LEUCAENA PSYLLID:
PROBLEMS AND MANAGEMENT

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The Winrock International Institute for Agricultural Development co-sponsored this workshop under the Forestry/Fuelwood Research and Development (F/FRED) Project, for which it serves as prime contractor. Funded by the U.S. Agency for International Development, F/FRED is designed to help scientists address the needs of small-scale farmers in the developing world for fuelwood and other tree products. It supports the Multipurpose Tree Species Research Network through which scientists exchange research plans, methods, and results. Research and development activities center on the production and use of multipurpose trees that meet the several household needs of small farmers.

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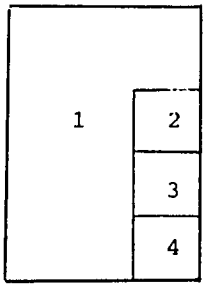
Cover photos:

1. *Leucaena leucocephala* plantation near Pune, Maharashtra State, India.
2. The leucaena psyllid, *Heteropsylla cubana*.
3. A coccinellid predator, *Curinus coeruleus*.
4. *Leucaena* in a screening experiment for resistance to the psyllid.



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Proceedings of an international workshop
held in Bogor, Indonesia
January 16-21, 1989

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Contents

	Page
PREFACE	iv
KEYNOTE ADDRESS	
Leucaena Psyllid Problems in Asia and the Pacific Banpot Napompeth	1
COUNTRY REPORTS	
Leucaena Psyllid in Australia - The Current Situation R.A. Bray, M.H. Julien and P.M. Room	8
Leucaena Psyllid in Republic of China - A Country Report Fuh-Jiunn Pan	12
The Status of Leucaena Psyllid, *Heteropsylla cubana* Crawford, in India G.K. Veeresh	14
Outbreak of Psyllid, *Heteropsylla cubana* Crawford on Leucaena and Its Outlook in Alley Cropping in India K. Krishnamurthy, M.K. Munegowda and D. Rajagopal	17
Progress and Future Activities of the Leucaena Psyllid Research Program in Indonesia Ida Nyoman Oka	25
Studies on Leucaena Psyllid in Malaysia Lim Guan-Soon, Tan Chai-Lin and Wong Choi-Chee	28
Leucaena Psyllid in the Philippines - A Country Report Fernando F. Sanchez	40
Status of Management of Leucaena Psyllid *Heteropsylla cubana* in Sri Lanka H.P.M. Gunasena, I.P. Wickramasinghe and H.M.G.S.B. Hitinayake	43
Leucaena Psyllid in Thailand - A Country Report Banpot Napompeth	45
Research on *Heteropsylla cubana* Crawford in Vietnam Bui Van Ich and Dam Quoc Tru	54
LEUCAENA PSYLLID RESISTANCE	
Resistance of Leucaena and Some Other Tree Legumes to *Heteropsylla cubana* in West Timor, Indonesia P. Mella, M. Zaingo and M. Janing	56
Secondary Metabolites in Leucaena Affecting Resistance to *Heteropsylla cubana* Crawford Jinadasa Darma and Irawan Sutikno	62

Field Observation of a Resistant *Leucaena* species in Bondowoso, East Java
Achmad Sulthoni, Subyanto and F.X. Wagiman 71

Evaluation of Leucaena Cultivars for Psyllid Tolerance
E.N. Crizaldo 73

Evaluation of Leucaena Germplasm for Psyllid Resistance
H.P.M. Gunasena, M.A.S.K. Ranasinghe, I.P. Wickramasinghe and H.M.G.S.B. Hitinayake 82

Psyllid Resistance in Four Leucaena Crosses
Fuh-Jiunn Pan 90

Leucaena spp. Resistant to Psyllid, *Heteropsylla cubana* Crawford, in Thailand
Panas Buranasilpin, Jiraporn Watanakul, Ponpimon Athipunyakom, Sayan Tunpanich and Siriphong Pattanavibuli 94

A Twelve Week Study of Leucaena Psyllid (*Heteropsylla cubana* Crawford) on Seven Leucaena Varieties in Hawaii
Robert A. Wheeler, Grant K. Uchida, John W. Beardsley, Jr. and James L. Brewbaker 99

New Tree Crops from Interspecific Leucaena Hybrids
J.L. Brewbaker, C.T. Sorensson and R.W. Wheeler 105

LEUCAENA PSYLLID ECOBIOLOGY

Seasonal Abundance of Leucaena Psyllid Populations in Yogyakarta, Indonesia
Soeprapto Mangoendihardjo, FX. Wagiman, Y. Andi Trisyono and Mohamad Sujono 111

Biology and Demography of *Heteropsylla cubana* Crawford (Homoptera: Psyllidae)
Aunu Rauf, Purnama Hidayat, Nina Maryana, and I Wayan Winasa 114

Laboratory Life Table of *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae), An Introduced Predator for Controlling *Heteropsylla cubana* Crawford (Homoptera: Psyllidae)
Aunu Rauf, Syaiful Rasyid and Ali Nurmansyahulur 119

Factors Affecting Leucaena Psyllid Populations in Leyte, Philippines
Lina T. Villacarlos, Rowena V. Paglinawan and Reynaldo P. Robin 122

Biological and Partial Ecological Life Tables of *Heteropsylla cubana* Crawford and its Predator, *Curinus coeruleus* Mulsant, in Thailand
Banpot Napompeth and Thotsaporn Manceratana 130

BIOLOGICAL CONTROL

Distribution of Leucaena Psyllid and its Natural Enemies in Mexico: Implications for Biological Control
A.S. McClay 139

Exploration for Biological Control Agents of Leucaena Psyllid in Tropical America
Jeff Waage 144

Status of Natural Enemies of *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) in Hawaii
George Y. Funasaki, Po-Yung Lai and Larry M. Nakahara 153

Endemic Natural Enemies of the Leucaena Psyllid in Indonesia
Soeprapto Mangoendihardjo, Eddy Mahrub and J. Warrow 159

Natural Enemies and Biological Control of *Heteropsylla cubana* on *Leucaena leucocephala* in Taiwan
An-ly Yao, Yao-Shi Hwang and Wei-Young Wang 162

Performance of *Curinus coeruleus* Mulsant as a Predator Against Leucaena Psyllid
F.X. Wagiman, Soeprapto Mangoendihardjo and Eddy Mahrub 163

Some Experiences in Mass Breeding, Release and Evaluating the Establishment of *Curinus coeruleus* Mulsant in Yogyakarta and Central Java
Soeprapto Mangoendihardjo and F.X. Wagiman 166

Study on Artificial Diet for the Rearing of *Curinus coeruleus* Mulsant
Soeprapto Mangoendihardjo, F.X. Wagiman and Agnes Tutik Purwani Irianti 171

Utilization of Natural Enemies for Biological Control of Leucaena Psyllid in Thailand
Banpot Napompeth, Amporn Winotai and Pimpun Sommartya 175

OTHER MANAGEMENT STRATEGIES

Transfer of Technology in the Utilization of *Curinus coeruleus* Mulsant
M. Soehardjan 181

Economic Impact of Leucaena Psyllid Infestation on Estate Crops and Teak Forest Plantation
Soeprapto Mangoendihardjo, F.X. Wagiman, Achmad Sulthoni and Subyanto 184

Cooperative Strategies for Leucaena Psyllid Research
K.G. MacDicken 189

RECOMMENDATIONS 192
LIST OF PARTICIPANTS 196
LEUCAENA PSYLLID BIBLIOGRAPHY 202

PREFACE

The leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), has been a serious pest of the multipurpose tree species *Leucaena leucocephala* (Lam.) de Wit in several countries since 1984. The psyllid has been a threat to both industrial and small-farm use of leucaena for some areas. This pest has seriously reduced the value of the species for fodder, shade and other uses.

Yet even after several years of research experience with the psyllid, there remain many unanswered questions about the reasons for the extreme population fluctuations, the effectiveness of biological control agents, and the stability of host plant resistance or tolerance of leucaena and *Leucaena* spp. hybrids.

The Proceedings of an International Workshop on Leucaena Psyllid: Problems and Management, held in Bogor, Indonesia from 16-21 January 1989, was an attempt to update and disseminate information on the psyllid and psyllid research. This volume is an edited record of the materials presented at that meeting. The editors would like to thank the following individuals for their contributions as reviewers of the papers in this proceedings: Robert Bray, George Funasaki, H.P.M. Gunasena, Guan Soon Lim, Max McFadden, Ida Nyoman Oka, Peter Room and Jeff Waage. We thank also Phatcharin Eiumnoh and Chaloamporn Rangaratna in the long tiring process of preparing the manuscript.

We believe this proceedings is a valuable addition to the growing body of literature on the leucaena psyllid and its control. We would like to thank the authors for presenting their work in this proceedings.

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KEYNOTE ADDRESS

LEUCAENA PSYLLID PROBLEMS IN ASIA AND THE PACIFIC

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Abstract

An overview is presented of various problems generated and encountered by the recent invasion of leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), in the Asia and Pacific region. Problems ranged from basic academic interests, to proper assessment of economic damage and impact, control and management strategies and anticipated advances through basic research. Attention has also been given to research methodologies, national, regional and international collaborative efforts as well as other relevant issues related to the leucaena psyllid.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), is a tiny homopterous insect, measuring about 2.0 mm in length. It is native to Central and South America which is also a native range of the leucaena plant, *Leucaena leucocephala* (Lam.) de Wit and other *Leucaena* spp. It is surprising how this little tiny creature has become an "instant" problem of worldwide recognition and global concern at this time especially in the Asia and the Pacific region.

The leucaena psyllid has been described since 1914 from Cuba as *Heteropsylla cubana* Crawford (Waterhouse and Norris 1987) and is considered a senior synonym of *Heteropsylla incisa* (Sulc) by Burckhardt in 1986 (CAB 1986, 1988; Nakahara *et al.* 1987). Yet, relatively little was known, nor significant research carried out, until its outbreak reported in Florida in late 1983 and its interception in Hawaii on April 26, 1984. Since then this insect has been detected and reported attacking leucaena in many countries in the Pacific Ocean, insular and continental Southeast Asia (NFTA 1987, Napompeth 1987). The insect is now causing devastating damage to leucaena plants westward from its native home through the Indian Subcontinent, and is speculated to reach Africa eventually.

Problems generated by the leucaena psyllid are dependent upon the economic value and status of its host, *Leucaena* spp., under various management and uses. Nevertheless, some, if not all, of these problems are of common interest of scientists, researchers and end-users in various affected areas to arrive at practical and satisfactory solutions to the psyllid problem. Such solution must be acceptable ecologically, economically and sociologically as required and emphasized in the context of an integrated pest management or IPM system and approach.

Leucaenas and Other Host Plants

As a leguminous plant native to the New World, the "common" leucaena has long been introduced to other tropical and subtropical countries of the Old World where it has become naturalized in many new areas. Of all the 13 *Leucaena* spp. and over 50 interspecific hybrids recognized, each of them has shown certain degrees of susceptibility, tolerance and resistance to the attack by leucaena psyllid (Brewbaker 1987). These leucaenas have found uses ranging from fuelwood and timber to food for humans, feed for animals, and in some cases as weeds along roadsides.

With the worldwide introduction of the "giant" leucaenas as a multipurpose tree for various uses, monoculture and single tree plantings of leucaena were not uncommon. The trees are used by small farmers as well as by large enterprises and corporations for a wide variety of products and services uses.

No drawbacks were foreseen to the widespread use of leucaena until the sudden appearance of a tiny creature called "the leucaena psyllid" or "the jumping plant lice" in the mid-1980s. Following its appearance and detection in Hawaii, the home of the Nitrogen Fixing Tree

Association (NFTA), in April 1984, *H. cubana* has been detected and observed to spread rapidly with devastating damage in almost all leucaena-growing countries in Asia and the Pacific as far eastward as the west coast of the Indian Subcontinent by 1987-1988.

In his nomenclatorial note on *H. cubana*, Burckhardt (1986) associated this psyllid with the legume genera *Leucaena*, *Mimosa* and *Piptadenia* in its native range. In a test using nine leguminous species in Hawaii (Nakahara *et al.* 1987), *H. cubana* was successfully reared on leucaena and monkeypod (*Albizia saman*). Among the 12 recognized species of *Leucaena*, some showed differential degrees of resistance, tolerance and susceptibility to the psyllid (Pan 1987, Sorenson and Brewbaker 1987). *L. collinsii*, *L. esculenta*, *L. pallida* and *L. retusa* showed evident resistance to *H. cubana* in Hawaii with similar observations made in Taiwan. Some lines of susceptible *L. leucocephala* reported highly resistant in one locality may become susceptible in another locality (Sorensson and Brewbaker 1987). In the study on resistance of some *Leucaena* species to the leucaena psyllid in Australia, Bray and Woodroffe (1988) found that all 4 *L. leucocephala* lines tested were susceptible while *L. collinsii* showed the least damage.

Of all *Leucaena* spp., *L. leucocephala* of both "common" and "giant" types became widespread since its worldwide introduction, intentional and unintentional. Common leucaena, in some areas, is considered a pest, and proper control and management may be required. Also in many situations it is considered a useful plant with varieties of uses and exploitation. The giant leucaena, on another hand, has been introduced and disseminated purposely and is used as one of the most beneficial multipurpose tree species. With various and diversified objectives for leucaena cultivation the management strategy for controlling leucaena psyllid would be basically simple or highly complicated depending on the urgency and economic value of the leucaena crops, trees or plantations.

Leucaena Psyllid

The leucaena psyllid was described from Cuba by Crawford in 1914 as *Heteropsylla cubana* but was also described in the same year by Sulc as *Rhinocola incisa* (Burckhardt 1986). Since the types of both are conspecific and Crawford's description has priority, the name *Heteropsylla cubana* Crawford remains valid although *Heteropsylla incisa* (Sulc) has also been frequently referred to. A short taxonomic description and key to identify some *Heteropsylla* spp. including *H. cubana* was given in Caldwell and Martorell (1951). Yang and Fang (1986) also redescribed and illustrated the adult and fifth instar nymph of *H. cubana* after its invasion of the Pacific islands and Taiwan.

During its early invasion and detection in Asia and the Pacific, the identify of *H. cubana* was not certain. It was left to the entomologists in affected regions to confirm its identity as an exotic pest being introduced unintentionally from its native range in the New World. It remains unclear how such a rapid outbreak and rate of spread occurred in a such relatively short period of time. Air traffic and air currents have been attributed to such a rapid movement. Having suitable host plants, leucaenas, in the affected areas, these "pest-free" leucaenas have thus provided ample opportunity and suitable ecological niche and habitat for the leucaena psyllid to occupy. Also, there remains a mystery of its sudden disappearance during certain time of the year in spite of host availability and conducive environment, as well as its more or less expected time of resurgence and sudden appearance on an annual basis.

It has been observed, at least in Thailand and other countries north of the equator such as the Philippines and Vietnam, that *H. cubana* is absent from many leucaena growing areas from roughly the end of March to the early part of October, (i.e. from the beginning of summer to late monsoon season). However, there exist "pockets" of *H. cubana* in some locations, even when the psyllid has disappeared from surrounding areas. During the month of June when *H. cubana* disappeared totally in most areas, such "pockets" were observed in at elevations of 200-500 m in Kanchanaburi, Chiang Mai and Pak Chong in Thailand, and in Leyte and Cavite in the Philippines. South of the equator, *H. cubana* populations were observed in the month of June in Bogor and the vicinity, but reports of psyllid populations dynamics from Australia are not available. Such populations dynamic exhibited by *H. cubana* is probably due to the influence of the physical or density-independent factors and not the biological or density-dependent factors consisting of the natural enemies and host plant availability. A thorough population dynamic investigation and analysis is quite challenging on this aspect.

