseph Hooker (In: "Flora of British India", 1881) reported its occurrence in Assam in the late 19th century, where it was said to rapidly replace the indigenous shrubs. Nevertheless, he also stated that the plant could have arrived in the ballast of cargo boats travelling from the West Indies to Singapore and entered India via Malaysia, Thailand (Siam) and Burma. Rai (1976) reported the common name in Bengal as "Assam lata", whilst Moni and George (1959) considered that the weed was introduced into Kerala during the last war by soldiers returning from the Assam Front, hence the name "Assam patcha". It has now replaced *L. camara* in the western parts of the Western Ghats (Muniappan and Viraktamath, 1993). Such was the concern over the impact of this relatively new weed in the region, that CIBC was contracted in the 1970's to import insect natural enemies from Trinidad, including the arctiid moth *Pareuchaetes pseudoinsulata* Rego Barros, but, despite extensive releases from 1982 to 1992, the results have been disappointing (Joy *et al.*, 1993). However, Cock (1982) listed other arthropods from the neotropics which merited consideration as biocontrol agents of *C. odorata* in the palaeotropics.

More recently, fungal pathogens collected in Trinidad have been provisionally evaluated (Elango *et al.*, 1993), and it was concluded that these agents "warrant further study, and would appear to have definite potential as part of an integrated control programme". Barreto and Evans (1994) reached essentially the same conclusion, and flagged three pathogens from Brazil as promising agents, and also recommended broadening the survey base in order to try to increase the choice of agents available. Similar optimism concerning the long-term potential of classical biological control for management of *C. odorata* has also been expressed by Cock (1982) and Waterhouse (1994).

PROTOCOL FOR INTRODUCTION OF PATHOGENS

Fungal pathogens as biocontrol agents of weeds have never been introduced into India and consequently no mechanism for their importation is in place. Ironically, it is almost certain that exotic entomopathogens for insect biocontrol projects have been introduced with little or no "red tape" - pathophobia rarely extends to insect pathogens. Therefore, a protocol or code of conduct for their introduction and release needs to be established with the relevant Indian authorities (normally the national plant protection organisation). One of the aims and outputs of the parthenium weed project discussed earlier, is to develop and promote such a protocol and Indian scientists from the four collaborating institutions will be actively participating in this exercise. In order to demonstrate the safety, or high host specificity, as well as the biocontrol potential, of the selected neotropical pathogens, the scientist will evaluate them against regionally important crop plants and local weed biotypes at IIBC (UK). This work will form part of a research document which will be prepared according to the recent publication on the "Code of conduct for the import and release of exotic biological control agents" (FAO, 1996), which lists the responsibilities of the governmental authorities and those of the exporters and importers of biocontrol agents. By setting standards, the code aims to promote, amongst other things, the safe use of biological control agents for the improvement of agriculture and human, animal and plant health. Thus, the document for submission to the designated Indian authority will include the following data:

1. Accurate identification of the target pest, its distribution, purported origin, economic importance and its known natural enemies.
2. Accurate identification or characterisation of the candidate biocontrol agent, and a summary of its origin, distribution, natural enemies, impact (in this case, pathogenic status), together with a detailed report of its specificity (from host range screening tests).
3. Potential hazards or risks posed by the agent.

These will be critically analysed and the risks assessed in accordance with the "International Standards for Phytosanitary Measures Guidelines" dealing with pest risk analysis. Within such projects, of course, monitoring of the release of the biocontrol agents is essential if their impact on both the target and non-target organisms is to be adequately evaluated. The "hands-on" training received in the U.K. by the collaborating Indian scientists will empower them to be actively involved in both the distribution and on-going monitoring of the agent(s), and thus, there should be provision within any project for post-release studies, particularly since the FAO Code states that this should be actively encouraged by the in-country authorities. For both the new Indian *Parthenium* and *Mikania* projects, it is planned that, by the end of the investigative phase, the protocol will be in place to ensure a trouble-free importation of the selected pathogens. It is hoped that these project initiatives will stimulate interest in the use of fungal pathogens as classical biocontrol agents of other major Indian weeds, in particular *C. odorata*.

DISCUSSION

Muniappan and Viraktamath (1993) highlighted the growing problem of invasive alien weeds in the Western Ghats and outlined the reasons for their success. The absence of natural enemies, and logically, therefore, of natural control pressures, was considered to be one of the principal factors. Thus, the planned introduction of coevolved arthropods or pathogens as biocontrol agents would seem to offer the most economic, environmentally-compatible and sustainable method for long-term control of these exotic neotropical weeds. It has been argued that in non-agricultural or natural ecosystems, the widespread use of pesticides against invasive plant species, especially by exotic weeds in conservation areas, will never be a viable option (Evans, 1995b). Even if a successful mycoherbicide were to be developed for use against any of these weeds, it is difficult to envisage how the product could be applied, both physically and economically, given the vastness and topography of the areas in India invaded by *C. odorata, L. camara* and *M. micrantha*. In certain situations, it may be possible to exploit such a product against *P. hysterophorus*, for example, where it poses a serious health hazard. In addition, there is the real danger that if only one of these weeds were targeted and controlled successfully, then another alien would take its place. An obvious example is the association of *C. odorata* and *L. camara* which often compete for the same ecological niches. In areas such as the Western Ghats, therefore, which "...play such an

important role in the maintenance of ecological balance and cultural and economic development in South India (Muniappan and Viraktamath, 1993)", projects aimed at controlling all the major invasive weeds would be the most sensible, and sustainable long-term approach.

Finally, as many authors have observed recently, there have been no concerted efforts at biological control of these alien weeds in India and that any future success for their management must lie in more holistic projects, involving an integrated strategy and a multidisciplinary approach (Sen Sarma and Mishra, 1986; Ambika and Jayachandra, 1990, Thakur *et al.*, 1992; Muniappan and Viraktamath, 1993). In particular, the former authors emphasised the long-term nature of such projects and that this should be taken into account by administrators and planners responsible for approving funding. It is to be hoped that international donors can be identified and persuaded to invest in these more ambitious, and hence more expensive projects which would benefit not only local agricultural and forestry schemes, but also help to preserve conservation areas from the actual and potential threat posed by invasive, alien weeds - such as *C. odorata, M. micrantha* and *L. camara* in the Western Ghats - otherwise these natural ecosystems and their inherent biodiversity, could cease to exist in the not too distant future.

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INFLUENCE OF ORGANIC MANURES ON THE INCIDENCE OF BLAST DISEASE IN RICE

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ABSTRACT

In the hill zone of southern India inorganic fertilizers form the main source of nutrients to improve the yields of rainfed rice cultivars. But incessant rain during the kharif season forces the farmers many times to postpone or skip application of fertilizers. Further, the recommended dosage of 75 kg/ha nitrogen has been observed to predispose the crop to higher infection by the fungus *Pyricularia oryzae*. Therefore, the feasibility of supplementation of nutrition through organic sources was investigated in three rice cultivars, Intan, Mahsuri and IET-7191 during 1989 and 1991. *Chromolaena odorata* green manure and farmyard manure (FYM) were incorporated singly and in combination with inorganic fertilizers. Significantly low blast disease incidence was observed in FYM treatment. In green manure treated plots the incidence of neck blast and grain yield were not significantly different from those observed in NPK treatment. Grain yield was affected by higher incidence of blast in Mahsuri where organic manures were integrated with NPK.

INTRODUCTION

Blast disease of rice caused by *Pyricularia oryzae* is endemic to the hill zone of Karnataka. It is a serious limiting factor in the successful cultivation of rainfed rice. Varieties resistant to blast and to suit various agro-ecological situations are lacking, and the local cultivars are highly susceptible to the disease, besides being non-responsive to inorganic fertilizers. Intan, the only ruling high yielding cultivar has also lost its resistance to the disease. Any effort to improve the crop productivity by using recommended dose of NPK has been observed to predispose the crop to blast disease (Maharudrappa *et al.*, 1993).

Organic manures serve as slow release nitrogen sources for plant nutrition (Flaig, 1984) besides improving the soil physical properties. About 25-30% nitrogen contained in composts and farm yard manures can be absorbed by rice plants during one crop season (Inoko, 1984). The advantage of this source of nutrient is not realised due to other considerations. The farmers produce farm yard manure on the farms, but they are reluctant to use this for paddy fields at the cost of more remunerative plantation crops. As a result, they depend solely on inorganic fertilizers. Crop management with fertilizer application has its own limitations. Incessant rainfall during the transplanting period in the high rainfall areas does not permit application of basal dose of fertilizers at planting, hence often this application is delayed by 25-30 days. Further, top dressing with nitrogen is done in short intervals to boost the growth of the crop. This practice has also been found to predispose the crop to blast disease (Anon., 1992).

The present study was conducted to explore the possibilities of reducing blast disease incidence and improving the productivity by using nitrogen from organic manures. The experiment was conducted at the Regional Research Station, Mudigere (13 °7' N and 75 ° 3' E : 980 msl), Karnataka, India.

MATERIALS AND METHODS

Farm yard manure (FYM) and *Chromolaena odorata* green manure were applied at the rate of 5 and 10 t/ha (0.5 and 1.0 kg/m2) respectively, singly and in combination with 75:75:87.5 kg NPK/ha. Fifty percent nitrogen was applied as basal dose and the rest in two equal splits as top dressing at 25 and 50 days after transplanting wherever NPK was applied. The experiment was laid out in split plot design with three replications during 1989 and 1991. FYM and green manure were incorporated to the puddled soil before transplanting the seedlings. Intan, Mahsuri and

IET-7191 cultivars, susceptible, highly susceptible and resistant to blast disease, respectively, were used. Observations were recorded on the incidence of leaf and neck blast and grain yield. The data were analysed employing 3 factor RCBD.

RESULTS AND DISCUSSION

Farm yard manure application was not found to influence either leaf blast/neck blast disease incidence or yield in the blast susceptible cultivars, Intan and Mahsuri. In green manure treated plots the incidence of neck blast and grain yield were not significantly different from those observed in NPK treated plots. However, they were significantly higher than those observed in FYM applied plots and control.

Integration of organic and inorganic manures always predisposed the crop for leaf/neck blast. Hence higher disease incidence was observed in these treatments. Despite this, higher yields were obtained in Intan, as also in the resistant variety IET-7191, but in a highly susceptible variety like Mahsuri the yield was severely affected by the highest incidence of the disease (Tables 1-3).

Table 1. Effect of source of nutrition on the incidence of leaf blast, neck blast and yield in Intan (Mean of 2 years)

Source	Leaf blast PDI	Neck blast %	Grain yield (q/ha)	% Increment over control
FYM	2.15 (0.055)	2.00 (0.052)	44.63	1.12
GM	3.22 (0.074)	5.00 (0.105)	50.28	12.79
FYM+NPK	6.43 (0.129)	6.42 (0.129)	52.45	17.65
GM+NPK	8.86 (0.171)	5.84 (0.115)	47.26	6.01
NPK	6.31 (0.127	5.59 (0.115)	50.12	12.43
CONTROL	2.73 (0.065)	2.17 (0.005)	44.58	
CD at 5%	0.108	0.134	1.27	

GM = Green Manure
PDI = Per cent Disease Index
q = 100 Kg

Table 2. Effect of source of nutrition on the incidence of leaf blast, neck blast and yield in Mahsuri (Mean of 2 years)

Source	Leaf blast PDI	Neck blast %	Grain yield (q/ha)	% Increment over control
FYM	3.01 (0.070)	8.00 (0.156)	39.93	- 2.20
GM	3.22 (0.074)	20.17 (0.361)	38.89	- 4.75
FYM+NPK	5.20 (0.108)	30.67 (0.525)	39.57	- 3.09
GM+NPK	8.37 (0.163)	36.50 (0.609)	27.91	- 31.64
NPK	6.64 (0.133)	22.00 (0.390)	38.40	- 5.95
CONTROL	1.98 (0.052)	8.67 (0.168)	40.83	
CD at 5%	0.108	0.134	1.27	

GM = Green Manure
PDI = Per cent Disease Index
q = 100 Kg

Table 3. Effect of source of nutrition on the incidence of leaf blast, neck blast and yield in IET-7191 (Mean of 2 years)

Source	Leaf blast PDI	Neck blast %	Grain yield (q/ha)	% Increment over control
FYM	0.00 (0.017)	0.00 (0.017)	47.62	3.61
GM	0.00 (0.017)	0.00 (0.017)	52.44	14.10
FYM+NPK	0.00 (0.017)	0.00 (0.017)	50.60	10.10
GM+NPK	0.00 (0.017)	0.00 (0.017)	54.02	17.54
NPK	0.00 (0.017)	0.00 (0.017)	52.20	13.58
CONTROL	0.00 (0.017)	0.00 (0.017)	45.96	
CD at 5%	0.108	0.134	1.27	

GM = Green Manure
PDI = Per cent Disease Index
q = 100 Kg

This study shows that *C. odorata* can be used as green manure since it is superior to inorganic fertilizers in terms of low incidence of leaf blast and comparable increment in grain yield. The feasibility of integrating a suitable fungicide for management of blast disease requires further study.

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EXPLOITATION OF *Chromolaena odorata* (L.) KING AND ROBINSON AS GREEN MANURE FOR PADDY

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ABSTRACT

Chromolaena odorata is a perennial shrub abundantly found in the deforested areas, marginal lands, gomal lands and by the side of roads in the Western Ghats of Karnataka, India. An experiment was conducted during 1990 and 1991 kharif seasons to exploit the biomass of *C. odorata* for enriching the nutrient status of rice fields. The succulent shoots were found to contain 2.65% N, 0.03% P_2O_5 and 1.90% K_2O on dry weight basis. This is comparable with 2.79% N, 0.02% P_2O_5 and 0.69% K_2O of *Pongamia.* sp. and 2.8% N, 0.02% P_2O_5 and 1.5% K_2O of *Glyricidia* sp. When *C. odorata* was used as green manure the increment in mean grain yield of rice (cv. Intan and IET-7191) was 12.4% over control. However *C. odorata* green manure along with NPK resulted in 32.7% increment and *Pongamia* sp. along with NPK resulted in 27.1% increment in yield over control. The yield increment due to NPK alone was 23.5% over control. *C. odorata* thus holds promise for its exploitation as an important non-cash source of nutrition for rice crop.

INTRODUCTION

Chromolaena odorata is a perennial shrub abundant in humid Western Ghats of Karnataka. The dominance of this plant as a ground cover is seen predominantly in the deforested areas. Besides, it is also found growing extensively by the side of roads, on marginal lands and gomal (range) lands. Its propensity to spread fast poses many problems in management of lands. It is a source of fire in the forests during summer months. Its spread into the gomal lands has denied the cattle natural fodder. However, it is not found to be a menace in coffee plantations, where the annual weeding work has kept it at bay. Some farmers were found using *C. odorata* as bedding in their wet cattle sheds during rainy months. Besides this, no other use of this plant was observed in the Western Ghats.

C. odorata begins to sprout soon after pre-monsoon showers in the months of April-May. Each clump produces 4-10 shoots that mature following the peak growth period in October and starts flowering from November. The flowered twigs start drying during January-February. Several attempts are underway to control this obnoxious plant by mechanical, cultural, chemical and biological methods.

The excellent green and succulent biomass of the weed during July-August months can be exploited as green manure since this season coincides with rice transplanting operations in the Western Ghats. Normally annual legumes are raised in situ prior to planting and the biomass is incorporated. Wild annual legumes and perennial legumes are also cut and transported to rice fields (Vachhani and Murthy, 1964 and Panse *et al.*, 1965). The availability of such biomass is dwindling due to unsustained interest in promoting their survival and maintenance in nature. Currently, the *C. odorata* biomass is the only green manure source abundant in and around rice growing areas. Since it is perennial in habit and capable of producing sprouts as long as wet weather prevails, it promises to meet the continuous demand for green manure.

A comparative evaluation of *C. odorata* and the traditionally used *Pongamia* as green manure in long duration rice varieties Intan and IET 7191 was made during the Kharif season of 1990 and 1991 at the Regional Research Station, Mudigere (13°7' N and 75° 3'E; 980 msl) Karnataka, India.

MATERIALS AND METHODS

The succulent shoots of *C. odorata* were incorporated into the puddled paddy field at the rate of 10 t/ha (1kg/m^2) alone and in combination with the recommended dose of inorganic fertilizer (75:75:87.5 kg NPK/ha). Fifty percent N was given as basal dose and the balance in 2 equal splits at 25 and 50 days after transplanting, wherever inorganic fertilizer was applied. The rice seedlings were transplanted the same day. The experiment was laid out in split plot design with 4 replications. Thirty days old seedlings of the long duration cultivars Intan and IET-7191 were transplanted. Grain yield data was recorded.

The oven dried plant samples were analysed for mineral constituents by procedures described by Jackson (1973) and Piper (1966).

RESULTS AND DISCUSSION

C. odorata biomass was found to contain 2.65% N, 0.03% P_2O_5 and 1.90% K_2O on dry weight basis. This is comparable with 2.79% N, 0.02% P_2O_5 and 0.69% K_2O of *Pongamia* sp. and 2.8% N, 0.02% P_2O_5 and 1.5% K_2O of *Glyricidia* sp. (Table 1).

Table 1. NPK content (per cent dry weight) of green manure plants

		N	P_2O_5	K_2O
1	*Pongamia* sp.	2.79	0.02	0.69
2	*Glyricidia* sp.	2.80	0.02	1.50
3	*C. odorata*	2.65	0.03	1.90

Table 2. Nitrogen yield of green manure plants

Source	Biomass applied (t/ha)	Moisture (%)	N content (%)	N yield (kg/ha)
C. odorata	10	69	2.65	82
Pongamia sp.	10	59	2.70	114

Thus application of *C. odorata* and *Pongamia* sp. as green manure at the rate of 10 t/ha would yield 62 and 114 kg of nitrogen respectively (Table 2). Neither *C. odorata* nor *Pongamia* sp. were found to be deleterious to rice crop. The crop remained more green in the green manure treated plots compared to other treatments.

Table 3. Effect of source of nutrients on grain yield in Intan

Source	Grain yield (q/ha) 1990	1991	Mean	% increment over control
C. odorata	51.49	45.25	48.37	9.19
Pongamia sp.	51.24	47.59	49.42	11.56
C.o + NPK	61.18	49.79	55.49	25.26
Po + NPK	58.53	50.42	54.48	22.98
NPK	55.31	50.21	52.75	19.10
Control	43.85	44.74	44.30	
CD at 5%	4.4	4.16		

Table 4. Effect of source of nutrients on grain yield in IET-7191

Source	Grain yield (q/ha) 1990	1991	Mean	% increment over control
C. odorata	50.85	46.57	48.71	15.84
Pongamia sp.	52.28	48.59	50.44	19.95
C.o + NPK	64.68	54.08	59.38	41.21
Po + NPK	59.67	50.93	55.30	31.51
NPK	53.23	54.56	53.90	28.18
Control	39.88	44.21	42.05	
CD at 5%	4.4	4.16		

C. odorata was found to increase grain yield significantly over control (Tables 3 & 4). Comparison of grain yield showed an increment of 9.19% and 15.84% over control in Intan and IET-7191 cultivars respectively. The performance of *C. odorata* did not differ significantly from *Pongamia* sp. when they are used alone. Integration of *C. odorata* with inorganic fertilizers resulted in significantly higher yields in both Intan and IET-7191 (25.26% and 41.21% respectively) compared to NPK alone (19.10% and 28.18% in Intan and IET-7191 respectively). There is thus a possibility of reducing the inorganic fertilizer usage.

The results indicate that incorporation of *C. odorata* biomass, plentifully available in the rice growing regions in the Western Ghats, could be profitably exploited for rice production. Utilisation of this plant as a green manure does not pose any pollution problem, but rather prevents the possible image to

the rice ecosystem by favouring reduced usage of inorganic fertilizers.

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A NOVEL APPROACH FOR COMBATING *Chromolaena* PROBLEM: POSSIBILITIES OF ITS USE AS A GREEN MANURE

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ABSTRACT

Chromolaena odorata is abundant in the Western Ghats of Karnataka all along road sides, edges of plantations, waste lands fallow lands, and in deforested areas. The plant puts forth vegetative growth from third week of May, immediately after the onset of monsoon and attains average height of 1.45 m, providing succulent and green biomass of 1.9 to 2.6 kg m^2 by the second week of July. An experiment was laid out at the Regional Research Station, Mudigere to study the usefulness of *Chromolaena* as a green manure in rice, comparing it with the traditional green leaf manures *Glyricidia maculata, Pongamia glabra* and *Sesbania rostrata,* in combination with inorganic fertilizers. There was no significant difference with respect to grain and straw yields in all the four green leaf manures when used in combination with 50% or 75% inorganic N compared to 100% recommended dose. Twenty five to 50% of inorganic N was saved by using green manures. *Chromolaena* supplied 0.82% N, 0.53% P_2O_5 and 1.37% K_2O which was higher than any other green manure crop studied. *Chromolaena* applied plots also stayed free of neck blast (PDI 1.0 to 4.0) compared to plots that received 100% inorganic fertilizers (PDI 5.0 to 18.0).

It is advantageous to use *Chromolana* as a green manure in rice because it is cheap, non-hazardous, easily decomposable, raises soil temperature resulting in very low or no incidence of leaf and neck blasts.

INTRODUCTION

In the hill zone of Karnataka, farm yard manure is not generally available in sufficient quantities and cultivation of a pure green manure crop is difficult in unprotected rice fields due to cattle grazing during the early part of the rainy season. Hence, green leaf manuring has an important role to play in rice culture. However, traditional green leaf manure plants are in short supply in the zone. In the present study, the possibility of using a locally available weed plant, *Chromolaena odorata,* as a green leaf manure in combination with inorganic fertilizers in rice was explored. Its usefulness is compared with that of traditional green leaf manures in rice production.

MATERIALS AND METHODS

The study was taken up at the Regional Research Station, Mudigere (mean annual rainfall 3000 mm), during the rainy seasons of 1994-95 and 1995-96. The soil of the experimental plots was sandy loam with a pH 5.4; organic carbon content of 0.91%; total nitrogen 0.30 per cent; available phosphorus 18 kg/ha and available potassium 81.8 kg/ha.

The organic carbon was determined by Walkley, and Black Rapid Titration method (Piper, 1966), total nitrogen by modified Kjeldahl's method (A.O.A.C.) 1975), available phosphorus by modified Olsen's method (Olsen *et al.*, 1954) and potassium by flame photometer (Hanway and Heidal, 1969). Chlorophyll content of green manures were analysed by adopting to DEMSO method (Hiscox and Isrelstom, 1979).

The experiment was laid out in a randomized block design with three replications and ten treatments. The treatments comprised three levels of inorganic fertilizer alone, three treatments of 5 t/ha of *Chromolaena* plus 3 levels of inorganic fertilizers, and three treatments were with 5 t/ha *Sesbania rostrata* with three levels of inorganic fertilizers. Nitrogen was supplied through urea containing 46% N; phosphorus through rock phosphate (18% P_2O_5) and potassium through muriate of potash having 60% K_2O. The

individual plot size was 6m x 4m (gross) and 5.8m x 3.90m (net) respectively. The variety Intan was sown in second week of June and healthy seedlings were transplanted in second week July. All other cultivation practices were followed as per the package of practices.

Sesbania rostrata is a stem nodulating legume, fast growing, suits high rainfall areas and withstands water-logged conditions. It flowers in 50 days after sowing (DAS), contains 0.78% N, 0.13% P_2O_5 and 0.45% K_2O (fresh wt. basis). It was applied at the rate 5 t/ha.

C. odorata is a common weed in the hill zone, available in plenty all along the roadsides, bunds, waste lands, edges of forests and plantations. It decomposes easily and quickly, has a higher N.C. ratio (1:16), 0.82% N, 0.23% P_2O_5 and 0.75% K_2O. It is drought tolerant, puts forth vegetative growth from the first week of May and reaches peak growth period with dark green leaves during second week of July. It was cut during July second week and incorporated at the time of transplanting at the rate of 5 t/ha.

Inorganic fertilizer application was as per the experimental plan with or without green manures to rice. *S. rostrata* was sown during first week of May and at the time of flowering (50-55 DAS) it was cut and incorporated into the main field two days before transplanting of rice at 5 t/ha. *C. odorata* growing nearby paddy fields was cut to ground level and incorporated into experimental plots after clipping into small pieces (5 to 10 cm) on the day of transplanting at the rate of 5 t/ha.

Nitrogen was applied in three splits (50% at transplanting and balance in two splits at 30 days after transplanting (DAT) and 60 DAT while phosphorus and potash fertilizers were applied at the time of transplanting.

Treatment details :

Design : RBD

Replication : Three

Treatments : Ten

Treatments :

T1 - Control (No NPK - No manure)

T2 - 50% recommended dose of NPK inorganic fertilizer

T3 - 75% -do-

T4 - 100% -do- (75-75-90) kg NPK/ha

T5 - 50% recommended dose of inorganic NPK + 5 t/ha *C. odorata*

T6 - 50% -do-

T7 - 100% -do-

T8 - 50% recommended dose of inorganic NPK + 5 t/ha *S. rostrata*

T9 - 75% -do-

T10 - 100% -do-

RESULTS AND DISCUSSION

The highest grain yield was obtained (5,182 kg/ha) at 100 per cent recommended dose of fertilizers. Incorporation of *C. odorata* or *S. rostrata* with 50 to 75 per cent recommended inorganic fertilizers produced grain on par with 100 per cent inorganic fertilizers (Table 1). This indicates that it is possible to save nitrogen to the extent of 25 to 50 per cent with incorporation of these green leaf manures. Relwani and Ganguly (1959) found that the green manuring of rice with *Sesbania bispinosa* Jacq increased grain and straw yields. Meelu and Morries (1984) also reported that green manure contributed 45-80 kg N/ha in rice.

Table 1. Effect of green manures on the growth and yield of Intan Rice

Treatment No.	Plant height in cm		Productive tillers		Grain yield in kg/ha	
	94-95	95-96	94-95	95-96	95-96	94-95
T1	94.4	83.2	255.0	375	3611	2878
T2	96.0	88.3	266.6	434	4255	3849
T3	97.9	92.2	277.3	470	4825	4476
T4	99.5	94.2	323.3	502	5637	4728
T5	99.4	92.7	320.0	489	5179	4797
T6	99.5	93.4	345.0	485	5462	4988
T7	99.4	95.4	362.3	517	5923	5082
T8	98.1	94.4	323.3	497	5163	4807
T9	101.2	95.9	350.3	508	5321	4940
T10	100.5	96.6	357.3	531	5838	5114
F.test	*	*	*	*	*	*
CD at 5%	0.856	1.261	29.28	32.16	254.6	262%
CV%	0.51	2.76	5.32	5.18	2.91	3.67%

Analysis of nutrient and chlorophyll contents showed that *C. odorata* was on par with other traditional green

Table 2. Nutrient content of *Chromolaena odorata* and other traditional green manures of hill zone of Karnataka

Sl. No.	Fresh weight basis (100kg)						
	Green manure	Nitrogen	Phosphorus	Potash	Calcium	Magnesium	Sulphur
1.	*Sesbania rostrata*	0.78	0.13	0.45	1.13	0.57	0.17
2.	*Glyricidia maculata*	0.68	0.21	0.49	1.28	0.65	0.12
3.	*Pongamia glabra*	0.76	0.14	0.49	1.45	0.47	0.15
4.	*Chromolaena odorata*	0.82	0.23	0.75	1.25	0.53	0.11
5.	*Sesbania acculata*	0.89	0.12	0.51	1.15	0.43	0.10

Table 3. Chlorophyll content of *Chromolaena odorata* and other traditional green manure crops

Name of the Green manure	Fresh weight basis		
	Chlorophyll (a) mg/g	Chlorophyll (b) mg/g	Total Chlorophyll (a+b) mg/g
Glyricidia maculata	0.110	0.079	0.1890
Pongamia glabra	0.086	0.091	0.1770
Sesbania rostrata	0.078	0.096	0.1840
Erythenia indica	0.076	0.106	0.1820
Chromolaena abrata	0.097	0.096	0.1930
Subabul	0.063	0.071	0.1350

manures (Tables 2 & 3), if not superior. The growth pattern of *Chromolaena* coincides with the time of rice transplanting and hence will be a readily available green manure for increasing the rice production in the zone. Hence, this would be a positive approach towards this otherwise noxious weed.

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EFFECT OF VARIOUS PLANT EXTRACTS ON MORTALITY OF *Radopholus similis*

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ABSTRACT

The efficacy of nine plant products was evaluated against the burrowing nematode, *Radopholus similis*, attacking coconut, arecanut, banana, black pepper and oil palm in South India. Water extracts of fresh leaves of eight plants and bulb of onion were prepared and tested for antihelminthic efficacy against *R. similis*. The results of the study revealed that leaf extract of *Chromolaena odorata* exhibited a very high degree of nematicidal action against the adults and larvae of *R. similis*. As high as 84 per cent mortality of *R. similis* was recorded from the leaf extract of *C. odorata* followed by 82.33 per cent in both *Ananas comosus* and *Mimosa invisa*. The mortality of nematodes was also found to increase in the leaf extract of *C. odorata*, *A. comosus* and *M. invisa* with time of exposure. No mortality was recorded in distilled water.

INTRODUCTION

The burrowing nematode, *Radopholus similis*, is the most important nematode problem on coconut, arecanut, black pepper and banana in south India. Though considerable amount of work has been carried out on control of this nematode by using different nematicides in relation to these crops by several workers (Koshy and Nair, 1979; Koshy and Sosamma, 1979; Koshy *et al.*, 1983; Sundararaju and Koshy, 1986 and Venkitesan and Charles, 1979), no detailed work was done with reference to plant products possessing nematicidal properties as a possible measure for controlling nematodes. In view of the above an attempt has been made to study the effect of plant products against *R.similis* under laboratory conditions.

MATERIALS AND METHODS

Fresh leaves of nine plants (*Vitex negundo* Linn; *Chromolaena odorata* (Linn.) King and Robinson; *Mimosa invisa* Mart., *Bougainvillea spectabilis* Wild., *Ocimum basilicum* Linn., *O. sanctum* Linn., *Brassica nigra*, *Ananas comosus* (L) Merr. and bulb of onion (*Allium cepa* Linn.) were collected and an extract of each was prepared in 99 per cent acetone. Fresh leaves and bulbs were thoroughly washed in sterile water. The water present on the surface area was allowed to dry up by spreading in a clean air flow chamber. Each gram of plant tissue was ground in five ml. of acetone by using a pestle and mortar. After thoroughly macerating the plant material it was squeezed through muslin cloth and filtered through Whatman No.1 filter paper. Acetone was evaporated by using a flash evaporator under reduced pressure. The temperature of the water bath was maintained throughout at 45°C.

From this extract 1:4 dilution was prepared by using distilled water. One hundred freshly collected *R. similis* were inoculated into a 5 cm petridish containing 10 ml. of 1:4 concentration of extract. Distilled water alone served as control. The petridishes were kept in BOD incubator at 20±1°C. Nematode mortality was counted at 24, 48 and 72 hours. Death of nematodes was confirmed after transfering to distilled water. Per cent mortality was calculated and the data gathered were subjected to Arc sine transformation and analysed statistically by applying factorial completely randomised design method.

RESULTS AND DISCUSSION

Percentage mortalities of *R. similis* caused by different plant products are presented in Table 1. Although none of the plant species caused 100 per cent mortality, all

Table 1 - Effect of plant products on mortality of *Radopholus similis* (means of five replications)

Sl. No.	Plant products tested	Percent Mortality			
		24 hour	28 hour	72 hour	Mean
1.	*Vitex negundo*	41.00 (39.80)	55.00 (47.85)	69.00 (56.15)	55.00 (47.93)
2.	*Chromolaena odorata*	64.00 (53.12)	90.00 (71.62)	98.00 (84.22)	84.00 (69.65)
3.	*Mimosa invisa*	57.00 (49.01)	93.00 (74.76)	97.00 (81.32)	82.33 (68.37)
4.	*Bougainvillea spectabilis*	23.00 (28.59)	45.00 (42.11)	59.00 (50.18)	42.33 (40.29)
5.	*Oscimum basilicum*	21.00 (27.25)	39.00 (38.63)	56.00 (48.43)	38.67 (38.10)
6.	*Oscimum sanctum*	10.00 (18.34)	36.00 (36.84)	71.00 (57.40)	39.00 (37.53)
7.	*Allium cepa* (bulb)	32.00 (34.44)	54.00 (47.28)	62.00 (51.93)	49.33 (44.55)
8.	*Brassica nigra*	46.00 (42.68)	73.00 (58.68)	93.00 (75.03)	70.66 (58.80)
9.	*Ananas comosus*	54.00 (47.28)	94.00 (75.99)	99.00 (87.11)	82.33 (70.12)
10.	Control (Distilled water)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Mean		34.80 (34.05)	57.90 (49.38)	70.40 (59.18)	

Figures in parenthesis are arc sine transformed values.

CD for treatment (2.117)
CD for hours (1.160)
CD for treatment X hours (3.667)

plants showed nematicidal effect against *R. similis*. Among the different plants tried, the maximum of 84.00 per cent mortality was recorded with *C. odorata* followed by 82.33 per cent each with *A. comosus* and *M. invisa*. The mortality of nematodes was found to increase with time. No mortality was recorded in distilled water.

All the plant extracts tried effectively increased the mortality of *R. similis*. The results clearly indicated that all the plant extracts exhibited a high degree of nematicidal action against the adults and larvae of *R. similis*. The leaf extracts of *C. odorata* recorded the highest per cent mortality. Subramaniyan and Selvaraj (1988) and Jasy and Koshy (1992) reported the nematicidal effect of water extracts of certain green manure plants against *R. similis*.

From this study it may be concluded that plants like *C. odorata, M. inivisa* and *A. comosus* which are commonly available in plantations can be effectively utilised for the control of *R. similis*.

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ESTABLISHMENT OF MIXED SIGNALGRASS (*Brachiaria decumbens*) PASTURE WITH LEGUME SPECIES IN SOUTHERN YUNNAN AS A WAY TO CONTROL FEIJICAO (*Chromolaena odorata*)

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ABSTRACT

It has been reported that an effective way of controlling the weed, Feijicao (*Chromolaena odorata* (L.) King and Robinson) is to plant signalgrass *Brachiaria decumbens* Stapf cv. Basilisk) on the pasture. But this artificial grassland, solely based on signalgrass planting, is not only low in nutrient contents, but also becomes less and less productive over long years, eventually deteriorating entirely and *C. odorata* reappears. For keeping signalgrass dominance constantly and raising the productivity of the pasture, it is essential to find another single legume species or a combination of leguminous plants with superior performances, which may be still maintaining the original symbiosis situation and resistance intensity to *C. odorata* invasion, besides adding a high input of nitrogen to the soil. So from 1991 to 1993, trials were conducted continuously using 8 legume species - signalgrass combination treatments in mixture planting. These key treatments were carried out with regard to their relative yields on a dry matter basis, stability of legume-grass ratios as well as their competitive effectiveness in fighting *C. odorata*. The final successful result of the study indicated that 2 legume species, *Flemingia macrophylla* (Willd.) Merr. and *Arachis pintoi* L. cv. Amadillo, can be planted with signalgrass for long term suppression of *C. odorata* and also to raise the crude protein content in the pasture from 5.6% to 12.2%.

A noxious weed species, Feijicao (*Chromolaena odorata* (L.) King and Robinson) (Asteraceae) has done much harm to the local plant vegetation and rangeland pastures since it spread into the southwest and mid-west areas of Yunnan from south-east Asia. This weed is highly productive and propagates in great density, sometimes even dominating at great speed large areas of land where plant vegetation is destroyed or where there are hilly slopes, burned wastelands as well as farmlands. It is found in some mountainous regions with elevations ranging from 500 to 1500 meters above sea level. In Yunnan province, it is mainly distributed in such prefectures as Dehond, Lincang, Jinghong, Simao, etc.

The signalgrass cultivar Basilisk (*Brachiaria decumbens* Stapf), was first introduced into Yunnan in 1984. It was sown on a large scale by the Manzhongtian State Farm, Simao County, where it proved effective in combating *C. odorata*. Three years after the establishment of signalgrass, *C. odorata* disappeared completely from the pasture (Wu Renrun and Xu Xuejun, 1991; Wu Renrun and Lu Xinshi, 1992; Kuang Chongyi, 1991; Xu Xuejun *et al.*, 1989).

In the first year after *B. decumbens* was established successfully, our report indicated that the crude protein content (CP) of the pasture was 8.36%, while five years later, the CP had declined to 3.13% (Kui Jiaxiang *et al.*, 1990). Obviously, the utilization of pasture over years would result in the loss of nutrients, which in turn will cause the pasturing ground to deteriorate completely, making it possible for *C. odorata* to come back again. In order to prevent this recurrence and to raise the C P content in pasture again, and to regain land productivity, it is essential to look for alternative treatments. These could be either application of nitrogenous fertilizer or sowing of new legume species onto the pasture for further symbiosis between legumes and grasses to a fuller extent. The first of these measures is very costly, and so is not considered further here; however, sowing some more

or newer species of legumes onto the signalgrass based pasture appears to be a better alternative.

MATERIALS AND METHODS

The geographical location of Manzhongtian State Farm, where the experiment work was undertaken, is 101° 17' E longitude and 22° 47'N latitude, with an elevation of 890 meters; annual rainfall is above 220 mm and the annual mean temperature is 20.6°C; the maximum temperature is 27.6°C and the highest temperature in summer is 42°C. The local climate is of the south asian tropical type, featured by both high temperature and humidity. Soil type is lateritic with pH value of 5.6.