Nothing is known of voltinism and diapause in *H. cubana*. It was obvious that they exhibited multivoltinism during the outbreak season from

October-November to March-April each year to the extent of being cryptovoltine. Whether they exhibit estivation or summer diapause in what stages of development during their absence remain a mystery. It is also of academic and management interest to analyze the populations of colonizers, settlers, and emigrants during the outbreak season to find out if there exists any difference in population age structures and adult forms as exhibited in many delphacids such as the corn planthopper, *Peregrinus maidis* (Ashmead), and the brown planthopper, *Nilaparvata lugens* (Stal).

Basic investigations have been carried out on biology, development and life cycle of *H. cubana*. Five nymphal instars of development are generally reported. In Thailand Maneeratana (1989) and Winotai (1989) reported five nymphal instars, but Chawanapong (1988) reported only four nymphal instars. In other studies including Stechman *et al.* (1987) and Takara *et al.* (1987), five nymphal instars of *H. cubana* were reported. The life cycle of *H. cubana* reported by these workers ranged from 10 to 18 days except Stechman *et al.* (1987) reported a range from 33 to 37 days. While adult longevity was reported from 5 to 17 days in females and 2-7 days in males (Takara *et al.* 1987, Winotai 1989), Stechman *et al.* (1987) reported the adult longevity of 35-42 days. It was not clear why such great differences occurred. In all cases, the females outlived the males.

Less studied were the construction and analysis of life tables of *H. cubana* to determine its biological attributes as population statistic parameters. Preliminary biological life table studies of *H. cubana* were carried out in Hawaii by Takara *et al.* (1987), and in Thailand by Maneeratana (1989) and Winotai (1989), but there exists a further need for standardized methodology. The capacity for increase designated as r, or r_m or r_c could be a useful parameter for the determination of degrees of susceptibility, tolerance, or resistance of various *Leucaena* spp. and varieties when used in rearing *H. cubana* for the construction of biological life tables. Investigation along this line could be both more quantitative and complementary to regular and conventional ratings employed in screening leucaenas for resistance to this psyllid.

Nature and Extent of Damage

Direct and indirect injury to leucaena plants is obvious from nymphs and adults desapping young shoots, leaves and inflorescences resulting in complete defoliation of plants of susceptible leucaena species and varieties. Such defoliation is due to repeated and accumulative attack by the psyllids. In severe cases, the plants cannot recover. In moderate cases of attack, the plants recovered with chlorotic leaves which soon disappear, especially under coppice management. The cause of the leaf deformation and chlorotic appearance in the regrowth is not known. It remains to be determined whether it is merely phytotoxemia, or it is due to transmission of certain virus or mycoplasma having the leucaena psyllid as a vector. If the psyllid is a vector further research is needed on the mode of transmission, whether mechanical or transovarial. Despite all these potential research topics of academic interest, the question should also be addressed if it is worthwhile, feasible or economical to engage into such investigations.

Leucaena itself is more than a multipurpose tree species by definition. It can be noxious and considered as a weed under certain situations. To determine economic threshold levels would certainly be complicated. When leucaena is categorized as a weed, *H. cubana* would be a potential biological control agent without attempted introduction and thus becomes a beneficial insect. The question would be raised again on its efficiency as a control agent because most leucaena plants could recover in spite of repeated attack. As a result, attempt to release another *Heteropsylla* sp. for biological control of the creeping sensitive plant, *Mimosa invisa* Mart. in Queensland, Australia (Waterhouse & Norris 1987) may face such a dilemma. This question is basic but theoretically fundamental to attempts to introduce exotic natural enemies for classical biological control of *H. cubana* in countries such as Australia where *M. invisa* is a problem weed. This is also true for other countries where *Heteropsylla* sp. is likely to be introduced in the near future if it works well in Australia. Incidentally both *H. cubana* and *M. invisa* are problems being encountered in the same areas of the Asia and Pacific region.

As a plant for multipurpose use, leucaenas have been utilized for a wide range of purposes from green vegetables for human consumption to afforestation and reforestation. What would be the criteria to develop management strategies for leucaena psyllids under these highly diversified uses? Will it be possible to determine practical economic threshold levels of *H. cubana* under these conditions? Or, is it practical at all to devise any economic threshold level? These immense questions will likely remain unanswered and pose a challenge for research workers engaged in leucaena psyllid management and control research.

Sampling of psyllid populations also poses a great deal of difficulty and obstacles ranging from sample units, sample sizes, time of sampling and sampling frequency to sampling locations and conditions when leucaenas are cultivated for diverse purposes. During a period of heavy egg-laying, a sample unit consisting of a terminal shoot, few folded leaves and the first unfolded leaf could vary in size and could contain thousands of eggs attached to these egg-laying substrates in addition to nymphs and adults. An absolute count made preliminarily by Stechman *et al.* (1987) of the first 5 terminal leaves revealed one of the shoots with 2,319 eggs and nymphs. The counting on this shoot took more than 12 hours. As a result, in most investigations rating of psyllid infestation and damage has been adopted and employed for a quick and timely analysis, though these methods may not accurately reflect the real damage and loss caused by the psyllid.

Management and Control Strategies

Since leucaena is a multipurpose plant species used for many purposes, leucaena cultivated for different purposes inevitably requires different psyllid management and control strategies. It is obvious that there will be no single suitable control strategy available and that an integrated pest management approach is the only complete solution. From an implementation point of view, the selected control strategy or strategies could face another challenge in terms of timeliness, practicability and economic feasibility.

To the delight of environmentally-concerned researchers but the disappointment of advocates of chemical use, the use of pesticides is obviously uneconomical and impractical to a large extent, environmentally undesirable, and not adequately effective. Non-chemical control strategies then become more acceptable choices. Among non-chemical control strategies, the use of resistant varieties and/or species and biological control emerge with the greatest prospects. Silvicultural control employing alternative species is also not likely to be widely adopted because it may lead to the decline of a uniquely useful multipurpose tree species.

It has been reported by various workers (NFTA 1987) that among the 13 *Leucaena* spp. and over 50 interspecific hybrids recognized, *L. collinsii*, *L. esculenta*, *L. pallida* and few other species are resistant to psyllid damage. They have been used for crossing with *L. leucocephala* which is of commercial and economic importance. Leucaena Psyllid Trials (LPT) have been conducted, but the progress has been relatively slow and inherently time-consuming. Although considered reasonably tolerant to the psyllid, *L. diversifolia* K 156 can not compete with *L. leucocephala* in fodder production. Anticipating a success in obtaining stable resistant varieties, commercial seed production has been speculated but its market feasibility remains uncertain at this time.

As one of the main components in an integrated pest management system, biological control of both classical and augmentative nature has become a prominent choice for management of the leucaena psyllid. It is supported with evidence that indigenous natural enemies, especially some predators and entomopathogens, could be utilized for augmentative purposes, together and in addition to other known exotic natural enemies. Soon after the discovery of *H. cubana* in Hawaii in 1984 an exploratory entomologist from the Hawaii Department of Agriculture then stationed at Trinidad was instructed to search for potential parasites of *H. cubana* in its native range. As a result, an encyrtid nymphal parasite, *Psyllaephaeus* sp. nr. *rotundiformis* (Howard) (Hymenoptera: Encyrtidae), a eupelmid parasite, *Tetrastichus triozae* Burks (Hymenoptera: Eupelmidae), which is now called *Tamarixia leucaenae* Boucek, and a coccinellid, *Cycloneda conjugata* Mulsant (Coleoptera: Coccinellidae) were obtained and introduced to Hawaii (Nakahara *et al.* 1987).

T. leucaenae failed to propagate under quarantine condition in Hawaii and *C. conjugata* was found not adequately specific, thus only *P.* sp. nr. *rotundiformis* was screened, tested and finally approved for field release in June 1987 to become widely established in Hawaii.

This is an excellent example of timely management using classical biological control approach in an integrated pest management system for *H. cubana* in Hawaii. It is also surprising, and of great interest that classical biological control agents introduced for other target pest species have turned augmentative. The coccinellids, *Olla obdominalis* (Say) (= *Olla V-nigrum*) and *Curinus coeruleus* Mulsant (Coleoptera : Coccinellidae) were introduced to Hawaii from Mexico in 1908 and 1922 to control the scale insects and the coconut mealybug, *Nipaecoccus nipae* (Maskell) (Homoptera: Pseudococcidae), respectively (Funasaki *et al.* 1988, Nakahara *et al.* 1987). With the invasion of *H. cubana* in Hawaii in 1984, both coccinellids became abundant and were found predating on *H. cubana*, assuming a dominant role and providing effective "augmentative"

biological control in Hawaii.

C. coeruleus has been introduced and become established in several Pacific Islands including Guam and Saipan, Indonesia (Oka *et al.* 1987), Philippines and Papua New Guinea during 1986 (Waterhouse and Norris 1987), and in Thailand from Saipan and Hawaii in 1987 (Napompeth 1988). *O. abdominalis* was also introduced from Tahiti to New Caledonia in January 1987 (Chazeau *et al.* 1989). *O. abdominalis* was introduced to Thailand in April 1989 for the same purpose. *C. coeruleus* from Thailand were also introduced to Vietnam in April 1988, India in October 1988, and Burma in November 1988.

The nymphal parasite, *P.* sp. nr. *rotundiformis*, was introduced from Hawaii to Thailand in October 1987 through September 1988 (Winotai 1989). It has become established at some release sites in the northern highland and the lower central highland areas of the country. The parasites should be available for introductions to neighboring Southeast Asian countries during the 1989-1990 outbreak season of *H. cubana*. Few species of hyperparasites were reported from *P.* sp. nr. *rotundiformis* in Hawaii. These included *Pachyneuron siphonophorae* (Ashmead) (Hymenoptera: Pteromalidae), *Syrphophagus* (= *Aphidencyrtus*) *aphidivorus* (Mayr) and *Syrphophagus* sp. (Hymenoptera: Encyrtidae) (G. Funasaki pers. comm.). In Thailand after establishment, *P.* sp. nr. *rotundiformis* was found hyperparasitized by *Coccophagus* sp. (*Hymenoptera: Aphelixidae*) and an unidentified encyrtid (Winotai 1989). The presence of these hyperparasites may lead to a decrease in the control efficiency of *P.* sp. nr. *rotundiformis* but such incidence is unavoidable and, nevertheless, the benefits of *P.* sp. nr. *rotundiformis* introduction and establishment does not justify hesitation in introduction.

A number of indigenous natural enemies, especially the coccinellids and several other predators, have also been reported from affected areas (NFTA 1987, Waterhouse and Norris 1987). Entomopathogens such as *Conidiobolus coronatus* (Constantin) Batko, *Entomophthora* sp., *Beavaria bassiana* (Balsamo) Vuillemin, *Hirsutella thomsonii* Fischer and *Paecilomycetes farinosus* (Holm) Brown & Smith have also been found in association with *H. cubana* (NFTA 1987, Winotai 1989). These indigenous natural enemies and entomopathogens should be further utilized in augmentative biological control of *H. cubana* in respective areas where they have been encountered.

A combination of the use of resistant varieties of *L. leucocephala* together with the augmentation of indigenous natural enemies complimented with the introduction of available exotic natural enemies, or vice versa, would be unarguably the most appropriate approach and management strategies. These could be integrated in an IPM approach with an overall objective to lessen the damage and loss caused by the psyllid, and to keep the psyllid populations at tolerable levels, assuming that eradication of the psyllid is an unreachable goal.

Regional Collaboration

It is obvious that an effort to manage and control the leucaena psyllid requires close regional cooperation and collaboration among countries in the afflicted areas in Asia and the Pacific. Within each country a collaborative and co-ordinate effort is also essential and needs strengthening. *Ad hoc* committees on leucaena psyllid control and management in appropriate structure, function and authority have been established in Indonesia, Sri Lanka and Thailand. The Regional Research Program for Leucaena Psyllid Control has also been established with support from the Forestry/Fuelwood Research and Development (F/FRED) Project administered by the Winrock International Institute for Agricultural Development consisting of an Leucaena Psyllid Advisory Committee and coordinated through a regional coordinator drawn from national coordinators for Australia, Indonesia, Malaysia, Philippines, Republic of China (Taiwan), Sri Lanka, Thailand and the United States. The regional research program may eventually be expanded to cover Bangladesh, Burma, India, Nepal, Vietnam and other countries.

Other than F/FRED, the International Development Research Center (IDRC) has also contributed financially to help support research on the leucaena psyllid in Indonesia, the Philippines and the CAB International Institute of Biological Control (CIBC). The Nitrogen Fixing Tree Association (NFTA), Hawaii, has made available leucaena seeds for use in Leucaena Psyllid Trials (LPT) being carried out in several South and Southeast Asian countries. The State of Hawaii Department of Agriculture (HDOA) has also made available and supplied natural enemies of *H. cubana* for introductions to several countries. This regional collaboration holds promise for areas of research other than the psyllid. As initiated by the invasion of leucaena psyllid, such a regional cooperation could serve as a model and form a strong foundation for future collaborative research not

necessarily confined to the leucaena psyllid alone but also expanded into other areas of common and mutual interest.

Conclusion

With its rapid invasion and damage inflicted to leucaena the leucaena psyllid has generated and created numerous problems in leucaena-growing areas in the Asia and Pacific region. Those affected with leucaena psyllid problems range from poor farmers utilizing leucaenas for the subsistence to commercial ventures using leucaena for animal feed and wood products to researchers, governmental and international assistance agencies. Although the problems are readily identified, it remains unknown if solutions to the problems will be substantially and economically realizable. It is also unpredictable how long the problems will linger or how long it will take to develop acceptable and satisfactory solutions.

The leucaena psyllid has also generated "conflicts of interest" among people involved in the solution of the problem. Chemical control advocates attempted to push and promote synthetic pesticides as a control strategy, neglecting their impact on the environment, if not the lack of economic feasibility. Attempts to obtain reasonably stable and resistant varieties have been met with inadequate support.

Supporters of biological control require time and support in the exploration and search for effective natural enemies in the native range of the leucaena psyllid. Indigenous natural enemies are being evaluated for possible utilization. Introductions of available natural enemies require not only necessary expertise but also need infrastructure. The kinds of natural enemies available for introduction into the Pacific where the creeping giant sensitive plant is noxious may complicate future use of the mimosa psyllid, *Heteropsylla* sp. indet., already released in Queensland, Australia. Even if these introduced exotic natural enemies have become established, will the control be partial, substantial or complete and sustainable? Nevertheless, it has been agreeable and widely accepted that the solution of the leucaena psyllid problem must be an integrated pest management approach emphasizing the use of resistant varieties and biological control, including classical, augmentative and probably microbial control. Chemical control should have a minimum role in such IPM programs.

Despite these direct and indirect problems and conflicts of interest, a great deal of knowledge and research progress has been achieved in various countries of Asia and the Pacific region. Collaboration and cooperation have been established not merely at the individual or national levels but have expanded into regional and international status. Both differences and indifference have led all concerned and paved the way into a common avenue aiming at the common objective of the practical, acceptable and satisfactory solution of the psyllid problem in a sound ecological and economic manner.

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COUNTRY REPORTS

LEUCAENA PSYLLID IN AUSTRALIA - THE CURRENT SITUATION

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Abstract

Following the rapid initial spread of the leucaena psyllid in Queensland (Bray and Sands 1987), infestations were reported throughout other parts of northern Australia (Western Australia and the Northern Territory). Leucaena in Australia is used almost exclusively for grazing by beef cattle and the most extensive plantings (ca. 20,000 ha) are in Central Queensland. Rainfall in this area is a highly seasonal 600-750 mm per annum, but growing seasons since the arrival of the psyllid have been unusually dry. Psyllid populations have fluctuated in all areas, but only in the higher-rainfall coastal areas has there been significant damage. In north and southeast Queensland production can be reduced by at least 50% due to the psyllid (Palmer *et al.* 1989, Bray unpublished data).

The psyllid is not considered a major problem by people growing leucaena in inland Queensland in the drier environments, although there is considerable apprehension about the possible effect of the psyllid if a wet season should eventuate. Agricultural extension authorities continue to recommend planting leucaena for fodder.

The following people are involved in research on the psyllid in Australia:

1. R. A. Bray (CSIRO Division of Tropical Crops and Pastures, Brisbane): Selection of leucaena for resistance and population trends of the psyllid in southeast Queensland.

2. P.M. Room, M. H. Julien (CSIRO Division of Entomology, Brisbane): Sampling methods and natural enemies of the psyllid.

3. R. Elder (Queensland Department of Primary Industries, Rockhampton): Population surveys and sampling methods in Central Queensland.

Results are being prepared for publication.

Resistance of Leucaena leucocephala to the Psyllid

Identifying resistant plants

We have looked for resistant plants in four main ways:

1. Observation of trees in nurseries or isolated plantings.

This was the first approach to selection for resistance, and the results of early observations have been reported (Bray and Sands 1987). Only gross differences can be observed using this method and often trees that appeared resistant would, upon further testing, not be confirmed as such. Although it is possible to observe large numbers of trees over long periods (an important consideration), the disadvantages of localized effects (such as moisture supply), the existence of different growth stages within the population, uneven psyllid infestation, and (frequently) a lack of replication or controls, make this method unreliable.

2. Growing hybrid populations as single plants.

We have screened about 1,000 F2 and F3 plants from various interspecific hybrids for psyllid resistance. These had been established in rows 2.5 m apart, with 50 cm between plants, before the appearance of the psyllid. *Leucaena diversifolia* was included in most of the crosses and provided a potentially useful source of resistance. We included a control in these plantings by establishing *L. leucocephala* cv.

Cunningham as every tenth plant. Thus, the performance of any hybrid can be compared to a known susceptible control. The hybrids have been rated for resistance three times over two growing seasons, with approximately 40 hybrids showing sufficient apparent resistance to be worthy of future study. Seed is being harvested where possible. There were problems with uneven plant growth (due to the poor choice of an experimental site) and the variable infestation of psyllids. However, these problems are not unique to this method.

3. Screening seedlings.

We have screened over 50 lines from a range of species (some selected for "resistance" in nursery plantings) using the technique described by Bray and Woodroffe (1988). Briefly, seedlings are raised in 20 cm pots (one per pot) and, when 30-50 cm tall, placed in psyllid-infested stands of leuceana in the field, with 10-12 replicates of each line. Data on psyllid infestation and plant resistance are obtained over several weeks. The first of these experiments enabled us to clearly distinguish different degrees of resistance between accessions of *L. diversifolia* and *L. pallida*. However, none of the *L. leucocephala* accessions that had been selected as resistant in the nursery proved to be resistant in the field (Bray and Woodroffe 1988).

Difficulties with screening seedlings are largely related to problems associated with maintaining potted plants in the field. If the plants get too large, they may be subject to wind damage and it may also be difficult to keep them properly watered. Adequate field populations of psyllids are not always available and one experiment failed due to a sudden dramatic decline in the psyllid population. We have used this method in an insect-proof glasshouse also, with reasonable results. However, the damage levels of some lines known to be resistant in the field (e.g. CPI46568, K784) were much higher in the glasshouse. Another problem with screening seedlings is the lack of any knowledge about the relationship between the resistance of seedlings and adult plants. The advantages of this method include the ability to have a range of controls (both susceptible and resistant), the ability to screen at least moderate numbers of accessions, and the confidence in results generated by adequate replication.

4. Leucaena psyllid trials (LPT).

We have established a site of the NFTA Leucaena Psyllid Trial (LPT) where plots of 40 plants are compared in a replicated experiment. In general, our results are consistent with those summarized by Glover (1988). K784 and K376 are both resistant and high-yielding in the replicated trial, while K785, KX1, CPI46568 and CPI84351 are very promising, although unreplicated. This type of trial is good for comparing small numbers of lines for resistance and yield. In our trial, the resistance established using seedlings in pots have been confirmed in the LPT. Whether resistance established in mixed plantings such as these reflect those in large monospecific plantings remains to be seen.

Methods of assessing resistance

There are only two published methods for assessing psyllid resistance. The methods of Bray and Woodroffe (1988) and NFTA use rating systems for assessing egg and nymph numbers and damage, but the methods differ in the plant parts assessed. The NFTA scheme assesses adults, eggs and nymphs on a 7 cm juvenile leaf, while we assess the whole shoot down to the first fully-expanded leaf. We feel that this is more appropriate since eggs may be confined to the very small unexpanded leaves but nymphs occur anywhere on the shoot. By restricting ratings to one juvenile leaf, important information about nymph abundance and distribution and other data may be missed. Both rating systems for nymphs are based on estimates of nymph numbers and, in hindsight, seem somewhat hopeful and optimistic. It is impossible to accurately count, in the field, the number of nymphs present and it is our experience that if any nymphs at all can be easily seen, then there are probably some hundreds present! We intend to modify our rating systems for eggs and nymphs to three simple categories: none, few, many! Neither method of assessing resistance can adequately handle the differences in plant form between species (e.g. *L. pallida* has vast numbers of very small leaflets compared to *L. leucocephala*). The damage ratings of the two systems are similar, although the rating scales differ slightly in the more severe cases.

The ultimate test of resistance is, of course, to establish the reduction in yield of a particular genotype due to the presence of the psyllid. This is a very difficult and time-consuming proposition. Furthermore, psyllid resistance is of value only when psyllids are present. In many locations psyllid populations fluctuate throughout the year, and the advantage of resistance may not be consistent. However, the cumulative effect of psyllid damage on subsequent growth may be significant.

The ideal method of assessing resistance should account for a number of factors, including variation in plant phenology (e.g. height, branching, foliage density, effects of shading, and age of plants) and availability of water and nutrients, which may confound any observed "resistance". Accurate experiments to assess resistance must be designed to provide sufficient replication of each variety, susceptible controls and a "saturated" psyllid environment, such as the high populations generated by stands of susceptible varieties. The plants being compared should be similar in age and phenology and be exposed to the same environmental conditions. Only when these conditions are fulfilled can there be confidence in the assessment.

Sampling Techniques to Assess Populations of the Psyllid

To be useful, a population sampling method must have the following attributes:

a. Provide statistically sound estimates for a range of insect population densities under a range of conditions of plant size, plant condition, climate, and season.

b. Be inexpensive enough to permit weekly sampling of populations, or daily sampling of populations for life table studies, at a number of sites over extended periods. Depending on the study undertaken, sampling weekly or daily are the minimum intervals likely to produce useful information for this insect which has a generation of about three weeks.

Several methods for rating population sizes have been developed (NFTA system, Bray and Woodroffe 1988), but they are insufficiently detailed for accurate population monitoring or life table studies and there are questions about their statistical reliability. A method of destructive sub-sampling and counting has been developed by Stechman *et al.* (1987) and another is being developed by Elder and Mayer in Australia. Both of these are yet to be tested for cost and reliability.

Assessment of techniques

We are attempting to develop a sampling method to fit the above attributes. So far the following techniques have been assessed.

1. Absolute counts of fresh living material.

Counting all individuals on each terminal was too time-consuming (also see Stechman *et al.* 1987). It has taken up to 4 hours to count all of the nymphs and eggs on a single leucaena terminal with average times of 1.5 to 2 hours per terminal when individuals were numerous. To obtain a coefficient of variance about the mean below 20%, more than 15 terminals must be assessed. On average, this method would require at least 22.5 man hours at the microscope per week per site. Furthermore, a coefficient of variance of 20% is not acceptable for detailed life table studies and, to achieve acceptable levels of variance, 20 to 30 terminals would be required.

2. Washing terminals in 70% alcohol to dislodge psyllids.

Terminals were placed in a container with 70% alcohol and shaken vigorously. Psyllids remaining on the plant were counted and those dislodged were filtered from the alcohol solution and counted. The number of psyllids washed from the plant varied with the most abundant stage of the psyllid. As expected, very few eggs were dislodged. Very few first instar nymphs were dislodged because they remained between the folded leaves near their egg cases. The likelihood of being dislodged increased with instar size, but the proportion dislodged varied between sample dates. These inconsistencies for the one site sampled suggested that this technique is unlikely to provide consistently accurate estimates of psyllid populations.

3. Fumigation in acetic acid.

The cut ends of terminals were inserted in various concentrations of acetic acid to encourage nymphs to retract their stylets prior to washing in alcohol. Uptake by the plant terminals, if it occurred, had no effect on the psyllids. However, when the container of acetic acid and the terminal were covered, for about 20 minutes, the acetic acid fumes affected the psyllid. Nymphs became more active but the results after washing and counting were not improved.

4. Use of ultrasound to dislodge eggs.

Preliminary tests were carried out using an ultrasound cleaning apparatus to break the egg stalk so that eggs could be washed from the plant prior to counting. The tests were carried out with the terminals in water. In all cases the plants disintegrated and the eggs remained attached!

5. Washing with 70°C water and brushing.

This technique is used to remove aphids from lucerne but was unsuccessful in removing psyllids from leucaena primarily due to the softness and pliability of the young leucaena tissues.

6. Fumigation with ethyl acetate (ether).

Fumigation with ether failed to dislodge the nymphs. Nymphs died with their stylets inserted and could not be shaken or washed from the plant.

7. Other methods not yet assessed.

There are a number of other methods yet to be tested, including the use of dry heat to drive nymphs from the plant, fumigation with methyl isobutyl ketone, used to sample pea aphids (Gray and Schuh 1941), and washing in 1-2% sodium sulphide.

Predator and Parasite Surveys

The psyllid has become prey to predators and possibly host to parasites that were part of the Australian fauna before the psyllid entered Australia. Surveys to identify organisms attacking the psyllid are underway. Later, we will determine whether any of these natural enemies significantly affect populations of the psyllid.

Preliminary surveys of predators began in late 1988 in Southeast Queensland and in January 1989 in Central Queensland. Sites are presently being selected for regular surveys in a variety of habitats and surveys of these sites will commence in February 1989. These surveys will include collections of psyllids and their parasites and predators. Information about natural enemies will assist our understanding of the factors affecting psyllid populations in Australia and in developing strategies to control the psyllid.

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LEUCAENA PSYLLID IN REPUBLIC OF CHINA - A COUNTRY REPORT

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I. Psyllid Status in Taiwan

Leucaena psyllids were first found in Taiwan in 1985, but attracted no attention to the researchers as well as farmers. Less damage was detected in leucaena plantations by the end of the year. However, when the damage was serious in 1986 and 1987, psyllids became the problem in this country. More and more leucaena plantations were replaced by *Eucalyptus camaldulensis*, *Eucalyptus grandis* and other tree species. In 1988, the psyllids population were observed to decrease. Leucaena was seen to recover and regrow quite well since then.

II. Action Control Plans

1. Chemical Control

Plantations of Jau-Fong Farm, Hualien, sprayed insecticides by airplane every four months in 1987 supported by the Council of Agriculture and Chung-Hwa Pulp Corporation. It worked well but lasted only few weeks. Many kinds of insecticides could be used for killing psyllids. Most ecologists and entomologists were against the method. So chemical control of leucaena psyllid is no longer used in Republic of China.

2. Biological Control

Survey of natural enemies is carried out by Dr. An-Li Yao, entomologist in Academia Sinica. Up to December, 1988, eight species of coccinellids, five species of bugs and one species of parasitic wasp were observed as natural enemies of the psyllids.

Entomogenous fungi were found to relate with the death of leucaena psyllid in the field since 1986. More than ten species of fungi were isolated from diseased psyllids. Three species were found most effective in killing the psyllids. The isolation and mass production techniques of the fungi have been developed. Field spray of the fungal spores over leucaena plantations was conducted in Eastern Taiwan, Hualien, supported by Chung-Hwa Pulp Corporation. Vigorous growth of the plants was observed after three times spraying in 1987. Data of the experiment are being collected and analyzed.

3. Genetic Improvement

Psyllid resistant species and accessions such as *Leucaena collinsii, L. pallida, L. esculenta, L. retusa, L. greggii* etc. have been introduced to Taiwan from Hawaii since 1985. Three sites of arboretum were established for the purpose of psyllid resistance survey and for conducting breeding programs. Hybrids from crosses of *L. diversifolia, L. leucocephala, L. pallida, L. collinsii* have been obtained.

Exploration of tolerant trees from existing leucaena plantations, supported by F/FRED funding, was initiated in 1988. Seeds of four trees of *L. leucocephala* and six trees of *L. diversifolia* ssp. *diversifolia* have been collected. Progeny test was conducted to assess whether the tolerance is inheritance or not. Selecting of both psyllid resistant and vigorous individuals from hybrids has been proceeded. Some hybrids has been extended to F_4's.

III. Research Related to Psyllid Control

1. Survey and sampling techniques - funded by F/FRED. Initiated by Dr. J. C. Chen. His six month's data show that leucaena psyllid is

randomly distributed in Taiwan.

2. Selection of dry and hot tolerant entomogenous fungi - supported by F/FRED. Dr. W. Y. Wang of Taiwan Forest Research Institute (TFRI) takes responsibility of the study.

3. Preference study of leucaena psyllid - Drs. J.T. Chao and F.J. Pan of TFRI.

4. Tissue culture of psyllid resistant species from mature plants-plantlets from *L. diversifolia* seedlings have been successfully produced by TFRI. Tissue culture from mature plants are the subject of 1989 study.

5. Induced polyploids from psyllid resistant species - Dr. F. J. Pan of TFRI.

6. Production of haploid leucaena by means of anther culture - Dr. F. J. Pan of TFRI.

THE STATUS OF LEUCAENA PSYLLID, *HETEROPSYLLA CUBANA* CRAWFORD, IN INDIA

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Abstract

Heteropsylla cubana Crawford in India was observed for the first time in the beginning of 1988 at Madras. It is suspected to have entered South India from Sri Lanka or Andamans or Northern India from the Southeast Asian countries.

Although *Leucaena leucocephala* was introduced to India during the 19th century, its real cultivation started in 1972. Now it occupies an area of 10,000 ha in Karnataka State alone. Within six months of its entry, the psyllid has invaded the entire area of Leucaena. The Karnataka Plantation Corporation planned to extend the area under leucaena to over 4,000 ha during 1988 but abandoned the idea for fear of loosing the plantation and destroyed the nursery of 200,000 seedlings raised for the plantation.

H. cubana primarily damages the new growth of leucaena, resulting in the total loss of fodder. The life cycle is completed in 10-21 days, and the population was as high as 1,675 nymphs and adults per compound leaf during May 1988. Among the different species of leucaena, *L. leucocephala* is the most susceptible and *L. pulverulenta* is the most resistant. A number of leucaena hybrids have varying degrees of resistance.

In addition to the psyllid, a number of other insects attack *L. leucocephala*. About 30 species belonging to Coleoptera, Hemiptera, Lepidoptera and Orthoptera have been observed in South India. Among these, the weevil, *Dereodus pollinosus*, and a moth larva, *Ascalenia* sp., are the most damaging.

In spite of a number of natural enemies available in India, none regulate *H. cubana* populations except the coccinellid, *Menochilus sexmaculatus* (F.).