The new exotic legume species introduced from abroad was *Arachis pintoi* L. cv. Amarillo (Wu Renrun, *et al.*, 1996) and the indigenous leguminous plant used was *Flemingia macrophylla* (Willd.) Merr. Both were used in trials in the following series of 8 mixed planting treatments, together with signalgrass and its related species paragrass for testing their joint performance in controlling the common weed, *C. odorata*.

M1 *Flemingia macrophylla* + *Brachiaria decumbens* cv. Basilisk (signalgrass)

M2 *Arachis pintoi* cv. Amarillo + *Brachiaria mutica* (Forsk.) Stapf (Paragrass)

M3 *A. pintoi* cv. Amarillo + signalgrass

M4 *F. macrophylla* + *A. pintoi* cv. Amarillo + signalgrass

M5 *Centrosema pubescens* Benth. cv. Belalto + signalgrass

M6 *Centrosema pubescens* Benth. cv. Belalto + *Stylosanthes scabra* Veg. cv. Seca + *Panicum maximum* Jacq. cv. Hamil (Guineagrass)

M7 *C. pubescens* Benth. cv. Belalto + *S. scabra* Veg. cv. Seca + *Cenchrus ciliaris* L. cv. Nunbank (buffelgrass)

M8 *C. pubescens* Benth. cv. Belalto + *S. scabra* Veg. cv. Seca + *Paspalum plicatulum* Forst. cv. Bryan

The experimental design used was the randomized block design, in which the number of replications was 4, and the total treatment combinations were 8 in all as listed above. There were thus 4 x 8 = 32 plots, with each plot area being 20 m^2, the whole trial area thus being 640 m^2.

The trial ran for 3 years, from 1991 to 1993. The land was prepared for planting by burning the *C. odorata* invaded land at the withering stage of the plants. Seeds of both grass and legume species were sown before the wet season started (in Yunnan usually in June and July every year).

During seeding, all the legume species were treated by inoculation with the correct Rhizobial strains and well mixed with basal fertilizers, together with the grass species in different genera, as the signalgrass and the other *Brachiaria* sp., paragrass, *Paspalum, Cenchrus* and *Panicum* according to the treatment before they were all evenly spread into the plots. The basal and maintenance fertilizers supplied annually comprises 400 kg calcium-magnesium- phosphate/ha + 100 kg potassium sulphate/ha + 5 kg borax/ha.

RESULTS AND DISCUSSION

The results of the three year study showed that only the M4 group had achieved the greatest dry matter yield, the most stable legume-grass planting ratio and the highest resistance force against the weed plant, *C. odorata* with M5 and M1 taking the second place; M2 and M7 fell far short of what was expected (Table 1). As for the legume-grass planting ratio on trial, M4 again ranked at the first place, with 55.0% remaining in the plot (3 years average value) in a state of equilibrium with the grass species. The M4 treatment similarly showed its comparative resistance intensity to check *C. odorata* invasion most strongly and almost brought it to the verge of nil state, while M1, M3 and M5 followed with only 0.13, 0.15 and 0.18 plants per square meter respectively.

The treatment combination of M4 provided strong evidence of raising the soil fertility The difference in quantity of CP contents between the 2 partner-plants is very close, that of perennial peanut *A. pintoi* is 17.1% while in *F. macrophylla* it was 0.7%. After 3 years the CP content under mixture planting treatment rose to 12.2% as a result of grass: legume seeding In M4, the seeding rate among 1 grass : 2 legumes was changed into 1:2, but in fact, the expressive form numerically should be 50:25:25 (in %), then the mathematical pattern for calculating the CP content would be as follows : [6.9 + (17.1 + 17.8) + 2] x 1/2 = (6.9 + 17.45) x 1/2 = 12.175 ~ 12.2 (in %) (Tables 2 & 3). The ratio of legume seeds to grass seeds was 6:4, the treatments were mixed planting, alternate parallel rows of grass seed and legume and signalgrass sward seeds singly (1985- 1990), the CP contents in 1991 was then: 7.21, 17.46, and 5.65 (in %), while 3 years later in 1993, under the same 3 treatments, the CP contents were raised to 20.74, 21.93 and 5.87 (in%).

Table 1. Relative DM yield, comprehensive stability of legume-grass mixture planting ratio and comparative resistance intensity to *C. odorata* at each plot in experiment conducted from 1991 to 1993

Sl. No.	Treatment	Relative DM yield (ton/ha)				Legume-grass planting ratio				Comparative stability	Plant No. of Weed Survived*
		1991	1992	1993	$\bar{x}$	1991	1992	1993	$\bar{x}$		
1	M1	2.39	2.31	2.92	2.54	33	50	32	31.7	relatively stable	0.13
2	M2	2.50	0.29	-	0.93	1	-	-	0.3	strongly unstable	0.38
3	M3	3.23	1.06	2.26	2.18	13	-	1	4.7	relatively stable	0.15
4	M4	4.55	1.75	2.82	3.04	55	45	65	55.0	mostly stable	0.00
5	M5	3.30	1.35	3.18	2.61	12	-	-	4.0	mostly unstable	0.18
6	M6	3.37	0.73	2.06	2.05	25	22	18	21.7	relatively stable	0.25
7	M7	0.65	0.02	0.45	0.37	-	-	-	0.0	mostly unstable	0.30
8	M8	2.27	0.82	1.60	1.56	12	1	13	8.7	mostly unstable	0.25

Note : *Plant number of Weed $\rightarrow$ *C. odorata* was recorded by quadrat samples taken at random per m^2 at 4 plots in the experiment

Table 2. Comparative nutrient contents (including mineral elements) of 3 plant species participants (grass and legume species) in treatment M4 plots

Plant spp.	Crude protein	Crude fat	Crude fiber	Crude ash	N	P	K	Ca	Mg	S	Cu	Zn
Brachiaria decumbana	6.9	1.7	31.4	8.4	1.1	0.20	2.3	0.48	0.24	0.32	6.0	62.0
Arachis pintoi	17.1	-	-	-	2.7	0.40	3.3	1.02	0.33	0.21	16.0	7.0
Flemingia macrophylla	17.8	-	-	-	2.9	0.14	0.5	1.20	0.09	0.10	3.5	14.7

Table 3. The main nutritive contents of signalgrass planted by single species and in mixture within the treatment combination M4

Treatments	Crude protein %	Crude fat %	Crude fiber %	Crude ash %
Brachiaria decumbens in single	5.60	1.39	38.19	7.51
Brachiaria decumbens in mixture	6.90	1.79	31.40	8.40.

Table 4. Comparative nutrient contents of signal grass planted in various types of soils in 3 different pasturelands on trial (in ppm excepting organic matter & entire N in %)

Treatments	Organic Matter %	Full N %	P ppm	K ppm	Ca ppm	Mg ppm	Na ppm	S ppm	Cu ppm	Zn ppm	Mn ppm	Fe ppm
C. odorata invaded land soil	2.9	0.2	0.7	17.0	5.3	0.9	10.1	42.7	0.9	0.6	21.4	59.7
Signalgrass land soil by single planting	2.2	0.1	-	22.0	3.1	0.6	9.3	83.0	0.5	0.6	20.6	81.0
Signalgrass land soil by mixture planting with legumes (M4)	3.8	0.7	18.4	105.0	29.4	5.8	-	9.1	0.7	13.2	11.9	26.4

As for the nutrient contents analytical evaluation in signalgrass, mixture planting treatment and check plots (signalgrass planting singly on trial) showed that with the exception of the crude fiber content, the remaining values showed an ascendant trend. The statistical data for comparison in Table 4 among *C. odorata* invaded land, the signalgrass check plots as well as among those grass-legume mixture planting treatment plots all had only a clear-cut situation to indicate that in *C. odorata* check plots only 3 out of the 8 figures are higher than those lands invaded by the weed with only single one being equal. In those plots with mixture planting treatment of plant species, among 10 figures from P to Fe, six are remarkably higher with only 4 being lower (in S, Cu, Mn and Fe, all mineral elements in minor grade). Thus, the main conclusion in our study is that mixed grass and legume pasture lands seem to improve the soil of *C. odorata* invaded lands.

In conclusion, sowing perennial peanut and big-leaved *Flemingia* in mixture with signalgrass reduced the noxious weed *C. odorata* and improved soil fertility.

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GROWTH PATTERN, SPROUTING ABILITY AND CHEMICAL CONTROL OF *Chromolaena odorata*

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ABSTRACT

Experiments were conducted to assess the year-round growth pattern of *C. odorata*, the sprouting ability of its stumps as well as root segments collected at different depths from soil, and to identify a suitable growth stage for effective control of *C. odorata* by herbicides. In a fairly established seedling, the shoot growth recorded in a year was up to 2.13 m while root peneration was up to 0.64 m. Shoot biomass increased 3.2 to 8.7 times more than root biomass as the growth stage advanced. Generally, RGR of stem was high compared to RGR's of leaf and root throughout growth stage. Thus, the stem is the prominent plant part and is the strong sink for nutrients, ensuring that the plant is readily able to resprout. During dry spells or when herbicide is sprayed on to the plant, the leaf and stem portion dried but the stem still had the capability of sprouting. Percent biomass distribution data suggests that up to 140 days after planting (DAP), stem and leaf had the same percent biomass while 140 DAP stem had higher percent biomass compared to leaf.

Logarithmic growth of *C. odorata* was observed only after 263 DAP; until then growth stage growth was linear. Sprouting ability decreased with the deshooting of stumps aged more than 150-200 DAP and sprouting ability was negatively significantly related to shoot or total biomass but not with root biomass. Sprouting ability of root segments collected at soil surface was more than root segments collected at deeper depth. 2,4-D Na salt (1.5 kg ai/ha), glyphosate (1.7 kg ai/ha), combination of glyphosate + chlorimuron ethyl (0.4 + 0.0025 kg ai/ha) applied 25 or 50 DAP; paraquat (0.5 kg ai/ha) and glufosinate of ammonia (0.1 kg ai/ha) applied at any growth stage proved effective in controlling the growth of *C. odorata* up to 100 days after spray.

INTRODUCTION

Chromolaena odorata is a serious weed in hilly areas of Karnataka, especially in forest areas of Western Ghats and coastal Karnataka. It is a highly competitive weed and over the years it has replaced the native weed flora of the forest areas of Western Ghats. Often the *C. odorata* shoots grow up to a height of 8 m (Rai, 1976). Both leaf and stem dries during summer season and become a source for forest fire which poses a serious threat to the vast area of forest floor and nearby coffee, cardamom, rubber, teak and other forest plantations. To prevent fire in the native bush, about 200 acres were sprinkler irrigated in north part of Hollywood in order to save the rich forest wealth (Fuller, 1981).

The spread of *C. odorata* over long distances is through windborne fruits and seeds. Once it touches the soil, it ramifies its spread through profused branching and rooting at the stem portion (Auld, 1981). Other characteristics like sprouting ability of deshooted stump, shade loving nature, year long growth, low seed dormancy, allelopathic nature of seeds and toxic nature of the seeds to the domestic animals (Muniappan and Viraktamath, 1993) make the weed highly competitive and aggressive. More sprouting ability (in terms of shoot height) was observed during rainy season (May to July) compared to other season (August to November) (Salgado, 1992).

The alteration of the growth of the plant can be achieved by retardant treatment before the commencement of logarithmic growth phase (Bhattacharjee *et al.*, 1986). Any weed control measures if imposed, may be more effective at the begining of the log growth phase. Thus, identification of log growth phase of this weed is essential for its effective control using suitable herbicide (contact or translocative). Richards (1969) showed that annual plants followed sigmoidal growth curve when biomass

was plotted against time and absolute growth rate (AGR) with time followed the bell shaped curve. Growth phases of annual plants thus can be differentiated as logarithmic, linear and senescence phases. At these corresponding stages, the AGR showed increasing, constant and decreasing trend against time. With this background information experiments were conducted to identify log growth phase, sprouting ability of deshooted stumps and root segments of *C. odorata*. Further, the effect of few important herbicides on suppression of the growth and sprouting ability of this weed was studied.

MATERIALS AND METHODS

Seedlings of *C. odorata* of 20 - 25 days age were transplanted into thoroughly washed 100 kg plastic bags filled with sand: soil: farmyard manure (FYM) in 1:1:1 proportion. Until 202 DAP, plants were continuously uprooted for growth analysis. After this period, entire plants with plastic bags were transferred into cement cisterns of 0.60 x 0.60 x 1.0 m (LxBxH) size and filled with required quantity of sand: soil: FYM in 1:1:1 proportion. Care was taken to see that plastic bags were removed without disturbing the soil mass while transferring the plants. After 15 days of estalishment further samples were taken for growth analysis up to 324 DAP. Five plants were harvested at each interval of time for both growth pattern and sprouting ability studies.

Growth pattern

At regular intervals of 15 days up to 120 days after planting (DAP) and 30 days from 120 to 324 DAP, growth parameters, viz., root and shoot length (cm), leaf area (cm^2) and biomass of root, stem and leaf (g) per plant were recorded. Total biomass (g/plant) was computed by pooling biomass of all plant parts. The leaf area and biomass of plant parts were log transformed and regressed with time. The best model appeared to be splined cubic polynomial function (eq.1)with two knots at 75 and 171 DAP.

$$Y\ (\log_e \text{ transformed biomass}) = a + bt + ct^2 + dt^3 \quad \text{—(1)}$$

wherein t denotes time (DAP) and a, b, c and d coefficients of the cubic function (Table 3). Instantaneous recorded growth rates (RGR) of different plant parts and whole plant average growth rates (AGR) were computed by differentiating the cubic polynomial, a functional approach (Hunt, 1982) (eq. 2 & 3). Percent biomass distribution in different plant parts over total biomass were computed.

$$\text{RGR at time 't'} = dy/dx \text{ of eq.1} = b + 2 \cdot c \cdot t + 3 \cdot b \cdot t^2 \quad (2)$$

$$\text{AGR at time 't'} = \text{RGR x Exp(Y) at time 't} \quad (3)$$

Sprouting ability of deshooted stumps of *C. odorata*

During 150-200 DAP, plants at 10 day intervals were deshooted to 5 cm level from the soil surface. At 10 day intervals newly sprouted leaves with twigs were removed, oven dried at 80^0 C for 3 days and dry weights were recorded. These dried sprouts were pooled for 120 days or till the sprouting was stopped, whichever was earlier.

Sprouting ability of root segments of *C. odorata*

During 200 DAP, primary roots were cut into different segments of 5 cm length each, from different depth of 0-5, 5-10 and 10-15 cm from the soil surface. These segments were planted in pots, one segment per pot. Percent of seedlings sprouted from segments out of total segments planted were computed.

Herbicide screening for suppression of *C. odorata* sprouting

As a preliminary trail, several herbicides at their recommended dosages were screened for their efficacy to suppress sprouting ability. From this a few herbicides were selected and tested for their efficacy when sprayed at three growth stages 25, 50 and 75 DAP. During these growth stages herbicides were sprayed and biomasses of various treatments were recorded 90 days after spraying (DASp). To overcome the problem of growth stage effect (as the growth stage (GS) advances biomass increases), grand mean of control over all growth stage (GM) was computed and GM - treatment effect over control (GM-T/C) was worked out as follows

$$\text{GM-T/C} = \text{GM X } \frac{\text{Treatment biomass of respective GS}}{\text{Control biomass of respective GS}} \quad (4)$$

In another experiment the effect of glufosinate of ammonia (contact type of herbicide) at different concentrations was tested on biomass of *C. odorata*. This herbicide was sprayed at 70 DAS old established

seedling and biomass produced was recorded after 63 DASp.

RESULTS AND DISCUSSION

Growth pattern of *C. odorata*

Year-round growth and biomass accumulation showed that there was no substantial increase in biomass up to 105 DAP (0.3 to 21.1 g/plant), while during 105-324 DAP drastic change in biomass was observed (21 to 1152 g/plant). However, log transformed biomass data suggested that growth was observed right from

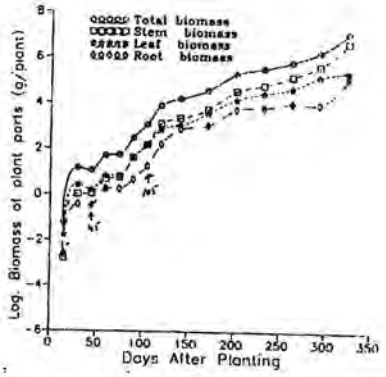

Figure 1. Periodic log transformed biomass of *C. odorata*

the date of planting and never reached a plateau (Fig.1). Such a growth was also observed for different plant parts.

Generally, growth depends on cell division followed by cell elongation. These primary physiological processes are involved in growth of the plant. As per Richards (1969), three growth phases viz., logarithmic, linear and senescence have been identified by plotting AGR against time in annual crops. In logarithmic growth phase, AGR increases exponentially with time while a constant AGR against time is observed during linear growth phase. However

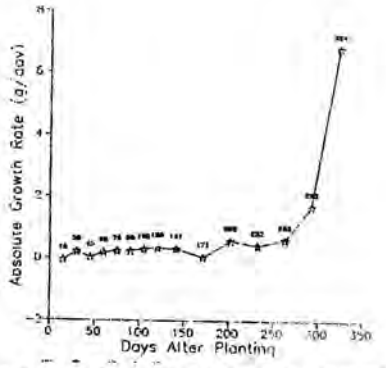

Figure 2. Periodic AGR (g/day) of whole plant of *C. odorata*

during senescence phase, the growth rate decreases against time as the plant reaches maturity and begins to senesce. In the present study, when AGR of the whole plant was plotted against time (Fig.2), linear growth phase was observed from planting to 263 DAP and later on with log growth phase in *C. odorata*, in view of perennial nature of the weed.The senescence

Table 1. Periodic percent biomass distribution in different plant parts of *C. odorata*.

DAP	Total biomass (g/plant)	Percent distribution in		
		Stem	Leaf	Root
15	0.3	20.6	55.0	24.2
30	3.2	31.8	47.7	20.5
45	2.9	26.0	42.4	22.0
60	5.2	37.5	41.3	21.2
75	5.7	37.5	40.0	22.5
90	11.9	42.2	41.3	16.5
105	21.1	41.6	41.8	16.5
120	48.4	46.0	35.3	18.7
141	66.0	42.2	31.4	26.3
171	95.8	42.7	36.2	21.1
202	197.1	47.0	32.0	21.0
232	248.9	48.0	34.0	18.0
263	332.9	52.4	31.5	16.1
293	509.0	55.0	34.7	10.3
324	1152.9	67.0	18.5	14.4

growth phase was not observed, perhaps due to growth parameters being recorded only up to 324 DAP, and summer season was not encountered during weed growth.

Percent biomass distribution in different plant parts suggested that percent biomass in stem was low or on par with leaf biomass (Table 1) from 15 to 105 DAP. After 105 DAP, percent biomass of stem was more than in the leaf and increased substantially as the growth stage advanced. On 324 DAP, the percent biomass accumulation was 67% in stem compared to 18.5 and 14.4 % in leaf and root biomass, respectively. Percent root biomass was relatively low throughout the growth period compared to percent biomass of leaf and stem.

In the established seedlings the shoot length recorded over a period of one year was up to 2.13 m, while for the same period root extension was up to 0.66 m (Table 2). Shoot to root biomass ratio during various growth stages ranged from 2.79 to 8.71. The growth analysis of biomass data and its distribution between different plant parts clearly suggested that the stem is the strong sink compared to other plant parts. In a species periodically leaf drop occurs and hence contribution to the leaf biomass decreases, whereas the

biomass accumulation in the stem is cumulative. To examine the fact that the stem is the major sink the relative growth rates of the different plant parts were computed.

Table 2. Periodic shoot and root length, shoot to root biomass ratio of *C. odorata*

DAP	Root length (cm)	Shoot length (c)	Ratio of shoot/ root biomass
15	4.8	10.3	3.26
30	16.1	33.1	3.92
45	21.2	32.1	3.55
60	24.6	48.8	3.30
75	23.8	63.2	3.45
90	22.2	81.5	5.06
105	27.1	90.0	5.05
120	36.0	95.5	4.34
141	37.4	105.4	2.79
171	46.1	106.9	3.74
202	55.2	116.4	3.76
232	51.9	119.2	4.55
263	58.5	145.7	5.21
293	64.9	183.2	8.71
324	66.0	213.5	5.94

Generally, RGR of the whole plant was relatively more during 15-75 DAP compared to other growth stages 90-171 and 202-324 DAP. Data on RGR of different plant parts (Table 4) further supported this conclusion that stem is the major sink. RGR of the stem was relatively more than leaf and root RGR's throughout the growth stages studied. Hence, in this weed the fact that the stem is the strong sink perhaps helps in regeneration when the plant is deshooted. Similar to this weed, bulb RGR was relatively high compared to other plant parts in *Oxalis latifolia* as the propagation is by bulb (Devendra *et. al.*, 1988).

Sprouting ability of deshooted stump

In this species, the number and vigour of sprouts depends on the stored carbohydrate status of the stem. In this regard, sprouting ability was assessed in deshooted stumps at different growth stages of the plant. Sprouting of new leaves and twigs, and their cumulative dry weight, was more in deshooted young stumps (150 DAP) compared to old stumps (200 DAP). Thus young plants when deshooted had more sprouting ability in terms of sprouted biomass and frequency of harvest in 4 month sprouting period. Strong significant negative correlation between sprouting ability and total biomass or shoot biomass was observed but not with root biomass (Fig.2). This may be due to certain anatomical changes in the stem. Observation of Kushwaha *et al.*, (1981) showed that regeneration of *C. odorata* was much less in older plants (>10 years) compared to younger plants (< 5 years). One of the reasons attributed for the poor sprouting ability in the present study was age of the plant.

Sprouting ability of root segments

Shoot mortality is common phenomenon either due to rainfree period or due to destruction of shoots by forest fire. Under these conditions the regeneration can occur from sprouts of the underground roots. To

Table 3. Various splined cubic polynomial function with two knots at 75 and 171 DAP for various plant parts.

DAP	a	b	c	d	R^2	RSS
Whole Plant						
15-75	-5.588	0.398	-7.4E-3	4.593E-5	0.95	0.294
75-171	-4.274	0.101	-2.9E-4	-	0.99	0.049
171-324	-17.21	0.267	-1.07E-3	1.473E-6	0.99	0.004
Stem						
15-75	-8.214	0.488	-9.1E-3	5.605E-5	0.97	0.298
75-171	-5.814	0.112	-3.3E-4	-	0.99	0.078
171-324	-21.42	0.311	-1.25E-3	1.739E-6	0.99	0.007
Leaf						
15-75	-5.888	0.376	-7.1E-3	4.469E-5	0.93	0.314
75-171	-4.587	0.092	-2.6E-4	-	0.99	0.051
171-324	-3.875	0.077	-2.5E-4	3.077E-7	0.99	0.032
Root						
15-75	-6.406	0.341	-6.1E-3	3.679E-5	0.95	0.268
75-171	-5.499	0.093	-2.5E-4	-	0.97	0.199
171-324	-32.921	0.457	-1.9E-3	2.589E-6	0.98	0.042

a, b, c, d are regression coefficient of polynomial function. R2 indicates coefficient of determination and RSS denotes residual sum of square.

Table 4. Periodic RGR (g/g/day) of *C. odorata* different plant parts

DAP	Stem	Leaf	Root	Whole plant
15	0.256	0.196	0.186	0.206
30	0.099	0.076	0.080	0.078
45	0.018	0.017	0.024	0.011
60	0.013	0.018	0.018	0.006
75	0.084	0.080	0.062	0.063
90	0.058	0.045	0.048	0.043
105	0.049	0.037	0.040	0.039
120	0.040	0.029	0.033	0.030
141	0.027	0.018	0.022	0.020
171	0.009	0.003	0.007	0.001
202	0.039	0.014	0.006	0.013
232	0.035	0.011	-0.006	0.006
263	0.041	0.009	-0.005	0.008
293	0.055	0.009	0.010	0.017
324	0.081	0.012	0.041	0.003

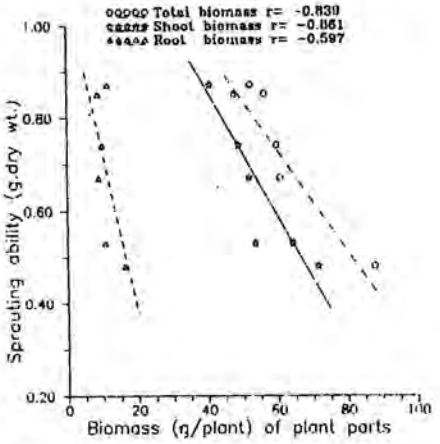

Figure 3. Regression between sprouting ability (150-200 DAP) and biomass of various plant parts

examine the extent of sprouting, sprouting ability of root segments was studied. Root segments collected at 0-10 cm depth had more percent sprouting and established into new seedlings better than segments collected at a deeper soil layer 10-15 cm (Fig.3). Some anatomical changes at the region of root and shoot junction facilitate sprouting (Yadav *et al.*, 1981).

Effect of herbicides on suppression of *C. odorata* growth

Foliar application of 2,4-D Na salt (1.5 kg ai/ha) or glyphosate (1.7 kg ai/ha) or glyphosate (0.4 kg ai/ha) + Chlorimuron ethyl (0.0025 kg ai/ha) at 25 or 50 DAP showed significant reduction in biomass even 100 DASp (Table 5). Similarly, paraquat (0.5 kg ai/ha) spray at any growth stage showed substantial low biomass compared to other herbicides. Glufosinate of ammonia at 0.1 or even 0.04 kg ai/ha sprayed at 70 DAP showed effective, upto 63 DASp, in reducing the biomass. In literature, several herbicides were tried to manage this weed. Application of 2,4-D (2.5 kg ai/ha) followed by establishment of leguminous cover crop or *Tephrosia purpurea* (pila), an ornamental crop or *Brachiaria brizantha* Stapf, a pasture grass, seemed to be effective in controlling *C. odorata* (Sheldrick, 1968; Risdiono, 1975; Salgado, 1992).

Owing to high sprouting ability, both contact (paraquat) or translocative (glyphosate, 2,4-D, chlorimuron ethyl) types of herbicides could not suppress the growth of this weed for a long period. Deshooting followed by 2,4-D EE 2000 ppm (Mogali *et al.*, 1989) or paraquat (0.5 kg ai/ha), 2,4-D Diethyl

Table 5. Effect of herbicides on biomass {GM-T/C(GS)} of *C. odorata* (90 DASp).

Herbicides	kg ai/ha	Growth Stage (GS)			Mean
		25 DAP	50 DAP	75 DAP	
Experiment I					
2,4-D Na	1.5	2.75 (0.6)	0.41 (0.37)	19.30 (1.19)*	7.63 (0.72)
Glyphosate	1.7	2.93 (0.68)	5.18 (0.77)	19.98 (1.30)	8.70 (0.92)
Paraquat	0.5	0.24 (0.35)	5.18 (0.86)	6.90 (0.83)	4.28 (0.68)
Glyphosate + CME	0.4+0.0025	1.06 (0.46)	4.24 (0.59)	37.6 (1.59)	14.3 (0.88)
Mean		1.74 (0.57)	3.75 (0.75)	20.94 (1.36)	
CD (0.05) for Herbicides	=	0.289			
GS	=	0.186			
Herbicides x GS	=	0.503			
Experiment II					
Glufosinate of NH_3	0.01			19.61 (4.52)**	
Glufosinate of NH_3	0.04			13.64 (3.82)	
Glufosinate of NH_3	0.1			12.03 (3.57)	
Control				35.21 (6.01)	
CD (0.05)				(0.67)	

** Data from another experiment sprayed on 70 DAP observation on 63 DASp & values in parenthesis are square root transformed values (X+2)

amine (1.1 kg ai/ha) (Panchal *et al.*, 1995) gave effective control.

Pests and herbicides destroyed the susceptible plant parts of the above ground shoot. Thus, the dried shoots during dry spells cause a fire hazard if they are not removed. In this context, there is a need to manually remove the dried shoots from the forest floor. Bean (*Phaseolus vulgaris*) plants treated with glyphosate died when grown in nonsterile soil, but survived in sterile soil (Johal and Rahe, 1988). Similar results have been obtained with *Sinapsis alba*, apple, wheat and corn (Rahe *et al.*, 1990). The major pathogens infecting glyphosate-treated roots are *Pythium* and *Fusarium* spp. This effect was associated with reduced phenolic incorporation into cell wall structures (Johal and Rahe, 1988). Thus, using the contact type of herbicides to kill the foliage and stem, at any growth stage, followed by glyphosate treatment may induce susceptibility of root to soil microbes. Integrated weed management by herbicide application with an approach to remove the dried shoot manually or by soil organism before the summer season sets in may have a significant impact in suppression of this weed in high rainfall forest areas of Karnataka.

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ADDITIONAL METHODS TO CONTROL *Chromolaena odorata* (L.) KING AND ROBINSON

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ABSTRACT

Chromolaena odorata, an obnoxious weed in the plantations is invading agricultural lands. It comes up in abundance in nurseries and forest areas freshly cleared for plantations. In the forests of Shimoga and South Kanara districts of Karnataka the weed has established itself over vast areas, reducing the amount of land available for cultivation, and has caused the failure of several new plantations.

Many herbicides have been tried to control *Chromolaena* in the plantations and several lakhs of rupees are spent annually by the forest department but the problem has remained unsolved. Field trials were laid out in the Malnad region of Karnataka to investigate the effect of growth regulators and herbicides on floral initiation, the viability of pollen and the cypsella with the objective of checking the spread of the weed effectively.

Maleic hydrazide at 8.3 kg ha^{-1}, Karmex and Weedone concentrate -48 at 1.6 kg ha^{-1} prevented flowering and seed formation in the weed when sprayed at the pre-floral initiation stage. In addition Maleic hydrazide reduced the number of branches and leaves while Karmex and Weedone concentrate at 8.3 kg ha^{-1} killed the whole plant in 15 days. At the post-floral initiation stage, Maleic hydrazide at 8.3 kg ha^{-1} induced 89-100% sterility in the pollen and the cypsella formed were non-viable. Karmex and Weedone concentrate -48 at 1.6 kg ha^{-1} induced 84-95% pollen sterility and 49-66% seed sterility. At higher concentration of 5 kg ha^{-1} these two herbicides produced 95-100% seed sterility. The feasibility of these control measures, their efficacy and economics are discussed.

INTRODUCTION

Chromolaena odorata (L.) King and Robinson is a weed of the forests, pastures and plantation crops in parts of Asia and Africa. It has a very high reproductive capacity and can also propagate vegetatively. It possesses allelopathic potentialities and growth inhibitors are present in all parts of the plant (Ambika and Jayachandra, 1980) and it is capable of suppressing even some of the aggressive cover crops. These attributes contribute to its successful spread and establishment. The forest department in Karnataka spends several lakhs of rupees annually to clear this weed in the nurseries and young plantations, but the problem has remained unchecked. The various methods to control this weed have met with only partial success. Hence, studies were undertaken to induce pollen sterility and loss of seed viability in the weed with certain growth retardants and herbicides so that at least the spread of the weed can be checked.

MATERIALS AND METHODS

The chemicals examined in the present trial for their effect on floral sterility and seed viability in *C. odorata* are listed in Table 1 along with the relevant information on the make and source.

Experiment 1: Effect of pre-emergence herbicides on the viability of seeds of *C. odorata* in soil

Shallow pots of 15.2 cm depth and 23 cm diameter were filled with red soil and the top 5 cm soil was mixed with 50g seeds of *C. odorata*. These were sprayed at the rate of 1 litre of water/suspension/solution of 0.3% (5 kg ha^{-1}) Karmex and Weedone concentrate -48 per pot in five replications and the pots were left in the open in the premises of the Department

Table 1. Chemicals tested for their effect on the sterility of pollen and cypsella in *Chromolaena odorata*

Sl. No.	Common name	Chemical name	Trade name	Make	Source
1.	Maleic hydrazie	1,2-dihydrophyridazine - 3,6-dione	Maleic hydrazide	BDH	Laboratory Supplies Co. Ltd., Bangalore
2.	2, 4-D Ester	Ethyl ether formulation of 2,4-D containing 360g of acid equivalent per ltr.	Weedone concentrate 48	Agrmore Ltd., Bangalore	Agrmore Ltd., Bangalore
3.	Diuron	A wettable powder containing 80% Diuron 3-(3,4,-dichlorophenyl)-1, 1-dimethyl urea-1	Karmex	E.I. Duponts De Nemours and Co., Inc., USA	Agrmore Ltd., Bangalore

of Botany, Bangalore University, Bangalore for a period of one year.

Seed samples were removed from the soil at intervals of 30 days for one year and examined for their germinability under laboratory light conditions with the mean temperature and humidity ranging from 21° to 28°C and 55 to 75% R. H. respectively. The germination counts were recorded daily for ten days.

Experiment 2: Effect of growth regulator/herbicides sprayed at the pre-floral initiation stage

An area of about 0.25 ha of teak plantation naturally infested with *C. odorata* at Segehalla project near Shimoga, Karnataka, India and Dubare near Kushalnagar (Coorg), Karnataka, India were selected for the trial. The experimental area was divided into 60 plots of 3 x 2m with an interplot distance of 2m that was marked by clearing the weed. In these plots *Chromolaena* plants were of an average height of 1.5m. The plants were sprayed at the prefloral initiation stage at the rate of 1 litre of water/ suspension/solution per plot with their concentrations/dosages as stated in Table-2.

Experiment 3: Effect of growth regulator/herbicides sprayed at the post-floral initiation stage

An area of 0.25 ha of teak and teak-rose wood plantations at Segehalla project near Shimoga, Karnataka, India, naturally infested with *Chromolaena* weed, was selected for the trials. The *Chromolaena* plants were of an average height of 1.5 m and at the stage of floral initiation. The teak and rose wood plants ranged in height from 0.5 to 1.5 m. The plots were prepared and the *Chromolaena* plants were treated as described under Experiment 2. The plots were kept under observation for five months (between November and March). The *Chromolaena* plants were studied for the effect of the treatments on vegetative growth, progress of flowering and seed set after one month.

The flowers were collected and stored cool in double layered polythene bags with an ice jacket in between. The flowers were crushed and the pollen grains were collected by centrifuging them at 300 x g for 15 min. The percentages of sterile and nonsterile pollen grains were determined following Alexander (1969).

Five months after the spray i.e., during March, data were collected on seed set and regeneration of shoots, the number of cypsella per capitulum (from 20 capitula/plot collected randomly), weight of 1000 cypsella (in five sets/plot) and their germinability (as under Experiment 1) after storage for three months under laboratory conditions.

Experiment 4: Effect of growth regulator/herbicides at anthesis

Two sites of about 0.25 ha each of teak plantations naturally infested with *C. odorata* at Segehalla project near Shimoga, Karnataka, India were selected for the trials. The plots were prepared and the *Chromolaena* plants at the anthesis were sprayed as in Experiment 2. The plots were kept under observation of four months (between December and March) and data were recorded on vegetative growth, progress of flowering and seed set.

The flowers that were collected 15 days after spraying (i.e. during third week of December) were carried in polythene bags and stored cool as in Experiment 3. The

pollen sterility, cypsella characteristics and the shoot regeneration were studied as in Experiment 3.

The data were analysed using F-test and the two-way analysis of variance with interaction following the procedure described by Sokal and Rohlf (1973).

RESULTS AND DISCUSSION

Treating *Chromolaena* plants with the growth retardant/herbicides was useful in retarding the growth, inhibiting flowering, inducing pollen sterility, reducing the seed set and germination to a significant extent (Table-2, 3; Fig.1). The effect depended more on the stage of development at which the treatment was administered. However, 0.3% Weedone concentrate - 48 (51 ha^{-1}) killed the whole plant and 0.3% suspension of Karmex (5 kg ha^{-1}) caused drying up of the aerial parts, irrespective of the stages at which these were applied (Table-2).

Maleic hydrazide at both 0.3 and 0.5% (5 and 8.3 kg ha^{-1}) applied before and after floral initiation and at anthesis, arrested the growth of *Chromolaena* completely. The leaves that were produced before the treatment increased in size, became thick, corky, leathery and chlorotic and abscised prematurely (Table-2). The young leaves of the treated plants also accumulated considerable amount of anthocyanins and similar accumulation following the application of the growth retardant has been reported for *Digitaria sanguinalis, Zea mays* and hybrid sweet corn "Golden delicious" (Moore, 1950).

The herbicides at the lower concentrations affected the vegetative growth of the weed. In the plants treated with low concentration of Weedone concentrate -48

Table 2. Infulence of growth regulators, herbicides on Chromolaena odorata (L.) King and Robinson (A, B and C respectively pre-post-floral initiation, and anthesis

Chemical sprayed	Stage of spray	Growing apex	Leaves	Further growth	Floral initiation (%)	% of Florets opened/head	Fruit set (%)
Unsprayed (Control)	A	Unaffected	Green	Normal	100	100	Normal
	B	"	"	"	"	"	"
	C	"	"	"	"	"	"
Water Sprayed (Control)	A	Unaffected	Green	Normal	100	100	100
	B	"	"	"	"	"	"
	C	"	"	"	"	"	"
Maleic hydrazide (0.3%) 5.0 kg ha^{-1}	A	Drooped	Thick, leathery corky & purplish	Arrested	Nil	Nil	Nil
	B	"	"	"	-	50	50
	C	"	Dried & abscised prematurely	Stunted	-	-	50
Maleic hydrazide (0.5%) 8.3 kg ha^{-1}	A	Drooped	Thick, leathery corky & purplish	Arrested	Nil	Nil	Nil
	B	"	"	"	-	50	50
	C	"	Dried & abscised prematurely	Stunted	-	-	50
Karmex (0.1%) 1.7 kg ha^{-1}	A	Drooped	Premature drying & abscising	Nil	Nil	Nil	Nil
	B	"	"	Nil	"	25	25
	C	"	"	Nil	"	-	25
Karmex (0.3%) 5.0 kg ha^{-1}	A	Dried	Premature drying & abscising	Nil	Nil	Nil	Nil
	B	"	-	-	-	-	-
	C	"	-	-	-	-	-
Weedone concentrate-48 (0.1% 1.7 L ha^{-1})	A	Drooped	Premature abscission	Nil	Nil	Nil	Nil
	B	"		"	"	25	25
	C	"	"	"	"	-	25
Weedone concentrate-48 (0.3% 5.0 L ha^{-1})	A	Killed	-	-	-	-	-
	B	"	-	-	-	-	-
	C	"	-	-	-	-	-

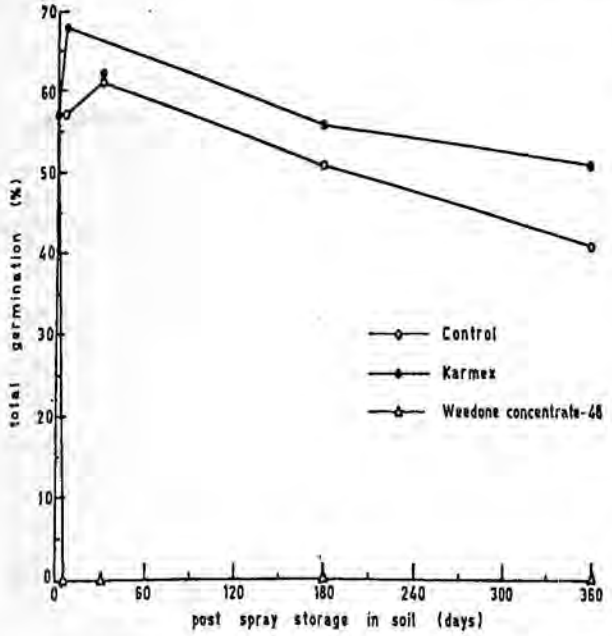

Figure 1. Germination of seeds of *Chromolaena odorata* following herbicidal treatment and storage under field conditions.

and Karmex, the twigs that had shed their leaves prematurely and dried up resprouted in three to six months, by which time shedding of the mature fruits in the untreated plants had commenced (Table-2). Adverse effect of the treatment was still quite evident in the reduced dimensions of the newly formed leaves (Table-4).

Maleic hydrazide and herbicides affected flowering in *Chromolaena* when applied at the prefloral initiation stage. Flowering was inhibited completely and the plants remained vegetative till they dried up in summer at both the concentrations. Maleic hydrazide applied after floral initiation delayed flowering by 15 to 20 days and inhibited opening of several florets in nearly 50% of the heads. The herbicidal sprays at the two stages also affected flowering as did Maleic hydrazide, but they were more effective than the latter at a much lower concentration. They inhibited the opening of nearly 75% of the heads, which became dry and abscised leaving many bare branches.

When Maleic hydrazide was sprayed after floral initiation, sterility was observed in 90% of the pollen grains at 0.3% of the chemical whereas at 0.5% sterility was total. The spray at anthesis was slightly less effective (Table-3). The sterile pollen grains were shrunken and were devoid of cytoplasm. The two herbicides were more effective than Maleic hydrazide as these could induce complete pollen sterility when applied at 0.1% after floral initiation, though the sterility percentage was lowered to 82-88% by postponing the spray at anthesis (Table-3).

The sprays also brought down the fruit production in *Chromolaena*. With Maleic hydrazide treatment after floral initiation and at anthesis, the fruits were formed only in 50% heads and even in these cypsella number per head was 4 to 9.3% less than the control, thus reducing the total number of cypsella per plant by a very high magnitude. Adverse effect of Maleic hydrazide on fruit set has also been known for a number of species (Muzik, 1970). The cypsella, though appearing as big as those of the control, were lighter by over 25 to 47% and were devoid of embryo (Table-3). In the plants sprayed with the herbicides before floral initiation there was flowering and fruiting, but in those sprayed at the young bud stage and anthesis, 75% of the heads dried up without the formation of fruits. In remaining 25% the cypsella formed were lighter than those in the control by 34-38% and 21.5-31% in those treated with Weedone concentrate - 48 and Karmex (Table-3).

All the treatments adversely affected the germinability of the cypsella produced. As has been stated earlier, in the Maleic hydrazide treated sets, the cypsella were devoid of embryo and hence not germinable. In the herbicide treated plants, the germinability of the cypsella was lowered by 71% and 87% (Table- 3).

The seeds mixed with the soil and sprayed with 0.3% weedone concentrate -48 lost their germinability completely in five days (Fig.1). In contrast Karmex at 0.3% enhanced the germination in this species by 11% but the seedlings with extremely small radicle and brown tips did not survive beyond emergence.

The foregoing data show that the growth retardant -Maleic hydrazide, the herbicides - Weedone concentrate -48 and Karmex can be used to affect the growth and reproduction in *Chromolaena* adversely to varying degrees. In view of the fact that *C. odorata* is an apomict (Mehra, 1977), the induction of pollen sterility in the weed may not be of very high significance. However, the adverse effect of the same chemicals on vegetative growth, fruit set and germinability, which contribute to a great extent to the control of *Chromolaena,* should be considered as highly significant.

Hand weeding thrice per year (June, September, December) is a common practice to control *C. odorata* in the plantations of the forest areas (personal communication from the Karnataka Forest

Table 3. Influence of growth regulators and herbicides on pollen sterility, seed setting and germinability in *Chromolaena odorata* (A,B,C refer to pre/post-floral initiation/anthesis stages respectively)

Chemicals Sprayed	Stage of Spray	Pollen Sterility (%)	% of Control	Cypsella no./ normal capitulum	% of Control	1000 Cypsella Weight (mg)	% of Control	Total germination (%)
Unsprayed (control)	A	-	-	31.4 (3.6)	-	244.1 (19.5)	-	70.0 (4.1)
	B	10.87 (2.9)	-	29.4 (2.6)	-	264.2 (14.5)	-	79.2 (7.8)
	C	12.33 (3.8)	-	29.6 (1.7)		235.0 (8.8)	-	75.5 (7.3)
Water Sprayed (control)	A	-	-	31.1 (2.3)	-	229.6 (12.8)	-	71.6 (4.3)
	B	14.50 (4.4)	-	31.2 (2.9)	-	223.9 (17.3)	-	71.4 (4.3)
	C	12.45 (3.5)	-	29.9 (1.8)	-	235.2 (5.2)	-	69.8 (6.9)
Maleic hydrazide (0.3%) 5.0 kg ha^{-1}	A	-	-	-	-	-	75.19	0.0
	B	90.39 (10.0)	623.38	29.9 (3.2)	95.83	190.9 (32.3)	75.19	0.0
	C	81.54 (9.7)	654.94 (9.7)	27.7 (9.2)	92.64	172.8 (21.5)	73.47	0.0
Maleic hydrazide (0.5%) 8.3 kg ha^{-1}	A	-	-	no fruits	-	-	-	-
	B	100.00 (0.0)	689.63	28.8 (4.1)	91.70	142.9 (17.7)	54.09	0.0
	C	87.07 (4.8)	691.32	28.2 (3.8)	95.92	129.6 (7.1)	55.10	0.0
Karmex (0.1%) 1.7 kg ha^{-1}	A	killed	-	-	-	-	-	-
	B	100.00 (0.0)	689.6	33.0 (2.5)	105.00	207.4 (21.8)	78.50	23.04 (4.0)
	C	87.94 (5.4)	706.34	31.5 (3.1)	107.14	162.1 (15.0)	68.92	16.00 (6.4)
Karmex (0.3%) 5.0 kg ha^{-1}	A	killed	-	-	-	-	-	-
	B	killed	-	-	-	-	-	-
	C	killed	-	-	-	-	-	-
Weedone concentrate-48 (0.1% 1.7 L ha^{-1})	A	killed	-	-	-	-	-	-
	B	100.00	31.20 (1.5)	106.12	164.40 (23.8)	62.22	10.59 (5.5)	13.37
	C	81.65	655.80	29.60 (2.3)	100.00	155.50 (7.9)	66.11	17.00 (3.5)
Weedone Concentrate-48 (0.3% 5.0 L ha-1)	A	killed	-	-	-	-	-	-
	B	killed	-	-	-	-	-	-
	C	killed	-	-	-	-	-	-

LSD 5%			
Between chemical treatments	1.57	0.33	3.12
Between stage of spray	2.93	0.61	5.40
Interaction	4.15	0.86	7.63

* CD 5% for 1000 cypsella weight - 12.14.
Figures in parenthesis are standard deviation

Table 4. Influence of herbicides and growth retardant on regrowth of *Chromolaena odorata* when prayed at different stages growth

Chemical sprayed	Stage of Spray							
	Post-floral initiation				Anthesis			
	Leaf Length (cm)	Percent of control	Leaf breadth (cm)	Percent of control	Leaf length (cm)	Percent of control	Leaf breadth (cm)	Percent of control
Water spray	4.71 (1.3)	-	2.84 (0.4)	-	4.98 (0.8)	-	2.80 (0.4)	-
Maleic hydrazide (0.5%) 8.3 kg ha^{-1}	4.08 (0.5)	86.60	2.08 (0.2)	73.23	4.06 (0.4)	81.52	2.79 (0.41)	99.28
Karmex (0.5%) 5.0 kg ha^{-1}	3.69 (0.5)	78.30	1.99 (0.3)	70.07	4.55 (0.6)	91.40	1.78 (0.3)	63.57
Weedone concentrage (0.1%) 1.7 L ha^{-1}	3.28 (1.4)	69.64	2.16 (0.5)	76.06	4.62 (0.5)	92.77	2.06 (0.3)	73.57

LSD 5%
Between Chemical Treatments 0.27
Between the stage of spray 0.38
Interaction 0.53

Figures in parenthesis are standard deviation

Department), and the cost of this is estimated as Rs 484/- per hectare. This level of weeding does not achieve effective control of the weed.

Although Maleic hydrazide has been found in the present study to be quite effective in arresting growth, causing premature drying and abscission of the leaves, inhibiting flowering completely and inducing complete seed sterility even when sprayed at the advanced stages of flowering of the weed, its prohibitive cost (Table-5) may preclude the chemical from being preferred. Weedone concentrate -48 on the other hand was quite effective in this regard at 0.1%. Considering the dosage required for effective control of the weed, the cost would range from Rs 86 to 260/- per hectare and hence is much cheaper than even the hand weeding operations. Application of Karmex for similar effect would be costlier than other herbicide by Rs 230-675/- per hectare.

Table 5. Economics of the trials on the induction of pollen sterility and loss of seed viability in *C. odorata*

Growth regulator/herbicide Dosages (kg ha^{-1})		Cost per hectare (Rs.)
Maleic hydrazide	5.0 8.3	3000.00 4880.00
Karmex	1.7 5.0	318.00 935.00
Weedone concentrate-48	1.7L 5.0L	86.00 259.00
Hand weeding (annually)		484.00

Hence, some of these methods tested in the present study such as the inhibition of flowering and induction of sterility are novel approaches in the control of the aggressive weed, *C. odorata*, and can be recommended as practices to achieve effective control of the weed in different situations.

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HERBICIDES FOR CONTROL OF *Chromolaena odorata*

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ABSTRACT

Chromolaena odorata is a very serious weed in plantation crops like coconut, rubber, cashew, pepper, etc., in Kerala. It was introduced into Kerala in the 1950's. A large number of labourers are required for the manual control of this weed. As labour charges are prohibitively high, scope of using pre-emergence and post-emergence herbicides for controlling this weed was evaluated at the Kerala Agricultural University, Trichur. The herbicides diuron, atrazine, oxyfluorfen, isoproturon, fluchloralin and simazine were tested at three doses each for controlling the germination and establishment of *Chromolaena* seedlings. Uniform quantity of weed seeds were sown in plots of 2 m size and the herbicides were applied on the next day. Count of the number of *Chromolaena* seedlings, one month later, showed that diuron (1.5 kg/ha) and atrazine (2.0 kg/ha) resulted in complete control of germination and establishment. Other herbicides also significantly reduced the count of *Chromolaena* seedlings compared to the unsprayed control. In another trial the optimum dose of the common post-emergence herbicides paraquat, 2,4-D and glyphosate were evaluated, at four doses each, for controlling *Chromolaena* in a rubber garden. All these herbicides were effective and the effect was found to increase with increasing dose of the herbicides. Thus, the highest dose of paraquat (1.00 kg/ha), 2,4-D (2.5 kg/ha) and glyphosate (1.6 kg/ha) resulted in the least number and dry matter production of the surviving *Chromolaena* plants, one month after the application of the herbicides. The systemic herbicides were more effective when sprayed on the new flushes emerging after slashing, than when applied on the normal growth. This was pronounced in the case of 2,4-D which resulted in complete drying of *Chromolaena* at doses 1.5 kg/ha and above when sprayed on the regrowth, whereas even 2.5 kg/ha sprayed on normal growth could not result in complete kill.

INTRODUCTION

The Siam weed (*Chromolaena odorata*) is a problem weed in Kerala, specially in plantation crops like rubber, coconut, cocoa, cashew, pepper, etc. Being a native of the neotropics the weed could establish very well in the humid tropical climatic conditions in the state. It has developed as a serious problem during the last four decades. Competition from *Chromolaena* adversely affects the growth of the crops, especially during the early stages. Hand pulling, digging with spade and slashing with sickle are the common practices for controlling the weed. However, these mechanical methods give only short term control (Muniappan and Marutani, 1991). Though biological methods are being tried, they do not give immediate results. Hence chemical methods are attempted as an alternative to the costly and labour intensive mechanical methods.

Common post-emergence herbicides 2,4-D, paraquat and glyphosate have been found to be effective in controlling *C. odorata*. Madrid (1974), Borthakur (1977) and Vernier *et al.* (1995) reported the efficiency of 2,4-D against this weed. Combination of paraquat and 2,4-D was found to be better than either of these herbicides applied separately (Mathew *et al.*, 1977; Rai, 1988). Parker (1978) and Leucas (1989) have found that glyphosate was effective against *Chromolaena*. It has also been reported that the herbicides are more effective when applied on the new sprouts after a slashing. Imazapyr applied to the cut surface of stumps was very effective for killing the plants (Denny and Naude, 1994). Pre-emergence herbicides atrazine, metolachlor and diuron are also found useful for preventing the infestation of *Chromolaena* (Leucas, 1989).

MATERIALS AND METHODS

Trials were conducted at the Kerala Agricultural University, to compare the efficiency of common pre-emergence and post-emergence herbicides for controlling *C. odorata*.

A uniform quantity of seeds of *C. odorata* (2.0 g per plot) collected during the previous season, were sown in plots of 2 m x 1 m size. Six common pre-emergence herbicides (diuron, atrazine, oxyfluorfen, isoproturon, fluchloralin and simazine) at three doses each and a control constituted the treatments (Table 1), which were laid out in RBD with three replications. The herbicides were sprayed on the day after sowing of the seeds, with a knapsack sprayer fitted with flat fan nozzle, using 400 litre spray fluid per hectare. The number of *Chromolaena* seedlings emerged was counted one month later.

Table 1. Effect of pre-emergence herbicides on the germination of *C. odorata*

Herbicide	kg/ha	Number of Chromolaena seedlings/s m^2
Diuron	1.0	2.0 (1.41)*
"	1.5	0.0 (1.00)
"	2.0	0.0 (1.00)
Atrazine	1.0	1.0 (1.41)
"	1.5	1.0 (1.41)
"	2.0	0.0 (1.00)
Oxyfluorfen	0.2	32.5 (5.45)
"	0.3	10.6 (3.37)
"	0.4	9.1 (3.02)
Isoproturon	1.0	14.3 (3.76)
"	1.5	10.3 (3.27)
"	2.0	8.6 (3.25)
Fluchloralin	1.0	10.6 (3.40)
"	1.5	6.3 (2.57)
"	2.0	9.6 (3.25)
Simazine	1.0	7.3 (2.27)
"	1.5	3.0 (1.72)
"	2.0	4.3 (1.91)
Unsprayed control		35.6 (5.90)
CD (0.05)		2.21

Values in parentheses are x+1 transformed values

In another trial, the optimum dose of common post-emergence herbicides for controlling *Chromolaena* was evaluated in a rubber garden with uniform infestation (4-5 plants/m) of the weed. The herbicides 2,4-D, paraquat and glyphosate were sprayed at four doses each and compared with the unsprayed control. The area between four rubber plants spaced at 5 m x 5 m was considered as a plot ($25\ m^2$). The treatments were laid out in randomised block design with three replications. The weeds were about 2.0 m height when the herbicides were sprayed.

A separate trial with the same set of treatments was conducted by spraying on the regrowth of *Chromolaena*, one month after slashing, to see whether the efficiency of the herbicide was improved when sprayed on the fresh regrowth.

The herbicides were sprayed using a knapsack sprayer fitted with a flood jet nozzle. The quantity of the spray fluid used was 600 l/ha for spraying on the normal unslashed plants, while it was 400 l/ha for spraying on the regrowth after slashing.

The efficiency of the treatments was compared by noting the number of surviving plants one month after the spraying and the dry matter produced by the surviving parts.

RESULTS AND DISCUSSION

Effect of pre-emergence herbicides

The number of *Chromolaena* seedlings one month after spraying the herbicides showed that all the herbicides tested significantly reduced the emergence of the weed, and the effect was greater at higher doses (Table 1). Among the herbicides, diuron at doses 1.5 kg/ha and above and atrazine at the highest dose of 2.0 kg/ha resulted in complete control of the germination of *Chromolaena*. The results indicate that the problems of *C.odorata* could be reduced considerably by the use of selective pre-emergence herbicides. In non-crop situations, diuron or atrazine at higher doses can be used to obtain residual control of the weed for longer periods.

Effect of post-emergence herbicides

Almost all the herbicide treatments resulted in drastic reduction in the number of *Chromolaena* plants (Table 2). When sprayed on the normal growth, even the lowest dose of paraquat (0.4 kg/ha) and 2,4-D (1.0 kg/ha) killed more than 80 per cent of the *Chromolaena* plants. Increasing the doses of these herbicides further increased the control of *Chromolaena*. For glyphosate, 0.4 kg/ha dose was not sufficient to give good control. However, its higher doses (0.8, 1.2 and 1.6 kg/ha) performed better than the higher doses of paraquat and 2,4-D. The dry matter production of the surviving plants broadly followed the trend of the surviving number of plants (Table 2).

Table 2. Effect of post-emergence herbicides on the number of surviving *Chromolaena* plants and their dry matter production (as % of the unsprayed control)

Herbicide and dose kg/ha		Sprayed on normal growth		Sprayed on regrowth	
		Surviving plants (%)	Dry matter production(%)	Surviving plants (%)	Dry matter production (%)
Paraquat	0.4	8.33	2.59	9.94	2.62
"	0.6	6.94	1.34	8.84	4.79
"	0.8	5.50	0.72	7.78	4.84
"	1.0	3.24	1.83	5.99	4.09
2, 4-D	1.0	16.40	13.74	2.86	0.33
"	1.5	10.46	6.70	0.00	0.00
"	2.0	7.94	4.22	0.00	0.00
"	2.5	4.48	1.98	0.00	0.00
Glyphosate	0.4	81.02	69.47	15.17	12.37
"	0.8	4.11	2.19	6.83	6.18
"	1.2	3.74	1.83	1.51	1.40
"	1.6	2.12	1.06	0.20	0.04
Unsprayed control		100.00	100.00	100.00	100.00

Systemic herbicides (2,4-D and glyphosate) were more effective when sprayed on the new flushes emerging after the slashing than when sprayed on the normal growth. This is because they interfere with the metabolism of the plants and are more effective on the actively growing plants. This was more pronounced in the case of 2,4-D which resulted in complete kill of all *Chromolaena* plants at doses 1.5 kg/ha and above when sprayed on the regrowth, whereas even the highest dose of 2.50 kg/ha could not result in complete kill of the normal plants. Olaoye (1974) also noticed that herbicides applied on the resprouts after slashing were more effective than the herbicides applied to unslashed plants. In contrast, the efficiency of paraquat was reduced when sprayed on the regrowth. Paraquat is a contact herbicide and hence it is more effective if maximum area of the plant is exposed to it. Slashing reduced the surface area of the foliage and hence the effect of paraquat also.

Even though the herbicides provided effective control of *Chromolaena*, complete control was not achieved in most of the cases. There were a few (5%) plants surviving even at the highest dose of most tests. This indicates the need for other methods as a follow up to chemical methods for better results, as suggested by Leucas (1989). By developing such an integrated method, *C. odorata* could be controlled more effectively at lesser cost.

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Chromolaena odorata IN AUSTRALIA: PROGRESS IN ERADICATION OF AN ESTABLISHED INFESTATION

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ABSTRACT

Infestations of *Chromolaena odorata* were discovered in the humid tropical region near Tully, far northern Queensland in July 1994. Pre-emptive listing of *C. odorata* as a declared (noxious) plant in Queensland enabled an immediate and intensive response. Surveys revealed the primary infestation on pastoral land drained by tributaries of the Tully River, with scattered, dense river-side infestations for 36 kilometres downstream to the Tully River estuary. Secondary infestations were also found at Bingil Bay, about 40 kilometres northeast of the primary infestation.

Morphological and phenological differences observed between plants at some of the infested sites, prompted an investigation of the genetic make-up of the populations. These revealed two distinct genotypes in the Queensland infestation. The most common genotype is widespread throughout the native and exotic ranges of *C. odorata* while the less common type is known only from southern Brazil. The most likely source of the weed is thought to have been a contaminated batch of pasture seeds imported from Brazil to the site of the primary infestation in the 1960's.

A 5-year eradication program was commenced within two weeks of the discovery. It is estimated that 90% of the original infestations were eliminated within the first 12 months, with subsequent efforts concentrating on mature plants which had been missed during the initial rounds of herbicide treatment, and the numerous seedlings which continue to regenerate wherever *C. odorata* had been established. Success of the program depends upon location of all mature and juvenile plants, and prevention of further seed production.

INTRODUCTION

Much of the coastline and adjacent hinterland of northern and eastern Australia is climatically suitable for the establishment of *Chromolaena odorata* (L.) R. M. King and H. Robinson (McFadyen and Skarratt, 1996). Its history of mobility and the recent, rapid consolidation and spread of infestations in south-east Asia and Indonesia, led to predictions of its imminent arrival in northern Australia (McFadyen 1989; Sipayung *et al.*, 1991). In recognition of the threat, the Queensland Department of Natural Resources (which is responsible for weeds legislation and control in Queensland) pre-emptively declared *C. odorata* as a noxious weed. *C. odorata* also became the principal "target" of weed surveys conducted in northern Australia and Papua New Guinea since 1990 (under the auspices of the Northern Australia Quarantine Strategy). Infestations of *C. odorata* were detected in Sandaun and Morobe Provinces in mid-1992 (the first records from mainland Papa New Guinea); and near Merauke in southeastern Irian Jaya in May 1993 (Waterhouse, 1992; 1993) as a direct consequence of these weed surveys.

Discovery and distribution in Australia

Scattered roadside clumps of flowering *C. odorata* were discovered near Bingil Bay, north Queensland (17° 48' S, 146° 04' E) on 15 July 1994. It was evident that these plants were not the primary infestation. Over the following two weeks the surrounding district was searched thoroughly, using teams of personnel from the Queensland Departments of Natural Resources and Primary Industries (Waterhouse, 1994).

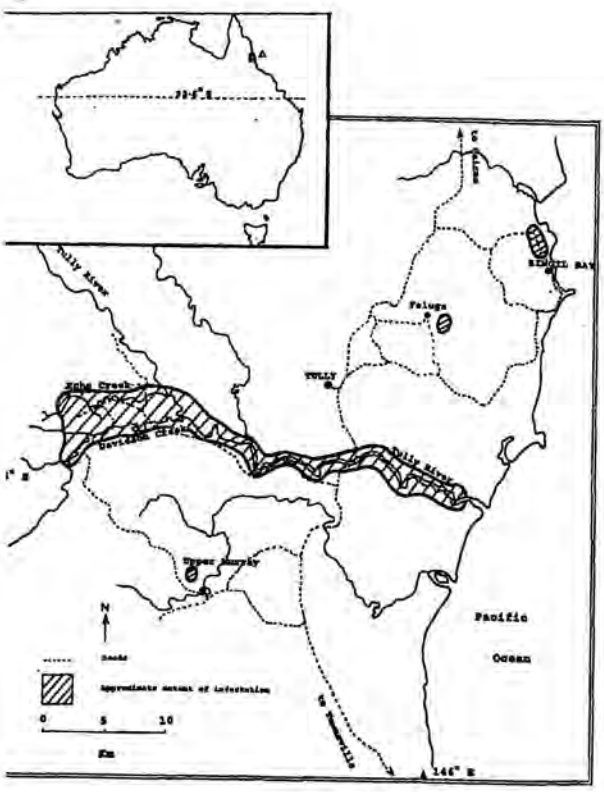

Fig. 1 Known Distribution of *Chromolaena odorata* Northern Queensland, Australia

The primary infestation was traced to pastoral land in the headwaters of Echo and Davidson Creeks (c. 17° 56' S, 145° 43' E), which are tributaries of the Tully River (Figure 1). Upto 200 hectares of improved pasture contained scattered to dense stands of *C. odorata*, particularly along the margins of rainforested gullies where individual plants climbed to 10 metres on adjacent vegetation. Infestations were detected along Echo and Davidson Creeks, and downstream along the Tully River to its brackish estuary, a distance of approximately 36 kilometres (Waterhouse, 1994). Plants were rarely found further than 20 metres from the banks of the Tully River. Waterborne dispersal of seeds downstream from the primary infestation had resulted in this distribution.

The secondary infestation at Bingil Bay was concentrated around a teak plantation and neighbouring youth hostel, with individual plants and occasional dense thickets beside roads, along animal tracks (e.g., used by horses and feral pigs) and throughout other gaps in disturbed forest.

Infested sites at Bingil Bay were estimated to occupy approximately 25 hectares, scattered over a much larger area. Smaller secondary infestations were found at Feluga (17° 52' S, 145° 59' E - a single mature plant and scattered seedlings), and Upper Murray (18° 05' S, 145° 48' E - a few plants) (Waterhouse, 1994). Equipment used for slashing grass, sugarcane harvesting equipment and vehicles are the most likely means of dispersal to these sites.

The overall extent of the infestations had been delineated within several weeks of the initial discovery, and no significant expansion of range has been reported since then. An intensive public awareness campaign using public meetings, newspaper articles, radio and television bulletins, assisted rapid determination of the extent of the infestations. Landholders, farmers, contractors and representatives of local authorities responded to the requests for information on the distribution of *C. odorata*.

Because the main infestation was confined to a single watershed and the secondary infestations were small in area, eradication was considered to be feasible. A five-year eradication campaign was commenced two weeks after the initial discovery.

Duration of infestation and probable means of introduction

Senescent plants with basal stem diameters of 7-10 centimetres were found at the primary infestation site. Farmers along the Tully River suggested that plants had been present on the river banks, well downstream from the primary site, for at least 7 years. After the initial survey, an infestation age of between 10 and 20 years was hypothesised.

Morphological and phenological differences observed at some infested sites prompted investigation of the genetic make-up of the primary and secondary infestations. This study revealed two genotypes within the *C. odorata* population at the primary infestation site. The more common genotype is widespread throughout the native and exotic range of *C. odorata*,

including the secondary infestations in northern Queensland. The less common genotype, found in the vicinity of Davidson Creek, is known only from southern Brazil (Scott and Lange, 1996). Batches of pasture grass and legume seeds imported from Brazil and sown at this site in the late 1960's and early 1970's (Hardwick, 1994), were probably contaminated with seeds of the two genotypes.

Factors which may have limited broader distribution

Elsewhere in the exotic range, *C. odorata* is particularly invasive in humid tropical or subtropical areas with a pronounced dry season (McFadyen and Skarratt, in press). For example, *C. odorata* was first reported from West Timor c. 1987. By 1995 it was the dominant weed species throughout the region.

In the estimated 20-25 years which have elapsed since *C. odorata* was accidentally introduced to northern Queensland, it appears to have hardly spread beyond the confines of a single catchment area. Fortuitously, climatic and landuse factors have probably restricted its rate of spread. The Tully region is the only part of Australia which experiences a "true" wet tropical climate. The average annual rainfall near the primary infestation site, and along the Tully River is approximately 4000 mm per year. High rainfall tallies were recorded every month of the year, with the heaviest falls between November and May. There is not a distinct dry season. *C. odorata* may be less invasive in this region because it is too wet throughout the year. Had the point of introduction been c. 100 kilometres to the north or south a different scenario might have unfolded.

Cattle grazing on improved pastures is the primary landuse at the site of introduction, but intensively managed sugarcane and banana plantations abut the Tully River over much of the infested area. While machinery used in these operations may have assisted seed dispersal, it can be argued that rigorous weed control programs on the plantations have probably suppressed the *C. odorata* populations and delayed its wider spread.

Progress in the eradication campaign

Prior declaration of *C. odorata* enabled the Queensland Department of Natural Resources to commence an eradication campaign immediately after its distribution had been determined. The campaign commenced in late July 1994, with the goal of achieving eradication over a 5-year period. The campaign is financed jointly by the Federal Government and mainland States, with the largest proportion being borne by the Federal and Queensland governments. Success of the campaign depends upon locating all existing infestations and preventing further flowering and seed production.

Intensive surveys of the distribution of *C. odorata* are undertaken three times each year (in May, July and October) and followed-up with herbicide treatment to all detected plants. In the Queensland infestations most mature plants flower, and are thus more conspicuous, in July. Recently emerged seedlings are the primary target in May and October. Until May 1996, picloram + triclopyr 1:300 (Grazon DS®) in combination with a wetting agent was the herbicide of choice. Its residual activity was considered desirable to help reduce the soil seed bank, but had the drawback of damaging nontarget native species. Since then, fluoxypyr (Starane 200®), which does not have residual action, has been used. In some situations mechanical control has been necessary over small areas (Hardwick and Waterhouse, 1996).

To date it is estimated that the *C. odorata* population has been reduced by 95-98% (Hardwick and Waterhouse, 1996). Mature plants which eluded earlier detection are still found occasionally. After the initial rounds of herbicide application there was massive germination of seedlings, but recently this has decreased as the soil seed bank is depleted (Eldershaw *et al.*, 1996). The total volume of herbicide used to treat the infestations has diminished substantially. Workforce hours spent searching for and treating *C. odorata* have also decreased since the first year of the campaign, but significant further reduction is unlikely in the short term, due to the time required to search for inconspicuous seedlings. In areas which were previously overrun, it is heartening to see that dense *C. odorata* has been replaced by vigorous swards of pasture grasses or regenerating native vegetation.

Prospects for the future

While the "last" seedling may never be found and treated before reaching reproductive maturity, it is unlikely that *C. odorata* will ever reach its potential status as a serious weed in Australia. Extension material (leaflets, posters, laminated specimens) has

been distributed widely throughout the regions most at risk, to facilitate early detection. *C. odorata* has also been proclaimed noxious in other states likely to be affected, thus enabling a prompt response if it is ever found there. In Queensland where the greatest risk of undetected infestations remains, the Department of Natural Resources has exercised a policy of rotating field personnel from other regions through the survey and control teams. This increases the likelihood that *C. odorata* will be recognised elsewhere, by providing first-hand experience of the weed in all its stages (Hardwick and Waterhouse, 1996). It also reduces the incidence of *C. odorata* "burn-out" where monotony tends to reduce survey effectiveness, especially where the work is performed under uncomfortable and sometimes hazardous circumstances.

ACKNOWLEDGMENTS

Dr. Rachel McFadyen is to be congratulated for her efforts in drawing *C. odorata* to the attention of the Queensland Department of Natural Resources and Australian weed scientists before it was ever a problem here, facilitating a prompt response when it was discovered. Special thanks are also due for her ongoing interest in *C. odorata,* willingness to provide advice, and for offering to present this paper at the Bangalore Workshop.

Graham Hardwick and the teams of personal from the Queensland Department of Natural Resources who have "sweated and toiled" to make eradication of *C. odorata* seem possible, also deserve special thanks for their efforts.

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A TECHNIQUE FOR SPREADING THE *Chromolaena* GALL FLY, *Procecidochares connexa*, TO REMOTE LOCATIONS

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ABSTRACT

The *Chromolaena* gall fly, *Procecidochares connexa*, is established and spreading at sites near Marihat in northern Sumatra. In November 1995, 251 mature galls of *P. connexa* were cut from plants growing near Marihat. Leaves were trimmed and exposed cut ends dipped in molten candle wax to slow desiccation. The stems were packed with cotton wool into a plastic bag and carried to Kupang in Timor. They were tied in small bundles to *C. odorata* plants at a release site, 48 hours after being collected. At the time, no parasites were detected from the galls at Marihat. A subsequent visit to the release site in April 1996, equivalent to two *P. connexa* generations later, revealed numerous galls on plants up to 300 m from the point of release. This technique, with modifications to avoid spreading parasites, has advantages over other techniques involving long-distance transport of adult flies or excised pupae. It can now be used with confidence to establish *P. connexa* as a biological control agent in many other areas where *C. odorata* is a problem, without the need to first create expensive infrastructure or to employ skilled staff on site.

INTRODUCTION

During the 1980's and early 1990's Dr. Rachel McFadyen of the Queensland Department of Natural Resources (formerly Department of Lands) continually urged the Australian Government to take seriously the threat posed by *Chromolaena odorata* to agriculture and the environment in northern Australia. At the time *C. odorata* was not known to occur in Australia, but was widespread and abundant in eastern Indonesia, just 500 km to Australia's north, in habitats and climatic zones similar to many areas of northern Australia. Her efforts were finally rewarded when in January 1993 the Australian Centre for International Agricultural Research (ACIAR) began funding a three year project entitled 'Biological control of *Chromolaena odorata* in Indonesia and the Philippines (McFadyen, 1995).

In 1993 a partnership was developed between the Northern Territory Department of Primary Industry and Fisheries and Nusa Cendana University (UNDANA) in Kupang, West Timor, to rear, release and monitor biological control agents against *C. odorata* on Timor. A culture of the arctiid moth *Pareuchaetes pseudoinsulata* was established and a number of field releases were made. However, releases of the moth on other islands in the province have not yet been carried out due to the scarcity of suitable facilities, skilled staff and transport.

The stem-galling tephritid fly *Procecidochares connexa* was released in Indonesia for the first time near Marihat in northern Sumatra in January 1995. It established quickly and easily, and appears to be having an impact on the weed, especially where it occurs in conjunction with *P. pseudoinsulata*. Field releases were made using adult flies.

In November 1995 the authors accompanied a team reviewing progress of the biological control project for ACIAR. Insect rearing facilities and field release sites in northern Sumatra were inspected. It was decided to attempt an immediate release of *P. connexa* in Timor, in spite of serious constraints. No adult flies were available at Marihat on the day of departure for Timor, and both authors would have only one full day in Timor to make the release before leaving the province for several months. There were insufficient potted plants available at UNDANA to establish a breeding colony, and no trained staff available to maintain a culture.

This paper outlines the technique used to overcome these constraints and gives preliminary results of field monitoring. The relevance of this work to establishing the gall fly in remote areas is discussed.

MATERIALS AND METHODS

Procecidochares connexa

Adults of *P. connexa* lay their eggs, usually two or more at a time, into the new leaf buds of *C. odorata*. The eggs hatch after 5-7 days and the larvae tunnel into the stems where they begin feeding. Galls become visible as swellings in the stem after about 15 days and larval development takes 20-30 days. Prior to pupation, a mature larva tunnels towards the surface of the gall leaving a thin epidermal layer visible from the outside as a small, grey, circular 'window' through which it will emerge as an adult fly. The pupal period is 20-27 days. In uncrowded conditions there are usually only two larvae per gall, but some galls can contain more than 10 larvae.

Transport of gall flies

The authors visited the Marihat Research Station, where *P. connexa* was being cultured for field release, during November 1995. This was an ideal time to attempt a field release of *P. connexa* in Timor as it marked the start of the wet season and with it the first flush of new growth in thickets of *C. odorata*.

There were three realistic options for transporting flies to Timor for field release:

The usual procedure for releasing *P. connexa* has been to manually extract pupae from mature galls, allow the adults to emerge into a cage and mate, and then release them into the field as mated adults. There were insufficient adult flies available in Marihat on the day prior to the authors return to Timor to make a field release of them worthwhile. In any event, it would be difficult to transport adult flies on a journey of over 24 hours without many dying.

A large number of pupae had been recently extracted from stems and could have been easily transported to Timor. The authors had no time to await the emergence of adult flies, and it was considered too risky to place exposed pupae into the field with the possibility of desiccation, inundation, predation or human interference (especially if a structure was made to avoid the first three)

Galls displaying a 'window' indicating that a mature larva, prepupa or pupa was within could be cut from plants in the field and easily and safely transported to Timor for release. The pupae would remain protected from predation, the stem pieces would be uninteresting to curious passers-by and most adult flies would successfully emerge. This was the technique chosen.

Field release

A total of 251 mature galls of *P. connexa* were collected near Marihat at the Tanah Gambus Estate on the morning of 23 November 1995 by Dr. Desmier de Chenon. A survey of galls at the site indicated that most contained two larvae or pupae. At the time, no parasites had been detected within galls, despite 18 months of exposure outside of quarantine and the dissection of many thousands of galls.

Leaves were trimmed to reduce transpiration losses and exposed stem ends were sealed with molten candle wax to delay desiccation. The galls were packed into a slightly-inflated, sealed plastic bag with cotton wool to absorb excess moisture and maintain humidity. The bag was transported in a suitcase as ordinary baggage on the flight from Medan to Kupang.

The galls were released in the field at Pariti, near Kupang in Timor, on the morning of 25 November 1995. They were tied with string into bundles of five or six and onto stems of the host plant that were hidden from view. Inside the bag of galls, four female flies and one male had already emerged and appeared to be in excellent condition.