Endosulfan, monocrotophos, quinoalphos and phosalone have been found effective up to 30 days after application. Introduction of the predator *Curinus coeruleus* Mulsant would be a possibility to manage the populations of this psyllid.

Current Status

Within a short time of its entry to India in early 1988, the leucaena psyllid, *Heteropsylla cubana* Crawford, has become ubiquitous wherever *Leucaena leucocephala* exists in the country. *L. leucocephala*, popularly known as 'Soo-babul' in India, was introduced to this country during the last century (Krishnamurthy and Munegowda 1982). Later, during 1952-53, it was introduced for research at the Agricultural Research Station, Kovilpatti in Tamil Nadu and was found to be a good green leaf manure, fodder, fuel and pole (Narayanan and Sivagnanam 1962). During the same period *L. leucocephala* was tested as a pasture crop for fodder and soil conservation in Uttar Pradesh (Sinha and Deys 1956, Khan 1957). It was also introduced to north Bengal (Palit 1980).

In 1974, the University of Agricultural Sciences in Bangalore collaborated with the Karnataka Dairy Development Corporation to expand the area under 'Soo-babul' cultivation. The Karnataka Forest Plantation Corporation initiated an ambitions plan to plant over 10,000 ha 'Soo-babul' to meet the fodder requirement of the state. By expanding the area under 'Soo-babul', the Karnataka Dairy Development Corporation hoped to alleviate the shortage of

fodder caused by the continuous drought during the previous four years. These hopes were shattered due to devastation of 'Soo-babul' by the psyllid. More than 30 species of insect pests have been recorded on leucaena in India, including Coleoptera, Hemiptera, Lepidoptera, and Orthoptera (Thakur and Pillai 1985) but no pest has threatened the survival of leucaena as the psyllid has done in less than one year.

The psyllid is suspected to have entered India from Sri Lanka or Andamans where it was observed earlier. In order to spread over a very large area of the Pacific Ocean land masses in less than two years, it must have been carried in moving air masses (Waterhouse and Norris 1987). Gopalan *et al.* (1988) reported a high incidence of the psyllid on *L. leucocephala* with more than 300 nymphs and adults per young shoot of 15 cm height and low incidence on *L. collinsii*, *L. pulverulenta*, *L. tricodes*, *L. lanceolata* and *L. diversifolia*. They found no incidence of the psyllid on *Mimosa pudica* L., a member of the same sub-family Mimosoideae, of the family Mimosaceae, as the genus *Leucaena*. In Karnataka the resistant or tolerant varieties include hybrids of *L. leucocephala*, K636, K-527, K-44; *L. diversifolia*, K-156, K-784, K-785; *L. pallida*, K-376, and *L. esculenta*, K-897. While *L. leucocephala* is the most susceptible, *L. pulverulenta* is the most resistant. According to Sorensson and Brewbaker (1986), the *Leucaena* species in Hawaii with outstanding psyllid-resistant germplasm are *L. collinsii*, *L. pallida*, *L. esculenta*, *L. retusa* and *L. diversifolia*.

The symptoms of damage observed in India are similar to those reported from other regions. Primary damage is to the young foliage. Leaflets turn yellow, curl, wilt, become black and wither. Trees look almost bare. Even isolated *L. leucocepha* plants in the middle of evergreen forests in the Western Ghats of Karnataka were not free of the psyllid attack.

The biology of the psyllid in regions of South India is similar to that in other regions. The incubation period (2-3 days), nymphal period (8-10 days), longevity of adults (7-10 days) and fecundity (350-400 eggs/female), are consistent with the reports from Hawaii in Waterhouse and Norris (1987).

The highest population of 1,675 nymphs and adults per compound leaf has been observed during May 1988 in South India (Parvathi *et al.* 1989). However, the density of the psyllid varies, not only from species to species of *Leucaena* but between hybrids of the same species of *L. leucocephala*.

A number of natural enemies have been observed feeding on the psyllid. Two coccinellids, *Menochilus sexmaculatus* F. and *Scymnus gracilis* Motsch, unidentified preying mantids, reduviids, mirids, and chrysopids have been reported feeding on various stages of the psyllid (Gopalan *et al.* 1988). The staphylinid beetle predator of brown planthopper and green leafhopper, *Paederus fuscipes* Curtis, feeds on all stages of the psyllid. The white muscardine fungus, *Beauveria bassiana*, is reported to give 64-100% control in 7-35 days after application (Gopalan *et al* 1988).

The National Center for Integrated Pest Management, Bangalore, has screened the following natural enemies on *H. cubana*.

Coccinellidae	-	*Menochilus sexmaculatus* (F.)
	-	*Curinus coeruleus* Mulsant introduced from Thailand.
Chrysopidae	-	*Chrysopa* sp.
Spiders	-	5-6 species of spiders.

Parvathi *et al.* (1989) observed a social wasp *Ropalidia montana* Carl (Hymenoptera: Vespidae) and a coccinellid predator *Harmonia* sp., predating on the nymphs, but concluded that the populations of these predators were too low to cause substantial reduction of the psyllid.

An anthocorid bug, *Cardiastethus* sp., was observed by this author feeding on the eggs and nymphs of the psyllid. The bugs hide under any cover during the day and feed during night. *Cardiastethus* sp. found in the galleries of the coconut leaf eating caterpillar (*Opisina oeronosella* Walker) feed on the eggs and early

larval instars. It also feeds on the eggs of *Corcyra cephalonica* (Lepidoptera), *Tribolium castaneum* (Coleoptera), *Bracon brevicornis* and *Parasierola nephantidis* (Hymenoptera) (Abdurahiman *et al.* 1982).

An anthocorid bug, *Paratriphleps laevisculus*, is reported to be abundant in Hawaii feeding on the eggs and nymphs of the psyllid (Nakahara *et al.* 1987). It may take more time before any of the indigenous natural enemies, including the anthocorid bug, prove to be effective in checking the psyllid population.

Little success has been achieved with other methods of control, including light traps, sticky traps and motorized suction trap at the Tamil Nadu Agricultural University (Gopalan *et al.* 1988).

At present the population of the psyllid fluctuates depending on the availability of the feeding space. In completely defoliated plants, a large number of adults overcrowd on older leaves for want of young shoots to lay eggs.

In the short-term, to save *L. leucocephala* from the ravages of the psyllid attack, the goals are to select suitable resistant or tolerant the varieties, and to search for and to introduce effective natural enemies.

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OUTBREAK OF PSYLLID, *HETEROPSYLLA CUBANA* CRAWFORD, ON LEUCAENA AND ITS OUTLOOK IN ALLEY CROPPING IN INDIA

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Abstract

Psyllid (*Heteropsylla cubana*) (Hemiptera: Psyllidae) on *Leucaena leucocephala* (Lam.) de Wit is assuming the status of a serious pest unknown prior to 1988, particularly in India, and is threatening the cultivation of leucaena. In India, the psyllid is widespread on leucaena and its population density varies from place to place. Leucaena plantations, less than three years old, are damaged extensively by the psyllid. The pest is more destructive in the isolated, drier areas in Southern India than in Northern India. There are unconfirmed reports of the psyllid attacking leucaena in alley cropping systems in all States of India. In screening of leucaena cultivars for psyllid resistance under field conditions for one year, cultivars such as K6, K8, K500 and K636 have shown higher field tolerance. Further testing is necessary and the resistant species or varieties must be substituted for the susceptible ones to sustain production. Evaluations of other traits, such as productivity, palatability, and nutritive value must be included in the screening process. Natural enemies, such as predatory beetles, bugs, spiders, larvae of syrphid flies, wasps, and dragonflies, have been associated with the psyllid on leucaena. Their role as biological control agents require further investigation. Insecticide applications have reduced the pest populations temporarily. However, an integrated pest management approach is required to make leucaena cultivation profitable in alley cropping and agroforestry systems in India.

Introduction

Leucaena leucocephala (Lam.) de Wit is a popular high-protein tropical legume. It is the primary leguminous crop in alley cropping systems in which food or forage crops are grown in alleys formed by hedge rows on marginal or sub-marginal lands. The principal food crops grown in alleys with leucaena are *Cenchrus* sp. and *Pennisetum pedicellatum* (Deenanath grass). In Uttar Pradesh, Madhya Pradesh, Maharashtra and Andhra Pradesh, cotton, sugarcane and cocoa crops are grown alleys with leucaena. Leucaena is also the most suitable shade tree in plantation crops.

The psyllid is a pest of leucaena in the Caribbean islands. In late 1982, they caused die-back by sucking the sap of crops in Florida (Othoman and Prine 1984). Subsequently, Mitchell and Waterhouse (1986) observed the psyllid in Hawaii in 1984 and later in Southeast Asia. Among the psyllids, *Heteropsylla cubana* Crawford is the only species observed in Asia and India. The pest entered India during February-March 1988 (S. Jayaraj pers. comm.).

Leucaena was introduced to Karnataka in late 1970. Through the courtesy of Dr. James L. Brewbaker, NFTA, Hawaii, U.S.A., Dr. Michael G. Fulloon, CSIRO, Australia, and USAID, as many as 67 varieties of five species were introduced for trial in one of the projects operated by the senior author and sponsored by the Karnataka State Government (Krishnamurthy and Munegowda 1985). A list of 67 varieties maintained at the University of Agricultural Sciences, Bangalore since 1970 is

Table 1. List of *Leucaena* varieties maintained at the University of Agricultural Sciences, Bangalore.

1. K-1	18. X-62	35. K-358	52. K-678
2. K-4	19. K-63	36. K-397	53. UAS-1
3. K-5	20. K-67	37. K-397-1	54. USA-2
4. K-6	21. K-69	38. K-500	55. UAS-3
5. K-8	22. K-72	39. K-584	56. UAS-4
6. K-12	23. K-72A	40. K-584-1	57. CPI.58396
7. K-22	24. K-74	41. K-595	58. CPI.74793
8. K-24	25. K-94	42. K-598	59. CPI.69189
9. K-26	26. K-132	43. K-605	60. CPI.34666
10. K-27	27. K-156	44. K-605-1	61. CPI.61227
11. K-28	28. K-217	45. K-607	62. CPI.23145
12. K-29	29. K-217-1	46. K-608	63. EC.60030
13. K-30	30. K-329	47. K-609	64. Cunningham
14. K-38	31. K-329-1	48. K-615	65. Carriedo
15. K-44	32. K-340	49. K-629	66. Local
16. K-45	33. K-340-8	50. K-636	67. Thailand
17. K-61	34. K-341	51. K-636A	

given in Table 1. Five leucaena species were *Leucaena leucocephala* Lam. de Wit., *Leucaena diversifolia* Benth., *Leucaena pulverulenta* Benth., *Leucaena esculenta* Benth., *Leucaena trichodes* Benth.

Identification

An ambitious program on leucaena production is jeopardized due to the psyllid invasion of India. Many farmers are likely to loose their leucaena crops due to psyllid infestation. There is an urgent need to initiate an integrated pest management program including biological control, use of resistant species and varieties, and agronomic manipulations.

In 1980, the leucaena psyllid was observed in the Dominican Republic where it caused serious damage in the dry season (Pound and Martinez 1983). The Dominican insect was identified as *Heteropsylla cubana* Crawford. The psyllid was first reported as a pest in South and Central America, the Caribbean islands. Florida and Hawaii

(Othoman and Prine 1984, Sorensson and Brewbaker 1984). Later the psyllid moved into India through Southeast Asia, Sri Lanka and spread into all States within 3-4 months. Now the psyllid has been established as a serious pest of leucaena in all States of India.

Distribution

The spread of the psyllid across the Pacific Ocean occurred very rapidly. They are carried probably by aircraft and large air masses at higher elevations. The original distribution appears from the Caribbean along with the east

coast of Mexico and northern South America. In 1982, the pest attacked leucaena plants and caused defoliation and die-back in Florida. The psyllid was first noticed in the Philippines in 1985 and defoliation occurred in Indonesia in early 1986 and Thailand in late 1986. The psyllid damaged crops in Sri Lanka during 1987 and then migrated to India. By February 1988, the psyllid was observed in leucaena plots in the Southern Indian States.

In Karnataka, the leucaena psyllid was observed for the first time in Mudigere, Chikmagalur district in May 1988; Hebbal, Bangalore district in June 1988; Navile in Shimoga, Kandali and Amruth Mahal Kaval lands in Hassan, and parts of Dharwad and Bijapur districts in August 1988. The intensity of infestation varied in these places.

Nature of Damage

The sudden outbreak of *H. cubana* threatens the planting of leucaena throughout the country. The psyllid is present in epidemic proportions in Southern India. The psyllid is exclusively a sap sucking pest of vascular plants. The pest infestation causes leaf curling and drying. Leucaena trees grown in alley crops under rainfed conditions provide the shelter for nymphal survival and development. Apparently a high psyllid population density caused severe damage to the host crop.

The weather parameters of the study site at Hebbal for 1987-1988 are shown in Table 2. Rains occurred from March through December with a relatively dry spell in June and July. The maximum temperature ranged from 25.4°C in December to 33.3°C in April. The minimum temperature ranged from 14.4°C in January to 21.8°C in May. The relative humidity ranged from 81% in March to 96% in December and January. Although data on the incidence of the psyllid in different months must be obtained, it appears that psyllid attack is relatively greater

Table 2. Weather parameters of study site at the University of Agricultural Sciences, Hebbal, Bangalore.

Month/year	Rainfall (mm)	Temperature(°C) Maximum	Minimum	Relative humidity (%)
1987				
June	64.1	30.9	20.9	87
July	18.0	30.7	20.1	89
August	98.0	28.8	20.1	92
September	73.5	30.1	20.3	90
October	73.5	28.5	19.8	96
November	45.3	27.4	17.6	93
December	25.1	25.4	19.6	96
1988				
January	Nil	27.4	14.4	96
February	Nil	30.1	18.2	91
March	29.5	32.0	19.0	81
April	72.9	33.3	21.0	84
May	117.9	32.8	21.8	87

during the drier period.

Psyllid damage ratings on some cultivars of leucaena are summarized in Table 3. Resistance was generally not observed in any cultivars. Higher field tolerance of psyllid (6-8 on rating scale) was observed for cultivars K6, K8, K500 and K636 where the loss of young leaves varied from 26 to 75 percent. The psyllid survived on these trees, reducing fodder productivity and having little or no effect on tree growth.

In almost all psyllid-infested States of India, coppice shoots were heavily infested by the psyllid. Infested shoots were completely covered with nymphs and their honey dew excretions. They congregate by hundreds on tender shoots, frequently causing complete defoliation. Pound and Martinez (1983) also reported that psyllid attack was severe on tender shoots during dry spells. A rapid damage assessment was conducted in 1988 (Table 4). Psyllid infested almost 100 percent of the trees in all ten stands observed in July and September. On average infestation occurred 60.5 and 77.0 percent of the shoots on each cultivar in July and September, respectively. Leaf curling damage was observed. The three-year-old trees were more heavily infested than younger trees.

Table 3. Psyllid infestation ratings at a tree height of 3 m for *Leucaena leucocephala* cultivars at the University of Agricultural Sciences, Bangalore.