Monitoring

It was decided to allow two full generations of *P. connexa* to elapse before revisiting the site. As a generation takes approximately 60 days, the site was inspected in late April 1996. The standard procedure adopted in northern Sumatra for monitoring gall numbers is to count those found during 10 minutes of searching. At the Pariti site in Timor, this procedure was followed within 40 m of the point of release, and repeated up to 100 m away. An untimed search was then made up to 600 m from the site.

RESULTS AND DISCUSSION

P. connexa became established at the Tanah Gambus Estate near Marihat in northern Sumatra following the release of 80 female and 100 male adult flies (R. Desmier de Chenon, pers. comm.). Within 10 months, or approximately five generations, galls were present on almost every plant at the release site and could be found nearly 5 km distant.

By releasing mature galls into the field in Timor, we were uncertain as to how many adult flies would successfully emerge. The 251 galls that we placed into the field at Pariti each contained two, or occasionally three, mature larvae or pupae. Any individuals that were still larvae at the time the galls were excised would probably have entered diapause in response to the cessation of sap flow and ultimately died. Some pupae may not have produced adult flies if the galls desiccated too quickly, trapping them inside. It is probable that only about 100, or perhaps as many as 200, adult flies would have emerged at the site.

When the Pariti site was visited on 21 April 1996, a 10 minute search by one person within 40 m of the release site revealed eight galls. Between 40-100 m from the site, two people searching for 10 minutes found another six galls. Further untimed searching around the site located many more galls, including one approximately 300 m away, as well as five adult flies. The galls were mainly mature, with emergence 'windows' visible, but only a few had emergence holes. Several of these latter galls were dissected and all had two empty pupal cases, indicating that two adults had successfully emerged from each.

The site was revisited on 23 April 1996 and many of the galls that had 'windows' two days previously now had emergence holes. Adult flies were again seen and several tiny swellings of shoot tips indicated that the third field generation was underway. In northern Sumatra the rate of spread of *P. connexa* was approximately 1 km per generation. A more extensive search was undertaken up to 600 m from the Pariti site, but no other galls were found. Perhaps we overestimated the initial number of emerging adults, but it is more likely that at very low densities in a complex habitat, galls are extremely hard to find.

We have demonstrated that *P. connexa* can be easily established at a site requiring 48 hours travel to reach. However, the possibility of spreading parasites along with the biological control agent is a serious concern which needs to be addressed, especially now that parasites have been found at Marihat (R. Desmier de Chenon, pers. comm.). Potted *C. odorata* plants can be exposed to adult flies in a quarantine insectary. When the resultant galls mature, they can be excised from the plants and transported in the manner described above to remote locations lacking basic infrastructure. In this way, it will be possible to safely and easily establish *P. connexa* wherever *C. odorata* is a serious weed.

In November 1995 an independent review recommended that ACIAR continue to fund the biological control project for a further three years, with a greater emphasis on eastern Indonesia, where the threat to Australia is considered most pressing. One objective of this phase of the project will be to extend biological control of *C. odorata* by *P. connexa* from Timor to other islands in eastern Indonesia.

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INTRODUCTION OF *Procecidochares connexa* (DIPTERA: TEPHRITIDAE) TO JAVA ISLAND TO CONTROL *Chromolaena odorata*

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ABSTRACT

Chromolaena odorata, Siam weed, a very important weed in Java island (Indonesia), is native to Central and South America. In the laboratory it showed rapid growth (1.15 g/g/week) in the first 8 weeks of its growth. The biomass was mainly as leaves (LAR: 317.50 cm^2/g total weight). It slowed down in the following month as the biomass was utilised for stems and branches. This behaviour supported the growth of *C. odorata* into a very dense stand. It flowered and fruited during the dry season, and senesced following maturity of seeds from inflorescence branches; these branches dried out, but soon the stem assumed an aggressive growth following the wet season. The leaf biomass was affected by the size of stem in its early regrowth, but later on it was more affected by the number of branches. The introduction of *Pareuchaetes pseudoinsulata* to Indonesia has so far been successful only in North Sumatera, while in Java it has not been reported as established successfully. Another biological control agent, *Procecidochares connexa* was introduced to Indonesia and was proved to be host specific. Upon release in West Java it established immediately and spread logarithmically in the first 6 months of its release. The field monitoring is being continued to evaluate the impact of the agents. Another one or two biocontrol agents (*Actinote anteas* and *Conotrachelus*) will be imported again to Indonesia in 1997 through ACIAR Project on the Biological Control of *Chromolaena odorata* in Indonesia and Papua New Guinea.

INTRODUCTION

The nature of *C. odorata* (Siam weed) as a weed in agricultural production systems is well recognized (Tjitrosemito, 1996; Tjitrosoedirdjo *et al.*, 1991) not only in perennial plantation crops (Syamsuddin *et al.*, 1993) and in forest teak plantations in Java island (Setiadi, 1989) but recently also from forest plantations outside Java island. Sagala (1994) for example, pointed out the role of *C. odorata* in providing inflammable fuel, leading to a 2-4 m high flame in forest fire. Moses (1996) also emphasized the important infestation role *of C. odorata* in reducing the pasture productivity in East Nusa Tenggara in a recent Regional Symposium in Kupang, East Nusa Tenggara.

Reports also came from Baluran National Park, East Java, indicating a severe reduction in herbage yield in the park, leading to the reduction of population of protected wild animals such as banteng (*Bos javanicus*) and deer (*Cervus timorensis, Muntiacus muncak*). The situation here is quite severe, since the infestation of *Acacia nilotica*, reaching a population of 1337 trees/ha (Alikodra, 1987) covered a greater part of the grassing land. The park manager, following an extensive mechanical control of *A. nilotica* using powerful bulldozers, hoped that native grasses will come back and take over the space, but *C. odorata* instead dominated the open space.

Another line of approach has recently been explored by a colleague from the Agroforestry Research Institute, that *C. odorata* may be useful as a fallow crop, following the research report by Slaats (1995) in Africa. The report (Kasniari, 1996) indicated a high yield of shoot biomass when the soil was fertile (12.44 Mg ha^{-1}), but not so high when the soil was less fertile (9.04 Mg ha^{-1}) and when burnt most of those biomass would have gone (0.77 Mg ha^{-1}). It further emphasized the importance of *C. odorata* as a weed in agricultural production systems with a very strong competitive power and the hazard of fire.

The role of *C. odorata* as a weed is particularly severe in the newly planted or established plantations (oil palm, rubber, coconut) particularly in Sumatera and

Kalimantan (Sipayung and de Chenon, 1995) where there is quite substantial financial investment. Various control techniques have been used, such as physical (manual, mechanical) as well as chemical means, and both are costly.

In an attempt to find a better method of *C. odorata* management, biological control trials on *C. odorata* in Indonesia have been carried out since 1989 (Sipayung and de Chenon, 1995) and was strengthened further through ACIAR project No. 9110: Biological Control of *Chromolaena odorata* in Indonesia and the Philippines from January 1, 1993 to December 31, 1995. *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) was imported from Guam, and after sufficient testing, this biocontrol agent was permitted to be released in the field in 1992. *P. pseudoinsulata* established in North Sumatera, but not so in Java; and although it established in Sumatra, its effect is not as expected, and another agent, *Procecidochares connexa* (Diptera: Tephritidae), was imported to Indonesia in 1993. After an extensive testing it was allowed to be released in 1995 by the Minister of Agriculture of the Republic of Indonesia.

This paper reports the results of *Procecidochares connexa* (Diptera: Tephritidae) introduction to Java island and its spread in the field.

MATERIALS AND METHODS

A. The Growth of *C. odorata*

The experiments were carried out in Parungpanjang, West Java, in a forest area developed for bee farming. The total area was about 1000 ha, planted mainly with *Acacia mangium* and about 10 ha planted with kapok trees (*Ceiba petandra*), which was infested with shrubs of various kinds including *C. odorata*, *Mimosa invisa*, *Hyptis* sp., *Melastoma affine*, *Ficus* sp., with coppice *Schima walichii*, and lianas such as *Meremia* sp., *Mikania micrantha*, *Passiflora* sp., etc.

Experiment I : Plant structure

Since October 1995 plots measuring 4 m^2 was slashed at monthly intervals, and the stumps were mapped. The diameter was measured into mm, counted and recorded, the biomass was separated into leaves and stems, dried in the oven at 80^{0}C for 48 hours or until the weight was constant; weighed and recorded. The data were analyzed to characterize the plant structure of established mature *C. odorata* populations.

Experiment II: The growth of *C. odorata* coppice

The growth of coppice was observed at monthly intervals on plots following the slashing treatment in Experiment I without destroying the plants. Particular attention was given to emergence of coppice from small diameter stumps. The data were recorded in terms of coppice number and height of each stem, number and position of branches. The data were analyzed statistically to obtain a picture of the plant structure as the population grew.

B. Rearing and release of *Procecidochares connexa*

B. 1. Rearing

Stem-cuttings bearing galls were collected from Marihat Research Station, North Sumatera, Indonesia, on July 18, 1995. Upon arrival at the laboratory, BIOTROP, Bogor, the galls were dissected; there were 17 galls altogether producing 48 pupae. The pupae were yellowish white when young and turned dark brown when mature. The pupae were subsequently reared in petridishes lined with moist filter paper and put in a rearing cage made of wooden frame with fine plastic mesh measuring 0.4 x 0.4 x 0.4 m, in an air conditioned room. From 48 pupae, 38 adults emerged consisting of 18 females and 20 males. Females were easily differentiated from the males by their conspicuous ovipositors.

The emerged adults were paired up in an 8 cm test tube to mate, and released into caged, potted *Chromolaena odorata* plants the following day in the green house. The cages were of medium size, 0.5 x 0.5 x 1 m, made of wooden frame with fine plastic mesh, housing a plastic pot of 5 litre capacity containing soil mixed with worm casting at 1:1 ratio as a medium to support the growth of *C. odorata*. The potted *C. odorata* plant was chosen to have at least 20 shooting buds, preferably more, upon which the female fly will oviposit. The caged potted *C. odorata* with the pair of flies was kept approximately one week or until the female fly died, to ensure that the female oviposited on the *C. odorata* plant. When the fly died, the potted plants were immediately taken out from the cage and put into the sun with plenty of water and fertilizer.

It took 50 days for the gall to develop and mature. The maturity of the gall was indicated by the appearance of a window opening on the gall, which was still closed

by a very thin cover of transparent lining, exposing the hole by which the emerging fly escaped.

When most of the galls showed the window opening, the galls were harvested and dissected. From 18 pairs of flies, 53 galls were obtained, and dissection of these produced 142 pupae. From 142 pupae, 118 flies emerged (83%) in a period of 11 days (Sept. 26 - Oct. 6, 1995), of which 64 were female and 54 male.

The 64 females of the first generation in the laboratory produced 407 galls, giving more than 1200 flies consisting of 640 males and 629 females. In the second generation, the mature galls were not dissected, but the harvested gall-bearing stem cuttings were collected and reared in the rearing cages by dipping the stem cuttings in jars of water to keep them fresh.

The emergence took place from December 12, 1995 up to January 12, 1996; some emerged later; so the emergence period was more than 1 month.

The third generation of *P. connexa* in BIOTROP produced 3232 flies consisting of 1646 females and 1586 males. The rearing procedure in the laboratory at BIOTROP was slightly modified and standardized as follows :

The emerging flies were collected using a small modified vacuum cleaner and were reared for at most 2 days in a rearing cage. The population of adults in 2 days emergence can reach 100 pairs of flies. These paired adults were released immediately in new potted *C. odorata* plants having at least 20 shooting buds each. The potted *C. odorata* plants were housed in a big cage made of iron frame with fine plastic screen measuring 2 x 3 x 3 m.

The plastic screen was lifted one week later, or when all flies died. The potted *C. odorata* plants were looked after with adequate water and fertilizer.

Approximately 50 days after lifting up the plastic screen, or when the galls were maturing, the plastic screen was once again put on to the cage and the emerging flies were collected with modified vacuum cleaner as above. About 250 pairs of flies obtained were once more released in Parungpanjang and 32 galls were sent to Yogyakarta.

The emergence lasted more than 1 month, so from February 26, 1996 up to April 7, 1996 at BIOTROP, everyday there was a new emerging imago of *P. connexa*.

The fourth generation emerged from May 10, 1996 to June 28, 1996. There were more than 3,835 galls, producing more than 4,000 flies.

B. 2. Release

Experiment III : Release

a. Permanent plot

Permanent plots were made in the area densely populated by *C. odorata* at 5 x 5 m, marked with wooden poles of 4 m at the corners of the plot, delineated with steel wire. Inside the plot individual plants of *C. odorata* were tagged with numbered aluminium tags attached to the bases of the plants. The precise location of *C. odorata* plants was plotted on grid paper. The number of plants and their growing shoots were recorded. The permanent plots were made in Parungpanjang and Sukabumi.

b. Field releases

The releases of *P. connexa* were made in the permanent plots at both Parungpanjang and Sukabumi.

b. 1. Parungpanjang

The release was made on December 19, 1995 with 75 pairs of mated adults, and was repeated again on December 30, 1995, with 100 more pairs of mated adults.

b. 2. Sukabumi

The release was made directly from the cage containing 100 pairs of mated adults in the center of the permanent plots on May 28, 1996, and when no gall was observed in the field on June 17, 1996, the following day (June 18, 1996) an additional 65 pairs of mated adults were released.

c. Field observation

The field observations were carried out in as well as outside the permanent plots.

c. 1. Permanent plots

In Parungpanjang permanent plots, every single plant was inspected on December 30, 1995. The galls found were recorded and counted, while in Sukabumi it was done on September 14, 1996.

c. 2. Outside permanent plots

Outside the permanent plots the observations were carried out using the line transect method. Four lines at four cardinal directions were followed using measuring tape. Along the way any *C. odorata* plants directly under the line were inspected for the occurrence of any galls; the number of galls and the distances at which the galls were found were recorded and used to estimate the area covered by *P. connexa.*

RESULTS AND DISCUSSION

A. The Growth of *C. odorata*

A. 1. The plant structure

The data of a mature, well established *C. odorata* community slashed in October was analyzed to see how the leaf biomass was affected by other variables (i.e. plant height, shootbase diameter, number of branches, and stem dry weight). Using linear multiple regression analysis with data from 52 plants, the following regression equation was obtained :

$$Y = 1.2258 - 2.8075\times10^{-3} X_1 + 4.561\times10^{-2} X_2 - 3.2034\times10^{-3} X_3 + 0.18373 X_4$$

$$(r^2 = 0.7349)$$

where:

Y = leaf biomass (g) (= 3.252 g)

X_1 = plant height (cm) (= 159.100 cm)

X_2 = shootbase diameter (mm) (= 4.981 mm)

X_3 = number of branches (= 10.520)

X_4 = stem dry weight (g) (= 14.000 g)

Further analysis of the regression coefficient indicated that only the X_4 variable was significant in affecting the total leaf biomass. This was so because this population of *C. odorata* just sprouted to produce coppice along the denuded stem after leaf shedding during the dry season following flowering and fruiting. It is interesting to compare the growth behavior of *C. odorata* in the laboratory, where in the first two months of growth most of the photosynthate is utilized for producing leaves, and consequently it has higher Relative Growth Rate (RGR) = 1.15 g/g/week (Tjitrosemito, 1996). It seems that this character is consistent whether it grows from seeds or when recovering from drought.

At this time of the year the growth of *C. odorata* was still recovering from drought. The tops of the stems and some branches that were carrying inflorescences had dried off following the dispersal of seeds as indicated by the negative sign of the coefficients. The greater the number of branches the less the biomass of leaf, because those branches did not carry leaves at that stage since the top part of those branches were dead. The situation was similar with the plant height, as the higher the plant the lesser the leaves, as the top part was still dry and dead.

The plant size was relatively small having an average height of 159.10 cm with leaf biomass of only 3.253 g/plant and total stem dry weight of 14.00 g/plant. The number of branches was relatively high, i.e. 10.520/plant, but some were still small and only carrying 2 leaves at that stage.

When slashing was done in May, the following regression line was obtained :

$$Y = -12.567 + 3.6413\times10^{-2} X_1 + 6.8146\times10^{-1} X_2 + 0.9645 X_3 + 2.9480\times10^{-2} X_4$$

where:

Y = leaf biomass (g) (= 5.583 g)

X_1 = plant height (cm) (= 199.1 cm)

X_2 = number of branches (= 7.243)

X_3 = stem diameter (mm)(= 5.608 mm)

X_4 = stem dry weight (g)(= 28.53 g)

Further analysis of regression coefficients indicated that the X_2 variable, i.e. number of branches, was highly significant in affecting the biomass of leaf. X_3 and X_4 were also significant in affecting the biomass of leaf. The number of branches represented new

growth, carrying leaves. Therefore, the greater the number of branches the higher the biomass of the leaf they carried and the sign was positive. Stem dry weight and stem diameter indicated the size of plant; the bigger the size of the plant the higher the biomass of the leaf, and the signs were positive. However, the constant had a negative sign, indicating that the growth of this population was very thick already with a lot of leaves in the upper layer so that some leaves at the lower level were shaded and some of them had already senesced. This plant structure was different from that in October when the population was still recovering from the drought.

The size of plant already reached mature stage; stem dry weight reached 28.53 g/plant with the leaf biomass of 5.839 g/plant, and the average plant height was 199.1 cm; the number of branches stabilized at an average of 7.243/plant and these branches were effective viable branches which will bear inflorescences when the time comes.

A. 2. The Growth of *C. odorata* coppice

The growth of coppice was recorded on all stumps from as small as 2 mm up to 10 mm. Slashing was done during the wet season, i.e. from October - June, while from July to September the regrowth was recorded only on plants with diameter of 5 mm or greater. At this period most of the seedlings (if seeds happen to germinate) will also die due to drought. It seems that the regrowth of coppice of *C. odorata* is mostly affected by soil moisture. It was unfortunate that we did not collect data on soil moisture. This information will be collected in future observations.

The above data revealed the plant structure in terms of biomass distribution, and to understand the plant structure in physical terms the data on coppice growth was quite revealing. When observation was carried out at 2 and 3 months after slashing (during the wet season) the following data were obtained (average of 78 plants).

At 2 months after slashing, when space was still available, the plant utilized its energy for producing branches, reaching a total of 26.07 branches/plant. The plant height varied up to a maximum of 240 cm, with an average of 162.5 cm, while the branches were distributed slightly skewing to the left, i.e. indicating that the plants were still investing their energy for growing; the peak number of branches was observed at a height of 80-100 cm above ground.

Table 1. The distribution of branches in *C. odorata* community at different stages of growth

	Harvested 2 months after slashing	Harvested 3 months after slashing
Plant height (cm)	162.50	220.600
Total living branches (plant)	26.07	18.95
Branches from :	0.5714	0.1818
0-20 cm height	1.9290	0.3939
20-40 cm height	8.6790	0.0150
40-60 cm height	17.00000	2.3030
60-80 cm height	22.40000	3.3940
80-100 cm height	20.7100	6.4550
100-120 cm height	18.2500	9.1360
120-140 cm height	11.9300	12.0000
140-160 cm height	6.8570	12.5200
160-180 cm height	3.0360	13.70000
180-200 cm height	0.9286	10.9500
220-240 cm height	0.4286	7.0450
240-260 cm height	-	2.9090
260-280 cm height	-	0.6364
280-300 cm height	-	0.1212

At three months after slashing, however, there was a stabilization of branches. The lower branches, with their leaves shaded out, were sacrificed by the plant; in their competition for photosynthate, they were dying off. The plants grew taller, reaching a maximum of 300 cm and an average of 220 cm. The branches were distributed slightly skewing to the right since at this time the lower branches and leaves were dying off. The plants formed a population architecture in such a way that most of the leaves were grown on the top branches so as to be able to harvest sunlight as much as possible at the expense of the lower leaves and branches. This is the final architecture with which the population will flower. When the time permits and moisture is available, the plant will grow to form a very dense thicket of *C. odorata*.

B. Laboratory rearing of *P. connexa*

The times of adult emergence are given in Table 2.

Table 2. The emergence of adult *P. connexa* from pupae

No.	Date of Emergence	Total	Female	Male
1.	07-27-1995	3	2	1
2.	-28-	2	1	1
3	-29-	4	2	2
4.	-30-	3	1	2
5.	-31-	-	-	-
6.	08-01-1995	7	4	3
7.	-02-	-	-	-
8.	-03-	3	1	2
9.	-04-	1	-	1
10.	-05-	-	-	-
11.	-06-	-	-	-
12.	-07-	3	1	2
13.	-08-	2	1	1
14.	-09-	3	2	1
15.	-10-	3	1	2
16.	-11-	2	1	1
17.	-12-	2	1	1
	Total	38	18	20

From Table 2, it appears that the time of emergence varies considerably from 9 - 25 days (from pupation/dissection to emergence). The emergence was about 79% with a sex ratio close to 1 : 1. So the initial culture of *P. connexa* at BIOTROP was 18 pairs of adults.

Table 3. The outcome of the rearing in the laboratory

Generation	Gall	Pupa	Emer-gence	Imago			Remarks
				Total	Female	male	
Initial colony	17	48	17	38	19	19	Dissected Stem cutting in jars Modified vacuum cleaner
Generation I	53	142	11	118	64	54	
Generation II	407	NR	30	1269	640	629	
Generation III	3177	NR	NR	3232	1586	1646	
Generation IV	3835	NR	NR	1027	2023	2004	

Assuming that the pupae represented the eggs laid by the female, each female in generation I, on average, laid 7.5 eggs. This was lower than reported by Sipayung and de Chenon (1995), which was 16, and was much lower than the total number of eggs that may potentially be laid by a female *P. connexa* (69 eggs).

However, the following generation the estimated number of eggs laid was higher: 19 per female. In the initial colony each gall contained about 3 pupae per gall, and this was maintained up to generation II at BIOTROP. It dropped at generation III and IV to about 1 pupa per gall. This condition may be attributed to the nature of the plant, being mostly flowering at this time of the year.

C. Field Experiments

a. Parungpanjang

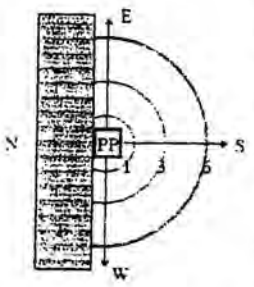
The population of *C. odorata* in Parungpanjang, West Java, a permanent plot of 5 x 5 m^2, was 145 *C. odorata* plants with 2333 shoots. The *C. odorata* vegetation was a very dense thicket of shoots.

In the permanent plot of 5 x 5 m^2, on December 30, 1995, 128 galls were found. This represented about 5% of the available shoots. This infestation is still low in terms of efficiency of controlling *C. odorata*.

The spread of *P. connexa* into the surrounding area is indicated by the data in Table 4.

Table 4. The distribution of galls in Parungpanjang

Time of Observation	Galls recorded in the direction of							
	N		W		S		E	
	No gall	Dist.	No gall	Dist.	No gall	Dist.	No gall	Dist.
Dec. 30 1995	4	5.82	11	78.0	23	13.5	19	7.5
Mar. 29 1996	14	7.60	28	24.0	39	32.8	19	54.8
June 25, 1996	11	20.00	103	290.0	50	201.0	34	229.0



E : Eastern direction
S : Southern direction
W : Western direction
N : Northern direction
PP : Permanent Plot
F : Forest
1 : one month
3 : three months
6 : six months

Figure 1. Diagram of the position of the permanent plot

The northern side of permanent plot was bordered by a forest of young *Eucalyptus,* mixed with *Calliandra callothyrsus* and *Ceiba petandra*. This forest seems to form a barrier to the spread of *P. connexa*.

The rate of spread may be estimated from the distance where galls were recorded. Assuming that the forest on the northern side of the plot constitutes a barrier, the available area of spread was semi-circular as in

Figure 1. So the area is approximately $^1/_2\pi r^2$ (where r = distance of gall found).

In the first month, the area covered by the infestation of *P. connexa* estimated from the distance of previously recorded galls, was about 150 m^2. The following 2 months the spread covered an area of approximately 2,203 m^2 and at 6 months after release the area covered was 120,580 m^2. The mode of spread seems to follow the logarithmic pattern, with relative spread rate = 111 % per month.

b. Sukabumi

The population of *C. odorata* in the permanent plot of 5 x 5 m^2, was 82 *C. odorata* plants with 2,140 shoots. This *C. odorata* vegetation was under coconut plantation; it seemed that this weed had been neglected for some reason, since although the population was less than that of Parungpanjang, the number of shoots was almost the same, in fact the average of Sukabumi (26.1 shoots/plant) was more than that of Parungpanjang (16.1 shoots/plant).

Two weeks after the release in Sukabumi no gall was observed, since *C. odorata* plants were in the process of fruit maturation, where shoots were dried out. So *C. odorata* plants were slashed and *P. connexa* was released again on June 18, 1996 with 65 pairs. On August 8, 1996, 120 galls were recorded. The rate of infestation is about 5% similar to the infestation rate in Parungpanjang, while the observation outside the permanent plot is still being evaluated.

In contrast with *P. pseudoinsulata*, *P. connexa* survived and reproduced well in Java island; this result is very encouraging, although the rate of infestation is still low (5%); it is hoped that with the coming wet season the infestation will be higher. The impact of *P. connexa* on the performance of *C. odorata* such as its growth, seed production and seed viability are still under investigation, and it is expected that one or two more biological control agents could be introduced to Indonesia.

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PROMISING NEW CANDIDATES FOR THE BIOCONTROL OF *Chromolaena odorata*

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ABSTRACT

The successful culturing and establishment of biocontrol agents for *Chromolaena odorata* has proved to be an arduous task. The moth *Pareuchaetes pseudoinsulata*, to date the most successful agent, has significantly reduced infestation by the weed in only a few of the areas in which it has been released. Despite this, the wealth of phytophagous insects, mites and diseases on *C. odorata* in its native habitat strongly suggests that biocontrol remains a good option. In South Africa, several promising agents, recently collected in the Americas, are being studied in quarantine. A world first has been recorded with the breeding of the tip-wilting fly *Melanagromyza eupatoriella* (Agromyzidae). A butterfly, *Actinote parapheles* (Acraeidae), whose larvae cause extensive defoliation, is undergoing host-specificity testing. A damaging stem boring weevil (Curculionidae) in the genus *Lixus*, has been successfully established in culture. Other species with which we have had partial success in rearing include a flea- beetle, *Longitarsus* sp. (Chrysomelidae), whose larvae are root-feeders, and a shoot-galling moth, *Adaina* sp. (Pterophoridae). Following establishment of the stem-galling fly *Procecidochares connexa* (Tephritidae) in Indonesia, a culture was imported into South Africa and appeared to develop on the local form of *C. odorata*. In addition to insects, strains of the fungus *Septoria ekmaniana* have been collected on *C. odorata* at many localities through the neotropics, although they have so far failed to establish on the southern African form of the plant. The recent progress with this programme raises hopes that the use of natural enemies may soon play a more significant role in the control of *C. odorata*.

INTRODUCTION

Chromolaena odorata (L.) R. M. King and H. Robinson (Asteraceae: Eupatorieae) (*sensu lato*), also known in South Africa as triffid weed, paraffin weed or simply as chromolaena, is a perennial scrambling shrub of neotropical origin, with a range that stretches from Florida to Argentina. Over the past century it has become one of the most devastating weeds in the Old World tropics and subtropics. It is a serious threat to agriculture and natural ecosystems in west and southern Africa, India, large parts of south-east Asia, some of the Pacific Islands, and recently, north-eastern Australia (Holm *et al.*, 1977, Macdonald, 1983; McFadyen and Skarratt, 1996). Climate matching indicates that on a global scale chromolaena has not yet achieved its full invasive potential and is likely to become a problem throughout tropical Africa, eastern Australia and all the Pacific islands (McFadyen and Skarratt, 1996).

In South Africa, chromolaena was first recorded as established around Durban in the 1940's (Pickworth, 1976). It spread throughout the subtropical areas of KwaZulu-Natal in the following three decades, and since the 1980's has also rapidly expanded its range through the Eastern Cape, Mpumalanga (bordering Mozambique) and Northern (bordering Zimbabwe) Provinces (Macdonald, 1984; Goodall and Erasmus 1996; J. M. Goodall pers. comm.). It has also invaded Swaziland, Mozambique and Zimbabwe (Goodall and Erasmus, 1996).

Conservation areas are the most threatened by *C. odorata* in South Africa, although it also impacts on plantations and pastureland (Macdonald and Jarman 1985, Goodall and Erasmus, 1996). It invades a wide range of vegetation types, from forest through to grassland, in frost-free areas of South Africa. Although it is most commonly associated with high rainfall regions, it is able to establish along

watercourses in areas which receive as little as 500 mm rainfall *per annum*. Chromolaena produces copious numbers of efficiently dispersed seeds and is able to become established even in undisturbed habitats. It forms dense, permanent thickets over large areas, thereby suppressing other vegetation. In South Africa, with the recent advent of democracy and consequent land restitution, it is likely to also become a problem for small-scale and subsistence farmers in future, as it has in West and Central Africa (M'Boob, 1991).

Chromolaena can be controlled by various means. Individual plants are easily killed using herbicides and fire. However, these are expensive and labour-intensive strategies, and are impractical over the large areas and under the conditions in which the weed is invasive. Consequently, Goodall and Erasmus (1996), the foremost experts on the integrated control and management of chromolaena in South Africa, state that "Successful biological control remains the only viable solution for reducing the current and potential impact of *C. odorata* in southern Africa". In other words, biocontrol is the only method with the potential to reduce this problem to a level at which the weed can be managed cost-effectively.

Woody weeds are rarely completely controlled using biological agents (insects, mites or pathogens), usually their competitive and reproductive abilities are merely reduced to a level at which other control methods become more practical. Also, it is very rare that a single agent provides adequate control; the usual objective is to release a suite of agents to attack different parts of the plant, resulting both in reduced vigour and competitiveness of established plants and in decreased reproductive output. Although chromolaena has been considered as a candidate for biocontrol since the late 1960's, few insects have been tested or released on it anywhere in the world, largely because most countries in which it is invasive (i.e. the Old World tropics and subtropics) do not have access to sufficient funding for original research (McFadyen, 1996). The insect which has been most frequently introduced is the arctiid moth *Pareuchaetes pseudoinsulata* Rego Barros, whose larvae may cause large-scale defoliation of chromolaena. Most early introductions failed (Cock and Holloway, 1982), but in recent years the proportion of countries in which the moth has established and is achieving at least some measure of control is higher (Seibert, 1989; Marutani and Muniappan, 1991; Julian, 1992; Timbilla, 1996). The moth was introduced into South Africa in Kwazulu-Natal in 1989, but failed to establish in the field (Kluge, 1994). However, recent successes in Ghana (Timbilla, 1996) and Sumatra (Desmier de Chenon and Sipayung, pers. comm) suggest that improved release techniques can often overcome such problems. Other agents released on *C. odorata* include the flower-feeding weevil *Apion brunneonigrum* Beguin-Billecocq, the shoot tip-mining fly *Melanagromyza eupatoriella* Spencer, the flower-feeding moth *Mescinia* sp. nr *parvula* Zeller, *Pareuchaetes aurata aurata* (Butler), also a defoliator (in South Africa in 1992), and the tephritid shoot-galling fly *Procecidochares connexa* Macquart (Julien, 1992; Kluge and Caldwell, 1996) of these, only *P. connexa* has established.

It is clear that more agents are needed to bring about adequate suppression of *C. odorata*. To this end, the South African (Plant Projection Research Institute) and Australian (Australian Centre for International Agricultural Research) programmes were set up (in 1988 and 1993 respectively) to conduct original research on neotropical insects as potential agents for chromolaena biocontrol. This paper reviews the most recent progress that has been made on the biological control programme on *C. odorata* in South Africa. Although in the past this programme has experienced some frustrations (Kluge and Caldwell, 1996), it has recently been given fresh impetus, and prospects for the successful release and establishment of one or more agents on the weed within the next three years are good.

Identity and origin of chromolaena in South Africa

The controversial revision of the large genus *Eupatorium* (King and Robinson, 1970), which involved a split into a number of smaller genera, has not fully resolved the problem of phylogenetic relationships within this former genus. *Chromolaena odorata* has many forms through its wide native range; several sources (Lorenzi, 1982; Badillo pers. comm.) consider some of these forms to constitute separate *Chromolaena* species, or even separate genera within the former *Eupatorium*.

This diversity of *C. odorata* morphology is reflected in the number of invasive forms throughout the Old World. The South African *C. odorata* is dissimilar to all other known invasive forms, most conspicuously by the colour of its young inflorescences (white rather than pinkish, lilac or blue), its relatively smooth, shiny leaves and non-hairy stems, and the odour of its leaves

when bruised. We consider it important to find the exact identity and origin of our chromolaena, in order to collect and use agents best adapted to that form; poor matching of highly specialised organisms, such as rust fungi and strictly monophagous insects and mites, may result in poor performance or non-establishment.

Various methods have been used to determine the origin of the southern Africa form of chromolaena. These include comparisons using macro- and micro-morphological techniques (examination of herbarium specimens and live plants, scanning electron microscopy), molecular techniques (iso-enzymes, DNA analysis) and bioassay techniques (use of highly specific fungal strains) (Vos, 1989; Scott and Lange, 1996; unpublished data; J. Morris pers. comm.). These studies have given broad indications of areas of origin and non-origin, and have elucidated differences between forms, but we still do not know from where our form originates. We now suspect that the southern African "form" may be neither *C. odorata,* nor *C.maximilianii* (Schrad) R. M. King and H. Robinson (as was previously proposed), but possibly an *Austroeupatorium* species or a hybrid of garden origin. We will continue to give attention to this question both by expanding on and re-applying previous techniques and by harnessing new approaches. In the interim we are concentrating on finding insect biocontrol candidates which accept a broader spectrum of chromolaena forms without feeding on closely related indigenous, crop or ornamental Asteraceae.

BIOLOGICAL CONTROL CANDIDATES

The ideal practice for exploration for biocontrol candidates involves the stationing of personnel for extended periods in the region where the weed originates. Due to financial and earlier political constraints, this has not been possible for the South African chromolaena programme. Instead, the project has depended on the yield of a few short exploration and collection trips to parts of South and Central America, the Caribbean and Florida (USA).

Research on insects as potential chromolaena biocontrol agents is carried out under quarantine conditions at two South African research stations (Pietermaritzburg and Pretoria) of the Plant Protection Research Institute (PPRI), Agricultural Research Council. The methods used in host-specificity testing of biological control candidates were described in Kluge and Caldwell (1993). Isolations and culturing of fungal pathogens are carried out at a third PPRI research station (Stellenbosch) but will not be reported on at more than a superficial level in this paper.

PRIORITY INSECT SPECIES: A SUITE ATTACKING DIFFERENT PLANT PARTS

Melanagromyza eupatoriella (Diptera: Agromyzidae)

This fly is considered to have potential in limiting the growth and flowering of chromolaena, as it kills shoot-tips. Until now, the failure to induce oviposition in the laboratory, both in South Africa and elsewhere, has prevented rearing and host- specificity testing of this species. In 1995 and again in 1996, females from Florida (USA), laid single eggs on the undersides of near-terminal leaves in our Pretoria quarantine laboratory. The larvae tunnelled spirally down into new shoots, causing die-back of the terminal 100 mm. Larvae successfully completed their lifecycle in the southern African form of chromolaena. Both these cultures were lost due to technical problems, but the success in breeding the species gives impetus for re-collecting it for testing.

Actinote spp. (Lepidoptera: Acraeidae)

Despite the disappointment with *Actinote anteas* (Doubleday and Hewitson) (Caldwell and Kluge, 1993), which died out in culture, larvae of the butterfly *Actinote* sp. prob. *A. parapheles* Jordan, fortuitously collected in South America in 1995, defoliated southern African chromolaena so dramatically in the quarantine laboratory that host-specificity trials have been initiated. Preliminary results from larval starvation tests indicate that the host range is no wider than within the tribe Eupatorieae. Large batches of eggs are laid on the underside of leaves and the larvae feed gregariously. At this stage, it is not possible to predict whether or not predation by ants may pose a problem to the establishment of this agent, although acraeids are often unpalatable (Henning, 1985) and bright warning colours in the imago, together with gregarious larval feeding, are typically associated with aposematism (Donaldson and Bosenberg, 1995). A probable third species of *Actinote,* from northern South America, is also in culture on the southern

African form of *C. odorata,* and is about to undergo host- specificity testing.

Lixus sp. (Coleoptera: Curculionidae)

A few adults of this stem-boring weevil were also collected opportunistically in South America in 1995, on a hairy chromolaena-like species. An agent which kills the woody stems of chromolaena is highly desirable, as stems are photosynthetic, facilitating regeneration after defoliation. *Lixus* sp. is proving to be an excellent alternative to the weevil *Rhodobaenus* sp. nr *cariniventris* Champ, previously targeted as a good agent for this purpose. Adult specimens have been encountered on similar species of chromolaena from Trinidad to Argentina. Under quarantine conditions, the adults have oviposited on the local form of chromolaena, and larval tunnelling resulted in the death of up to 500 mm of stem. Studies on the biology of this species are under way and host-specificity tests are soon to be initiated.

Longitarsus sp. (Coleoptera: Chrysomelidae)

About 60 adults of this flea beetle, which has been targeted as an agent for several years as the larvae feed on young roots, were collected in Trinidad in 1996. A large number of eggs were laid in quarantine, larvae were placed on plants but did not complete their development, more probably due to problems with rearing techniques than to incompatibility with the local form of chromolaena. This species remains a priority, as it complements the suite of agents described above, and could be useful in controlling the spread of chromolaena by reducing seedling survival and also possibly weakening established plants. *Longitarsus* species have previously been successfully used as biocontrol agents of weeds (Julian, 1992).