Cultivars	Rating	Remarks
K-6	6.9	Fairly tolerant
K-8	6.4	Fairly tolerant
K-28	8.0	Susceptible
K-29	7.1	Susceptible
K-67	8.0	Susceptible
K-500	6.3	Fairly tolerant
K-636	6.3	Fairly tolerant
UAS-1	7.8	Susceptible
UAS-2	7.7	Susceptible
UAS-3	8.0	Susceptible

Rating Scale:

6 Loss of 26 to 50% of leaves.
7 Loss of 51 to 75% of leaves.
8 Loss of 100% leaves and blackening of lower leaves.

The ratings of the abundance of different stages of the psyllid on leucaena cultivars at Bangalore are presented in Table 5. A 1-10 score was used to evaluate psyllid abundance (adults, nymphs and eggs) and shoot tip damage on young vegetative shoots (Table 5). A score of 1-3 represents high resistance or evidence of resistance, 4-6 represents tolerance, and 7-9 represents susceptibility and often severe damage. High numbers of adult psyllid were found on the new sprouts. Psyllid abundance

Table 4. Extent of psyllid infestation on leucaena in Karnataka during July and September 1988 (Age of trees = 6 years).

Leucaena cultivars	Number of trees				Percent infested shoots/trees	
	July		September			
	Examinea	Infested	Examined	Infested	July	Sept
K-6	8	6	10	6	51	75
K-8	7	7	7	7	40	81
K-28	4	4	4	4	64	78
K-29	5	5	5	5	63	74
K-67	9	9	10	10	72	86
K-500	6	6	6	6	78	92
K-636	7	5	7	5	44	46
UAS-1	8	8	8	8	71	85
UAS-2	9	9	9	9	66	68
UAS-3	6	6	6	6	56	85

differed among leucaena species. There were fewer psyllids on the upper storey foliage of older leaves than on the new sprouts. Psyllid infestation caused defoliation, deformation, stunting and die-back of tender shoots, and pre-mature fruit drop.

Agronomic Manipulations

The early control of the psyllid included short term measures, such as pruning and burning of heavily infested shoots and smoking the trees. These treatments enhance the regrowth capacity of the plant. Agronomic measures including weed control and litter removal also deter the pest away for a short period.

Resistance to Psyllid Among Leucaena Species and Cultivars

Strategies for developing psyllid resisant/tolerant species or varieties were initiated in 1988. In many parts of the country, *L. diversifolia* (K156, K784), *L. collinsii, L. pallida* (K376), *Acacia angustissima, A. villosa, Gliricidia sepium, Calliandra calothyrus, Sesbania grandiflora* and *Sesbania sesban* grew well and were not attacked by psyllid. In alley crops, the pest populations were high during the dry season and lower during the rainy season but population build up once again threatened leucaena plantings.

Five species, *L. leucocephala, L. pallida, L. collinsii, L. diversifolia,* and *G. sepium*, were evaluated for psyllid resistance in a Nitrogen Fixing Tree Association trial. The plant damage and number of psyllid present per treatment are shown in Table 6. Of these species, *L. leucocephala* showed fair growth and was susceptible to the psyllid infestation. *L. diversifolia* (K785 and K156) and *L. pallida*

Table 5. Ratings of the abundance of different stages of psyllid on *Leucaena* spp. at the University of Agricultural Sciences, Bangalore.

Species	Rating*		
	Adults	Nymphs	Eggs (% leaf cover)
Leucaena leucocephala K636	4-6	4-7	6-8
L. pallida K376	1-2	2-4	3-4
L. collinsii	1-7	4-6	6-7
Hybrid K1 (*L. diversifolia* x *L. pallida*)	3-7	3-5	4-6
Hybrid K2 (*L. leucocephala* x *L. pallida*)	2-4	5-7	7-8
Hybrid K3 (*L. diversifolia* x *L. leucocephala*)	1-2	4-6	6-8
L. diversifolia x 156	1-2	2-4	3-5
L. diversifolia 46568	2-4	4-6	5-8
L. diversifolia 33620	1-2	5-6	6-8
L. leucocephala KB	4-9	7-9	8-9
Gliricidia sepium	1-2	2-4	3-5
Leucaena diversifolia K785	2-4	3-5	6-8

*** Psyllid count rating scale**

Adults	Nymphs	Eggs
1. No adults	No nymphs	No eggs present
2. 1-5 adults	1-5 nymphs	Occasionally eggs present
3. 6-10 adults	6-10 nymphs	Eggs on most leaflets
4. 11-15 adults	11-15 nymphs	Egg masses on less than 10% of leaflets
5. 16-20 adults	16-20 nymphs	Egg masses on 25% of leaflets
6. 21-30 adults	21-30 nymphs	Egg masses on 50% of leaflets
7. 31-40 adults	31-40 nymphs	Egg masses on 75% of leaflets
8. 41-50 adults	41-50 nymphs	Egg masses cover leaflets
9. 51-90 adults	51 and above	Egg masses cover leaves and stem
10. Total defoliation	Total defoliation	Total defoliation

(K376) grew well and were psyllid resistant. *L. leucocephala* (K8 and K636) were fairly tolerant to psyllid and showed moderate to good adaptation. Of the hybrids, KX3 was resistant to the psyllid and well adapted to the local conditions.

Biological Control

The psyllid, like all other plant feeding insects, has natural enemies (predators, parasites, and pathogens) which regulate their populations. In

Table 6. Psyllid scoring in Nitrogen Fixing Tree Association trial at the University of Agricultural Sciences, Bangalore (Gandhi Krishi Vignana Kendra Campus). (Age of trees - 6 months).

Species	No. of plants Surviving/10 plants		Plant height	Plant damage	Scoring Means of 10 plants/plot		
	July	Nov	(cm)	(mean)	Adults	Nymphs	Eggs
L. leucocephala K636	3.0	2.0	16	0.1	0.1	C	0
L. pallida K376	4.0	3.5	12	0	0	0	0
L. collipsii	4.0	3.8	29	0.2	0.1	0	0.1
Hybrid KX1	0.8	0.4	17	0.1	0.5	0	0.5
Hybrid KX2	0.9	0.5	11	0.6	0.2	0	0
Hybrid KX3	1.0	0.8	15	0.1	0.1	0	0
L. diversifolia K156	3.1	2.0	10	0	0	0	0
L. diversifolia 46568	1.1	1.0	21	0.2	0.4	0	0.1
L. diversifolia 33820	2.0	2.0	23	0.3	0.2	0	0
L. leucocephala K8	4.0	3.0	35	1.0	1.0	0	8
Gliricidia sepium	4.0	2.5	16	0.4	0.3	0.1	0
L . diversifolia K785	4.0	3.7	18	0.9	0.4	0.3	0.5

R = Resistant T = Tolerant S = Susceptible
WA = Well adapted MA = Moderately adapted PA = Poorly adapted
Plot size = 5.0 x 3.0 m

India, predatory beetles (especially different species of coccinellids), larvae of syrphid flies, wasps, dragonflies, predatory bugs and spiders are associated with the psyllid. However, these natural enemies have not reduced the pest problem. Researchers are also monitoring leucaena cultivars for their resistance or tolerance to the psyllid. Due to their rapid reproduction and widespread infestation in the absence of natural enemies, there is a need to evaluate endemic natural enemies and to introduce potential biological control agents into India. The coccinellid *Curinus coeruleus* Mulsant has been introduced in October 1988 from Thailand (B. Napompeth pers. comm.) and field colonization is being attempted.

Chemical Control

Several contact and systemic insecticides are being evaluated for psyllid control under field conditions. In preliminary trials, insecticides, such as endosulfan, phosalone, quinalphos and monocrotophos (all at 0.05 percent a.i.), control the pest for at least two weeks. The adult pest infestation was reduced markedly in the sprayed plots. However, the nymph populations were unaffected in many trees. Thus, the insecticides gave control for a short period.

Integrated Pest Management

An integrated pest management approach is required to minimize the psyllid infestation in

leucaena. Identification of suitable cultivars of leucaena and less use of susceptible alternate host trees would help to eliminate the primary source of infestation. In addition, agronomic manipulations, judicious use of insecticides, and augmentation and conservation of natural enemies will aid leucaena cultivation as a multipurpose tree in alley cropping, particularly in rainfed areas of India. Otherwise, leucaena cultivation would become uneconomical and cultivation of other multipurpose trees in alley cropping becomes inevitable.

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PROGRESS AND FUTURE ACTIVITIES OF THE LEUCAENA PSYLLID RESEARCH PROGRAM IN INDONESIA

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Introduction

Indonesia has planted 1.2 million ha of leucaena trees ("lamtoro") for a wide variety of uses:

- shade tree for cocoa, tea, coffee, vanilla
- fodder
- reforestation and soil reclamation
- charcoal and fuel wood
- green manure
- timber
- leaf meal
- vegetables

For example, the provincial government of East Nusa Tenggara (NTT) supports programs on leucaena for shade, land stabilization and fodder. On Timor island, a cattle-fattening system with leucaena significantly increased the farmers' real income. Almost all plantations of cocoa, tea, coffee and vanilla run by estates (±20 percent of plantations) or individual farmers (80 percent of plantations) use leucaena trees for shade. Recently, 3,000 ha of giant leucaena were planted in South Lampung for energy source. The Department of Forestry has used leucaena for extensive reforestation and soil reclamation.

Prior to 1986, no economically significant pests attacked the leucaena trees. However, since April 1986, an exotic insect pest, *Heteropsylla cubana*, defoliated and killed the trees around Bogor. In July and August of 1986, the pest had spread throughout the whole archipelago. The conducive climate and the absence of significant natural enemies (parasitoids, predators and diseases) of this pest in Indonesia allowed the psyllid populations to increase rapidly.

During 1986, the economic loss was estimated at Rp 538 billion (more than US$316,000,000). If there were no control action taken, the estimated losses suffered by the sub- sectors of estate crops, animal production, and forestry during five years could have been around Rp 1.4 trillion, Rp 1.2 trillion, and Rp 42 billion, respectively, which could make a total loss of Rp 2.64 trillion (US$1.00 = Rp 1,700).

The pest was declared a national disaster and a Ministerial Decree in 1986 established the National Task Force for Control of the Psyllid. The two main objectives of the task force are research and implementation of psyllid management. Terms of experts from various universities and research organizations in Indonesia were organized under the leadership of a competent national research program leader to conduct comprehensive and well-programmed research. Critical research topics were identified for immediate action.

The goal is to protect the leucaena trees from the pest attack because of the very high value of the tree to large sections of our agriculture. Other tree species should replace leucaena only if there are no satisfactory controls for the psyllid.

Identification of the critical research areas was guided by the concept of integrated pest management (IPM) in which the pest ecology, biological control, and plant resistance are exploited to manage the pest. While IPM for the psyllid is being developed, the economic and safe application of pesticides were evaluated for short term and emergency action, particularly

for estate enterprises who can afford pesticides.

Biological Control

The introduction of the predator *Curinus coeruleus* into Indonesia was motivated by Dr. Max W. McFadden's report that it was very effective in controlling the psyllid in Hawaii. A total of 8,300 beetles were shipped by air and hand-carried into Indonesia in August 1986. The predator's biology and predation behavior and simple rearing methods were studied. The results of these studies were transferred to the extension agents from the provinces in a 1-2 week training program. After the training, each of the agents was given 50-100 adult *C. coeruleus* to be reared in their own provinces. In turn, they trained the local extension agents and farmer leaders to rear the predator. This training program accelerated the multiplication and distribution of the predator throughout Indonesia.

The first official release of the predator took place in November 1986, in the Tea Experimental Garden, West Java. Soon predators were released in 50 other locations.

Predator releases and evaluation of the predator's performance were carried out periodically. The climate significantly affects the survival of the predator. In regions with almost uniform rainfall distribution throughout the year, the predator performs very satisfactorily. The trees remain green almost all year, and psyllid populations are low. However, in regions with a long dry spell, the predator survival is poor.

The trees which are heavily infested with the psyllid during the short rainy season may be defoliated or killed. During the subsequent long dry spell, the surviving trees are unable to produce new flush and the psyllid population almost disappears. Consequently, *C. coeruleus* population declines. The exploitation of plant resistance to the psyllid in the regions with dry and wet seasons may be more effective than biological control.

There are several examples in Indonesia on the use of the predator for controlling the psyllid. In coffee plantations that use leucaena for shade cover around 133,000 ha, in about 18 months after the release of the predators in 39,900 ha of coffee plantations (± 30 percent of the shaded plantations), the canopy of the leucaena trees turned lush green. Healthy shade trees will assure the continued production of high quality coffee beans. The predators eventually will be released into the rest of the shaded coffee acreage. Almost all of the 12,000 ha of vanilla plantations in Bali have leucaena trees for supporting the vanilla vines. Reports indicated that the predator is doing well in four compact stands of vanilla plantations covering 3,000-4,000 ha. Recently, individual farmers have distributed the predator by collecting adult *C. coeruleus* from nearby gardens and releasing them in their own gardens.

Plant Resistance

Research on psyllid resistant leucaena trees includes the following programs:

1. The establishment of a 100-ha leucaena field for collection of species and cultivars and experimentation located at Pondok Gedeh, about 25 km South of Bogor.

2. Periodic collection of domestic and exotic materials.

3. Active participation in Nitrogen Fixing Tree Association (NFTA) trials to speed up the program and to better facilitate exchange of promising provenances.

The results are very encouraging.

The Bogor Research Institute for Estate Crops and the Institute for Animal Production collected around 300 accessions of both domestic and foreign origin. A few domestic collections, viz PG79 (RSB01), PG66 (KD1), PG65 (TA), PG62 (SW1) and PG63 (SW2), showed resistance to the leucaena psyllid. Those collections originated in East Java. A few accessions of the NFTA trials was found

resistant to the psyllid. The seed production trials are still underway. When the seeds are available, they will be distributed to the provinces, particularly to areas where *C. coeruleus* does not do well.

Seminars

Two seminars (one day each) have been conducted on biological control and plant resistance. Recently, researchers and extension agents from the provinces of Central Java and Yogyakarta, coordinated by the Gadjah Mada University, held a one-day seminar on the psyllid problem.

Future Plan

Indonesia will continue to conduct its research program on psyllid control. Further investigations are needed on how predator-prey relationship of *C. coeruleus* and the psyllid is affected by climatic conditions in various regions. There is interest in introducing other exotic natural enemies, such as *Psyllaephagus* sp. nr. *rotundiformis*, into Indonesia. Collection of domestic and exotic leucaena accessions and their evaluation for resistance to the psyllid will be intensified. When the seeds of the resistant accessions become available, they will be distributed immediately to the other provinces. The seeds also may be available to interested countries through NFTA. Indonesia will continue participating in NFTA's Leucaena Psyllid Trial (LPT). Periodic seminars at the national level will be held as soon as enough research results are obtained.

STUDIES ON LEUCAENA PSYLLID IN MALAYSIA

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Abstract

Heteropsylla cubana Crawford is a new pest of leucaena in Malaysia. During its outbreak, extensive areas were severely defoliated.

Eggs are laid between developing leaflets with the majority (81.6%) deposited on terminal shoots. Each of the first four nymphal instars develops in 2-3 days and the fifth instar develops in 2-5 days. The total developmental period from egg to adult takes 12-20 days.

The majority of the arthropods on leucaena are *H. cubana* and other insect species. In general, rain, pruning and cattle grazing suppress the psyllid populations.

To date, no parasitoid of leucaena psyllid has been found in Malaysia. However, the nymphs and adults were infected by several entomogenous fungi, including *Fusarium, Paecilomyces* and *Hirsutella*.

Of forty-one leucaena hybrid accessions screened for psyllid resistance and acid soil adaptability, the leucaena hybrid Mahut 38 and leucaena hybrid Mahut 2 had the highest vigor scores. However, leucaena hybrids Mahut 36 and 38 were least affected by psyllid attack. The most promising was leucaena hybrid Mahut 38 which was tolerant to both psyllid damage and an acidic soil.