OTHER INSECT SPECIES UNDER CONSIDERATION

Adaina sp. (Lepidoptera: Pterophoridae)

The larvae of this moth feed inside stems, causing gall formation which results in the stunting of the stems. Larvae and pupae collected in Florida in 1995 and 1996 were successfully reared in quarantine. The resultant adults accepted the local, as well as the west African form of chromolaena for oviposition, and normal galls developed. Attempts are being made to build up a culture, but obtaining satisfactory oviposition in captivity has so far proved difficult. Adults are also small, delicate and difficult to handle, and this species is of low priority.

Procecidochares connexa (Diptera: Tephritidae)

The larvae of this fly cause gall development on young chromolaena stems, resulting in stunted plant growth. A congeneric species was released and successfully established on a weed closely related to chromolaena, *Ageratina adenophora* (Sprengel) R. M. King and H. Robinson, in South Africa and elsewhere (Julien, 1992). Following the successful establishment of *P. connexa* in Sumatra in 1995 (Desmier de Chenon and Sipayung, pers. comm. 1997), a shipment of galls containing larvae and pupae was obtained from Indonesia early in 1996. Despite doubts as to whether the fly would accept the southern African form of *C. odorata,* adults oviposited on plants in quarantine. However, too few adults emerged to start a culture, perhaps due to partial incompatibility or egg predation by mites. A second shipment of this species will be obtained in an attempt to re-establish a culture and, if successful, to proceed with host-specificity testing.

Pareuchaetes insulata (Walker) (Lepidoptera: Arctiidae)

Although this third *Pareuchaetes* species proved to be host specific during trials (Kluge and Caldwell, 1993), it was not released in South Africa as it was thought that predation by ants would hamper its success, in view of its egg-laying strategy, which is similar to that of *P. pseudoinsulata.* We have recently applied for permission to release this moth, although it is presently of low priority in comparison to the other promising biocontrol candidates now in culture.

P. pseudoinsulata (Lepidoptera: Arctiidae)

Following the recent successful establishment of, and high defoliation levels caused by, this species in Ghana (Timbilla, 1996) and Sumatra (Desmier de Chenon and Sipayung, pers. comm. 1997), we plan to initiate a mass-rearing programme to re-release it in South Africa, in conjunction with a review on its history of release and establishment worldwide. This programme may be expanded to include *P. insulata* and *A. parapheles* (pending the outcome of specificity testing) in future.

FUNGAL PATHOGENS UNDER CONSIDERATION

Because of the characteristic specificity of certain fungal groups, e.g., rusts, they may yield the most useful and effective biocontrol agents. Various destructive fungal diseases have been recorded on forms of chromolaena in South and Central America (Barreto and Evans, 1996; M. J. Morris, pers. comm.). A number of species have been collected as part of the South African programme, including isolates of *Septoria ekmaniana* Petrak and Ciferri and several cercosporoid fungi. These have been inoculated back onto chromolaena plants, but so far typical symptoms have not developed on the local form of the plant. Further work on this aspect is continuing but this subject is not dealt with further in this paper.

CONCLUSIONS

The South African biological control programme against chromolaena has received new impetus, following several successful exploration and collection trips in the past three years to South and Central America, the Caribbean and Florida, with an expansion of research capacity following the recent appointments of researchers to the project, and with the upgrading of quarantine research facilities. Although we have not yet determined the origin of the South African chromolaena, we hope to solve this problem within the next few years, in the interim, the use of oligophagous insects, if possible, may prove satisfactory. A positive consequence of using oligophagous insects as biocontrol agents on the southern African chromolaena is that they are more likely to be compatible with forms of chromolaena which are invasive elsewhere in the world. However, the successful use of fungal biocontrol agents may have to await resolution of the origin question.

Biocontrol of chromolaena has thus far concentrated on the attack of the vegetative parts of the plant, with a view to reducing seedling establishment and the density of existing chromolaena stands. The second major prong of the biocontrol approach will involve the use of flower- and seed-attacking insects to reduce the density of regrowth as well as to control the rate of spread. Apart from the weevil *A. brunneonigrum*, there are various insects on *C. odorata* in Trinidad, including a tephritid fly, cecidomyiids and several lepidopterans (Cruttwell, 1972), which have considerable potential in this regard. These species may be more difficult to work with, as little is known about their biology in relation to the flowering phenology of *C. odorata*.

Funding for the project remains unpredictable and insufficient, particularly for exploratory and collection trips. The only extensive survey of the insects associated with chromolaena was carried out about twenty-five years ago in Trinidad (Cruttwell, 1972). Further exploratory work is required, especially in view of the wide geographical range and variability of chromolaena in the neotropics, and the possibility that organisms from insular equatorial regions may not be suitable for use on large land-masses or at higher latitudes. Exploratory work should preferably be conducted by researchers based in the countries of origin. Besides, the promising agents that have been discussed in this paper, there are various other Central and South American insect, mite and fungal pathogen species that could potentially aid the biological control of chromolaena in South Africa (S. Neser pers. obs.; M. J. Morris pers. comm.); these include unreported shoot-boring lepidopterans and a *Conotrachelus* sp. (Curculionidae), shoot-, stem- and crown-boring cerambycid larvae, and undescribed eriophyid mites on leaves. It is quite likely that more intensive searches, as well as first-time searches in countries such as Cuba and Mexico, may yield a variety of other candidates. Collection trips should be conducted separately from exploratory work, as they need to be flexible in timing and to have fewer goals than at present.

Although chromolaena has proved such a devastating weed over so much of the Old World tropics and subtropics for many years, little innovative work has been done to effect its biological control. However, the recent development of programmes in South Africa and Australia to search for, test and release new agents, and their collaboration with other countries in which the weed is invasive, gives new hope that within the next two decades chromolaena may become less of a problem worldwide.

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THE SIAM WEED INFESTATION IN THE FEDERATED STATES OF MICRONESIA — SEVEN YEARS OF ATTEMPTING TO CONTROL IT

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ABSTRACT

Field releases of mass reared larvae and adults of *Pareuchaetes pseudoinsulata* were undertaken in *Chromolaena odorata* infested areas on Kosrae, Pohnpei and Yap. Despite extensive releases made, the biological control agent became established and controlled the weed only in one area at Kosrae and one municipality at Pohnpei. No establishment of *P. pseudoinsulata* occurred on Yap; possibly the number of mass released larvae was not enough to start an infestation. The non-establishment of *P. pseudoinsulata* in other 4 municipalities of Pohnpei and 3 municipalities of Kosrae remained unexplainable, although it was suspected to be due to the presence of predaceous fauna in the release areas.

INTRODUCTION

The Siam weed, *Chromolaena odorata* (L.) R. M. King and H. Robinson, has been the primary target pest for biological control in Federation States of Micronesia (FSM) since 1989 (Esguerra *et al.*, 1991). Through the Agricultural Development in the American Pacific (ADAP) project on Biological Control Agent Exchange, the Federated States of Micronesia was fortunate to receive the biological control agent, *Pareuchaetes pseudoinsulata* Rego Barros, from Guam. The biological control agent became known to us because of its successful control of the weed in Rota, Commonwealth of the Northern Marianas Islands and Guam.

Laboratory multiplication of *P. pseudoinsulata*

Some *P. pseudoinsulata* larvae were released in a Siam weed infested area in Wenik, Kitti while about 60 larvae were reared in the laboratory to start a new culture of the insect. Since 1989, mass rearing of *P. pseudoinsulata* has been done following the technique used by the University of Guam in culturing the insects. However, problems in mass rearing *P. pseudoinsulata* in the laboratory were encountered.

Many mature larvae prior to pupation were killed by a bacterial disease. This problem was solved by disinfecting the 25 gallon sized containers with Pinesol after cleaning them with soap and water. Transferring the larvae to clean disinfected containe every 2 days prevented the recurrence of the diseas

Pupae of *P. pseudoinsulata* were killed by maggots a fly when they remained for more than 2 days at t bottom of containers with fermenting larval excre This problem was solved by transferring prepupati larvae to clean and disinfected containers a transferring the pupae to clean petri dishes and placi them in rearing cages.

Ants interfered with the cultures by feeding on eggs *P. pseudoinsulata* in rearing cages placed on top steel chairs. This problem was solved by anchoring t legs of the chairs in plastic cups with water.

Successful mass rearing of *P. pseudoinsulata* w attained and mass releasing either larvae or adults w undertaken on the islands of Kosrae, Pohnpei and Y

Mass releases of *P. pseudoinsulata* and curr status of Siam weed infestation on Kosrae

For almost a year, 500-1000 larvae of *P. pseudoinsul* were released monthly on three different sections the island. Releases were made on *Chromolae* infested areas along the airport runway, at Agricult Station, Lelu and at Utwe Municipalities.

After 9 months of releasing them, clear symptoms larval feeding on the leaves, yellowing of leaves a presence of larval excreta on leaves of *C. odorata* w visible along the airport runway. Within three mont the Siam weed was completely defoliated and m than 3 larvae could be seen on each plant. The major

of the larvae of *P. pseudoinsulata* even tried to cross the main road outside the perimeter fence of the Airport possibly trying to look for *Chromolaena* to feed and survive. In other release areas, however, *P. pseudoinsulata* failed to get established permanently. A few days after releasing them, minor feeding symptoms occurred on the leaves of *C. odorata* in the release sites, but infestation subsequently disappeared.

On June 14, 1996, many larvae of *P. pseudoinsulata* were observed again on some patches of *C. odorata* inside the perimeter fence at the airport. Some larvae were even noticed crossing the main road going to the airport terminal. About 400 larvae of *P. pseudoinsulata* were collected and released on *Chromolaena* infested areas at the Agriculture Station. The Quarantine officer was even advised to continue collecting more larvae for release at other locations on Kosrae. It is not known yet whether the biological control agent would be able to get established finally in other release areas.

Kosrae Agriculture started culturing *P. pseudoinsulata* in their laboratory in 1993. However, after a few months it was stopped. Mass rearing the insect was a problem because no staff could find time and patience to attend to the cultures on Fridays and weekends.

Mass releases of *P. pseudoinsulata* and current status of Siam weed infestation on Pohnpei

Ever since 1990, mass releases of larvae and adults of *P. pseudoinsulata* were undertaken in different locations on the main island of Pohnpei. Particularly, field releases of larvae were conducted at the municipalities of Nett, Sokehs, Madolenihmw and Kitti in areas that showed extensive occurrence of *C. odorata* to ensure larval survival. Newly emerged moths were also released in Madolenihmw, Kitti and Sokehs far from electric posts to insure adults would not be attracted to lights and be eaten up by toads and lizards, but would prefer to stay on *Chromolaena* and laid their eggs.

Many *Chromolaena* infested areas were defoliated by caterpillars of *P. pseudoinsulata* and suppression of the weed became known in areas under the municipality of Sokehs. Unluckily, despite continuous releases of *P. pseudoinsulata* on Siam weed infested areas in Kitti and Madolenihmw, the biological control agent failed to get established. It was observed that one day after release, larvae could not be found, but predatory ants and ground lizards became frequently noticeable.

Mass rearing of *P. pseudoinsulata* is a continuing activity in the laboratory on Pohnpei. The objective is to produce about 2000 larvae each month for release in Kitti and Madolenihmw.

Mass releases of *P. pseudoinsulata* and current status of Siam weed infestation on Yap

Field releases of caterpillars of *P. pseudoinsulata* were done twice at three different locations on the main island of Yap. Six months after the second release, no sign of establishment had occurred. It is possible that the number of larvae released was not enough to start an infestation in the presence of some predatory fauna.

Guam even sent some larvae of *P. pseudoinsulata* to Yap state division of agriculture, but mass rearing could not be done because of lack of laboratory tools to accommodate a large culture. The division of agriculture ended up releasing a few larvae over some months.

DISCUSSION

The restricted establishment of the biological control agent, *P. pseudoinsulata,* at the runway at Kosrae Airport and in some locations in Sokehs municipality on Pohnpei remains unexplainable despite extensive releases of larvae and adults. For example, on Kosrae, where establishment of *P. pseudoinsulata* occurred at the airport runway and keep on occurring on patches of *C. odorata,* lizards and birds are also present. However, in Tafunsak which is separated from the Airport by a small bridge, *P. pseudoinsulata* could not get established.

Major portions of *C. odorata* on the main islands of Pohnpei and Kosrae remain free of any feeding damage by *P. pseudoinsulata.* It is felt that continuous field release of the biological control agent has still to be done to find possible reasons for its restricted establishment.

It is high time too that other promising biological control agents that have been introduced to the Philippines, Indonesia and other countries should be released against *C. odorata* on Pohnpei and Kosrae. By doing this, it is possible that better control of the weed can be achieved in wider areas of each island where *C. odorata* is a problem pest.

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THE STATUS OF *Chromolaena odorata* IN PAPUA NEW GUINEA

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ABSTRACT

Infestations of Siam weed (*Chromolaena odorata*) have been found at four localities in Papua New Guinea (PNG). The detrimental effect of this weed is becoming increasingly apparent in these areas. It has the potential to spread to most parts of the country and seriously affect all forms of agricultural practices. There has been little or no strategies to control this weed. There are now plans to introduce and release two biological control agents, the moth *Pareuchaetes pseudoinsulata* and the stem-galling fly *Procecidochares connexa* on *C. odorata*.

INTRODUCTION

The Siam weed, *Chromolaena odorata* King & Robinson (Asteraceae) is a serious weed in many countries in Asia and Africa. In Papua New Guinea (PNG) the first collection of *C. odorata* was on the Gazelle Peninsula of East New Britain province (Henty and Pritchard, 1975). Records of the PNG National Herbarium show that this collection, made on November 5, 1970, was at Malabunga, near Rabaul on the Gazelle Peninsula, where it was reportedly growing as a weed on the edge of a coconut plantation.

Current distribution

The known infestations of *C. odorata* in PNG are shown in Figure 1.

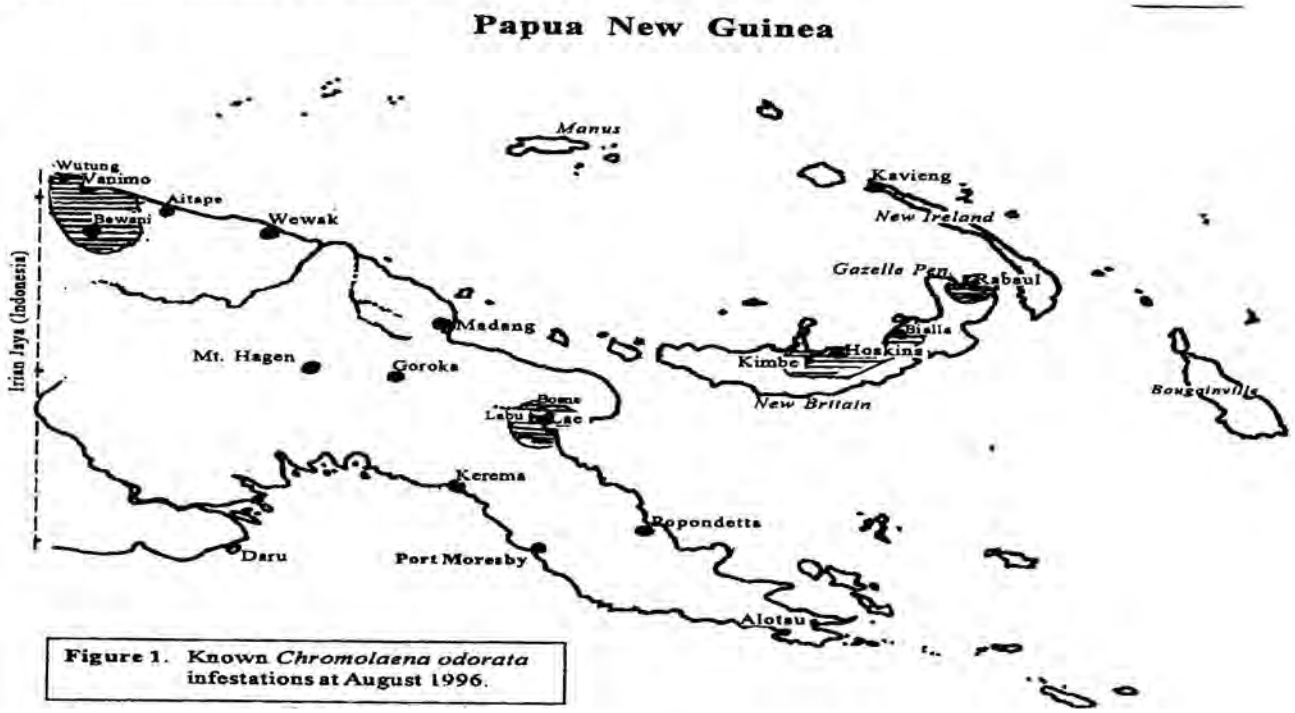

Figure 1. Known *Chromolaena odorata* infestations at August 1996.

New Britain

On the Gazelle Peninsula in East New Britain Province, *C. odorata* was seen growing as isolated plants along the roadsides near Keravat and as tall scrambling plants in a disturbed forest in February 1994. This confirmed the earlier record by Henty and Pritchard (1975). Since no proper surveys have been conducted to locate infestations, its exact distribution in this area is not known.

During May 1995, a widespread infestation was found in the Kimbe District of West New Britain Province. It was seen growing alongside the road from Hoskins to Kimbe (30 km), and along 40 kilometres of the Kimbe-Bialla road as far as Lake Lauli. It has also been reported growing as far as Bialla. Other large stands were seen at several resettlement areas, where it grows as a weed in small oilpalm blocks. Immature stands were seen in old fallow land near the Klinwara river at Kapore. Few stands were found on cattle paddocks owned by the provincial Division of Primary Industry (DPI) at Kapore Livestock Centre. At the time of the discovery there was no sign of flowering.

Most provincial DPI workers at Kimbe were not aware of the identity of Siam weed nor its seriousness as a weed. In contrast, Oil Palm Industry project officers have indicated that *Mimosa invisa* Martius (Mimosaceae) and *C. odorata* were the two main weed problems in both the smallholder scheme areas and large scale plantations (P. Tainole, pers. comm.) but had not reported the existence of the weed to the national Department of Agriculture and Livestock.

These findings from New Britain were made while surveying for water nyacinth (*Eichhornia crassipes*) (Pontederiaceae). Additional infestations and the extent of the reported infestations are now known but the weed is thought to be more widespread than has so far been recorded.

Sandaun province

In May 1992, *C. odorata* was found for the first time on mainland PNG in the Vanimo district by the North Australia Quarantine Strategy (NAQS)/PNG Joint Border Survey team (B. Waterhouse, 1993, NAQS Internal Report). On May 1994 the weed was seen in the areas reported by the survey team. The weed occurs as thick clumps along the roadsides to Wutung Village (35 km west of Vanimo) on the border, with stands scrambling vigorously against the hillside forest. In some places village food gardens were seen to have been invaded. Thick stands occur along the road to Bewani in the south (40 km) and on several logging roads. Mature stands were seen along the road to Ningra village near an old refugee camp (once occupied by Irianese refugees from Indonesia), about 20 km east of Vanimo township. Acres of *C. odorata* occur on fallow land on Vanimo Hill, in the middle of town.

Morobe province

C. odorata was reported growing in an old coconut plantation at Labu, 16 km from Lae city in 1992 but no specimens were collected (R. Banka, pers. comm.). Confirmation of this occurrence was made when Dr. R. Muniapan visited the site in 1995. During a visit in mid August 1996 to Labu, flowering plants were seen near the roadsides. Another report of an infestation on the road to Boana, further inland from Lae, has yet to be confirmed. It is believed that the weed may be more widespread than known in this province.

Lae is well connected to most provinces, especially the agriculturally important highlands region and Madang by road. Spread will occur along these roads to new areas if unhindered. Most of the highlands region would be affected if *C. odorata* invades the deforested agricultural areas which are mostly below 1500 metres altitude, the known altitudinal limits in the New World tropics (McFadyen, 1991).

Age of infestations and spread

It is not clear when or how *C. odorata* was introduced into all the areas. It appears that several different accidental introductions were made.

Introduction on the Gazelle Peninsula could have occurred during the Second World War, with contaminated war machinery from areas in south-east Asia infested with *C. odorata*. Another possibility is that towns like Rabaul, Kimbe and Kavieng have always had a high number of migrant Asians - many could have originated from areas affected by *C. odorata*. The infestation in West New Britain Province appears to have resulted from seeds moved from the Gazelle Peninsula or as contaminant seeds from infestations in oilpalm growing regions in south-east Asia attached to machinery, planting material, and on workers' personal effects.

The introduction into the Vanimo area appears to have taken two routes. The first scenario involves seeds introduced by contaminated logging machinery from

south-east Asia, where logging companies normally import equipment and machinery. The other is from across the border. It is growing along the logging roads near Vanimo and on the road to Wutung, the northwest village on the PNG-Indonasia border. Siam weed has been in the Jayapura district for a number of years and has been seen spreading east along the road which is yet to connect Vanimo (Sipayung *et al.*, 1991). Movement of people between Jayapura and Vanimo, which occurs regularly, appears to have assisted the spread of *C. odorata* eastwards. This scenario may also provide an explanation for the heavy stands seen along the Vanimo-Wutung road.

The infestations in Morobe Province could have come from the large infestations in the other three provinces or from seeds accidentally introduced from Asian sources. It is not known if the weed is already present in other provinces. Lack of knowledge on *C. odorata* by agricultural extension workers and farmers and the general inaccessibility of most areas appear to be the major causes for infestations occurring without detection.

During the 1992 NAQS survey it was reported that Siam weed may be present in the Goroka area of Eastern Highlands Province but this has not been confirmed.

C. odorata will continue to spread to other areas from these infestations.

Potential distribution and problems

Local spread in the Vanimo area has been assisted by movement of vehicles and people. There is a large logging operation in the district and vehicles and heavy machinery appear to be assisting the spread of *C. odorata* into new areas. The weed may also spread east to Wewak if a plan to link it with Vanimo goes ahead. Spread from New Britain to other islands and the mainland could occur easily because inter-provincial travel, movement of plant material and goods are unrestricted. *C. odorata* may find its way into Madang, the highlands provinces and other unaffected coastal provinces from the Lae infestations. Lae is the centre for most of the trade in PNG. The greatest risk of introducing the weed to unaffected provinces is from travellers moving from affected areas because of the ability of the seeds to adhere to clothing.

C. odorata would establish well in most parts that are below 1500 m above sea level, an altitudinal range that covers much of the country except the higher central cordillera of the mainland. Where and when established it will have serious consequences since much of the population depends on limited land for agriculture. All the farming activities exist within this altitudinal range, and are practised by 85 per cent of the population who practise subsistence farming. *C. odorata* is a successful competitor and suppressor of young vegetation in disturbed well-lit conditions, thus becoming problem in most areas where shifting cultivation is practised.

Plantation crops (oilpalm, coffee, cocoa, rubber) are increasingly becoming important in West New Britain, Sandaun and Morobe provinces where *C. odorata* is already present. Reductions in yield and economic loss may result if crop areas are invaded and the weed not controlled.

In some of the provinces like Morobe, Central and Madang, the weed may threaten important pastoral areas by out-competing pastures. Cattle could avoid feeding on the leaves and young shoots in these areas because of the high nitrate levels normally found in *C. odorata* (Aterrado and Talatala-Sanico, 1988). Normally, cattle avoid feeding on *C. odorata* but may be forced to feed on them under conditions of overgrazing (SEAMEO BIOTROP, 1991).

Management of *C. odorata*

Since 1975 chemical spraying of 2,4-D (at 2.8 kg/ha) and 2,4-D plus 2,4,5T (at 5.6 kg/h) as foliar treatments and the use of diuron and atrazine for pre-emergence treatment (Henty and Pritchard, 1975) were recommended. It appears that not much was done to chemically control *C. odorata* on the Gazelle Peninsula using these outdated recommendations.

It has been over 3 years since the seriousness of *C. odorata* was made known to decision makers in the Department of Agriculture and Livestock (DAL) by the NAQS Border Survey Team. No attempts have been made to eradicate or control the weed at the reported sites because of basic limitations. Resources and manpower are seriously limited for such work. All the infestations were discovered after they had increased over too large areas for any eradicative measures to be taken. Some infestations occur in inaccessible areas and may not be easily reached.

Plans are currently in place to extend the biological control program in Southeast Asia to PNG in 1997. It is hoped that the leaf-feeding moth *Pareuchaetes pseudoinsulata* Rego Barros (Lep. : Arctiidae) which has given good control of the weed in Guam (Siebert, 1989) and some areas of Sumatra (Indonesia) would be introduced. The stem-galling fly *Procecidochares connexa* Macquart (Dipt.: Tephritidae) which has been found to be host- specific during tests in Indonesia (R. E. McFadyen, pers. comm.) may also be considered for introduction and release to control the major infestations reported.

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A REVIEW OF BIOLOGICAL SUPPRESSION OF *Chromolaena odorata* (LINNAEUS) KING AND ROBINSON IN INDIA

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ABSTRACT

Chromolaena odorata (Linnaeus) King and Robinson (Asteraceae), a native of West Indies and continental Americas, is a serious weed of pastures, forests, orchards and commercial plantations. It is a serious weed mainly in Karnataka, Kerala, Assam, and also all along the Western Ghats. Extensive surveys conducted for indigenous natural enemies revealed that none have biocontrol potential. In India, three exotic weed insects introduced were *Apion brunneonigrum* Beguin-Billecocq (Coleoptera: Curculionidae), *Mescinia parvula* (Zeller) (Lepidoptera: Noctuidae), and *Pareuchaetes pseudoinsulata* Rego Barros (Lepiodoptera: Arctiidae). *P. pseudoinsulata* was declared safe after extensive host specificity tests. The insect has several constraints in breeding and field effectiveness, which include infection by a nuclear polyhedrosis virus and predation by ants. The Trinidad strain failed to establish but the Sri Lankan strain was found to be better and has established in the field. It has established in several areas in Karnataka and Kerala and caused extensive defoliation in Sullia (Dakshina Kannada) and Vellanikkara (Thrissur).

INTRODUCTION

Weeds cause enormous direct and indirect losses to ecosystems. Terrestrial weeds interfere with cultivation of crops and cattle grazing. In India many of the noxious weeds are of alien origin. They were either introduced negligently or accidentally into our country and in the absence of host-specific natural enemies have become serious problem in the new environment. Most of these weeds have occupied such niches where chemical or mechanical control measures are neither feasible nor economical. Such situations include forest areas, tea, rubber and other plantations.

In spite of the fact that the first outstanding success in biological suppression of weeds was achieved in India when *Dactylopius ceylonicus* (Green) introduced from Brazil in 1795 for production of cochineal dye suppressed *Opuntia vulgaris* Miller (Sankaran, 1973), sustained work was only pursued after the launching of the All India Coordinated Research Project on Biological Control of Crop Pests and Weeds in 1977.

The Weed

Chromolaena odorata (Linnaeus) R. M. King and H. Robinson (Asteraceae) is a native of West Indies and continental America. It migrated to Assam during First World War (1914-18) where it is locally kn as Assam-lata or Assam-lota. It is also knowr German-ban, because of its introduction du German War. Soon after its introduction to Assa spread all over north-eastern region. In 1924-2 further spread to the West Bengal forests. By 193 it invaded the forest rapidly and became a pest in Duars with subsequent difficulty of establis plantations.

Its infestation in 1933-34 in plantations of Buxa Jalpaiguri divisions resulted in suppression of *Ac catechu* (Roxb.) Willd. and *Dalbergia sissoo* Rox regenerations in high forests (Sen Gupta, 1949). F West Bengal it also spread to Orissa. From the ea region the weed spread to Kerala in 1942 by the s stuck to the beddings and clothes of the labo returning from the Assam front (Moni and Ge 1959). From Kerala the weed spread rapidly to al southern states.

In India it is now very well distributed in north-ea and southern states particularly in Assam, Bengal, Orissa, Karnataka, Maharashtra, Tamil N and Kerala.

The distribution of C. *odorata is* directly related to the areas receiving rainfall of 150 cm and above in India (Muniappan *et al.*, 1989).

C. odorata has occupied pastures, marginal lands and open areas. It has become a menace in coconut, rubber, oil palm, tea, teak, coffee, cardamom, citrus and other plantations, orchards and forests. It impedes access to crops and wild life management programmes. In forest ecosystems it decreases the value of timber, forest seed, orchards, increases the cost of seedling production in nurseries, hampers the harvesting operations in the forest and affects the overall productivity of the forest ecosystem. During dry season, it can be a serious fire risk in the forests.

Control options

The physical method of removal of the weed in a vast area of its current distribution is impossible. Herbicides are effective but their large scale application is neither economical nor environmentally sound. Therefore, the alternative strategy i.e. classical biological control approach seems to be feasible.

Biological control attempts

The work on survey and identification of indigenous biotic agents and biological suppression of *C. odorata* by introducing host specific insects from their native home, are discussed in the following sections.

Native natural enemies

Survey of native insect complex of *C. odorata* was carried out extensively in Karnataka, Tamil Nadu and Kerala. But none of those found were promising as biocontrol agents. *Icerya purchasi* Maskell was recorded defoliating *C. odorata* (Mathur and Singh, 1959). Yadav *et al.* (1981) reported that the sap sucking aphid *Toxoptera odinae* van der Goot was found in large numbers and reduced the flower and seed production which in turn reduced the plant population. Two other insects recorded were *Myzus persicae* (Sulzer) and *Idiocerus* sp. in North and South Kannada and Shimoga districts of Karnataka. *Myllocerus viridanus* (Fabricius), a common defoliator of teak, caused considerable defoliation of *C. odorata* in Tamil Nadu, Kerala and Karnataka (Ahmad, 1989).

Joy *et al.* (1979) reported the occurrence of *Aphis citricola* van der Goot, *A. fabae* Scopoli and *Brachycaudus helichrysi* (Kaltenbach) in Kerala. Later on, a total of 21 insect species were recorded and most abundant were *A. spiraecola (=citricola)* Patch and *A. fabae* in Kerala (Lyla *et al.*, 1987). *A. spiraecola (=citricola)* was recorded earlier (Bennett and Rao, 1968). However, it is reported to be a vector of citrus tristeza virus (Naidu, 1980). Ramani and Haq (1983) recorded an oribatid mite *A. fronothrus orboreus* Ramani and Haq in addition to 6 other oribatid mites in Kerala. However, none of them had any biocontrol potential. Other mite species recorded on *C. odorata* included *Galumna sp., Lamellobates* sp. and *Schaloribates sp.* (Singh, 1994). Muniappan and Virakatamath (1986) recorded eleven species, 8 insects and 3 mites feeding on *C. odorata* but indicated an eriophyid mite *Calacarus sp.* may hold some promise, if found specific. Recently the same authors have recorded 4 additional species (Viraktamath and Muniappan, 1992) but none were considered promising.

Frequently fungal pathogens, *Cerocospora eupatore* Peck, and others have been recorded but fungal pathogens have never been evaluated seriously especially in combination with arthropods (Singh, 1989).

Introduced natural enemies

Apion brunneonigrum Beguin-Bellecocq (Coleoptera: Curculionidae)

Adults of this seed feeding weevil were obtained in 1982 and 1983 from Trinidad and supplied to Kerala Agricultural University (KAU), Thrissur and Central Horticulture Experiment Station (CHES), Chethalli. In January, 1983 about 800 weevils were released in the field in linen bags on C. *odorata.* Similar releases were made at CHES, Chethalli. Periodic observations revealed feeding holes but no grub could develop. Establishment has not been reported but perhaps their re-evaluation is necessary (Singh, 1989).

Mescinia parvula (Zeller) (Lepidoptera: Noctuidae)

During 1986 two shipments of the stem borer *Mescinia parvula* (Zeller) were obtained and attempts were made to culture it under quarantine conditions. However, the number of adults that emerged were few and the culture could not be established. Perhaps its re-evaluation is necessary after ascertaining host specificity.

Pareuchaetes pseudoinsulata Rego Barros (Lepidoptera: Arctiidae)

Pareuchaetes pseudoinsulata Rego Barros was imported by the Commonwealth Institute of Biological Control (CIBC), Indian Station, Bangalore in 1970. The culture obtained was infected with nuclear polyhedrosis virus (NPV) and a pure culture was raised after careful selection and rearing.

The experiments conducted on *P. pseudoinsulata* are presented.

Host specificity tests

Host specificity tests were conducted by CIBC, Bangalore after successfully multiplying the insect in the quarantine laboratory. Out of the 13 plants tested, nibbling was observed on *Eucalyptus odorata* and slight feeding on *Sesamum indicum.* However, larvae failed to develop normally (Giriraj and Bhatt, 1970). Subsequently in further tests, 95 species of plants representing 46 families were screened (Sankaran and Sugathan, 1974). Slight feeding or nibbling by larvae was recorded on *Lactuca sativa* L. (Asteraceae), *Brassica oleracea* Var. *capitata* L. (Cruciferae), *Raphanus sativius* L. (Cruciferae), *Melia composita* Willd. (Meliaceae), *Gliricidia maculata* Steud. (Papilionaceae), *Sesamum indicum* L. (Pedaliaceae), *Ziziphus oenoplia* Mill. (Rhamnaceae), *Lycopersicon esculentum* Mill (Solanaceae), *Coriandrum sativam* L. and *Daucus carota* Linnaeus (Umbelliferae). Ten day old larvae fed on *S. indicum* up to 31 days, but their development was retarded and they failed to pupate; however, freshly hatched larvae fed only up to four days. On *D. carota* one larva could complete development up to adult stage. The plants tested might have initially incited a feeding response but they were not nutritionally suitable for larval development (Sankaran and Sugathan, 1974).

Host specificity tests have also been carried out with as many as 42 plant species of forestry importance belonging to 21 different families, using third instar larvae. Initial nibbling was observed on six species viz., *Artocarpus lakoocha* Roxb. (Moraceae), *Bombax ceiba* Linnaeus (Bombaceae), *Cassia siamea* Lamk. (Caesalpiniaceae), *Cupatosium triplinervae* Vahl. (Asteracae), *Santalum album* Linnaeus (Santalaceae) and *Terminalia bellirica* (Caertn.) Roxb. (Combretaceae), but the larvae failed to survive for more than 4 days (Ahmad and Thakur, 1991). The insect was declared safe for making field releases in the country (Sankaran and Sugathan, 1974; Ahmad and Thakur, 1991).

Bioecology of *P. pseudoinsulata*

Studies on the biology at CHES, Chethalli indicated that the egg stage lasted 5 to 9 days (average 7), larval stage 30 to 51 (39.6), pupal 8 to 22 (15.4) and adult 2-20 (8.3) days. Similar studies at KAU, Thrissur indicated that males outnumbered the females and sex ratio was 1:1.5. Fecundity was about 225. The egg, 5 larval instars, prepupal and pupal period were 3-5, 3.2, 3.0, 2.8, 4.0, 4.6, 2-4 and 8-9 days, respectively. The moths lived for 3-8 days.

The hatching percentage of the eggs in different generations was about 28% in the first and 48% in the second generation. However, a steady decline was observed during the third, fourth and fifth generations. By the sixth generation of continuous rearing in the laboratory, the culture nearly perished and only nine larvae hatched out of around 300 eggs collected.

Adult females started laying eggs from the second day of emergence onwards and egg laying lasted until the eighth day. A few females were found laying eggs on the ninth day also. Egg laying and hatching percentage was maximum for the eggs laid on the third day. The maximum fecundity recorded for an adult female was 755 and minimum 33 in sex ratio of 2 male:1 female, while hatching was maximum when adults were kept in 1:1 ratio.

Most suited food combination was found to be 50% honey solution + sodium chloride combination, in which egg hatchability was 85.2% followed by 83.7% in 50% honey solution and vitamin E combination when adults were kept in ratio of 1:1. However, in the case of 2:1 (male: female) ratio, maximum hatching was recorded for 50% honey solution + Vitamin E (73%) followed by 50% honey solution + sodium chloride + vitamin E (71.8%).

A temperature of 25°C and 75% RH was found to be more suitable when compared to 30°C and 60% RH. Many of the larvae were found dead at 30°C, and adult longevity, fecundity and egg hatching was drastically reduced.

The relationship between the instars and the width of the head capsule, and length and width of the faecal pellets was worked out. The measurements of the faecal pellets could be effectively used for identification of instars of caterpillars in the field. The

consumption index, growth rate, efficiency of conversion of ingested food, approximate digestibility and efficiency on conversion of digested food for different instars were worked out (Muniappan *et al.*, 1989).

Studies at IIHR, Bangalore indicated that eggs kept at 32°C dried up. At 20°C the life cycle took an average of 77.75 days. Egg, larval and pupal period were completed in 64.0, 9.95 and 21.9 days, respectively. At this temperature each female laid 207 eggs in 12-16 days of its life. The sex ratio was 1.2: 1.90 (female: male).

At 30°C the life cycle was completed in 38.4 days - egg, larval and pupal periods were completed in 4.5, 22.6 and 8.2 days, respectively. The sex ratio was l: 1.7 (female:male). Each female at this temperature laid 254 eggs.

At 20°C, about 40% of the larvae underwent a sixth instar, while at 30°C only 20% of the reared larvae had a sixth instar.

Adopting 20°C for mass multiplication will facilitate augmentative field releases to control *Chromolaena.* At this temperature the life cycle is extended twice, whereby no significant effect on fecundity or mortality were observed.

At Bangalore the duration of egg, 1st, 2nd, 3rd, 4th, 5th and 6th instar larvae; prepupae, pupae, larval period and the entire development period lasted 7 (7), 4(4), 3-5(3.8), 3(3), 3-5(3.4), 3-7(4.9), 5-8(6.6), 1-2(1.7), 10-13(11.9), 21-32 (25.7) and 39-54 (46.3) days, respectively (Muniappan *et al.*, 1989).

At Coimbatore pre-oviposition, oviposition and post-oviposition periods lasted 2.12 0.61, 6.36 2.18, and 1.62 0.84 days, respectively. Egg, larval and pupal periods were completed in 6.4 1.52, 29.6 3.69 and 8.5 3.24 days (Ahmad and Thakur, 1991).

Maximum daily consumption (7.28 cm leaf area) was observed in the fourth larval instar while 145.83 cm of leaf area was consumed by a single larva during its entire larval period of 29.60 ± 3.69 days (Ahmad and Thakur, 1991). In cage studies, 50 larvae between fourth instar to pupation defoliated 78.9 - 82.4% of a plant 1 m high within 15 days after infestation (Muniappan *et al.*, 1989).

Storage studies with *P. pseudoinsulata*

Developmental times could be extended at 20°C up to 68 days, without affecting the fecundity and longevity of the emerging adults, or could be shortened to 34.3 days by rearing them at 30°C for augmentative field releases during vegetative phase and 20°C for storing the insects during the flowering stage of the weed. This observation made at IIHR, Bangalore at high temperature is in variance with findings of KAU, Thrissur.

A large scale accumulation method was developed at 15°C in BOD incubator with 14 hours day light. Storage for up to 45 days with feeding at 7-10 day intervals did not significantly affect pupation, adult emergence, fecundity and viability of eggs.

Susceptibility of *P. pseudoinsulata* to pesticides

Toxicity of various pesticides used in plantations and orchards was bioassayed at IIHR, Bangalore against *P. pseudoinsulata* in the laboratory. All the tested fungicides viz., Tridemorph, Mancozeb, Sulphur and Carbendazim were found relatively non- toxic to all the stages. Among the herbicides, Paraquat was toxic to the egg stage causing 100% mortality. 2, 4-D, Glycel and Karmex were comparatively safe to all the stages of the insect. However, all the tested insecticides viz., Quinalphos, Ethion, Malathion, Dimethoate and Dicofol were toxic to all the stages of the insect.

Studies on antifeedant and repellent properties of the fungicides and herbicides showed that larvae were least attracted when *C. odorata* leaves were treated with Karmex, Glycel, Mancozeb and Carbendazim. Glycel, Karmex, Sulphur and Calaxin were found to have antioviposition properties for *P. pseudoinsulata* females.

Field trials

The results of several field trials conducted (Ahmad, 1991; Anon; 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995; Jayanth, 1987; Joy *et al.*, 1993; Sankaran and Sugathan, 1974: Sathesan *et al.*, 1987; Singh, 1980, 1989, 1994) are presented below.

Field releases initiated in 1971 at Kodagu did not result in establishment, probably due to detrimental activities of predatory ants (Sankaran and Sugathan, 1974). Renewed efforts were made under All India Coordinated Research Project on Biological Control of Crop Pests and Weeds with the same stock.

Between September and December 1978, 20,750 larvae at different stages and 600 gravid females were

released in three different forests (one near Chethalli, one near Kushalnagar and one near Puttur on Mercara-Mangalore road). Different timings and methods of release were tried. Although feeding was observed initially in all the areas of release, the expected degree of defoliation was not observed. Larvae were recovered only up to the tenth day after release, after which they could not be seen (Singh, 1980).

It was proposed to make releases in other climatic regions of Kodagu district as well as in Kerala. However, an outbreak of granulosis virus disease destroyed the culture. In the field, predatory ants were hampering the activities of larvae (Singh, 1989).

The Trinidad strain of *P. pseudoinsulata* failed to establish, although large numbers of larvae were released (Anon., 1983). Field collected material was obtained from Sri Lanka in September 1984. A laboratory culture was established and cultures were also supplied to Thrissur. In Karnataka, a total of 42,000 larvae were released in Kodagu, Shimoga, Chickmagalur and South Canara districts of Karnataka. Signs of establishment were noticed at one spot in Mallesara, near Teerthalli in Shimoga district. The 1987 releases have resulted in complete defoliation of weed in 5 acres of land in Dakshina Kannada (Anon., 1985, 1986, 1987). During 1992-93, the insect was found to have spread over 1,000 sq km area from about 400 sq km during the previous year. The insect was also supplied to the Rubber Research Institute and Boyce Estate (Harrison Malayalam group), Kottayam for multiplication and field releases (Anon., 1992, 1993).

In Kerala, the first consignment of about 250 caterpillars of the Trinidad strain of *P. pseudoinsulata* was sent from CHES, Chethalli, in December, 1981. One hundred caterpillars were released near the Horticultural College, Thrissur on *C. odorata* bushes, protected by a mosquito net of 1.8 x 1.5 m. A few caterpillars were observed the next day inside the cage but none was visible during subsequent observations. After about three weeks, the cage was opened carefully and thoroughly searched, in vain, for any symptoms of survival. During the ensuing January, 469 caterpillars were again released and they too perished.

The second consignment of 115 first instar caterpillars was sent from the Project Headquarters, Bangalore in July, 1982. Field releases commenced in the Horticultural College premises at Vellanikkara during August 1982 using 418 third, fourth and fifth instar caterpillars. But even after one month, no sign of establishment was observed and hence another lot of 602 fourth and fifth instar larvae was released during October 1982. This time, minor feeding symptoms and a few caterpillars were noted after a few days in the field, but subsequently they disappeared.

A third release of about 360 final instar caterpillars was made during November, 1982. No field establishment was observed from these releases. A fresh consignment of 446 larvae of the Sri Lankan strain of *P. pseudoinsulata* was sent from the Project Headquarters, Bangalore in October, 1984. These were multiplied in the laboratory and field releases commenced during the last week of November 1984.

Altogether, about 7,500 caterpillars of various instars (mostly fourth and fifth) were released in November. In addition to the caterpillars, about 300 moths were also released during the same period. However, the moths were mostly spent, having laid most of their eggs in the laboratory.

This time the field establishment of *P. pseudoinsulata* was rather quick. Within ten days of release, clear symptoms of feeding and damage to *C. odorata* were visible in the release site. By the third week of December, *P. pseudoinsulata* moths were found in the field. However, another lot of 9,600 caterpillars was again released in the same area during the first week of January 1985. No further releases were made in the locality until the end of June, 1985. But the presence of the insect and its feeding symptoms were detectable even during summer months in the vicinity of the release site. By July 1985, *C. odorata* in about 0.5 ha area in the release site was severely defoliated. Moreover, even after the receipt of the monsoon showers, there was not much of the regrowth of *C. odorata* because of the continuous defoliation by the caterpillars.

The third consignment of 3,700 caterpillars was released during the last week of June 1985. In July, during the period of heavy rains, a few dead caterpillars were noticed in the field. On examination, the caterpillars were found to be infected with bacteria. Birds of various species were found frequenting the area and were suspected to be predacious on *P. pseudoinsulata*. However, the gut contents of the birds showed no remnants of the caterpillars. By September and October, *P. pseudoinsulata* spread farther to cover an area of about one hectare. Yellowing of the affected weed was conspicuous at the feeding locations and

wild plants like *Ficus* sp., *Mikania scandens, Centrosema pubescens, Ipomoea* sp., *Clerodendrum* sp. etc. were found growing in *C. odorata* cleared patches.

After the initial establishment of *P. pseudoinsulata* in the abandoned rubber plantations near the College of Horticulture, releases were continued at other locations in Vellanikkara estate.

During 1985, about 40,000 caterpillars, released at the instructional farm and adjoining rubber plantations, failed to establish. In 1986 and 1987, two batches of 20,000 caterpillars were released. By 1988, sporadic appearance of caterpillars was noted and *C. odorata* was defoliated in about 12 hectares of rubber plantations in one of the release sites.

From 1988 to 1991, 90,000 caterpillars were released at Vellanikkara. In 1991, 15,820 larvae, 750 pupae and 200 moths were released at Vellanikkara (Thrissur) and Kinaloor (Calicut). However, by 1992 there was a drastic reduction in the field population of *P. pseudoinsulata* at Vellanikkara. Suppression of *C. odorata* was not visible anywhere in the release sites. In fact some of the areas cleared earlier by the caterpillars showed signs of reinfestation by the weed (Anon., 1989, 1990, 1991).

Simultaneous with the field releases at Vellanikkara, *P. pseudoinsulata* was also released at many other locations in Kerala extending over various districts and bio-climatic zones. These locations included Taliparamba (Cannanore district), Kinaloor (Calicut district), Veluppadam, Kuthiran and Palappilli (Trichur district), Vadakkancherry, Alathur and Mannarkadu (Palghat district) Vyttilla (Ernakulam district), Puthuppalli (Kottayam district), Palode and Vellayani (Trivandrum district). Around 58,750 larvae were released. But it failed to establish in all these locations except at Puthuppalli (Kottayam). Even at Puthuppalli, the establishment was temporary and the biocontrol agent vanished from the release site after about six months.

The culture of *P. pseudoinsulata* could not be developed at the AAU, Jorhat centre due to disease infection at the pupal stage of the insect.

During 1993-94, releases were made in 3 districts of Kerala and a total of 29,300 larvae were released. However, little impact was observed at any of the release sites (Anon., 1994).

Due to frequent incidence of nuclear polyhedrosis virus (NPV), the whole culture of *P. pseudoinsulata* at Vellanikkara (Kerala) was lost during May-June, 1994. Eight caterpillars were collected from a thin stand of *Chromolaena* in a rubber plantation in Sullia taluk, Dakshina Kannada district, Karnataka. These caterpillars were multiplied in the laboratory and field releases commenced in November, 1994. A total of 3,550 larvae and 235 mated moths were released in Velluppadam and Vellanikkara in Thrissur district (Anon., 1995).

P. pseudoinsulata has been recovered after release around Thunakadavu and Parambiculum (Anamalai Hills) (Ahmad, 1991).

CONCLUSIONS

P. pseudoinsulata has established in Kerala and Karnataka, but it has failed to provide suppression of *C. odorata.* For future introductions, the primary emphasis should be on those insects that affect the stem and the roots, the flower and the fruits and the foliage in that order.

Biological weed control is a long term research. It requires appreciation and support from funding agencies. There is a need to strengthen the international co-operative research initiatives.

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CURRENT STATUS OF BIOLOGICAL CONTROL TRIALS AGAINST *Chromolaena odorata* IN INDIA

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ABSTRACT

Biological control trials were initiated against *Chromolaena odorata* (L.) King and Robinson (Asteraceae) in India with the importation and releases of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) in 1973. Repeated trials with this insect, obtained from Trinidad, over a period of ten years in Karnataka and Kerala, failed to result in establishment. Therefore, a culture of the same insect was obtained from Sri Lanka, where it had established from a stock obtained from Trinidad. The Sri Lankan strain of *P. pseudoinsulata* was multiplied at the Indian Institute of Horticultural Research and supplied to Kerala and Guam (USA), besides carrying out releases at many locations in Karnataka. Although the insect established under field conditions in India, it could bring about successful biological control of the weed only in Guam.

In Karnataka field releases were carried out during 1984 to 1987 at many locations in Bangalore, Mysore, Kodagu, Shimoga and Dakshina Kannada districts. However, establishment was noticed only at one location in Dakshina Kannada, from where it dispersed over 1000 sq km area causing large scale defoliation sporadically at many spots during 1991 to 1994. But during surveys carried out in the above areas in 1995 the insect was not noticed to cause any defoliation, although it was observed to survive in the field.

Earlier attempts at introduction of *Apion brunneonigrum* Beguin-Billecocq (Coleoptera: Apionidae) and *Mescinia* nr. *parvula* Zeller (Lepidoptera: Pyralidae) were also unsuccessful. The present paper examines the probable causes for selective establishment of *P. pseudoinsulata* and the failure with the other insects. It is recommended that efforts be made to import additional insects such as *Procecidochares connexa* Macq (Diptera: Tephritidae), so as to bring about biological control of this noxious weed.

INTRODUCTION

Chromolaena odorata (L.) King and Robinson (Asteraceae), of Neotropical origin, is a serious weed in plantations, grazing lands and open forests along the Western ghats in Karnataka, Tamil Nadu and Kerala. It is also a common weed in Assam, Maharashtra, Orissa and West Bengal (Chacko and Narasimham, 1988). In its native home *C. odorata* is attacked by about 225 species of insects (Cruttwell, 1974). Among these *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) was recommended for introduction into India and other countries, where the weed occurs as a pest (Bennett and Cruttwell, 1973).

Following a request by the Karnataka Agricultural Department *P. pseudoinsulata* was imported by the Commonwealth Institute of Biological Control (CIBC) from Trinidad, its safety to economically important plants confirmed and field trials initiated in 1973, at many localities in Kodagu district in Karnataka (Sankaran and Sugathan, 1974). However, these efforts did not result in field establishment. Further attempts made during 1978-79 also did not yield positive results (Singh, 1989). The failure of these attempts was attributed to detrimental activities of predatory ants in the field and infection by a granulosis virus in the laboratory.

P. pseudoinsulata was imported again by the Indian Institute of Horticultural Research (IIHR) in 1982 under the All India Coordinated Research Project on Biological Control of Crop Pests and Weeds. As releases of these insects in Kodagu and Kerala also did not result in establishment, about 70 larvae of the

insect collected from the field in Sri Lanka were obtained in September 1984 through CIBC. Releases of the insect in Sri Lanka in 1973 had resulted in establishment and defoliation of the weed (Dharmadhikari *et al.*, 1977).

Attempts at colonization of two other insect species were unsuccessful. The flower feeding weevil *Apion brunneonigrum* Beguin-Billecocq (Coleoptera: Apionidae), imported and released directly in the field, without attempting laboratory multiplication, in 1976 by CIBC (Chacko and Narasimham, 1988) and in 1982 by IIHR, apparently has not established. In 1986 IIHR obtained a culture of *Mescinia parvula* Zeller (Lepidoptera: Pyralidae) but could not establish a laboratory culture due to paucity of material received.

MASS REARING OF THE SRI LANKAN STRAIN OF *P. pseudoinsulata*

P. pseudoinsulata was reared in the laboratory on its natural host *C. odorata*. Since the weed was not widespread in Bangalore it was raised in 45 x 45 x 60 cm cement pots. To prevent spread of the weed special care was taken to clip off and destroy the flower buds formed during October to February.

Separate egg laying and larval rearing cages were used for multiplying *P. pseudoinsulata* under laboratory conditions. Wooden cages (30 x 30 x 30 cm) with wire-mesh on the sides and top and a glass front were used as egg laying cages. About 20 pupae were placed inside the cage, the bottom of which was lined with a moist sponge sheet, and 50% honey in cotton swabs was provided inside for adult feeding. Eggs were collected on bouquets of *C. odorata* twigs, with their cut ends dipping in water collected in small plastic containers, through holes in the lid.

Bouquets with eggs were collected once every one or two days and placed in larval rearing cages. These were prepared from 16 x 20 cm clear plastic jars by fixing wire-mesh windows on their lids for aeration. Eggs hatched in 4-5 days. The newly hatched larvae were transferred at the rate of 20 per cage into fresh larval rearing cages. Bouquets of leaves, prepared as described above, were used for larval rearing. Fresh bouquets were provided inside the cages as and when required.

After feeding for 18-20 days, fully formed larvae pupated inside silken cocoons formed between the leaves on the twig or at the bottom of the cage. The rearing cages were left undisturbed during pupation and pupae were collected after 5 days. These were placed in egg laying cages and the process repeated. By initiating 3-4 batches of 20 young larvae each per week it was possible to obtain about 3000 larvae every week for field releases.

RESULTS OF FIELD TRIALS

During October, 1984 a nucleus culture of about 500 F1 larvae of the Sri Lankan strain of *P. pseudoinsulata* was supplied to Kerala Agricultural University, Trichur for multiplication and releases in Kerala. Releases of about 40,000 larvae and 400 adults resulted in establishment and partial control of the weed in the campus of the College of Agriculture, Kerala Agricultural University (Joy, *et al.*, 1985). Further releases resulted in establishment of the insect in a rubber plantation and clearance of the weed in an area of about two hectares (Anon, 1986). However, additional releases of the insect since then have failed to increase its spread (Joy, P. J., 1995, personal communication).

During 1984 *P. pseudoinsulata* was multiplied and supplied to Dr. R. Muniappan of University of Guam, who was in India on a Fulbright Fellowship. He in turn supplied the same to different centers in Karnataka, Tamil Nadu and Kerala for further multiplication and field releases. However, none of these efforts resulted in field establishment (Ahmad, 1991).

The Sri Lankan strain of *P. pseudoinsulata* was also supplied to the University of Guam through the CIBC Indian Station. Field releases of this insect in Guam, along with material collected from other sources, resulted in immediate establishment and extensive defoliation. By 1989 *C. odorata* was reported to have lost its status as the predominant weed in Guam (Marutani and Muniappan, 1991).

Between October 1984 and December 1987 a total of 61,345 larvae of *P. pseudoinsulata* were multiplied in the laboratory at IIHR, Bangalore and released at different locations in Bangalore, Chikmagalur, Dakshina Kannada, Kodagu, Mysore and Shimoga districts in Karnataka (Table 1). Since the release spots, other than in Bangalore district, were located more than 250 km away, a method was developed to store young larvae at 15°C in a B.O.D. incubator for up to 45 days (Jayanth and Ganga Visalakshy, 1989).

Table 1. Field releases of *P. pseudoinsulata* (Sri Lankan strain) in Karnataka

Date	District	Location	Number Released
October 30, 1984 to January 6, 1985	Bangalore	Campus of Indian Institute of Science	18,625
September 7, 1986	Chikmagalur	Reserve forest in Mudigere - Sringeri road, 15 km from Balehonnur	4,230
September 10, 1986	Mysore	Gulladahalla reserve forest at Bylukuppa	2,800
November 5, 1986	Kodagu	Ontenangadi - Kushalnagar road and Nanjarayapatna	2,450
November 5, 1986	Kodagu	Forest area near CHES farm, Chethalli	2,740
November 19-28, 1986	Bangalore	Chikbettahalli near GKVK campus	4,500
January 17, 1987	Kodagu	Forest area near CHES farm, Chethalli	11,000
August 3 & 7, 1987	Shimoga	Karabyle near Tirthahalli	5,000
September 26, 1987	Dakshina Kannada	Kamela in Sulya Taluk	5,000
December 9, 1987	Dakshina Kannada	Kamela in Sulya Taluk	5,000
		Total	**61,345**

It was thus possible to accumulate larvae for carrying out large scale releases at distant locations.

Among the release spots in Karnataka, establishment of *P. pseudoinsulata* was noticed in July 1988, about 9 months after releases, at Kamela in Suliya taluq of Dakshina Kannada district. The insect was noticed to cause large scale defoliation of *C. odorata* in a one hectare area of uncultivated land, fully infested by *C. odorata*, in a private estate growing rubber, arecanut and black pepper. Defoliation by the insect was found to prevent flower production by the weed. About 75% reduction in weed cover and increase in the growth of local vegetation were noticed by October 1990. During our visit to the release spot in November 1991 the above area was covered by shrubs and small trees, some of which were identified by Dr. S. Joshi of University of Agricultural Sciences, Bangalore as *Osbeckia zeylanica* (Melostomaceae), *Glycosmis mauritiana* (Rutaceae), *Calicopteris floribunda* (Combretaceae) and *Ipomoea carnea* (Convolvulaceae).

Surveys carried out during the same period revealed that *P. pseudoinsulata* had dispersed naturally over more than 400 sq km area. However, the insect was found to be distributed sporadically in the above area, defoliating the weed in pockets. Extensive surveys in January 1993 showed that the area of dispersal had increased to about 1000 sq km. Large scale defoliation extending over several km along the road was noticed in areas around Subramanya in reserve forests as well as rubber and cashew plantations. But observations carried out during October 1995 revealed that although *P. pseudoinsulata* population continued to survive in the field, the insect was noticed to cause only minor damage to the leaves of the weed. Laboratory observations carried out on field collected insect stages did not indicate incidence of parasitoids.

CONCLUSIONS

Various explanations, including attack by ants, have been cited as the reasons for non-establishment of the Trinidad strain of *P. pseudoinsulata* (Singh, 1989), releases of which were carried out between 1973-84. This gives the impression that the Sri Lankan strain, released subsequently, is some way superior and also that it is resistant to attack by ants. The Trinidad strain was mainly released in Kodagu district in Karnataka. However, the Sri Lankan strain also failed to establish in Kodagu district, although nearly 16,000 larvae were released there. In Dakshina Kannada, where this insect established only about 10,000 larvae had been released.

Dakshina Kannada district is located in the high rainfall area (about 2000 mm) of Western Ghats. Initial releases were made in an undisturbed area, adjacent to a perennial mountain stream, due to which green leaves were available throughout the year for sustaining a population of the insect. *P. pseudoinsulata* probably disperses from this focal point to the

surrounding areas during the rainy season and causes extensive defoliation if the rainfall is well distributed.

Larvae of *P. pseudoinsulata* could be located at the release site in Bangalore up to 20 days after releases. Although a few pupal shells were also noticed, indicating adult emergence, no signs of insect establishment could be noticed. It is possible that adults were disoriented by intense lights during night and therefore could not locate the weed for egg laying, since *C. odorata* was present only in a few pockets. However, non-recovery of the insect from the other release sites in Karnataka does not rule out establishment, especially since adults are capable of flight. Thus in Sabah, Malaysia recoveries were reported in localities far away from original release sites, about 10 years after releases (Ooi, *et al.*, 1988).

These observations clearly suggest that *P. pseudoinsulata* can effectively suppress the weed only in areas that receives well distributed rainfall almost round the year, so that leaves of the weed are available to it for feeding. Although *P. pseudoinsulata* has now established under field conditions the results are far from satisfactory. There is thus an urgent need for initiating concerted efforts involving redistribution *of P. pseudoinsulata*, reintroduction of *A. brunneonigrum* and *M. parvula* besides importation and releases of additional host-specific natural enemies such as *Procecidochares connexa* Macq (Diptera: Tephritidae). Since earlier attempts at introduction of *Apion brunneonigrum* Beguin-Billecocq (Coleoptera: Apionidae) and *Mescinia* nr. *parvula* Zeller (Lepidoptera: Pyralidae) were unsuccessful, it is recommended that efforts may be made to import additional insects such as *Procecidochares connexa* Macq (Diptera: Tephritidae).

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EFFECT OF BIOLOGICAL CONTROL OF *Chromolaena odorata* ON BIODIVERSITY : A CASE STUDY IN THE ASHANTI REGION OF GHANA

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ABSTRACT

Pareuchaetes pseudoinsulata, the biological control agent of *Chromolaena odorata* released at Fumesua in the Ashanti region of Ghana in 1991, has effectively controlled the weed in a pilot project. The successful establishment of *P. pseudoinsulata* was due to continued releases of large numbers of the insect on *Chromolaena* fields. Currently, the distribution of *P. pseudoinsulata* from the release site has a radius of about 85 km and has covered an area of about 12,195 km^2, an estimated half the total land area of the Ashanti region, within a period of five years. The feeding activities of the insect have reduced the populations of *Chromolaena* from an average of 85% in infested fields to 32.9% in places where control of the weed has been achieved. Populations of other herb species in danger of extinction have increased from 13.0 to 38.0% as well as grasses from 2.0 to 29.1%. The number of plant species per unit area has also increased from an average of 3 in *Chromolaena* infested fields to 6 in controlled fields. The study indicated that *P. pseudoinsulata* has a potential in preventing the further spread of *Chromolaena* and also enhancing forest regeneration and biodiversity.

INTRODUCTION

Chromolaena odorata (L.) (Asteraceae, Eupatorieae) is a self-propagating weed plant native to America (from Paraguay to Florida).

The weed was first observed in Ghana in February 1969 at the Legon Botanic gardens (Hall *et al.*, 1972). Since 1937, when the first introduction of *C. odorata* into Africa was recorded in Nigeria, the weed has invaded most of West and Central Africa and continues to spread into new areas; particularly in Africa. *Zebeyou* (unpublished report, 1996) reported that the normal altitude of 1,200m has been exceeded as *C. odorata* was collected in Bafoussam in Cameroon at an altitude of 2,000m. In addition to this *C. odorata* was also recorded in Chad, where the rainfall is only 600 mm per year as opposed to the normal rainfall requirement of 1,000-2,000 mm per year. This limit is further exceeded as *C. odorata* is reported to grow in arid bushveld vegetation with annual rainfall less than 500 mm in South Africa (Goodall and Erasmus, 1996).

These reports give further evidence to the predictions regarding the potential distribution of *C. odorata* in most countries between Tropics of Cancer and Capricorn including South Africa (Gautier, 1992; McFadyen and Skarratt, 1996). In South Africa a number of National Game Reserves have been infested by this weed. More recently in 1991 it was observed near Phalaborwa on the western border of Kruger National Park (Erasmus and Goodall, unpublished data). Indications are that the weed is fast replacing fodder for game animals in the Kruger National Park (R. E. McFadyen, personal communication, 1996). Thus, further spread of this noxious weed is a threat to game animals.

The introduction of *Chromolaena* into Africa has given rise to the pestilence of *Zonocerus* grasshoppers as a result of a non-nutritional relationship existing between the weed and the insect (Boppre, 1991; Timbilla and Braiman, 1996). On the other hand *C. odorata* is claimed to have some useful attributes in checking erosion, reducing fallow periods and improving soil fertility. These attributes of the weed have often generated a conflict of interest regarding the control of the weed in some countries. There is no

controversy about the weed status of *C. odorata* in South Africa since 1983 . Timbilla (1996) and Timbilla and Braimah (1996) are, however, of the view that there is need to look at the pestilence of *C. odorata* in an ecological context. In South Africa, *C. odorata* is known to decrease the carrying capacity and species diversity in both grassland and forest (Pickworth, 1976; Liggit, 1983; MacDonald, 1984; Erasmus, 1985; Byford-Jones, 1989; Erasmus, 1991). This situation is not different in Ghana and other infested parts of Africa.

Realizing the constraints of the weed to agricultural production in Ghana, a biological control programme using the arctiid moth, *Pareuchaetes pseudoinsulata,* was initiated in 1989 in a pilot project in the Ashanti region.

Following two years of preliminary investigations, field releases were made between 1991 and 1993 and subsequently the insects established in 1994. By the end of 1995 dramatic damage was recorded up to 45 km from the release site (see Timbilla, 1991; Timbilla, 1996; Timbilla and Braimah, 1996). This paper reports on the present distribution and direction of spread of the control agent and preliminary results obtained from a case study on the merits of biological control of *Chromolaena* in forest regeneration and biodiversity.

MATERIALS AND METHODS

A case study was conducted in *Chromolaena* fields in the Ashanti region where the control agent, *P. pseudoinsulata,* established in 1994 and 1995. Sites were selected at Boamang, Abrade, Bonwire, Feyiase and Fumesua where *Chromolaena* was completely defoliated by the insect. The study covered the period January to August 1996. Two metre square quadrats were used to estimate the percentage vegetative cover of *C. odorata,* grasses and other plant species after damage by *P. pseudoinsulata,* and the number of different plant species per quadrat was determined. Data was taken from a minimum of 5 and a maximum of 15 quadrats from each study site. As a control, similar data was obtained from a *Chromolaena* field without *P. pseudoinsulata* damage. The current distribution and direction of spread of the insect were also determined through survey.

RESULTS

Current distribution and direction of spread of *P. pseudoinsulata*

As of January 1996, the insect had spread to about half of the total land area of the Ashanti region following field establishment in late 1994. The field surveys indicated that the control agent has spread as far south as New Edubiase, 85 km from the release site (Fig.1) and a northern limit of Teacherkrom, 80 km from the release site. To the east the insect has spread to Konongo 51 km from the release site. The spread of the insect to the west is however limited by buildings within the Kumasi metropolis.

The spread of *P. pseudoinsulata,* appears to be in all directions and does not seem to be limited by the two major prevailing winds (S.W. Monsoon and N.E. Trade Winds) in the country. The insect is only 20 and 25 km from reaching the Central and Eastern regions respectively.

Field releases of *P. pseudoinsulata* (January- June, 1996)

Due to the barrier of buildings within the Kumasi metropolis limiting the spread of *P. pseudoinsulata* westward, new releases of the insect totalling 50,225 larvae and 1,485 adults were effected between January and June 1996.

The balance of *Chromolaena* grasses and other plants in insect infested and non-infested sites is given in Table 1.

Table 1 : Percentage vegetation cover of *C. odorata,* grasses and other plant species at six locations

Location	*C. odorata*	Grasses	Herbs
Boamang	35.5	42.5	22.0
Abrade	43.0	18.0	39.0
Bonwire	30.0	24.3	45.7
Feyiase	41.0	20.0	39.0
Fumesua	15.0	40.5	44.5
Overall average	32.9	29.1	38.0
Danyase (Control)	85.0	2.0	13.0

The study indicated a reduction in *Chromolaena* coverage from 85% in the control to an average of 32.9% in fields damaged by *Pareuchaetes.* The population of grasses and other plant species on the

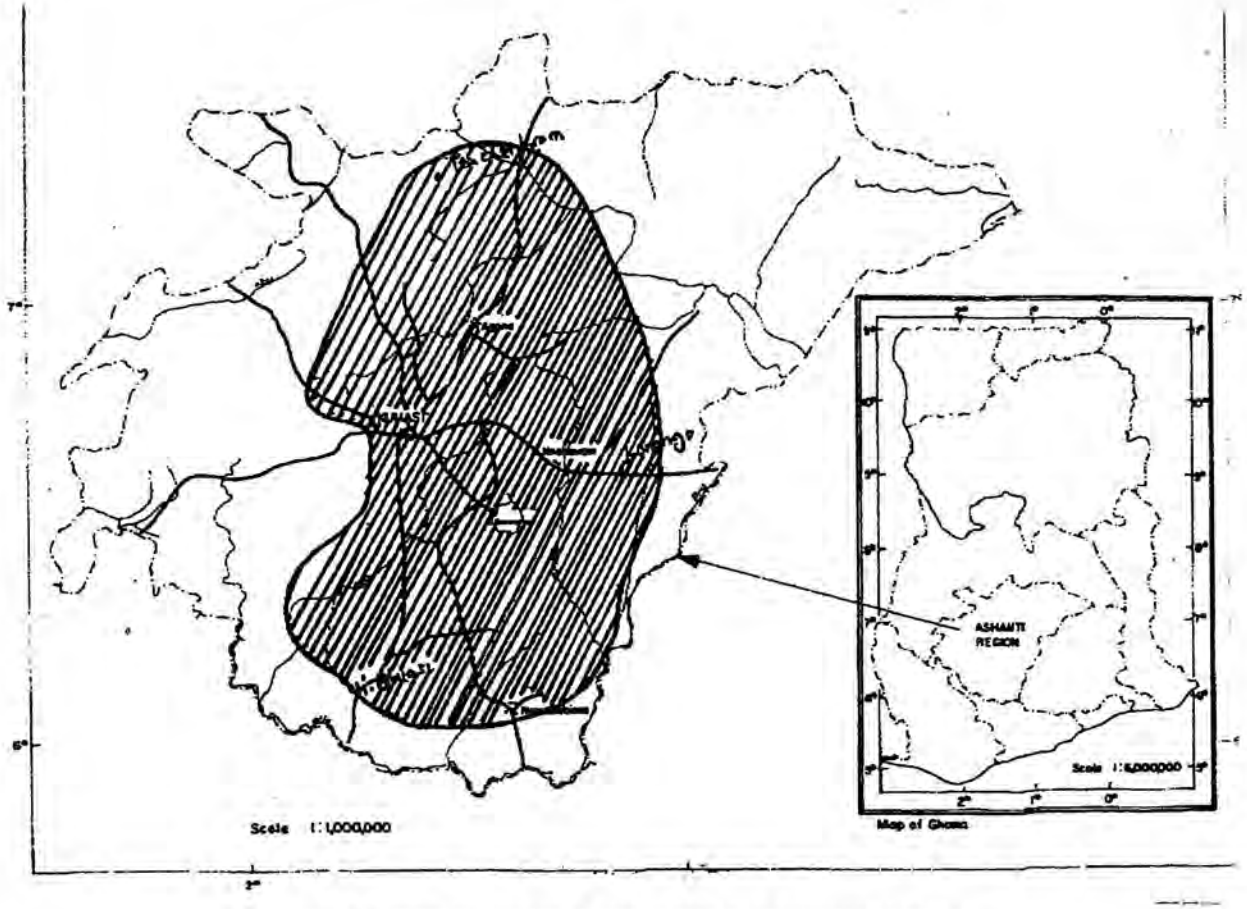

Fig. 1. Present distribution of *Pareuchaetes pseudoinsulata* in ghana

other hand remained at 2.0% and 13.0% in the control while it increased to 29.1% and 38.0% respectively in the damaged fields.

Species distribution in *Chromolaena* fields defoliated by *P. pseudoinsulata*

Following the damage caused to *Chromolaena* by *Pareuchaetes* within the study area, a number of new plant species sprang up to contribute to the biodiversity of the vegetation. The results recorded an average of 6 plant species per quadrat as against 3 in *Chromolaena* infested fields not previously damaged by the insect. Common among these plants were *Ipomoea* spp., *Panicum maximum, Asphilia* spp., *Lantana camara, Centrosema pubescens, Pennisetum purpureum, Momordica* sp. *Mimosa pudica, Spolobolus pyramidalis, Ficus asparapholia* and *Gliffornia simplicifolia.* Others included *Urena lobata, Sida acuta, Andropogon* sp. *Tridax procumbens, Melampodium* sp., *Synedrella nodiflora, Talinum triangularis, Eleusine indica, Dactylotenium aegyptium, Solanum* spp., *Sorghum* spp., *Emilia* spp., *Stachytarpheta cayanensis, Boreria* sp., *Rawolfolia* sp., *Mareya spicata, Glyphea laterifolia, Achormea* sp., and *Poincena regia.*

DISCUSSION

The establishment of *P. pseudoinsulata* in Ghana was due to the continued release of large numbers of the insect in heavily infested *C. odorata* fields. A total of 119,256 larvae and 6,265 adults were released between 1991 and 1993 in an area of about 250,000 sq.metres for the present success (Timbilla, 1996).

Within 8 months (i.e., from January-August, 1996) *P. pseudoinsulata* spread and caused damage to *C. odorata* in an area of about 6,000 sq.km (i.e., at the rate of 750 sq. km. month). The efficacy and rate of spread of *P. pseudoinsulata* demonstrates its potential as a biocontrol agent in mitigating the menace of *C. odorata* in Ghana and neighbouring countries. Field monitoring in the Ashanti region shows that the insect is still spreading and would soon reach the Central and Eastern regions of the country. Further

releases, particularly in the other infested regions, will however be necessary to curtail the problem of *C. odorata*.

Even though the results presented above are preliminary, indications are that the feeding activities of *P. pseudoinsulata* is reducing the population of *C. odorata* i.e., from an average of 85.0% in undamaged fields to 32.9% in places where some amount of damage has occurred. The populations of other plant species have also increased from 13.0 to 38.0%, and from 2.0 to 29.1% in grasses in *C. odorata* fields without and with *P. pseudoinsulata* damage respectively.

Indications are that the damage caused by *P. pseudoinsulata* to *C. odorata* is opening up spaces for the growth of the other plant species.

Also the increase in number of plant species per unit area from an average of 3 to 6 in undamaged and damaged *C. odorata* fields by *P. pseudoinsulata* raises hope for salvaging the extinction of some plant species as a result of the allelopathic effects of *C. odorata*. This would also enhance the reclamation of fodder in game reserves, forest regeneration and biodiversity. Studies conducted in Benin indicate that there are a number of forest plant species growing under *C. odorata* thickets (O.W. Fischer, personal communication, 1994). If damage caused by *P. pseudoinsulata* and other potential bio-agents can open up spaces within *C. odorata* thickets, these forest plants could emerge and speed up succession. This observation has been made in the Ashanti region of Ghana along a 4 km road leading from Bonwire junction to Bonwire on the Juaben road and from Abono to the first village leading out of Lake Bosumtwi (2 km). On these roads, there are no signs of *C. odorata* following complete defoliation by *P. pseudoinsulata* in 1995.

The appearance of other native plant species as a result of damage caused by *P. pseudoinsulata* to *C. odorata* would also complement the usefulness of the weed in enriching the soil since humus formed from many plant species would be better than from a monocrop.

The different climatic regions of the world provide certain ideal conditions for the natural growth of various plant species, giving rise to the various vegetation types. Man, however, in his quest for comfort and satisfaction has often disturbed this natural distribution of organisms and hence the unending global problems of today. In other situations problems have arisen accidentally and such is the case of the introduction of *C. odorata* into most of the places where it has established today. Naturally, there are regulating factors that maintain equilibrium between flora and fauna and where one of these is wanting, the other dominates and assumes pest status.

Before the introduction of *C. odorata* into areas where it has colonized today, there were plants and animals which formed the natural ecosystems. These plants provided specific needs to the soil flora and fauna, terrestrial organisms and agriculture. However, since the introduction of this noxious weed, there has been a gradual reduction of the natural vegetation giving rise to decreased number of plant species per unit area due to its allelopathic effects. In Ghana, agriculture in pre-*C. odorata* days did not employ the use of fertilizers and yet crop yield was good (Timbilla, 1996). One could argue that the fallow periods in those days were prolonged. Notwithstanding, there were natural herbs like *Asphilia* sp. which also recycled nutrients though we have no empirical data on the amount of nutrients added to the soil with regard to time. In Ghana, *Asphilia* sp. and the other plant species coming up would be better alternatives to *C. odorata* since they are indigenous and also have potential in recycling nutrients. An added advantage to the growth of these indigenous plants is that most of them serve as fodder for game animals.