Presently, *H. cubana* is posing a serious threat to the development, expansion and utilization of leucaena in Malaysia. Therefore research will be intensified, with the objective of developing an integrated pest management system for the control of the psyllid.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford, was first detected in Malaysia on leucaena trees at FRIM (Forest Research Institute Malaysia) on July 3, 1986 (Tho 1986, 1987). Around the same period, it was infesting leucaena in the area of Batu Tiga (Ooi 1986). Subsequently, the psyllid was discovered on leucaena trees in several other locations, such as Taman Titiwangsa, Zoo Negara and Sungei Buloh in the same state of Selangor (Tho 1987). At the same time, it was present in the northern state of Perlis. In May 1986, an extensive area of cultivated leucaena at MARDI (Malaysian Agricultural Research & Development Institute) was heavily infested with the psyllid. On isolated leucaena trees scattered at UPM (Malaysia Agricultural University) and the surrounding area, the psyllid was also abundant. The damage was extensive with many of these plants severely defoliated.

The sudden and serious impact of *H. cubana* on leucaena, which is considered an important potential fodder for the livestock industry in Malaysia, has motivated studies of the biology and management of the pest. Some preliminary studies address the biology and ecology of the psyllid, its natural enemies, its damage impact on the crop, leucaena varietal susceptibility evaluation, and the effect of local cultural practices.

Extent of Infestation and Damage

The psyllid infests very young and fresh leaf growth of leucaena, particularly the unopened leaves (Ooi 1986). Within a few days, many of the young shoots begin to dry up. As the psyllid population escalates, all of the new plant growth dehydrates. With high populations of more than 50 adults/nymphs per shoot, feeding becomes very intensive (Tho 1986, 1987). Consequently, all of the young shoots fail to develop and the older leaves drop. In cases of severe infestation, trees are completely defoliated.

During the psyllid outbreak, many hectares of cultivated leucaena in MARDI (Serdang) were defoliated. Defoliation from 95-100% was observed among older trees of 1-2 years (Table 1). The psyllid also attacked the young pods. Defoliation was much lower (percent) among the younger plants between 6 and 8 weeks old. In general, the level of psyllid infestation was greater in older trees than in younger trees. Among 1 year-old trees, where defoliation ranged from 60 to 80 percent, infestation levels were variable. Some fields had mean population of about 9 nymphs/adults per shoot while many other fields had a mean of 33 nymphs/adults per shoot (Table 2). In spite of such severe attacks and extensive defoliation, the trees were not killed. Eventually, the trees recovered and produced new flushes of leaves.

During the psyllid outbreak, the leucaena varieties exhibited different susceptibilities to the psyllid attacks. For example, *Leucaena leucocephala* had about 14 times more psyllid than *Leucaena diversifolia*. Also, the former suffered extensive defoliation while the latter suffered no defoliation.

Life Cycle and Description

Egg

Eggs are laid on very young shoots where they are lodged between the folds of the developing leaflets. They are oval, 0.3 mm long and 0.1 mm wide. When newly laid the eggs are whitish. They turn light tan after about one day. In general, mature eggs are orange or reddish-brown. About one day before eclosion, a pair of red eye spots of the 1st-instar nymph usually appear at the pointed end of the egg.

Nymphs

Nymphs are dorso-ventrally flat and oblong in dorsal view. Although whitish when newly hatched, they eventually turn various shades of colors, such as yellow, yellowish or light green, green, tan, or orange. The majority of nymphs, however, are yellowish green.

Table 1. Extent of defoliation of leucaena during an outbreak of *Heteropsylla cubana* in 1986 in Serdang, Malaysia.

Age of plants	Percent defoliation
6-8 weeks	< 11
1 year	60-80
1-2 years	95-100

Table 2. Abundance of *Heteropsylla cubana* in different fields of leucaena (1 year-old plantings) during an outbreak in 1986 in Serdang, Malaysia.

Field	Shoots/leaves conditions	No. of plants sampled	Mean no. of nymphs and adults per shoot
I	Normal flush	17	9
II	Normal flush	18	33
III	Regenerated shoots	6	14

Adults

The adult psyllid is slender and about 1.5 - 2 mm long. It is generally yellowish green, although some may be varying shades of brown. On average, the female is 2 mm and the male 1.8 mm long. The wings of newly emerged adults are opague and gray.

Life cycle

According to Tho (1987), the incubation period in Malaysia is 2-5 days. However, in more recent studies (Said pers. comm.), the incubation took 2-3 days under greenhouse conditions. In general, these findings differ little from that (3-4 days) reported by Braza (1988) in the Philippines.

In Malaysia, the psyllid undergoes five nymphal instars (Said, pers. comm.). The first four instars develop in 2-3 days, and the 5th instar develops in 2-5 days. The total nymphal period takes 10-17 days which is much longer than that (8-12 days) observed by Braza (1988) in the Philippines.

In Malaysia, the psyllid takes 12-20 days to develop from the egg to the adult stages. In the Philippines, the developmental period was only 11-16 days (average 12.8 days).

The slight difference is probably due to the different environmental conditions especially temperature and relative humidity under which the studies were conducted.

General Biology

Oviposition

The females lay groups of eggs on the very young leaves of terminal shoots. They prefer to oviposit on the upper surface of the leaflets of the folded young leaves, which may become virtually covered and yellowish with eggs. In a field examination of 6 plants of 2 year-old leucaena at the MARDI farm in Serdang, all of the psyllid eggs were confined to the terminal shoots. Most of the eggs (81.6 percent) were deposited on the first 1-4 young, unopen leaves that were still soft and yellow (Table 3). No eggs were found beyond the 6th leaf.

Feeding Habits

Immediately after hatching the 1st-instar nymphs begin feeding near the oviposition site. As the nymphs grow, they colonize and feed on other terminal portions of stems or branches, and on leaf petioles of young leaves.

Both the adults and nymphs of the psyllid feed by sucking from the phloem of the developing shoots and the young foliage. Their feeding activities produce many visible punctures in the veins and leaf ribs (Tho 1986). The insects exude drops of sticky fluid on the leaves causing

Table 3. Distribution of *Heteropsylla cubana* eggs on leaves of a 2 year-old leucaena planting (Serdang, Malaysia).

Leaf sample (from tip of branch)	Leaf condition	Egg distribution	
		Number*	Percent total eggs
1 (First 1-4 folded leaves)	Generally comprised of 1-4 youngest leaves, with leaflets still folded. Leaflets yellow and texture soft.	4,796	81.6
2 (Next lower leaf after sample 1)	Leaflets unfolded but still yellow.	730	12.4
3 (Next lower leaf after sample 2)	Leaflets fully green and texture hard.	350	6.0
4-10 (Subsequent leaves consecutively)	Leaflets fully green and texture hard.	0	0

*Mean of 6 samples taken at random from 6 leucaena plants.

the leaflets to stick together firmly, thereby preventing the leaves from developing naturally.

Ecological Investigation

Associated Arthropod Fauna

Because *Leucaena* is a relatively new crop and *H. cubana* is a new pest in Malaysia, there is presently a negligible information about their ecology. In particular, information about the associated arthropod fauna is lacking. Consequently, the arthropod community was surveyed in a half hectare plot of 4-year-old unpruned and ungrazed stands at MARDI (Serdang), beginning in late September 1988. The plot was surrounded by a 15-ha field of regularly pruned or grazed leucaena. Three sampling sub-areas (replicates) were selected for arthropod collections. The arthropods were knocked down by mist-blowing with DDVP (dichlorvos) at a concentration of 4 ml/l of 50% EC stock solution. In each replicate, the arthropods were sampled monthly over an area of 2 x 5 m using 1 x 1 m trays placed below the fumigated trees. The specimens were stored in 75 percent alcohol for subsequent detailed examination.

From September 1988 to January 1989, *H. cubana* and other psyllid species were the most abundant group of arthropods. Other major groups included Acarina, Arachnida, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Neuroptera, Orthoptera, Psocoptera and Thysanoptera. Among these groups, at least 76 families were represented.

In the Order Homoptera, Cicadellidae constituted the next most abundant group of sap-sucking insects after the psyllid. Families within the Orders Heteroptera and Hymenoptera were more equally abundant. The heteropterans were represented by 4 families (Anthocoridae, Hydrometridae, Lygaeidae and Miridae) and the hymenopterans were represented by 17 families.

In the Order Diptera, Mycetophilidae (fungus gnats) and Ceratopogonidae (biting midges) were the most abundant families. This was not surprising because the larvae of both of these families usually breed in damp places with abundant decaying vegetation or fungi.

In the Order Orthoptera, the main families were Acrididae, Gryllidae, Tettigonidae and Tetrigidae. The Acrididae was the most abundant group in this order.

Seven families of Lepidoptera were collected. Pyralidae, whose larvae are mostly leaf-feeders, formed the bulk of these. In Neuroptera, both Chrysopidae and Hemerobiidae were represented. For Coleoptera, *Nodina* spp. (Chrysomelidae) was the most abundant among seven families. A few thrips and psocopterans were also found.

Among the non-insect arthropods, there were some ticks, mites, and three families of spiders (Araneidae, Clubionidae and Oxyopidae). Of the Collembola, *Saina celebensis* (Entomobryidae) was the dominant species. Among the non-arthropod, only 1 snail was found.

This study showed that the psyllid is the most abundant species on *Leucaena* and that the arthropod fauna in Malaysian leucaena ecosystem is diverse. The ecological roles of other species are currently poorly understood. The elucidation of the ecological relationships among arthopods may benefit psyllid management.

Seasonal Changes and Psyllid Population Build-up

The population size of *H. cubana* on leucaena decreases during dry spells and increases during wet periods (Fig. 1). In Malaysia, the first heavy attack of the psyllid on leucaena was coincided with the dry spell (Tho 1986).

To determine to what extent weather influences the build-up of psyllid on leucaena, a 0.5 ha field of 1-year-old plantings was set aside for periodic sampling of the psyllid. During each sampling period, 20 plants were taken at random for determination of the infestation level using the "beating board" technique.

As in the earlier studies, psyllid populations were low during the wetter periods of the year and high during the dry seasons when populations increase to 88.5 psyllids/shoot (Table 5). It was evident that rain has some significant adverse effects on the psyllid. The rain may simply wash off the psyllid. Tho (1986) observed that, during heavy rainfalls, the rain will dislodge the nymphs from the leaves of leucaena.

Natural Enemies

Ooi (1986) noted that *H. cubana*, being an introduced and exotic pest, should prove highly suited to a classical biological control approach. However, very little is known about its local associated fauna, some of which may be useful as biological control agents. Therefore, a survey and evaluation of the natural enemy fauna associated with the psyllid in Malaysia is necessary prior to an exploration for exotic biological control agents.

Parasitoids

In November 1988, a study was initiated to determine whether any parasitoids attack the eggs of the leucaena psyllid. Young shoots heavily infested with psyllid eggs were collected

Table 4. Associated arthropod fauna of cultivated leucaena in Malaysia (MARDI, Serdang).

Order	Number of individuals at each sampling date*				
	23.9.88	6.10.88	2.11.88	6.12.88	5.1.89
Homoptera					
Psyllid	480	6,689	101	2,232	1,901
Others	16	38	30	14	73
Heteroptera	2	12	5	3	6
Hymenoptera (excluding ants)	24	47	31	34	78
Ants	7	69	24	5	17
Diptera	137	335	32	116	127
Coleoptera	14	74	43	9	65
Orthoptera	16	16	22	7	22
Lepidoptera					
- Adult	2	9	4	2	4
- Larva	1	3	5	3	7
Collembola	196	209	430	460	724
Thysanoptera	6	36	16	7	20
Neuroptera	0	3	6	13	2
Acarina	64	103	147	76	183
Arachnida	9	28	41	16	58
Others	-	-	-	1**	7***
Total	974	7,671	937	2,998	3,294

* Values are means of 3 replicates except for 23.9.88 where the values are means of 2 replicates.
** Snail
*** Psocoptera

Table 5. Weather condition and the population size of *Heteropsylla cubana* on leucaena in Serdang, Malaysia.

Date	Mean number of nymphs and adults per shoot (N = 20)	Weather condition
1986:		
27 October	32.8	Dry
28 November	49.3	Beginning to rain
12 December	27.0	Wet
1987:		
9 January	9.2	Very wet
13 February	11.2	Wet
7 March	6.6	Wet
27 Mach	1.0	Wet
17 April	0.7	Drying up
16 May	3.7	Dry
3 July	88.5	Very dry
14 August	9.1	Wet
9 September	32.6	Dry
6 November	54.8	Dry
1988:		
8 January	6.8	Wet
4 March	17.1	Wet
2 April	19.0	Wet

at random from the MARDI farm on a weekly basis. During each sampling, between 100-200 shoots were picked. These were maintained for two weeks in vials containing water and observed daily for psyllid nymph hatching and emergence of parasitoids from the eggs, if any.

The samples collected on November 24 and December 2, 10 and 16 did not yield any parasitoid. Psyllid nymph hatching, however, was good. Totally 973, 768, 3,240 and 1,572 individuals emerged on the respective sample dates. This study is being continued on a wider scale.

Entomopathogens

In the initial survey for local entomopathogens of *H. cubana*, psyllid were collected at random from 3 locations. UPM and MARDI in Serdang, and Ijok (Kuala Selangor). The number of diseased and non-diseased individuals of both nymphs and adults were recorded. Diseased psyllid were plated on PDA (potato dextrose agar) and SDA (Sabraud dextrose agar).

Preliminary results showed that several common entomogenous fungi infect the psyllid (Said pers. comm.): *Fusarium*, *Paecilomyces* and *Hirsutella*. Some unidentified and less common ones also were found. These were sent to CMI (CAB International Mycological Institute) for identification.

Effects of Grazing/Pruning

The periodic and continuous monitoring of psyllid populations showed that psyllid numbers may crash suddenly and drastically shortly following cattle grazing or pruning of the leucaena. For example, in one field the mean psyllid counts of 152 per shoot on 7 October 1988 declined sharply following the brief introduction of 50 heads of cattle. It fell to 10.3 psyllid per shoot on 5 November 1988. The number rose again to 72.2 psyllid per shoot on 10 December 1988, soon after the cattle were moved to another field. A similar impact was also observed for in leucaena fields which were pruned instead of grazed by cattle.

These preliminary observations clearly showed that some cultural methods, such as grazing and pruning, can be important in leucaena psyllid management and should be investigated further.

Varietal Susceptibility

In many countries, individual trees and some varieties of leucaena have shown tolerance to the leucaena psyllid. For example the cultivars K527, K538, K584, K591, K636 and K658 (all giants from northeast Mexico) have been identified as psyllid-tolerant in Hawaii (NFTA 1987). Elsewhere, psyllid-tolerant cultivars are #58396 in Australia and K72 and K636 in Taiwan.

Since resistant leucaena varieties are available and can be important in an integrated pest management system for psyllid, many varieties are being screened for psyllid resistance. Initially, the screening was conducted in conjunction with other investigations on acid soil adaptability. Forty one leucaena hybrid accessions were evaluated. These were established in MARDI (Serdang). The acid-tolerant hybrids are derived from the F2 and F3 generations of *L. leucocephala* x *L. diversifolia* crosses.

The plants were grown in polyethylene before field transplanting after two months. Plant height was measured at monthly intervals and plant vigor was rated on a scale of 1 (poor) to 5 (best). Psyllid damage of the entire terminal shoot was rated on a 1-9 scale. The sample size was 10 (5 trees with 2 samples each). The damage ratings were as follows:

1 .....No damage

2 ..... Slight curling of leaves

3 ..... Tips and leaves curled and yellowish

4 ..... Tips and leaves badly curled and yellowish

5 ..... Loss of up to 25 percent of young leaves

6 ..... Loss of 26 to 50 percent of young leaves

7 ..... Loss of 51 to 75 percent of young leaves

8 ..... loss of 100 percent of leaves and blackening of lower leaves

9 ..... Blackened stem with total leaf loss.

Table 6 shows the results at the six-month stage during June 1988. Leucaena hybrid Mahut 2 and leucaena hybrid Mahut 38 had the best vigor score. However, leucaena hybrids Mahut 36 and 38 were least affected by psyllid attack. Several other hybrids showed some degree of tolerance, although curling and yellowing of leaf tips were evident. The hybrids with psyllid damage scores of less than 3 include leucaena hybrid Mahut 3, 11, 22, 23, 24, 25, 26, 28, and 34, *L. pulverulenta* Mahut 14, *L. diversifolia* Mahut 18 and *L. macrophylla* Mahut 40. Among these cultivars, leucaena hybrid Mahut 38 is most promising because it is tolerant to psyllid damage and an acidic soil. This hybrid deserves more detailed investigations.

Presently, one major constraint on the exploitation of some of the potential hybrids is that they are shy seeders, especially the selected ones (Hybrid 11 x 25 F2). Researchers are analyzing the shy seeding condition and evaluating the hybrids for seed production at different sites, such as Cameron Highlands, Jeram Pasu and possibly Bukit Tangga.

Discussions

Many leucaena trees have thrived in nature for a long time in Malaysia, particularly in limestone cliff areas. *L. leucocephala* was first introduced and evaluated for its potential as fodder for livestock in September 1974. Since then, leucaena has been evaluated for its agronomic performance and animal nutrition (Tham *et al.* 1977, Eng *et al.* 1978, Wong *et al.* 1981, 1982a, Chen *et al.* 1982). Leucaena forage has considerable potential for the production of animal feed in Malaysia and should be given priority for exploitation (Wong *et al.* 1982b). Of special significance is the potential utilization of leucaena in leafmeal industries.

Currently, Malaysia is importing over 48,000 tons of leaf meal annually at an estimated cost of over M$20 million for the requirements of pig and poultry feeds (Jalaludin 1987). Locally-produced leucaena leafmeal, when available, can be a major import substitution. Leucaena can readily replace the present imported leafmeal in available commercial rations for up to 5% of the overall feed formula. It is also an excellent high protein feed. Moreover, the potential market for use of leucaena in layer diets (mainly as a source of xanthophyll and vitamin A) is relatively large. Therefore, development of leucaena production is important to the feedmill industry and also to the national economy (Ahmad Mustaffa 1987).

The immense potential benefits of leucaena to the Malaysian livestock industry have generated great interest in leucaena. The main obstacle to its further development, expansion and utilization is the *H. cubana* infestation. Therefore, psyllid management is of a high priority.

Although many currently available insecticides provide reasonably effective control of the psyllid, the chemical control approach will not be adopted because of the usual concerns about residues, cost and proper use. Instead, the major emphasis is on exploring varietal, cultural and biological control approaches, with the objective of developing an integrated pest management system. The studies reported here will be expanded and the ecology of the psyllid will receive more attention.

Malaysia collaborates with the research network of the F/FRED Regional Research Program for Leucaena Psyllid Control. This program facilitates the sharing of information and promotes collaboration among researchers working on the psyllid problem, particularly in Asia and the Pacific region. Because of the many mutual benefits of the network, Malaysia will contribute to and support the activities of the network. This cooperation will expedite the development and implementation of an integrated pest management program for the leucaena psyllid.

Table 6. Evaluation of *Leucaena* hybrids for soil acidity tolerance and psyllid resistance. (N = 10 = 5 trees x 2 samples).

Leucaena hybrids	Psyllid* damage	Plant height (cm)	Vigor** score
1. *Leucaena* hybrid Mahut 1	7.3	80.7	1.8
2. *Leucaena* hybrid Mahut 2	3.4	95.0	4.4
3. *Leucaena* hybrid Mahut 3	2.5	78.2	2.2
4. *Leucaena* hybrid Mahut 4	6.5	69.2	2.6
5. *Leucaena* hybrid Mahut 5	5.4	81.0	2.2
6. *Leucaena* hybrid Mahut 6	5.4	64.2	2.2
7. *Leucaena* hybrid Mahut 7	6.8	97.5	2.8
8. *Leucaena* (Cunningham)	3.6	51.6	3.3
9. *Leucaena* hybrid Mahut 9	8.3	155.7	3.8
10. *Leucaena* hybrid Mahut 10	-	-	-
11. *Leucaena* hybrid Mahut 11	2.3	129.9	3.1
12. *Leucaena* hybrid Mahut 12	8.9	125.0	3.8
13. *Leucaena* hybrid Mahut 13	3.4	100.8	3.5
14. *Leucaena pulverulenta* Mahut14	2.4	104.0	3.1
15. *Leucaena diversifolia* Mahut15	6.7	95.4	2.4
16. *Leucaena diversifolia* Mahut16	7.2	116.5	2.2
17. *Leucaena diversifolia* Mahut17	3.8	87.0	3.5
18. *Leucaena diversifolia* Mahut18	2.8	101.7	2.8
19. *Leucaena diversifolia* Mahut19	7.6	85.0	2.3
20. *Leucaena diversifolia* Mahut20	5.9	112.9	3.1
21. *Leucaena* hybrid Mahut 21	3.8	107.8	3.3
22. *Leucaena* hybrid Mahut 22	2.2	96.8	2.0
23. *Leucaena* hybrid Mahut 23	1.5	67.2	1.3
24. *Leucaena* hybrid Mahut 24	2.5	133.4	2.7
25. *Leucaena* hybrid Mahut 25	2.3	118.2	2.6
26. *Leucaena* hybrid Mahut 26	2.7	139.7	2.7
27. *Leucaena* hybrid Mahut 27	3.3	178.1	3.4
28. *Leucaena* hybrid Mahut 28	2.1	-	1.9
29. *Leucaena* hybrid Mahut 29	-	-	-
30. *Leucaena* hybrid Mahut 30	6.5	104.5	2.6

Table 6. (Continued).

Leucaena hybrids	Psyllid* damage	Plant height (cm)	Vigor** score
31. *Leucaena collinsii* Mahut 31	-	-	-
32. *Leucaena* hybrid Mahut 32	-	-	-
33. *Leucaena* hybrid Mahut 33	-	-	-
34. *Leucaena* hybrid Mahut 34	2.1	71.7	2 8
35. *Leucaena pallida* Mahut 35	6.0	142.5	2.0
36. *Leucaena pallida* Mahut 36	1.1	79.6	2.9
37. *Leucaena lanceolata* Mahut 37	-	-	-
38. *Leucaena* hybrid Mahut 38	1.0	125.8	4.5
39. *Leucaena* hybrid Mahut 39	-	-	-
40. *Leucaena macrophylla* Mahut40	1.7	107.0	3.3
41. *Leucaena leucocephala* Mahut41	5.5	66.4	3.4

* Score 1 (least) to 10 (worst) for psyllid damage.
** Score 1 (low) to 5 (best) for vigor habit.

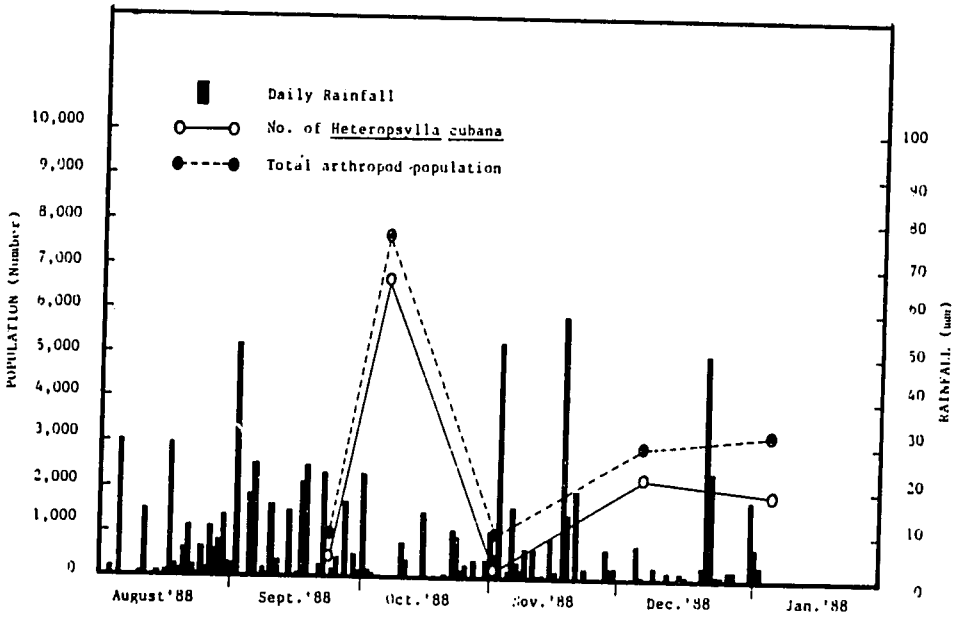

Figure 1. Effect of rainfall on *Heteropsylla cubana* and other arthropods on *Leucaena* in Malaysia (MARDI), Serdang.

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LEUCAENA PSYLLID IN THE PHILIPPINES - A COUNTRY REPORT

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Introduction

The jumping plant lice, *Heteropsylla cubana* Crawford, continue to seriously damage leucaena (ipil-ipil) more than three years after the pest arrived in the Philippines. The income of the leafmeal gatherers, tree farmers, fuelwood gatherers and charcoal producers was most reduced and damage to other sectors of the economy continue.

In 1987 the Philippine Council for Agriculture and Resources Research and Development (PCARRD) initiated a research program to help solve the psyllid pest problem. Research efforts are focused in the areas of the biology, ecology and population dynamics of the pest, the development of control measures including biological control, and the economic impact of the pest. The on-going psyllid research programs in the Philippines are summarized in Table 1. Most of the programs will continue for part or all of 1989.

Highlights of Research Results

Biology, ecology and population dynamics:

a. The biological study is almost complete. Descriptions and observations of the various stages of *H. cubana* were made.

b. Using varieties of *Leucaena leucocephala*, *L. macrophylla* and a hybrid (*L.leucocephala* x *L. diversifolia*), the shortest psyllid developmental period was observed in *L. macrophylla* (11.32 days) while the longest was recorded on K8 (12.6 days).

c. Two years of observations indicated that field populations of *H. cubana* dropped to almost zero in the months of April and May. The psyllid population flourish during the dry months beginning in December or January.

d. The predator, *Curinus coeruleus*, introduced to the Philippines in 1986 from Hawaii, did not perform well. Apparently the climatic conditions (distinct wet and dry seasons) in most parts of the country are detrimental to its survival.

e. Two potential alternate hosts of *H. cubana*, the monkey pod tree, *Albizia saman*, and the poinciana tree, *Delonixregia*, were evaluated. The psyllid successfully developed only on the monkey pod tree.

f. A population assessment method was developed using the shoot tip instead of the whole shoot as the sampling unit. A population regression coefficient of 0.93 was obtained.

g. The important factors affecting psyllid populations were: arthropod predators, food shortage, overcrowding, entomopathogens and climatological factors, particularly rainfall.

Control measures including biological control and resistance evaluation:

a. Survey and collection of predators of the psyllid over a two-year period (1987-88) produced at least 45 species of insects, 14 identified spider species and at least 10 more

Table 1. Research activities on the leucaena psyllid in the Philippines.

I. On-going research activities (2 yr-old)

Program: Biology and control of *Heteropsylla cubana* infesting *Leucaena* sp. (PCARRD/RRDP-supported)

Project 1 - Biosystematics of ipil-ipil pests (*H. cubana*). V. Calilung/UPLB/IBS)

Study 1 - Biology of psyllid infesting ipil-ipil. V. Calilung/UPLB-IBS

Project 2 - Population dynamics of ipil-ipil psyllid

Study 1 - Life table analysis of the ipil-ipil/psyllid. R. Lucero/UPLB-CF

Project 3 - Biological control of ipil-ipil psyllid

Study 1 - Evaluation of promising natural enemies of ipil-ipil psyllid. C. Baltazar/UPLB-IBS

Study 2 - Entomopathogenic control of jumping plant lice of ipil-ipil. E. Militante/UPLB-CF

Study 3 - Biological control of ipil-ipil psyllid in Leyte. L. Villacarlos/VISCA

Project 4 - Silvicultural management for control of psyllid infesting *Leucaena*

Study 1 - The economics of losses for psyllid-infested leucaena plantation. M. Rivera/ERDB

Study 2 - Screening of leucaena cultivars for their relative resistance against psyllid insect pest. E.Crizaldo/ERDB

II. F/FRED-supported research

On-going:

Study: Selection and evaluation of field resistant *Leucaena* in the Philippines. E.N. Crizaldo

Soon to be activated:

Project 1 - A study of the biology and mass-rearing of two predators of *Heteropsylla cubana*. *C.R. Baltazar and V.P. Gapud/UPLB/Entom.*

Project 2 - Psyllid infestation: Its socio-economic impact on leucaena tree farmers and end-users in the Philippines. M.N. Rivera and A.J. Tabiar/ERDB

Project 3 - Seed production and evaluation of psyllid- resistant *Leucaena* selection. E.N. Crizalo/ERDB

III. Biological control using exotic natural enemies of the leucaena psyllid - part of IDRC-supported Regional Leucaena Psyllid Project.

unidentified spider species.

b. Five different groups of fungi with potential to control the psyllid were produced and will undergo field evaluation this year. A candidate from the *Fusarium* group looks very promising.

c. In field trials for resistance, only two leucaena cultivars have shown resistance to the psyllid. They were K784 and K785.

Economic impact studies:

a. Preliminary results indicated that leucaena farmers in many parts of the country were adversely affected by the psyllid. In particular, the reduction in leafmeal production was pronounced.

b. The psyllid infestation caused almost a doubling of the price of products derived from leucaena (ipil-ipil). The price of ipil-Ipil fuelwood, for instance, jumped from Peso 60/m^3 to Peso 100/m^3 and the price of leafmeal increased from Peso 1.10/kg to Peso 2.00/kg.

c. Many farmers are reluctant to grow leucaena because of the psyllid problem. It may take some convincing before they start planting again, even after the problem has been solved.

Outlook

While some degree of control is being exerted by indigenous predators, the damage inflicted by *H. cubana* on leucaena in the Philippines is still serious. While no definitive studies are available, rough estimates indicate a production loss of at least 50 percent in many areas of the country. Unless *H. cubana* is controlled more effectively, there is a bleak future for the industries and development programs which are dependent on leucaena.

We hope that resistant leucaena cultivars become available soon or that exotic beneficial insects are introduced to help solve the psyllid problem.

STATUS OF MANAGEMENT OF LEUCAENA PSYLLID, *HETEROPSYLLA CUBANA*, IN SRI LANKA

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Leucaena leucocephala, commonly known as "Ipil Ipil" in the Philippines, was introduced to Sri Lanka about a decade ago for a joint research program between Sri Lanka and the International Institute of Tropical Agriculture (IITA), Nigeria. The goal of this program was to develop stable systems of agriculture to replace shifting cultivation, which was widely practiced in the dry zone. Leucaena's performance under rainfed highland conditions was remarkable. It replaced most of the other fast- growing tree species. Since then, this legume has become naturalized both in the dry and wet zones of Sri Lanka, except at high elevations where the soils are too acidic.