CONCLUSION

The above results, though preliminary, raise hope for mitigating the menace of *C. odorata*. The use of other bio-agents in addition to *P. pseudoinsulata* would speed up control of this noxious weed.

The suggestion is that biological control is the most viable, modest and environment friendly way of salvaging the further spread of *C. odorata*, and should be seriously considered in a global perspective since the weed cuts across many boundaries.

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TEMPERATURE DEPENDENT DEVELOPMENT OF *Pareuchaetes pseudoinsulata* (LEPIDOPTERA: ARCTIIDAE), AN EXOTIC BIOCONTROL AGENT OF *Chromolaena odorata*

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ABSTRACT

Development of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae), an exotic insect introduced for biocontrol trials against the noxious weed *Chromolaena odorata*, was studied at constant temperatures of 10°, 20°, 30° and 40° C. The insect was found to successfully complete its development within 77.6 and 26.8 days, at 20° and 30° C respectively. There was no development at 10° and 40° C. Though initial development up to the black-headed stage was observed at 12° and 32° C, hatching was affected, resulting in hundred percent mortality. The results indicate that initial field releases may be carried out in places experiencing temperatures between 20° and 30° C, for establishment and successful suppression of the weed.

INTRODUCTION

Chromolaena odorata, a plant of West Indies and South American origin, is considered as a serious weed of plantations and forests of south and north-eastern parts of India (Bennett and Rao, 1968). Attempts to control the weed by releasing the Trinidad strain of *Pareuchaetes pseudoinsulata* did not give promising results (Chacko and Narasimham, 1988). Hence, in 1985, a culture of the same insect was obtained from Sri Lanka by the Indian Institute of Horticultural Research, Bangalore. Mass multiplication and field releases initiated during the same year resulted in establishment and defoliation of the weed, in the released areas (Joy *et al.*, 1985; Anonymous, 1986-89). However, observations over the years indicated that the insect appears soon after the monsoon rains in the months of June-July and remains in the field for two to three months. During this period feeding and localized defoliation were observed (Anonymous, 1993-95). With the onset of summer, they disappear from the field (Dr. P. J. Joy, personal communication). No parasitoids, predators or pathogens were found attacking the insect in the field, which indicates that abiotic factors could be affecting the insects. As no information on the effect of temperature is available, a study was made to determine the effect of different temperature regimes on the bionomics of the insect.

MATERIALS AND METHODS

The study was carried out at six different temperature regimes varying from 10°- 35° C, with intervals of 5° C, 14 hours photoperiod and 40-60 % R.H. *P. pseudoinsulata* was maintained on *C. odorata*, under laboratory conditions, where the temperature varied from 24 ± 2°C with 60 -70% R. H. Fertile eggs laid by laboratory bred adults were placed in petri-plates (10 cm dia.) with moist filter paper discs at the base and placed in B. O. D. incubators, maintaining the above conditions. The larvae, on hatching, were transferred to aerated plastic jars (10 x 7 cm) with *C. odorata* twigs and reared individually till pupation. The pupae were sexed and kept separately in glass vials (5 x 3 cm) for adult emergence. The study was made with 50 eggs maintained at each temperature regime.

Studies were also made on the fecundity of adults reared at different temperatures. The newly emerged adults were released into wooden cages of 30 x 30 x 30 cm., having wire-mesh on three sides and top, with a wooden base and sliding glass front. The base was covered by a moist sponge for humidity. *C. odorata* bouquets and a cotton swab dipped in 50% honey were provided as oviposition and feeding sites

respectively. The studies were replicated thrice with three pairs at each replication.

RESULTS AND DISCUSSION

Eggs

Normal embryonic development was observed at temperatures ranging from 15-30° C. With the increase in temperature, there was a reduction in the egg period (Table 1). Thus when eggs were maintained at 15, 20, 25 and 30° C, development was completed in 10.5, 7.3, 5.8 and 4.3 days respectively. While 100% hatching was obtained at 20, 25 and 30° C, 20% mortality observed at 15°C. No development was obtained at 10 and 35° C respectively. Further observations indicated that though development up to the black-headed stage was observed at 12 and 32°C, no hatching was obtained.

Larvae

Normal development and pupation were observed when larvae were reared at temperatures varying from 15-30°C. As observed in eggs, a reduction in larval duration was observed with increase in temperature (Table 1). Thus, it took 59.8, 46.8, 30 and 19.4 days for completion of development, when reared at 15, 20, 25 and 30°C, respectively. Associated with this, survival was found to be affected. Rearing of larvae at 15, 20 and 25°C caused 32, 12 and 2% mortality, respectively. It was found that when larvae were reared at 15 and 20°C about 20 % had a sixth molt, while at 25 and 30°C 40% had a sixth moult.

Table 1. Effect of temperature on development of *Parachaetus pseudoinsulata*

Sl. No	Treatment (°C)	Egg period	% mortality	Larval period	% mortality	Pupation period	% mortality	Total duration
1	10	-	100.00	-	-	-	-	-
2	15	10.5	20.00	47.9-59.8	32.00	27.8	8	86.2-98.1
3	20	7.3	0	37.2-46.3	12.00	21.9	0	66.4-75.5
4	25	5.8	0	26-30	2.00	9.2	0	41-50
5	30	4.3	0	15.2-19.4	0	8.2	0	27.7-31.9
6	35	-	-	-	-		-	-

Pupae

Pupation and adult emergence were obtained at temperatures varying from 15-30°C. Except for 8% mortality at 15° C, there was 100% adult emergence at other temperatures (Table 1). Also there was no difference in the sex ratio of the adults reared at different temperatures.

Duration of total development

The total development period was found to vary from 27.7-98.1 days at 15-30°C. Optimum survival of eggs, larvae and pupae were observed between 25-30°C.

Fecundity and egg hatchability

Temperature was found to affect the fecundity, which was found to vary from 215-288 eggs per female. Significant differences in the egg hatchability was also observed. About 28% hatchability were obtained when adults were reared at 15° C, while it was 94-96% with adults reared at 20 and 30° C respectively (Table 2).

Table 2. Effect of temperature on the fecundity and egg hatchability of *P. pseudoinsulata*

Treatment	Fecundity/Female	% egg hatchability
10	-	0
15	215	28
20	221	94
25	227	95
30	288	95
35	0	0

It was found that the range of tolerance of *P. pseudoinsulata* to varied temperatures differed depending on the life stage of the insect. Pupae, followed by larvae, showed widest range of tolerance, while eggs showed a narrow temperature tolerance. Also, low temperature reduced the fecundity of adults and egg hatchability.

The above observations reveal that temperature could be a limiting factor in the population build up of *P. pseudoinsulata*. It is noteworthy that areas where releases are carried out experience warm climate for most part of the year. Temperature in these places goes beyond 32° C, reaching to a maximum of 40°C during the summer months. Based on the present study it could be concluded that temperature may be a limiting factor inhibiting the effectiveness of the insect under field conditions. The study thus recommends importation of more natural enemies with wider

temperature tolerance, for successful suppression of the weed in India.

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EFFECT OF INBREEDING ON THE FUNCTIONAL POTENTIAL OF *Pareuchaetes pseudoinsulata*

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ABSTRACT

A study was carried out to determine the effect of continuous laboratory rearing on the bionomics and reproductive potential of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae), introduced for biological control trials against *Chromolaena odorata* (L.) King and Robinson. The fecundity of females bred continuously in the laboratory was found to be reduced by 35% compared to the wild type, which was released into the field five years earlier from the same stock. However, significant differences were not observed in the development duration, sex-ratio and egg viability, between the lab-reared and the wild type. Based on the results obtained, it is recommended that field releases of exotic natural enemies should be initiated at the earliest after importation for successful establishment. The studies also indicate the necessity of rejuvenating laboratory cultures with field collected material at regular intervals, for maintenance of healthy stock.

INTRODUCTION

Biological control agents of crop pests and weeds are mass multiplied under ambient environmental conditions for timely mass releases. However, this has been reported to effect the fertility, fecundity, longevity and searching behavior of the bioagents, resulting in gradual deterioration and reduction in their effectiveness under field conditions (Mackauer, 1981; Hopper *et al.*, 1993).

The Siam weed *Chromolaena odorata* (L.) King and Robinson, of Neotropical origin, is a serious weed of plantation crops and forests in southern and north-eastern parts of India (Bennett and Rao, 1968). Mass rearing and large scale releases of *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) in different parts of Karnataka were initiated by the Indian Institute of Horticultural Research (IIHR) in 1985. The insect established under field conditions at one release spot in Dakshina Kannada district. During 1991 eggs, larvae, pupae and adults of this insect were collected from the field, where releases had been made in 1985. The present studies were carried out to determine whether continuous laboratory rearing affected the fecundity, longevity and sex ratio of *P. pseudoinsulata* by comparing continuously laboratory reared and field collected populations of the insect.

MATERIALS AND METHOD

A population of *P. pseudoinsulata* that had been reared in the laboratory at IIHR, continuously from 1985, was used as the continuous laboratory culture population (denoted CLR). This culture was initiated from pupae received from Sri Lanka in 1985, from which mass culturing and large scale field releases were initiated. A culture of F_1 eggs laid by the adults collected from the field in 1991 is referred to as the wild type population (denoted WT).

P. pseudoinsulata was multiplied in the laboratory as described elsewhere in this proceedings (Jayanth and Ganga Visalakshy, Current status of biological control trials against *Chromolaena odorata* in India). Since Bangalore has equable climate throughout the year, regulation of laboratory temperature, humidity and photoperiod were not considered necessary. An air conditioner was used to cool down the temperature below 30°C during peak summer months (March - April).

The eggs and larvae collected from the field were reared in the laboratory and eggs laid by the F1 adults were used for the experiment. Fecundity and longevity studies were carried out with newly emerged adults. For determining development duration and sex ratio, about 50 eggs from each population were used.

The experiment was replicated five times, with five pairs of adults per replication.

RESULTS AND DISCUSSIONS

There was no significant variation in the development duration of CLR and WT populations. CLR population took 46 days while the WT took 40 days to complete development, under identical conditions. Observations on sex ratio indicated that the WT female: male ratio was 1.5:1, while in CLR population it was 1:1 which was not significant. The percentage of the male emergence from CLR population was 10% more than that of the WT. However, no differences in the longevity of females and males were observed in the two populations (Table 1).

Table 1. Comparison of wild type (WT) and continuous laboratory reared (CLR) populations of *P. pseudoinsulata*

Treat-ment	Develop-ment (days)	Sex ratio (Female: Male)	Eggs/ female	Longevity (days)	% egg hatcha-bility
WT	40	1.5:1	356	10.6	96
CLR	46	1:1	254	4.5	95.4

Longevity studies indicated that the WT population survived longer than the CLR population. The WT adults survived for 10.6 days (range 3-14), while in the CLR population the adult longevity was only 4.5 days (range 3-9). Similarly, the WT population was found to have a higher fecundity compared to the CLR population. The WT females laid an average of 356 eggs (range 336- 490), while in the CLR population it was only 256 (range 212- 343). Observations on egg hatchability indicated no significant differences between the WT and CLR populations (96 and 95.4%, respectively).

The present studies clearly indicate that continuous laboratory rearing adversely affects the fecundity, longevity and sex ratio of the insect. Fecundity of the CLR population was reduced by 42.3% as compared to the WT ones. The WT adults were observed to have twice the longevity as that of the CLR population. This could be one of the reasons for the reduced fecundity in the CLR population. Although the difference in the sex ratio was not significant, in due course the population of the females could be reduced gradually, affecting the quality and survival of the laboratory culture. Studies by Jayanth and Geetha Bali (1995) and Nagarkatti and Nagaraja (1978) have also indicated that continuous laboratory rearing affected the quality of *Zygogramma bicolorata* Pallister (biocontrol agent of *Parthenium hysterophorus*) and *Trichogramma chilonis* Ishii, respectively.

The present observations also suggest that continuous laboratory rearing deteriorates the potentiality of the insect, whereby its effectiveness in the field could be reduced. In view of this, it may be advisable to carry out field releases as soon as possible after introduction for better chances of establishment. To increase chances of establishment initial releases may be carried out in large walk-in cages erected directly in the field on naturally occurring infestations of the weed. Once adults start emerging the cage can be opened and the insect may be permitted to disperse on its own. Once field establishment is obtained it may be better to redistribute the insect after collecting it from the area where it has already established. In case laboratory rearing has to be continued over a longer period of time it is desirable to rejuvenate the laboratory culture with field collected material at frequent intervals.

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STUDIES ON FEEDING BEHAVIOUR OF *Pareuchaetes pseudoinsulata* REGO BARROS (LEPIDOPTERA: ARCTIIDAE) ON *Chromolaena odorata*

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ABSTRACT

Laboratory experiments were conducted during 1995-96 at Central Horticultural Experiment Station, Chettalli, India, to study the feeding behaviour of larvae of *Pareuchaetes pseudoinsulata* on the weed *Chromolaena odorata*. The leaf area consumed by larvae of different age groups has been worked out. The early stage larvae, up to 3 days, scraped the green matter of leaves and only afterwards started feeding on leaf lamina. A single first instar larva could scrape on average 16.12 mm^2 leaf area in 24 h, while a one week old caterpillar can eat 37.62 mm^2 leaf area in one day. The maximum amount of leaf matter (1400-1700 mm^2 leaf area) was consumed by larvae of 15-17 days age. Taking 1840 mm^2 as an average leaf area, about 90% leaf matter was consumed within a day by final instar larvae. However, feeding activity reduced by the pre-pupal stage.

The larvae preferred older leaves to tender ones but did not feed on leaves that had turned yellow. Within a leaf, more than 70% of larvae started feeding from the lower half, i.e., towards the petiole. The total life cycle of *P. pseudoinsulata* was completed in 52-55 days

INTRODUCTION

Chromolaena odorata (Asteraceae), commonly called Gandhi gulabi is a serious weed found widespread in the areas receiving rainfall of 150 cm and above in India (Muniappan *et al.*, 1988). In south India, especially towards Western Ghats, the weed is predominantly found growing in coffee, rubber and other orchards as well as on road sides. In view of its presence in large areas, including uncultivated and other public areas, chemical and mechanical measures like slashing and burning are not practicable to check this noxious weed. Hence biological control using insects which feed on this plant has been advocated as an important strategy for its long term management. Among the insects recorded feeding on *C. odorata* in its native home, *Pareuchaetes psuedoinsulata* Rego Barros (Lepidoptera: Arctiidae), was reported to be a promising defoliator and host specific and thus has potential as a successful biocontrol agent (Kluge and Caldwell, 1993).

In order to evaluate its potential for control of the weed, the feeding capacity of larvae in a given time has to be established. The quantification of the damage that the larvae can inflict upon the plant is difficult under field conditions. The present paper reports the results of laboratory studies conducted at Central Horticultural Experiment Station, Chettalli, India during 1995-96, where the damage caused by caterpillars of different age groups has been measured in terms of the leaf area consumed in 24h. Observations were also recorded regarding the larval preference for leaves of different ages and leaf lamina portions within a leaf.

MATERIALS AND METHODS

Tender twigs of *C. odorata* having 5-6 leaves were collected from the field and freshly hatched larvae from laboratory culture were released individually on them in plastic containers having optimum aeration. The leaf material was changed every day, and leaf area fed by larvae was measured using graph paper. While measuring the area, more than half of a mm^2 was considered to be one mm^2 and less than half was not

considered. During the course of observation, dead larvae, if any, were replaced with larvae of the same age. There were 4 replications and 10 larvae constituted one replication.

In another experiment, designed to study the larval preference for leaves of different age groups, 10 larvae each of second and fourth instar were released separately on *Chromolaena* twigs with three types of foliage, viz., tender (top 5 cm of a shoot), full grown (expanded dark green leaves) and leaves that had turned yellow. The frequency of larval attack on different kinds of leaves was recorded. There were four replications. The larval preference for different portions of lamina within a leaf was observed by recording the initiation of larval attack on different portions of leaf, i.e., top, middle and lower.

RESULTS AND DISCUSSION

The data presented in Table 1 reveal that the extent of leaf area fed by larvae increased significantly, but not in the same proportion, with the age of the larvae. The early stage larvae up to 3 days scraped the green matter, by preferance under the surface, and as the age advanced, started feeding voraciously by eating out the leaf lamina and leaving behind only the vein. A single larva of 1-3 days age fed over a leaf area of 16.12 mm^2 in 24h. The maximum leaf area (1662.40mm^2) was consumed by 15-17 day old larvae, which was almost 90% of an average total leaf area of 1840 mm^2. Muniappan *et al.* (1988) also recorded fourth instar larva eating 19.14 cm^2 leaf area and 50 such larvae causing more than 80% defoliation. However, feeding activity reduced during pre pupal stage by 21.18%. The increase in feeding rate over the previous stage was the highest (624.66%) in 8-11 day old larvae and the lowest (133.37%) in 4-7 day old ones.

Table 1. Leaf consumption of *Chromolaena odorata* by different age group larvae of *Pareuchaetes pseudoinsulata*

Larval age (days)	Leaf area fed in 24 h (mm^2)	Prcent increase in area fed over previous stage
1-3	16.12	-
4-7	37.62	133.37
8-11	235.74	624.66
12-14	974.35	413.16
15-17	1662.40	190.20
18-20	1310.35	-21.18*
C.D. at 5%	18.74	

* '-' indicates decrease
values are means of 4 replications

Larvae found comparatively fully expanded dark green leaves more palatable than tender foliage (Table 2). This might be due to the more glabrous nature of tender leaves and shoots. More than 65% of second and 72.5% of third instar larvae preferred older leaves. But interestingly, none of them fed on leaves that had turned yellow. Preference of larvae of *P. pseudoinsulata* for green leaves and non-feeding on yellow leaves was also reported by Marutani and Muniappan (1991).

Table 2. Larval preference to leaves of *Chromolaena odorata*

Type of leaves	Percent larval incidence	
	2nd instar	4th instar
Tender leaves and buds	34.50	27.50
Full expanded dark leaves	65.50	72.50
Yellow turned leaves	0.00	0.00

Studies on larval preference for different portions of the leaf lamina within a leaf indicated that the lower half, i.e., towards the petiole, was more palatable to *P. pseudoinsulata* as more than 70% of the larval population started feeding from that portion and many larvae shifted to other leaves, instead of continuing on the same leaf, after feeding on lower half. This was followed in palatability by the middle half (19%) and only 5% larvae attacked the leaf from the tip side (Fig.1)

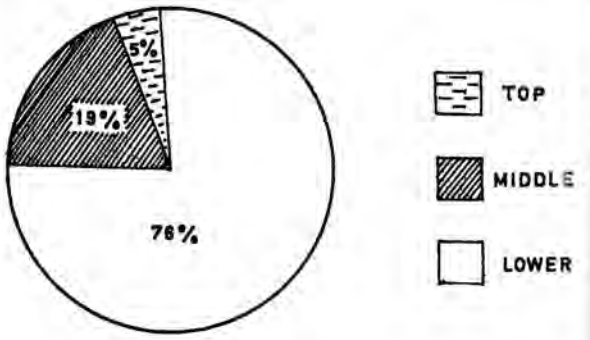

Figure 1 Larval preference of *P. pseudoinsulata* to leaf lamina of *C. odorata*

Preliminary observations made during three generations of *P. pseudoinsalata* reared on *C. odorata* showed that it takes 52-55 days to complete its total life cycle. The egg, larval and pupal periods were 3-4, 20-22 and 16-19 days respectively. Adults started egg laying from the 3rd day after their emergence, and adult longevity was 7-9 days. Satheesan *et al.* (1987) reported completion of the total life cycle

within 45 days in Kerala, while Muniappan *et al.* (1988) observed the developmental period varying from 39-54 days at Bangalore. The differences could be attributed to variations in climatic factors.

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STUDIES ON FECUNDITY AND FERTILITY OF *Pareuchaetes pseudoinsulata* REGO BARROS (LEPIDOPTERA: ARCTIIDAE)

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ABSTRACT

The arctiid caterpillar, *Pareuchaetes pseudoinsulata* Rego Barros, has been identified as a potential biocontrol agent of the Siam weed, *Chromolaena odorata* (L.) King and Robinson. To determine the effect of different concentrations of adult food and adjuvants on fecundity and egg hatching of the insect, an experiment was conducted in the College of Horticulture, Trichur, Kerala, with treatments consisting of different food combinations at different sex-ratios and temperature - humidity regimes. Highest fecundity and egg hatching were obtained when the parental sex-ratio was kept at 1:1 level followed by 1:2 and 2:1. The fecundity and egg hatching percentage were significantly higher at 25°C and 75% RH as compared to 30°C and 60% RH. It was found that adult nutrition did not influence the fecundity. However, when the adults were fed water alone the egg hatching was significantly lower than with other food combinations. The three level interaction showed that the female-male sex-ratio of 1:1 at 25°C and 75% RH gave significantly higher fecundity for all the food combinations than 1:2 and 2:1 sex-ratios. Regarding hatching percentage, the results showed that all the three sex-ratios at 25°C temperature and 75% RH recorded high egg hatching for all the food combinations except water. Least hatching occurred at 2:1 sex-ratio when water alone was given at temperature 30°C and RH 60%.

INTRODUCTION

The arctiid caterpillar, *Pareuchaetes pseudoinsulata* Rego Barros, has been identified as a potential biocontrol agent of the Siam weed, *Chromolaena odorata* King and Robinson. Field establishment of *P. pseudoinsulata* has been achieved in Sri Lanka (Dharmadhikari and Ramaseshiah, 1970) and Guam (Muniappan and Marutani, 1988). In spite of extensive field releases of various stages of the insect, the establishment was not satisfactory under Kerala conditions. Climatic factors could be a factor for the low field population of the insect in Vellanikkara (Trichur, Kerala) and non-establishment of it in many locations in Kerala (Joy *et al.*, 1993). Torres *et al.* (1991) reported that one of the major problems encountered in the use of *Pareuchaetes* is the low hatching of its eggs. Most of the egg masses laid by the moths were infertile, resulting in complete loss of a laboratory stock. According to him, imbalance in the proportion of males and females resulting from inbreeding is perhaps the most important factor that leads to absence of mating. Napompeth *et al.* (1988) observed that almost all the eggs laid failed to hatch in spite of successful mating observed in the egg laying cages. Napompeth (1990) recommended feeding of adults with sucrose solution to which a little sodium chloride is added, to improve the fertility of adults. The influence of environmental conditions, particularly temperature and humidity on the biotic potential of the insect, is a factor of considerable importance that can regulate the multiplication of the insect. Detailed studies have not so far been taken up in Kerala to study the factors affecting the fertility of the insect. The present studies on sex-ratio, temperature - humidity regimes and food combinations were taken up to evaluate their effect on fertility of the insect.

MATERIALS AND METHODS

To determine the most suitable concentrations of adult food and adjuvants, an experiment was conducted in the laboratory with 12 treatments consisting of different food combinations. Based on hatching of eggs, the fortifications consisting of 0.4% vitamin E, 0.1% sodium chloride and 0.2% sucrose in 1:1 honey solution were selected for further experimentation. The selected treatments were then evaluated at two

temperature - humidity regimes and three adult sex-ratios, with 20 replications in each treatment, in growth chambers.

a) Fortifications

1. Honey and water (1:1)
2. Honey and water (1:1) fortified with 0.4% vitamin E
3. Honey and water (1:1) fortified with 0.1% sodium chloride
4. Honey and water (1:1) fortified with 0.1% sodium chloride and 0.4% vitamin E
5. Sucrose solution (0.2%) fortified with 0.1% sodium chloride and 0.4% vitamin E
6. Water

b) Temperature - humidity regimes

25°C and 75% RH

30°C and 60% RH

c) Sex ratios

1:1 Female: male

1:2 Female: male

2:1 Female : male

Adults on the day of emergence were collected and kept at the above three sex-ratios in plastic containers of size 12 cm height and 8 cm diameter. Different food combinations were prepared and supplied in sterile cotton balls, hung from the cloth cover by pinning. Tender shoots of *Chromolaena* with wet cotton wraps at the cut ends were placed in the containers and were offered for resting and egg laying. After the death of the female moth, total number of eggs laid per female were counted to assess the fecundity. The eggs were allowed to hatch at the same temperature - humidity regimes itself and the hatching percentage recorded.

RESULTS AND DISCUSSION

Based on the results of the observational trial (Table 1) a factorial experiment with three sex-ratios, two temperature - humidity regimes and six food combinations was conducted to study their effect on adult fecundity and hatching. The results are explained below.

Table 1. Adult fecundity and hatching as influenced by adult nutrition

Treatments	Egg laid	Egg hatched	Percentage hatching
1. Honey alone	179.33	108.00	60.2
2. Vitamin E alone	172.00	81.00	47.1
3. Water alone	176.38	98.02	55.6
4. Honey+water (1:1) + 0.2% vitamin E	221.80	145.94	65.8
5. Honey+water (1:1) + 0.4% vitamin E	331.16	261.00	79.0
6. Honey+water (1:1) + 0.6% vitamin E	164.00	98.60	60.1
7. Honey+water (1:1) + 0.1% sodium	257.00	213.00	82.9
8. Honey+water (1:1) + 0.2% sodium	153.00	112.00	73.2
9. Honey+water (1:1) + 0.3% sodium chloride	253.00	179.00	70.8
10. Honey+water (1:1) + 0.1% sucrose	207.00	153.00	73.0
11. Honey+water (1:1) + 0.2% sucrose	300.75	222.60	74.2
12. Honey+water (1:1) + 0.4% sucrose	154.66	102.00	66.0

Effect of sex ratio

Evaluation of the three parental sex-ratios showed that maximum fecundity was realized for 1:1 female-male ratio (214.70) followed by 1:2 (205.80) and 2:1 (163.20) ratios in that order (Table 2). According to Danthanarayana and Gu (1991), in *Epiphyas postvittana* (Lepidoptera: Tortricidae) the viability of eggs was highest for 1:1 parental sex-ratio (61.98) followed by 1:2 ratio (58.19). The present studies showed that for the realisation of the reproductive potential of females, parental sex-ratio at optimal level is an important criterion and further that the ratio of 1:1 is definitely better in this context. When more or less males are present, the fecundity showed a reduction and this might be due to the competition of the individuals which adversely influences the process of successful mating and fertilization of ova. Boggs and Gilbert (1979) also found that optimal sex ratio is 1:1 for population growth, fecundity and fertility in *E. postvittana*

Table 2 Effect of sex ratio on fecundity and hatching

Sex ratio	Eggs laid/female	Percentage hatching
1:1	214.70 a	61.98 a
1:2	205.80 a	58.19 ab
2:1	163.20 b	51.40 b

Means followed by same letter are not significantly different at 5% level

Table 3 Effect of temperature - humidity regimes on fecundity and hatching

Temperature humidity regimes	Eggs laid / female	Percentage hatching
25°C, 75% RH	216.27 a	69.14 a
30°C, 60% RH	163.71 b	44.34 b

Effect of temperature - humidity regimes

The fecundity of adults was 216.27 at 25°C and 75% RH and 163.71 at 30°C and 60% RH, the outputs being significantly different. Similarly, significantly higher hatching percentage was observed at 25°C and 75% RH (69.14) than at 30°C and 60% RH (44.34) (Table 3). Joy *et al.* (1993) found that above 30°C, the hatching percentage of *P. pseudoinsulata* eggs was very low and this lends support to the present results.

Effect of food combinations on fecundity and hatching

Assessment of the influence of various food combinations on the adult fecundity showed that honey + water (1:1) fortified with 0.1% sodium chloride gave maximum egg output (282.80). Next in the order of efficiency was honey + water (1:1) fortified with 0.1% sodium chloride and 0.4% vitamin E. However, the fecundity levels were not statistically significant and they were on par with the treatment in which water alone was supplied to the females (Table 4). It can thus be concluded that adult diet has no influence on fecundity. This is explainable on the basis of provigenic reproduction in which the adults emerge with a full complement of developed ova. Adult nutrition is not, therefore, of any consequence in the realisation of egg production potential. The report of Oceterubio (1982) in *Spodoptera littoralis*, that the presence or absence of food had no effect on its fecundity corroborates the present results. Regarding hatching percentage, it was observed that the adults fed with water alone gave a significantly low hatching percentage (30.82). All the other treatments were on par with a maximum of 65.54% for honey + water (1:1) fortified with 0.1% sodium chloride.

Effect of interaction between sex-ratio, temperature - humidity regimes and food combinations

When the three factor interactions were evaluated, adults at 1:1 ratio at 25°C temperature and 75% RH gave maximum egg output, when they were fed with honey + water (1:1) fortified with 0.4% vitamin E. Always a lower fecundity was recorded for 2:1 sex-ratio at temperature 30°C and 60% RH. Lowest fecundity was observed in 1:1 ratio at 30°C temperature and 60% RH, when supplied with honey + water (1:1) fortified with 0.1% sodium chloride and 0.4% vitamin E. This shows that food combinations had no effect on fecundity, but had a decreasing trend at sex-ratio 2:1 and when the temperature was raised to 30°C and humidity decreased to 60%. Regarding percentage hatching, the results showed that all the three sex-ratios at 25°C temperature and 75% RH recorded high hatching percentage for all the food combinations except water. Least hatching occurred at 2:1 sex-ratio, when water alone was given at temperature 30°C and 60% RH (12.51). It is also clear from the results that the female-male sex ratio of 1:1 at 25°C and 75% RH gave significantly higher fecundity for all the food combinations. But, the egg output of females at 1:1 sex-ratio was considerably reduced at 30°C and 60% RH, thereby indicating the deleterious effects of this particular physical environment on fecundity. The egg viability was adversely affected at all the sex-ratios under this temperature - humidity combination (Table 5). As the adult foods, other than water, were found to be useful to improve the egg hatching at optimal ambient environment, it would be advantageous to resort to such feeding techniques in the mass culturing programmes.

Table 4 Effect of food combinations on fecundity and hatching

Food combinations	Fecundity	Percentage hatching
1. Honey + water (1:1)	226.10 cd	58.58 a
2. Honey + water (1:1) + 0.4% vitamin E	242.30 bc	63.17 a
3. Honey + water (1:1) + 0.1% sodium chloride	282.80 a	65.54 a
4. Honey + water (1:1) + 0.1% 0.4% vitamin E	264.00 ab	63.21 a
5. Sucrose 0.2% + 0.1% sodium chloride + 0.4% vitamin E	217.30 d	61.82 a
6. Water	261.40 ab	30.82 b

Table 5 Effect of sex-ratio, temperature-humidity regimes and adult nutrition on fecundity and egg hatching

	Fecundity	Egg hatching c/o
Sex ratio 1:1 at 25°C and 75% RH		
1. Honey + water (1:1)	228.20 bcdefg	76.38 abc
2. Honey + water (1:1) + 0.4% vitamin E	306.60 a	84.55 a
3. Honey + water (1:1) + 0.1% sodium chloride	269.90 abc	87.54a
4. Honey + water (1:1) + 0.1% 0.4% vitamin E	251.90 abcd	76.96 abc
5. Sucrose 0.2% + 0.1% sodium chloride + 0.4% vitamin E	226.90	79.96 ab
6. Water alone	279.30 ab	34.97 ijklmn
Sex ratio 1:1 at 30°C and 75% RH		
1. Honey + water (1:1)	179.20 ghijklmno	52.18 defghijkl
2. Honey + water (1:1) + 0.4% vitamin E	226.40 bcdefgh	58.33 bcdefghi
3. Honey + water (1:1) + 0.1% sodium chloride	240.60 bcde	62.74 bcdefgh
4. Honey + water (1:1) + 0.1% 0.4% vitamin E	114.30 p	33.55 hijklmn
5. Sucrose 0.2% + 0.1% sodium chloride + 0.4% vitamin E	146.80 lmnop	47.66 ghijkl
6. Water alone	208.00 defghijk	39.31 ijklm
Sex ratio 1:2 at 25°C and 75% RH		
1. Honey + water (1:1)	221.10 cdefghi	74.93 abcde
2. Honey + water (1:1) + 0.4% vitamin E	187.50 efghijklmn	76.71 abc
3. Honey + water (1:1) + 0.1% sodium chloride	232.50 bcdefg	80.44 ab
4. Honey + water (1:1) + 0.1% 0.4% vitamin E	172.00 hijklmno	73.99 abcd
5. Sucrose 0.2% + 0.1% sodium chloride + 0.4% vitamin E	235.70 hijklmno	75.99 abcd
6. Water alone	235.70 hijklmno	21.40 mn.
Sex ratio 1:2 at 30°C and 75% RH		
1. Honey + water (1:1)	177.10 ghijklmno	43.75 hijklm
2. Honey + water (1:1) + 0.4% vitamin E	210.00 defghijk	51.23 efghijkl
3. Honey + water (1:1) + 0.1% sodium chloride	203.40 defghijk	57.45 bcdefghij
4. Honey + water (1:1) + 0.1% 0.4% vitamin E	170.80 hijklmno	55.34 cdefghijk
5. Sucrose 0.2% + 0.1% sodium chloride + 0.4% vitamin E	155.80 klmnop	49.95 fghijkl
6. Water alone	195.40 efghijklm	48.38 ghijkl
Sex ratio 2:1 at 25°C and 75% RH		
1. Honey + water (1:1)	128.90 op	74.84 abcde
2. Honey + water (1:1) + 0.4% vitamin E	178.80 ghijklmno	74.98 abcde
3. Honey + water (1:1) + 0.1% sodium chloride	177.80 ghijklmno	70.72 ab
4. Honey + water (1:1) + 0.1% 0.4% vitamin E	161.10 jklmnop	70.53 abcdefg
5. Sucrose 0.2% + 0.1% sodium chloride + 0.4% vitamin E	202.50 defghijkl	68.74 abcdefgh
6. Water alone	212.40 defghij	36.13 ijklmn
Sex ratio 2:1 at 30°C and 75% RH		
1. Honey + water (1:1)	146.50 mnop	29.38 lmn
2. Honey + water (1:1) + 0.4% vitamin E	168.00 ijklmnop	33.22 klmn
3. Honey + water (1:1) + 0.1% sodium chloride	141.10 mnop	53.09 cdefghijkl
4. Honey + water (1:1) + 0.1% 0.4% vitamin E	137.30 nop	34.57 ijklmn
5. Sucrose 0.2% + 0.1% sodium chloride + 0.4% vitamin E	164.90 jklmnop	33.57 ijklmn
6. Water alone	140.40 mnop	12.51 n

Means followed by the same letter are not significantly different at 5% level

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THE ACIAR PROJECT FOR THE BIOLOGICAL CONTROL OF *Chromolaena odorata*: FUTURE DEVELOPMENTS

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ABSTRACT

Siam weed, *Chromolaena odorata* (L.) King & Robinson, is a major weed of pastures and plantation crops in South-East Asia. Siam weed is now in Timor, Irian Jaya and Papua New Guinea, and continues to spread south towards Australia. The first infestation in Australia was discovered in Queensland south of Cairns in 1994 and is currently being eradicated, but it is likely that other infestations exist or will occur shortly. The Australian Centre for International Agricultural Research (ACIAR) is funding a biocontrol project, through which suitable insects are sent from South America for detailed host-testing in quarantine in Indonesia and the Philippines, followed by field release if the insects prove safe. The initial 3-year project, started in January 1993, was extended to December 1996, and it is now hoped that the project will be extended for a further 3 years to December 1999, and will include Papua New Guinea. To date, the project has carried out release and field evaluation of the moth *Pareuchaetes pseudoinsulata*, and host-testing, field releases and evaluation of a stem-galling fly *Procecidochares connexa* in Indonesia. The leaf-feeding butterfly *Actinote anteas* and other potential agents will be trialled in the next three years.

INTRODUCTION

Siam weed *Chromolaena odorata* (L.) King and Robinson, is native to the tropical Americas, where it is found from Florida to northern Argentina in most areas below 1000 m altitude except undisturbed rainforest. In its native range, it is common but not a serious weed. Siam weed was introduced into Asia in the 1840's, probably via the Botanical Gardens in Calcutta, and has since spread throughout south-east Asia to the south Pacific (McFadyen, 1989). In Asia, Siam weed is a major weed of pasture and plantation crops in areas receiving at least 1000 mm of rain annually. It can be of value to peasant farmers practising slash-and-burn agriculture, as it rapidly dominates the fallow vegetation and the labour required to clear *C. odorata* is much less than that required to clear *Imperata* (Baxter, 1995). However, where cattle raising is practised, or in areas with natural savannas, it is a very serious weed with no redeeming features. For example, in West Timor, where it was first recorded in the 1970's, it is now the worst weed of pasture, contributing to the poor nutrition and low calving rates of the local cattle (Dr. A.Bamualin, pers. comm., 1995). It is most competitive in tropical wet-dry climates, burning readily and surviving fires to regrow rapidly in the wet season. Siam weed is now present in Timor, Irian Jaya and Papua New Guinea, the islands immediately to the north of Australia. Coastal northern Australia from Arnhem Land in the Northern Territory to Cape York in Queensland is threatened by Siam weed. Biological control of the weed in Indonesia and the Philippines was proposed as a strategy to reduce the risk to Australia as well as benefit these countries directly (McFadyen, 1991), and the Australian Centre for International Agricultural Research (ACIAR) agreed to fund a 3 year project commencing in January 1993, with a total budget of about US $263,000. The project was favourably reviewed in November 1995 and ACIAR agreed to extend the project for a further 12 months while a proposal for a further 3 years was considered. The original project involved collaborating institutions in Indonesia and the Philippines, but the proposed new project will involve institutions in Indonesia and Papua New Guinea.

Among the organisations involved in the ACIAR project in Australia, the commissioned organisation is the Queensland Department of Natural Resources,

Alan Fletcher Research Station (AFRS), with Dr. Rachel McFadyen as project leader and Graham Donnelly as entomologist. The Northern Territory Department of Primary Industry and Fisheries is a collaborating organisation, with Colin Wilson as entomologist. In Indonesia, the collaborating institutions are: The Indonesian Institute for Oil Palm Research (IOPRI) at Marihat Research Station, on the north western island of Sumatra. The project leaders are Ir Sipayung and Dr. Roch Desmier de Chenon. SEAMEO BIOTROP in Bogor, on the main island of Java, where the project leader is Dr. Soekisman Tjitrosoedirdjo. Gadjah Mada University, Yogyakarta, in eastern Java is involved in the project through BIOTROP, with Dr. Soeprapto as project leader. The University of Nusa Cendana, Kupang, in West Timor, where the project leader is Ir Eko Widayanto, with Ir Wayan Mudita also involved. In Papua New Guinea, the collaborating institution is: Agriculture Protection Division, Department of Agriculture and Livestock in Lae and the project leader is Mr Warea Orapa of the Department of Agriculture and Livestock in Boroko.

Procedures

The earlier investigations in the West Indies in the 1960's have provided basic information on potential biocontrol agents (Cruttwell, 1974; Cock, 1984). The Queensland Department of Natural Resources has an entomologist, Dr. Cesar Garcia, based on the Caribbean coast of South America, who is rearing insects found on *C. odorata* in its native range. From these insects, a priority list of 2 or 3 species which are damaging, easy to rear, and host-specific has been selected for initial study. Scientists at the AFRS supply available information on these insects to the Marihat Research Station in Indonesia, who then apply for permits to import the insect into their quarantine for detailed host-testing. When permits are granted, the insects are sent from the AFRS field station in South America to quarantine in Marihat, where a parasite-free colony is established. Once a colony is established in quarantine, host- tests are carried out on a list of plants determined by the Indonesian authorities. When the tests are completed, and the scientists are fully satisfied that the insect is safe to release, an application is made for permission for field releases. Once this has been granted, mass-rearing and field releases can begin on all islands of Indonesia. When Papua New Guinea becomes involved in the new project, their project leader will apply for permission to import the agents into PNG for mass-rearing and release. The application will include the results of the host-testing and field releases undertaken in Indonesia. If the PNG authorities require any further tests, perhaps on additional plants, these will be undertaken at Marihat as PNG does not have an insect quarantine. Mass-rearing will then begin at Lae, and field releases will be made in Lae, Vanimo on the Irian Jaya border, Rabaul in New Britain, and other sites where *C. odorata* is found. The project provides training, minor equipment and facilities upgrading, to ensure safe and effective handling of insects in quarantine. Regular visits by entomologists from the AFRS assist in establishing and maintaining the quarantine colony and in devising safe host-testing procedures of each insect. Field-monitoring methods are being developed for evaluation of results achieved.

Biocontrol agents

The arctiid moth *Pareuchaetes pseudoinsulata* has been introduced, host-tested and field-released in Indonesia by the Marihat Research Station, initially funded by the EEC/IRHO project (Deat, 1991). The ACIAR project supported the continued mass-rearing and releases of this insect on other islands of Indonesia, particularly Java and Timor. The new project will continue this support, and extend it to include releases on the other islands of eastern Indonesia and in Papua New Guinea. The next insect to be trialled was the stem-galling tephritid fly *Procecidochares connexa* (Macq.) from South America, previously known to be specific and damaging (Cruttwell, 1974). Two other species in this group have already been used for biocontrol of related weeds, *Procecidochares utilis* for the control of Crofton weed *Ageratina adenophora* and *Procecidochares alani* for the control of mistflower *Ageratina riparia* (Julien, 1992). The import permit from the government of Indonesia was granted in September 1993 and a colony was sent from South America to quarantine at Marihat. Host-testing was completed by July 1994 and the permit to release granted in June 1995. Mass-rearing and field releases began immediately and have continued since, with releases made in Sumatra, Java and Timor. Releases will continue until the fly is established in all areas where *C. odorata* occurs. Subject to permission from the Papua New Guinea authorities, releases will also be made on mainland PNG and New Britain. The leaf-feeding butterfly *Actinote anteas* (Doubleday and Hewitson) is currently being reviewed for importation and testing. Larvae were first collected

from *C. odorata* in Costa Rica in 1967 (Cruttwell, 1974). The species is also recorded from *Ageratum* in Trinidad (Barcant, 1970) and from *Mikania sericea* in Southern Brazil (Silva *et al.*, 1968). *A. anteas* probably occurs widely throughout central and south America, though there may be local strains with different host plants within the *Eupatorieae*. *A. anteas* is a large, colourful, day-flying butterfly, which breeds readily in cages exposed to sunlight. Females lay up to 500 small orange eggs in large batches on the leaves, and the larvae feed gregariously until the last instar. Larvae are voracious feeders, and whole plants are left stripped of leaves. Mature larvae pupate hanging attached to the underside of stalks or leaves. Although *A. anteas* attacks the leaves, as does *P. pseudoinsulata*, both larvae and adults are active in the daytime and so will be subject to completely different parasitoids and predators, and hopefully may be abundant and damaging at seasons or places where *P. pseudoinsulata* is ineffective. After studies on *A. anteas* have been completed, and if specific, field releases made, the decision on the next insect to import will depend on progress made by our entomologist in South America and by the South African research team. If the stem-fly *Melanagromyza eupatoriella* has been successfully reared in South Africa, it would be a priority choice for further work, as would be the stem-galling moth *Mescinia parvula*, if this is successfully reared. The decision will be based on the information available at the time, and on the success of tests and releases made in other countries.

Collaboration with other projects

The ACIAR project will concentrate on the three named host-specific insects in the first instance. If other agents prove successful in other countries, these will become the priority for trial within this project. Conversely, now that parasitoid-free colonies of both *P. pseudoinsulata* and *P. connexa* are established at Marihat, nucleus colonies of these insects can be sent to other countries which request them for testing and release. *P. connexa* has already been sent for trial in both South Africa and Ghana. Interim results will be made available through the *Chromolaena odorata* Newsletters, prior to publication in international scientific journals.

The Philippines

The original ACIAR project included the Philippines, with collaborating institutions in Los Banos and Davao city. Both groups commenced rearing and releasing *P. pseudoinsulata*, already present in the Philippines through natural spread from Sabah. Both institutions also set up monitoring and evaluation projects to determine the effect of the insects on the spread and density of *C. odorata*. Unfortunately, a permit to import the new strain of *P. pseudoinsulata* from Guam was not granted, nor was an import permit for *P. connexa* from Indonesia. The permit sought for *P. connexa* was to bring the insect into quarantine in Manila or Los Banos for further host-testing there, but despite the fact that *P. connexa* has been tested and released in Indonesia, this permit has still not been granted, 3 years since it was first requested. Consequently, in November 1995 the project reviewers recommended that the project not be continued in the Philippines, unless import and later release permits for *P. connexa* could be obtained, and at present the project remains suspended. The problem appears to be that the permit approval process in the Philippines is slow and involves many different steps both within the applying institution and the national system. At each step, there are scientists who do not fully understand biological control and continually request further details or clarification, with concomitant delays. There are also institutional blockages, where individuals who do not accept biological control as a method, refuse to approve work on the topic within their institution. This would be more acceptable if the individual concerned were prepared to state their views publicly, where they could be answered, and the costs of alternatives to biocontrol discussed in public as well. For example, any risks from introducing an agent such as *P. connexa* could be weighed against the damage to agriculture and the environment caused by the weed itself, or by the chemicals otherwise used to control it. Unfortunately, because opposition is not openly stated, the arguments for and against biocontrol cannot be aired, and decisions are stalled. This is contrary to the recently approved FAO Code of Conduct for the Import and Release of Exotic Biological Control Agents, where a clearly stated purpose of the code is to "promote the safe use of biological control agents for the improvement of agriculture." We can only hope that adoption of the FAO Code will result in improved processes for the granting of permits to import and release biocontrol agents in the Philippines and elsewhere.

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COUNTRY REPORT - SOUTH AFRICA

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Chromolaena odorata has been present in the country since about 1940. It initially spread along the east coast in KwaZulu-Natal, and later an infestation was found in the Northern Province. In recent years new infestations were discovered at places in the Northern Province (as far north as the Zoutpansberg near the Zimbabwe border) and in Mpumalanga. Infestations are now also known in adjacent Swaziland and Mozambique.

The South African *C. odorata* differs from the form in West Africa and also from the plants in Asia, Australia and those examined so far in South America, the Caribbean and Florida in the USA, and its exact origin has not been determined.

Much work has been done on chemical, mechanical and cultural control aspects (see Goodall, J. M. and Erasmus, D. J. 1996. Review of the status and integrated control of the invasive alien weed, *Chromolaena odorata*, in South Africa. *Agriculture, Ecosystems and Environment* **56**: 151-164). Although various chemicals have been shown to be effective and management practices like burning and oversowing are known to work, it is realized that biological suppression using fungi and arthropods will provide the only long-term solution in suppressing the weed economically on a sustainable basis.

Pareuchaetes pseudoinsulata, obtained from Guam and released in the late 1980's did not get established, and ant predation was implicated. Later *P. aurata aurata* from Argentina was released in large numbers, but no establishment was achieved. *P. insulata* and the acraeid butterfly *Actinote anteas* were also imported and tested, and although they appeared to be acceptably specific, they were not released because of microsporidian infections in the cultures that could not be eliminated.

Surveys for insects and pathogens were made in Argentina, Paraguay, Brazil, Bolivia, Venezuela, Trinidad, Jamaica, Florida (USA) and various islands in the Caribbean. Results are reported on elsewhere in this publication. Amongst the species imported in small numbers for initial rearing attempts or for identification were :

Mescinia sp	Pyralidae	Brazil, Trinidad	Twig borer
Longitarsus sp	Chrysomelidae	Brazil, Trinidad	Adults on leaves, larvae on roots
Adaina n. sp	Pterophoridae	USA (Florida)	Twig galling
Lixus sp	Curculionidae	Brazil	Shoot borer
Melangromyza sp	Agromyzidae	Trinidad, Florida	Shoot tip borer
Conotrachelus sp	Curculionidae	Venezuela	Shoot tip borer

A number of so far unidentified species, apparently not reported in earlier studies from mainly Trinidad, e.g., a twig boring lepidopteran, and stem-boring curculionids and cerambycids were encountered in South America. Two species of eriophyid mites were generally encountered, but have not been imported so far.

At present we have in quarantine cultures of *Lixus* sp., *Actinote* sp. cf. *parapheles*, as well as a different sp. from Venezuela, and *Pareuchaetes pseudoinsulata*. *Melanagromyza* sp. was reared for more than one generation on two occasions.

Numerous isolates of *Septoria ekmaniana* from Belize, the Caribbean, Florida and South America were tried on the South African form of *C. odorata*, but none proved to achieve normal infections, indicating poor host matching. Various cercosporoid fungi have been isolated and infections are being attempted. Infections by *Cionothoix* sp. have not been achieved.

FOURTH INTERNATIONAL WORKSHOP ON BIOLOGICAL CONTROL AND MANAGEMENT OF *Chromolaena odorata* OCTOBER 14-18, 1996 AT BANGALORE

TECHNICAL SESSION - I
Chromolaena Network Programmes

Chairman : Dr. S. P. Singh
Rapporteur : Dr. C. T. Abraham

Five reports were presented in the Session. Dr. R. Muniappan, University of Guam, reviewed the history of introduction of *Chromolaena* from the neotropics to the tropical areas in Asia, its subsequent spread over the years and problems as a weed. *Chromolaena* became a problem in Guam in 1986. After the successful control of the weed by *Pareuchaetes pseudoinsulata* in Guam, the First International Workshop on Biological Control of *Chromolaena odorata* was organised in Bangkok in February, 1988. The second and third workshops were held in February 1991 in Bogor, Indonesia and in November 1993 at Abidjan, Ivory Coast, respectively. Following the recommendations of the first workshop, the Secretariat was established at Guam to publish the *Chromolaena* Newsletter. The Second Workshop recommended setting up the Network on Biological Control and Management of *Chromolaena odorata*. Following the recommendation of the third workshop, an IOBC Working Group on *Chromolaena odorata* was also established with headquarters at the University of Guam. So far, 10 issues of the *Chromolaena odorata* Newsletter and the Proceedings of the three workshops have been published. Copies of articles on *Chromolaena* have been supplied to research workers in different parts of the world.

The support for the Network is obtained from ACIAR, Agricultural Experiment Station of the University of Guam and the Tropical and Sub-tropical Agricultural Research programme of the USDA.

Dr. R. E. McFadyen of the Alan Fletcher Research Station, Australia, presented the activities of the Australian Centre for International Agricultural Research (ACIAR). The centre has funded a biocontrol project from 1993, through which suitable insects are sent from South America for detailed testing in quarantine in Indonesia and the Philippines. Field releases are made, if the insects are safe, in these two countries and Papua New Guinea. The procedures followed for selection, import, host testing, mass rearing, field release and evaluation of the biocontrol agents against *Chromolaena odorata* were also presented.

Dr Harry Evans of the International Institute of Biological Control, UK, outlined the activities of the EEC projects on evaluation of fungal pathogens as bio-control agents against weeds of neotropical origin like *Parthenium hysterophorus, Chromolaena odorata* and *Mikania micrantha*. It is hoped that the outcome of these projects would lay the groundwork and establish protocols for importation and release of fungal biocontrol agents to India and other countries.

Dr. R. Desmier de Chenon presented a report on Centre for International Co-operation in Agronomic Research for Development, Department of Perennial Crops (CIRAD), in France. CIRAD was the leader of a biological control programme on *Chromolaena* from 1989 under an EEC project involving the Cote d'Ivoire in West Africa, Indonesia in South East Asia and IIBC for providing new biological agents. In Indonesia the partner of the project was the Indonesian Oil Palm Research Institute at Marihat in North Sumatra.

During this project a special unit for biocontrol of this weed was built, and staff and workers trained. *Pareuchaetes pseudoinsulata* from Guam was imported, established and released successfully in many places in Indonesia. Monitoring in the fields and culture of this insect in insectarium is still going on.

Using these facilities, studies on the biocontrol of *Chromolaena* have been continued with the current ACIAR Project starting in 1993 at IOPRI, Marihat,

with as co-leaders of the project the head of Plant Protection of this institute, Dr. A. Sipayung and Dr. Desmier de Chenon.

Among the results achieved are the importation of the gall-fly, *Procecidochares connexa* (Diptera: Tephritidae), including rearing and host plant testing in quarantine conditions and, after permits were obtained, releases in the field. This insect is now available at Marihat, and the following organisations have already been provided with the technique to rear and use the insect in Indonesia: estate plantations, universities, BIOTROP, in Sumatra, Java, Kalimantan, and Timor. Outside Indonesia, the insect has been sent to South Africa and Ghana, thus establishing a network to supply biological agents with ACIAR financial support. Therefore, at the Indonesian Oil Palm Research Institute, research on the Biological Control of *Chromolaena odorata* with CIRAD involvement has already been under way continuously for more than seven years.

Dr. K. P. Jayanth of IIHR, Bangalore, India, presented the activities of the AICRP on Biological Control of Crop Pests and Weeds on biological control of *Chromolaena odorata. Pareuchaetes pseudoinsulata* was released during 1973-76 by the Commonwealth Institute of Biological Control. Later on, several releases were made under the AICRP in Karnataka and Kerala. However, only sporadic successes could be obtained as the insect did not establish well. The reasons for the failure of establishment of *P. pseudoinsulata* are not yet understood.

In the discussions which followed, it was felt that international collaboration for research on control of *C. odorata* must be strengthened. More funds have to be secured from international agencies for which proposals should be prepared. There is also a need for training programmes to familiarise scientists with the selection, testing, field release and evaluation of biological control agents against *Chromolaena odorata.*

TECHNICAL SESSION - II
Country Reports

Chairperson : Dr. R. E. McFadyen
Rapporteur : Dr. M. Syed Anwarulla

The Chairperson invited the speakers representing different countries to present their country reports. Delegates from Australia, India, Indonesia, Papua New Guinea, South Africa and USA (Guam) presented reports.

Australia

Dr. R. E. McFadyen presented the country report for Australia. The potential distribution of *Chromolaena odorata* in the country was described. In 1985, it was declared as a noxious weed in the country. The weed was first noticed during 1994 in the Tully region south of Cairns in the north of Queensland. Research concentrated on control and eradication of the weed through chemical methods. Local people are being actively involved in its identification and the eradication program. She suggested that the high rainfall climatic conditions helped restrict the growth and spread of the weed in the coastal site.

Dr. P. L. Tandon wanted to know the reason for adopting only chemical means of control in the country. The speaker replied that since the infestation is only in small patches, in order to have quicker and complete eradication, chemical methods are being adopted in Australia.

Dr. Viraktamath presented the country report of India. The weed was introduced as an ornamental plant in north-east India in the 1840's. It spread to the entire north-east India and Bangladesh by 1919. After the Second World War returning soldiers from north-east India probably brought it to Kerala in their clothing or baggage. Now it is distributed along the Western Ghats upto Rathnagiri district, from Kerala. Recent spread was noticed in the Shevroy hills and Khandala.

It is a serious weed in wild life sanctuaries, plantations of rubber, cashew, arecanut, coconut, tea, coffee, citrus, etc. It smothers native vegetation and in turn native fauna. It is a serious concern in India as it has invaded the two most species-rich areas of India, namely north-east India and the Western Ghats.

Attempts to control it by mechanical and chemical methods are not economical and effective. Biological control attempts using the arctiid *Pareuchaetes*

pseudoinsulata, Apion brunneonigrum and *Mescinia parvula* were not successful because of a casual approach to their establishment.

About 9 species of native mites and 35 species of insects attack the weed in India. Of these the host specific eriophyid mites *Calacarun* sp. and *Acalitus adoratus* are important.

Replying to Dr. McFadyen, Dr. Viraktamath said *Chromolaena* entered the country through tourists from Indonesia and in containers.

Papua New Guinea

Mr. Warea Orapa presented the country report for Papua New Guinea. He mentioned that the weed *Chromolaena* entered the country from the Indonesian border during the 1970's, and by 1975 moved into different parts of the country along the roads. Dr. Gopalan enquired about the control measures taken up. The speaker said that except for cultural methods, no control measures have been followed in the country.

He concluded the report by stating that the area currently affected by this weed is confined to low altitude areas but it is moving into the central and southern parts.

USA

Dr. R. Muniappan presented the country report for the USA (Guam). He said *Chromolaena* became a serious problem in Guam and the neighbouring islands in the Marianas. *Pareuchaetes pseudoinsulata* was introduced and established in 1985. *C. odorata* is allelopathic and exhibits insect induced defense to *P. pseudoinsulata* feeding. This defensive reaction is reversible.

Indonesia

Dr. Soekisman Tjitrosemito reported that *Chromolaena* entered Indonesia from Sumatra Island from the coast and spread to perennial crops and plantations of coconut, rubber, bananas, etc., and field crops of sugarcane. It is not a serious weed in food crops but it is severe in forest areas of the country, causing much damage to forests. He also reported work on growth and structure of the weed, and its distribution in the country. He reported that natural agents were not found to be effective in control of this weed in the country.

South Africa

Dr. S. Neser presented the country report for South Africa. He said the weed entered South Africa during the 1940's through packing material in Durban harbour probably from Argentina or Central America. From 1962, research on *Chromolaena* has been under way.

Regarding control measures followed in the country, he said at present integrated control using mechanical and chemical means is being followed to manage the weed. No biocontrol measures were followed up to the 1980's. Recently, signal grass is being used to suppress the growth of the weed. He also said that insects released to control the weed were not successful to date. Dr. Gopalan enquired about collection of such enemies on this weed from Florida. Dr Neser said he does not know about natural enemies of *C. odorata* in Florida.

The Chairperson thanked the speakers from different countries for their informative reports.

TECHNICAL SESSION - III
Ecology of *Chromolaena*

Chairman	:	Dr. S. Neser
Rapporteur	:	Dr. P. V. Rami Reddy

Results of the survey on the situation of *C. odorata* in West Africa: this paper was not presented as the authors could not attend the workshop.

Seed dispersal of *Chromolaena odorata* reconsidered: this paper was presented as a poster, however, on the request of the chairman, Dr. C. Zachariades briefed the participants on the salient features. Wind dispersal is only short-range. Dr. R. E. McFadyen added that long distance dispersal in Asia is also due to people not winds. Dr. P. L. Tandon observed that if the spread was 400% per year, the weed must have covered the entire

area but that did not happen, and wanted to know whether any seed mortality factors were working. Dr. R. Muniappan and Dr. M. Gopalan also added to the topic.

Major Indian weeds of Neotropical origin and the possibilities for collaborative biocontrol projects : In presenting this paper, Dr. H. C. Evans stressed the problem of pathophobia and mentioned various fungal and bacterial pathogens affecting important weeds. Dr. Soekisman from Indonesia wanted to know about pathogen mutants. It was verified that pathogens are very specific. Dr. M. Gopalan asked if there is any examples of pathogens being used against weeds in developed countries. Dr. R. E. McFadyen replied that in the USA, Hawaii and Australia several pathogens such as *Puccinia* have been released.

Abundance, density and frequency of *C. odorata* and its enemies in Kerala and Tamil Nadu : The paper was presented by Dr. M. Gopalan, who apologised for the data being five years old. A survey for the weed revealed that infestation of *C. odorata* were severe in arecanut and cashew plantations in Kerala. Loss of viability of eggs after 3-4 generations was a serious problem in mass production of *P. pseudoinsulata,* and incorporation of 0.2% Sodium Chloride enhanced the viability of eggs.

Distribution of some exotic weeds in South West India: Dr. R. Muniappan presented the findings of a survey conducted in 28 sites in south-western parts of India. Four species, *C. odorata, Lantana camara, Ageratina adenophora* and *Parthenium,* were the major weeds. *C. odorata* replaced *L. camara* in some years.

Dr. C. T. Abraham said that *Mikania* sp. is replacing *C. odorata* in Kerala. Dr. Muniappan agreed that this was possible, since the observations he presented were from five years earlier. Dr. Evans said that biological control must be applied against all three major weeds which affect biodiversity. Dr. Muniappan said *Mimosa* is also increasing, with the spineless mixed with the spined variety. Administrators and policy makers need to be made aware of the problem. The need for an integrated approach involving entomologists, agronomists and pathologists was stressed.

Growth pattern, sprouting ability and chemical control of *Chromolaena odorata* : Dr. R. Devendra presented this paper. The root has low biomass followed by the stem and leaf. A significant negative relationship was observed between biomass and sprouting ability. Application of glyphosate reduced the phenolic contents of cell walls, thus making it a more effective herbicide. Use of *Fusarium* was advocated for effective control. Dr. Muniappan asked if we can reduce the dosage of glyphosate by controlling with *Fusarium,* and Dr. Devendra replied Yes, upto 10 times. However, detailed studies are to be conducted.

Ecological adaptations of *Chromolaena odorata* : Dr S. R. Ambika presented this paper. Different habitats such as tree tops and roof tops were observed for *C. odorata.* Collections of *C. odorata* from Bangalore, Madikeri and Shimoga differed in many morphological and biochemical attributes, and the possibility of different ecotypes was not ruled out.

Dr. P. K. Raphel and Dr. P. L. Tandon queried about altitude up to which *C. odorata* will grow; the reply was that studies did not cover that aspect. Dr. P. V. Rami Reddy brought to the notice of the author that three collections did not differ significantly in many attributes such as plant height and amino acid content, so it could not be concluded they were different ecotypes.

Distribution of *Chromolaena* in different parts of Karnataka: This paper was presented by Dr. M. B. Doddamani, who reported that about 23,000 sq.km. area in Karnataka is infested with this weed, with the highest levels observed in Shimoga and the lowest in the Mysore district.

Dr. McFadyen wanted to know where the weed was first noticed in the area. Dr Muniappan said that *C. odorata* was spread as *Eucalyptus* was planted.

Influence of growth conditions and the efficacy of herbicides on growth and development of *Chromolaena*: Dr. U. V. Mummigatti presented this paper, which mainly emphasised anatomical and morphological differences at different light intensities. Sunlight is one of the important factor affecting the efficacy of herbicides and carriers are needed under shade conditions to increase the efficacy of herbicides.

Studies on the demography of *C. odorata* in secondary successional community: this paper could not be presented as the authors were not present.

The Session ended with brief remarks from the Chairman thanking speakers for the information presented in the Session.

TECHNICAL SESSION - IV
Conflicting interests and utilization of the weed

Chairman : Dr. M. Gopalan
Rapporteur : Dr. S. R. Ambika

The following two papers were presented: Possibilities of using *Chromolaena* as a green manure : Dr. Syed Anwarulla who presented the paper mentioned that *Chromolaena* attains maximum vegetative growth by July after rains in May, providing maximum succulent and green biomass (upto 2.9 kg m^2) in the Western Ghats of Karnataka. *Chromolaena* could be used as a green manure in paddy and horticultural crops such as guava and sapota. Out of the five other plants used as a green manure, *C. odorata* proved the best and it could supply 0.82% of N, 0.53% of P_2O_5 and 1.37% of K_2O in paddy fields. The paddy field under this treatment was free from neck blast disease. When *C. odorata* was used as manure in sapota and areca plantations, the incidence of white termites and ants was very low. Recommended dose is 50% of NPK and 5 tons of *C. odorata*, and leaves should be incorporated into the paddy fields at the time of transplantation for best results.

Dr. Tandon asked how much time it takes for the *Chromolaena* to decompose and whether there is any pH change during the decomposition. Dr. Evans asked what was the mechanism of the control of rice blast; are phenolics involved in this? Dr. Soekisman asked whether *Chromolaena* extract is toxic to fungal spores? Dr. Muniappan suggested there should be no speculation regarding the induction of resistance and disease control but that the facts should be presented.

Prof. Gopalan asked in which other crops *Chromolaena* leaves are used as a manure.

Effect of *Chromolaena* leaf extract on mortality of *Radopholus similis*: This paper was presented by Dr/ Sundara Raju. Acetone extracts of fresh leaves of eight plants and of onion bulbs were tested for their antihelminthic property against *Radopholus similis*. The results indicated that the *C. odorata* leaf extracts caused 84% mortality of *R. similis*, followed by *Ananas comosus* and *Mimosa invisa* with 82.33% mortality.

Dr. Tandon said that as the extract is in acetone, the control should also be acetone instead of water, and asked about the phytoxicity of the extract to crop plants. Dr. Muniappan said that the trials are in the lab in petri dishes and suggested that the trials should be carried out in pots and then in the field to confirm the results. Dr. Soekisman asked if the toxicity was due to the phenolics in the extract.

In the discussion which followed, led by Prof. Gopalan, it was stated that *C. odorata* leaves are used as a packing material for transporting vegetables, and as bedding material for cattles in Ooty. Dr. Muniappan highlighted that *C. odorata* contains a *pyrrolodizine* alkaloid which is toxic and is picked up by honey bees and other insects.

TECHNICAL SESSION - V
Control methods : Cultural and Chemical

Chairman : Dr. C. A. Viraktamath
Rapporteur : Dr. M. B. Doddamani

In this Session there were three papers on control of *Chromolaena* by weedicides, and two papers on its usage as a green manure and subsequent benefit on reduction of incidence of blast disease in rice.

Dr. McFadyen who presented the paper of Dr. Barbara Waterhouse, outlined the procedures adopted to eradicate the small establishment of *C. odorata* in the humid tropical region for about 40 km along the Tully River which constituted the primary infestation, and the much smaller secondary infestations in northern Queensland during July 1994. The five year eradication programme involved use of weedicides as 100 per cent kill of the weed is desired. The weed apparently was introduced during the 1970's in pasture seeds and because of dense vegetation, humid conditions and competition from native grass species, was confined to a narrow strip along the river Tully even though the infestation was 2-4 years old when discovered.

Dr Ambika presented a paper on the use of herbicides in tea plantations. Among the weedicides tested, Maleic hydrazide at 8.3 kg/ha applied before flower initiation, though expensive compared to hand weeding, prevented flower formation. If sprayed after flower initiation, it caused sterility in the seeds. Other weedicides which caused pollen and seed sterility at different concentration were Karmex and Weedone-concentrate.

Dr. Abraham recommended the usage of Diuron and Atrazine at 2.0 kg/ha. Among the post emergent weedicides tested, paraquat and 2-4, D were promising. The systemic weedicides such as 2-4, D and Glyphosate were very effective even at lower doses on regrowth.

Dr. Chandrashekar presented a paper on the use of *Chromolaena* as a green manure in rice paddies. He claimed that 10 tonnes of *Chromolaena* replaced 82 kg Nitrogen. He also compared the incidence of blast disease in the FYM applied, green manure applied and fertilizer applied rice. Though green manure application reduces the blast incidence in rice to certain extent, the yield increase is significant in blast resistant paddy varieties compared to straight fertilizers.

Recommendations were made that weedicides can be used against *Chromolaena* only in a crisis such as an eradication programme of an infestation in a country where the weed does not otherwise occur. Under other situations, they should be used in an integrated weed management strategy.

TECHNICAL SESSION - VI
Biological Control

Chairman	:	Dr. H. C. Evans
Rapporteur	:	Dr. U. V. Mummigatti

According to Dr. Colin Wilson, the *Chromolaena* gall-fly *Procecidochares connexa* is a potential biocontrol agent for *Chromolaena.* He explained a simple technique to spread this gall-fly, by collecting the galls from infected sites in north Sumatra and tying them to *Chromolaena* plants in non- infected sites in Timor. Each gall contains 2 to 8 pupae and the pupation period extends up to 60 days. In about 5 months after release, new galls were noticed upto 300 m away. This technique is inexpensive and simple.

Effect of biological control of *Chromolaena* on biodiversity - a case study in the Ashanti region of Ghana: This paper was presented by Dr. Rachel McFadyen in the absence of Dr. J. A. Timbilla. Biocontrol of *Chromolaena* weed which occupies 20% of the vegetation in Ghana, was started in 1970 but was unsuccessful. Later during 1989, the Crop Research Institute, Kumasi, Ghana, started releases of *Pareuchaetes pseudoinsulata* for *Chromolaena* control. After the first release in 1991, the insect has spread about 60 km from the releases sites, defoliating the *Chromolaena* weed and restoring the natural vegetation.

Dr. S. Tjitrosemito of Indonesia emphasised the use of the tephritid *Procecidochares connexa* as a bioagent to control *Chromolaena,* instead of *P. pseudoinsulata* which was successful only in north Sumatra. He also highlighted the use of other biocontrol agents such as *Actinote anteas* and *Conotrachelus* sp. for control of *Chromolaena.*

In view of the limited success of *P. pseudoinsulata* against *Chromolaena* in South Africa, Dr. Zachariades described the promising new candidate bioagents. The butterfly, *Actinote parapheles;* stem boring weevil, *Lixus* sp.; flea beetle, *Longitarsus* sp.; stem galling moth, *Adiana* sp. were identified as other promising agents. In addition to these, strains of a fungus *Septoria ekmaniana* were also isolated from *Chromolaena* and preliminary testing of this bioagent is in progress. He also suggested that a search for *Chromolaena* flower and seed attacking insects would be most effective.

The release of *P. pseudoinsulata* in the *Chromolaena*-infested Federated States of Micronesia, Kosrae, Pohnpei and Yap has given a poor response in Pohnpei and Yap. The inability of the insect to control *Chromolaena* may be due to a low population of the insect larvae. However, Dr. Nelson Esguerra is of the opinion that the failure of *P. pseudoinsulata* to control *Chromolaena* was probably due to predaceous fauna (mostly ants) in the release areas.

According to Dr. Desmier, the use of *P. pseudoinsulata* in the *Chromolaena*-infested oil palm estates in Sumatra, Indonesia, has resulted in successful control. But in order to develop a complex of natural enemies to control this weed, a gall-fly *Procecidochares connexa* was imported from South America.

Dr. K. P. Jayanth explained the current status of biological control of *Chromolaena* in India. In spite of a series of attempts to establish *P. pseudoinsulata* imported from Sri Lanka into different locations of Karnataka like Bangalore, Mysore, Kodagu and Dakshina Kannada districts, limited success was obtained only at Dakshina Kannada. The causes of failure and success of the insect to control *Chromolaena* were discussed.

Dr. Henry Evans, Chairman of the Session, thanked the speakers and the members of the Organising Committee for providing him an opportunity to chair this session.

TECHNICAL SESSION - VII
Biology and Physiology of Insects

Chairman : Dr. P. L. Tandon
Rapporteur : Dr. Sushil Kumar

Only four out of the seven papers in the session were presented. The abstracts of first two papers were read by the Chairman of the Session.

The third paper entitled 'Temperature dependent development of *P. pseudoinsulata*, an exotic biocontrol agent of *C. odorata*' was presented by Mrs. P. N. Ganga Visalakshy. Development at 10°C and 35°C was not possible. The best temperature observed was around 30°C. It was suggested that the author carry out studies on diapause behaviour and development linked with different humidity range.

The fourth paper entitled 'Effect of inbreeding on the functional potential of *P. pseudoinsulata*' was again presented by Mrs. Ganga Visalakshy. She concluded that continuous laboratory rearing may affect the viability of the insect; field releases should be carried out as soon as possible for better results. It was suggested that the author should also do some studies on feeding on different parts of the plant and with different ages of insects.

The fifth paper was presented by Dr. P. V. Rami Reddy on 'Studies on feeding behaviour of *P. pseudoinsulata*'. He concluded that the consumption by the larvae increased significantly with larval age, and reached a peak between 15-17 days. He also concluded that larvae do not prefer yellow leaves. There were questions about the longer pupal period observed during the study.

The sixth paper could not be presented as the author was absent.

The seventh paper entitled 'Circadian activities and behaviour in the fields of the *P. pseudoinsulata* caterpillars' was presented by Dr. R. Desmier de Chenon. The author concluded that caterpillars restrict their feeding on the stem epidermis to between 10.00 to 13.00 hrs with 50% R. H. and around 25°C temperature.

At the end of the session, a lively discussion was invoked by Dr. R. E. McFadyen with a question on parasitism of *P. pseudoinsulata* in the field.

PANEL DISCUSSION
Regional and International Programmes

Chairman : Dr. R. Muniappan
Rapporteur : Dr. O. K. Ramadevi

Panel Members : Dr. R. E. McFadyen; Dr. S. Neser; Dr. H.C. Evans; Dr. R. Desmier de Chenon; Dr. K. P. Jayanth.

Dr. Muniappan, Chairman of the Session, invited the panel members to join the discussion on regional and international programmes on *Chromolaena* research. He explained the various international organisations which may act as donor agencies to fund the *Chromolaena* Research programmes throughout the world. He listed about 20 international agencies (ODA, World Bank, USAID, IDRC, USDA, FFTC, FAO, etc.) and national organisations like DBT, ICAR, ICFRC, etc., which can be approached for funding of research programmes.

Other than the procedural details to apply for these funds, the technical problems involved were discussed in depth by the panel members. The major one seemed to be importing biological control agents in countries where there are strict rules of quarantine. Dr. McFadyen gave the example of closure of a project because a permit could not be obtained to import the agents for testing. Dr. Jayanth explained the procedure to import natural enemies to India. The permit is procured through the Director of the PDBC, and quarantine and host specificity tests are done at IIHR. Dr. Tandon expressed the hope that in future no great problems should be expected.

Dr. McFadyen talked about agencies in Australia for funding and also suggested that the *Chromolaena* problem may get more attention as it is a serious threat to grass-eating wildlife. Dr. Evans, Dr. Neser and Dr. Desmier gave information on other agencies.

As well as funding agencies, Dr. Muniappan talked about the future activities in *Chromolaena* research. Dr. Viraktamath suggested that many organisations can join together and propose projects for funding.

Dr. Muniappan concluded by promising all possible help to undertake *Chromolaena* research, by providing literature or even collaboration in the research programmes.

RECOMMENDATIONS

1. So far only *Pareuchaetes pseudoinsulata* has been used for biological control of *C. odorata* in many countries. Importation of other effective natural enemies such as *Procecidochares connexa, Mescinia parvula, Melanagromyza eupatoriella, Actinote anteas,* etc., should be considered.

2. Countries wherein *Pareuchaetes pseudoinsulata* has been introduced should consider introduction and establishment of *Procecidochares connexa* from IOPRI in Indonesia. Host specificity testing of this natural enemy has been carried out in Indonesia and the information on host plants tested is available.

3. The Workshop highlights the importance of the complex of alien invasive weeds including *Chromolaena odorata,* in the Western Ghats, and other ecologically important regions in the humid tropics which are threatening biodiversity of these regions; this should be brought to the attention of the Indian and other Governments and international donors in order to seek support and funding for multi-disciplinary programmes of management of these weeds.

4. National Governments should promote collaborative programmes nationally and internationally on management of *Chromolaena odorata, Parthenium hysterophorus, Mikania micrantha, Lantana camara, Ageratina adenophora* and other alien invasive weeds.

5. National Governments through their agricultural research agencies should include use of pathogens in biological and integrated control programmes against noxious weeds.

6. For immediate suppression of *C. odorata* in certain conditions, where alternative technology is not available, research on herbicide and other methods should be encouraged.

7. Alternative uses of *Chromolaena,* such as use as a green manure crop, in certain agro-ecological systems should be explored.

8. It is recommended that a national network should be formulated to co-ordinate the research programmes on *Chromolaena odorata* in India.

9. Training programmes on biological control of exotic weeds at national, regional and international levels should be encouraged.

10. In view of the serious problems caused by *C. odorata* in developing countries in Asia and Africa to the livelihood of small and medium scale farmers, and the threat to biodiversity in natural ecosystems, countries of origin of the plant (tropical Americas from Argentina to the USA) are requested to assist researchers from affected countries and their agencies by allowing exploration for, and collection and export of promising candidate organisms for biological control of the weed, without imposing administrative and other barriers to the export of live materials.

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