Without much extension, the farmers in the dry zone accepted this multi-purpose tree species and planted it along fences for feeding dairy cattle, buffaloes and goats, and for fuelwood for domestic cooking. Leucaena is used in agro-forestry systems, such as alley cropping and avenue cropping, for shade for annual and some perennial crops, for compost for vegetables and horticultural crops, and for inexpensive rural energy.

The greatest impact of leucaena has been in the livestock industry. Nestle's planted 100 acres of leucaena on very sandy coastal soils in the North Western province, where many crops (except coconut) have failed. In their program to produce leaf meal for livestock, leucaena was planted very densely and the leaves harvested at three monthly intervals. The leaves were sun-dried and the leaflets were separated from the branches using simple machines. Finally, the leaflets were ground into a meal. The Oils and Fats Corporation substituted this leaf meal in up to 15 percent of the feed formula without any deleterious effects on the livestock. In studies by the University of Peradeniya for Nestle's, the leucaena leaf meal could be substituted in 35 percent of the cattle feed formula without any side effects, such as loss of hair. The mimosine content was far below toxic levels in *L. leucocephala* and *L. macrophylla*.

Later, the University of Peradeniya evaluated leucaena varieties and several other species of nitrogen-fixing trees obtained from NFTA in the mid 1980s. In these trials, *L. leucocephala* K 636 showed some resistance to psyllids. Nestle's planned to plant 100 acres of this species when the psyllid, *Heteropsylla cubana,* infested the mid-country Livestock Development Center of the National Livestock Development Board in February 1987. By that time, the psyllid had spread to many other areas in the dry and wet zones. Due to the psyllid attack, most of the farmers gave up leucaena and shifted to *Gliricidia maculata*, or *Gliricidia sepium*, which are fast-growing, dependable legumes in Sri Lanka.

The institutes most interested in resurrecting leucaena were the National Livestock Development Board, the Coconut Research Institute, the Department of Agriculture and the University of Peradeniya. These research organizations evaluated various psyllid control techniques, such as pruning, spraying, and intercropping *Leucaena* and *Gliricidia*, but the results were not promising. The psyllid populations fluctuated widely, particularly in the rainy season when they were washed off the leaves, and they resurged in the dry season. Leucaena grew rapidly in the wet season and recovered from the psyllid damage. However, the psyllid damaged the leucaena again in the

dry season. Some insects, particularly the coccinellid beetles and their larvae and dragonflies, prey on the psyllid.

The present activities of the National Committee on Psyllid Control include annual cropping between the alleys of leucaena to achieve a biological stability in the system, pruning and burning leaves infested with the psyllid, spraying small scale experimental plots, and testing resistant species obtained from NFTA, Hawaii. Future plans include multi-locational trials under the Leucaena Psyllid Trial (LPT) program and identifying natural biological control agents to manage the psyllid.

LEUCAENA PSYLLID IN THAILAND - A COUNTRY REPORT

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Abstract

Of all the known and recently introduced insect pests in Thailand, no other insect pest has received as much attention as the leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae). A similar situation is also being experienced in several countries and territories in Asia and the Pacific region. A review was made on various attempts on research and implementation to develop appropriate management strategies for leucaena psyllid management program in Thailand. Most obvious and outstanding among available control tactics and strategies were biological control, both classical and augmentative, determination and selection of psyllid resistant leucaena species and varieties, and development of an integrated pest management (IPM) program for the leucaena psyllid. Current research being undertaken in collaboration with other countries within and outside of the region included ecological investigations, determination of economic threshold levels (ETLs), evaluation of native natural enemies for augmentation purpose, introduction of exotic natural enemies for classical biological control, evaluation of microbial control agents, development of IPM program, determination of nature of psyllid resistance and evaluation of resistant genotypes, psyllid population sampling and monitoring methods, development of sequential sampling plans, and evaluation of farmer-generated control methods and techniques.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), was first detected in Thailand in September 1986 in Chachoengsao, a province east and adjacent to Bangkok and in Chumphon on the peninsular region by J.L. Brewbaker (Yantasath and Watanakul 1987). It was found in Bangkok on leucaena hedges on the campus of Kasetsart University on October 6, 1986 (Napompeth 1987). The invasion of *H. cubana* in the Pacific islands westward to the insular and continental Southeast Asia including Thailand had been much earlier anticipated soon after its detection in Hawaii in April 1984 through regular communication and early warning by G.Y. Funasaki and L.M. Nakahara of the Plant Pest Control Branch, Hawaii Department of Agriculture. In spite of its devastating effect on leucaenas, both the "common" and "giant" types, in the lower Central Plain region, the Northeastern Plateau area, and the Southern Peninsular region, during November 1986 until March 1987, *H. cubana* was not detected in the Northern Highland areas of Chiang Mai, Chiang Rai and vicinity until March 1987. By May 1987, practically all leucaenas susceptible to *H. cubana* attack in all areas of the country showed varying degrees of damage from moderate to severe. In many instances all leucaena trees and leucaena plantations for fodder were bare of leaves. Soon the psyllid population disappeared altogether in all areas surveyed and observed. *H. cubana* populations resurged again in October 1988 and disappeared again after May 1988 and then resurged again in October 1988. So far the annual infestation period of *H. cubana* has been definitely seasonal in Thailand approximately from October-November to April-May.

It was, however, found from regular field surveys that during its absence in most areas, there existed year-round leucaena psyllid "population pockets" of low population densities. Such "population pockets" were detected in the Western Highland area of Kanchanaburi, the Northern Highland area of Chiang Mai, the rim of the Northeastern Plateau area at Muak Lek in Saraburi, Pak Chong in Nakhon Ratchasima, and in Buriram. Such pockets could also exist in the Southern Peninsular area as well. All these "population pockets" shared a common topography and microclimate, viz, at the elevation ranging from 100 to 500 m and the average temperature ranging between near 20°C to lower than 30°C.

It was speculated that these sedentary "population pockets" served as sources of reinfestation by *H. cubana* probably together with additional and seasonal route of invasion corresponding with the typhoons from the South China Sea sweeping through the outlying islands

to continental Southeast Asia. Similar seasonal infestation and "population pockets" were also observed in the coastal and inland areas of Vietnam.

Invasion of Leucaena Psyllid

The invasion of the leucaena psyllid in Thailand was so obvious and damage so visible that its devastating effect could not escape attention by researchers, agencies and authorities concerned. In recent history a rapid invasion of insect pests occurred in a similar manner but received practically no attention. In the early 1960s the Cuban laurel thrips, *Gynaikothrips ficorum* (Marchal) (Thysanoptera: Phlaeothripidae), devastated ficus trees especially *Ficus retusa*, and the thrips still damages susceptible *Ficus* spp. An anthocorid predator, *Montandoniola moraguesi* (Puton), native to Southeast Asia, was found associated with this thrips and kept the latter from causing higher economic damage. An invasion of the spiraling whitefly, *Aleurodicus dispersus* Russell (Homoptera: Aleurodidae), was witnessed in the late 1970s and early 1980s attacking a wide range of economic crops and fruit trees, especially *Psidium guajava* L., Both invaders have now been more or less contained by "no action" and most probably by ignorance of the problems. Several indigenous natural enemies have been recovered from these introduced insect pests. Such pests have also occurred in other Southeast Asian countries and the problems were eventually solved by the often undervalued naturally-occurring biological control.

Unlike these exotic invaders, the rapid devastation of the leucaena psyllid has not escaped attention. Individual and group efforts have been established to cope with the problems in Thailand soon after its detection in late 1986. A small grant was made to the National Biological Control Research Center (NBCRC) by the National Research Council of Thailand (NRCT) to investigate the possibility of biological control of the leucaena psyllid. A similar proposal to use chemical control by the Department of Agriculture, Ministry of Agriculture and Cooperatives (MOAC) was however rejected to the disappointment and dismay of the chemical companies. A collaborative effort, at the national and regional level, was crystallized at the Workshop on Leucaena: Psyllid Problems and Solution, organized and supported by the Forestry/Fuelwood Research and Development Project (F/FRED), and the NRCT Subcommittee on Research and Development of Multipurpose Tree Species (MPTS), held in Bangkok, March 26-27, 1987. The National *ad hoc* Committee for the Control of Leucaena Psyllid was also formed under the NRCT Committee on Agriculture and Biology in 1987, consisting of representatives from the Faculty of Forestry, Kasetsart University (FFKU), Royal Forest Department (RFD), Department of Agriculture (DOA), Department of Livestock Development (DLD), Department of Agricultural Extension (DOAE), Thailand Institute of Scientific and Technological Research (TISTR), and the National Biological Control Research Center (NBCRC).

Extent of Damage and Problems

The extent of damage and problems caused by leucaena psyllid in Thailand were reviewed and discussed by Napompeth (1987). *Leucaena leucocephala* (Lam.) de Wit trees growing naturally or cultivated for other diversified purposes were all attacked, showing some degree of damage ranging from the terminal shoots devoid of any vegetative development to complete defoliation and drying-up or die-back of whole plants. Although a majority of the plants recovered with the inexplicable disappearance of the psyllid, the new flushes of leaves showed some deformities and an unhealthy appearance. Fortunately with its high coppicing and regrowth ability leucaenas have generally recuperated before being again attacked by the psyllids.

An annual reinfestation of the leucaena psyllid from October to April was observed since its first attack in 1986-1987. This seasonality exhibited by the psyllid is readily observed but it is not known how long such a definite cycle will persist.

The invasion by leucaena psyllid and its subsequent damage have created problems affecting a wide range of people in rural and urban areas. Young terminal shoots of leucaena plant and, to a less extent, green seeds in the young pods are commonly consumed by the Thai people in the form of salad green alone or together with other vegetables. It is also an essential ingredient in certain traditional cooking. Bunches of young leucaena terminal shoots are normally sold in markets but disappeared altogether during the peak psyllid season. Farmers engaged in leucaena cultivation for animal feed and fodder could no longer supply leucaena to the animal feed mills located in Ratchaburi, Kanchanaburi and Saraburi in the Central Plain areas. Leucaenas utilized in alley-cropping in the highland areas of the northern parts of the country were highly affected. The extent of damage and problems caused by the psyllid in agroforestry projects utilizing leucaenas cannot be underestimated. It is also complicated to arrive at an accurate assessment of psyllid damage and problems in these systems.

Unlike several other insect pests whose problems may be confined to a small portion of the human population, leucaena psyllids create problems on a much wider scale, ranging from poor subsistence farmers to middle-class farmers and government-sponsored agroforestry and afforestation projects.

Impact and Economic Status of Leucaena Psyllid

The economic status of leucaena in Thailand is difficult to assess quantitatively and monetarily. The "native" or "common" leucaena varieties have long been introduced in Thailand (Nielson 1985), and have become naturalized and adapted to local agroclimatic conditions. However, the "giant" leucaena is a recent introduction of the 1970s (Manidool 1983) as a fast-growing multipurpose tree for various agroforestry practices, fodder, nitrogen fixation and other uses. It has been widely planted in plantations for animal feed and forage, as a crop for supplementary income, ornamental and "edible" hedges as well as for various community forestry programs. According to Napompeth (1987), the total acreage under both types of leucaena has yet to be estimated. It can be considered weedy and noxious under certain situation and of rather intangible economic importance in other situations. Unlike other known introduced plant species such as the giant sensitive plant, *Mimosa pigra* L., and the creeping giant sensitive plant, *Mimosa invisa* Mart ex Colla, which are considered highly noxious, the benefit of leucaenas outweighs its demerits.

The impacts of leucaena psyllid in Thailand and its economic status have been moderate to very severe. Those keeping leucaena in their kitchen garden for occasional consumption or those who at times picking terminal shoots from their hedges or from roadside leucaena for home use or sales in the local market complained of the defoliation caused by the psyllid. Leucaenas planted for fodder and forage for animals were bare of leaves. Commercial plantings could no longer supply or meet the quota. Fortunately, leucaenas were only one of the many feed ingredients required, otherwise the animal feed industry would be highly jeopardized. Farmers growing leucaena to supplement their income were also desperate. Many leucaena plantations were either abandoned or plowed up and replaced by other crops.

The occurrence of the leucaena psyllid and the magnitude of damage on leucaena came as a shockwave never encountered before in the history of leucaena in Thailand. Stands of leucaena were bare of leaves as well as the commonly encountered roadside leucaenas. Unhealthy and ugly-looking leucaena trees dotted the countryside as well as the urban areas. Although few insect species have been found associated with leucaena, such as some geometrids and pseudococcids, but none of these insects or the nematode, *Meloidogyne* spp., reported by Yantasath and Watanakul (1987) has ever caused such devastating damage to leucaenas in Thailand. Farmers and the authorities responsible began to panic and resorted to using insecticides to control the psyllids. The results were however discouraging, uneconomical and impractical, if not ineffective.

The impact of the leucaena psyllid provides a classical pest management case study having high academic value in spite of the poorly understood economic value of leucaenas in Thailand. A number of other psyllid species were reported from Thailand. Hongsapruk (1987) reported 13 species of psyllids associated with certain plant species but none of them except the citrus psyllid, *Diaphorina citri* Kuwayana, were of any obvious economic importance. Even *D. citri*, which is so far a psyllid of economic importance serving as the vector of greening disease or citrus decline (Schwarz *et al.* 1973) resulting in not so obvious "shifting" citrus cultivation, has not received wide interest among researchers and responsible agencies compared to the leucaena psyllid in Thailand and other countries.

Current Research Activities on Leucaena Psyllid

Immediately after its detection in Chacheongsao and Bangkok, specimens of the leucaena psyllid were sent by NBCRC to State of Hawaii Department of Agriculture in October 1986 for definite identification and confirmation. Earlier predictions of the leucaena psyllid invasion to Southeast Asia in 1984 (G.Y. Funasaki and L.M. Nakahara, pers. comm.) became reality with the invasion of leucaena psyllids in Guam (R. Muniappan, pers. comm.) and Saipan (J. Tenorio, pers. comm.) in 1985. Warning of the possible invasion in Thailand was also made by Attajarusit (1986) and Rumakom (1986). The detection of the leucaena psyllid in Thailand in September-October 1986 coincided with reports of its occurrence in peninsular Malaysia by Ooi (1986) and Tho (1986). The widespread damage caused by leucaena psyllid was also observed in the coastal areas of Viet Nam. Psyllid populations were low in the northern provinces to very heavy in the central provinces to being moderate in the southern provinces of Viet Nam along the Kampuchean border in October-November 1986.

Since the leucaena psyllid is a newly introduced exotic pest it is essential to know how wide its

distribution is. Mapping of its occurrence and presence was launched by extensive field survey made by NBCRC and its collaborators at the NBCRC Regional Substations in Chiang Mai, Khon Kaen and Hat Yai commencing in December 1986. Up till early March 1987 the front line of the psyllid invasion moved northerly from the peninsular area and central plain, and westerly from the northeastern plateau. The psyllid was not detected in the northern highland area of Chiang Mai and Chiang Rai until the end of March 1987. By this time the psyllid had already spread and covered the total area of the country. Heavy infestations along the Burmese border and Mekong River also indicated the spread of the psyllid into Burma and Laos.

It was not anticipated then that the psyllid would exhibit a distinctive seasonality even when psyllid populations disappeared almost altogether in April 1987 in all areas observed. The resurgence of the psyllid population later in October 1987 and total disappearance in March-April 1988 together with the recent surge of population in October 1988 and its eventual disappearance in April 1989 would confirm such a definite seasonality. The cause of such a phenomena remains unclear and is beyond any simple explanation.

The detection of psyllid "population pockets" associated with leucaenas grown or planted at relatively higher elevations in Kanchanaburi and Saraburi in the central plain area, Pak Chong and Buriram in the lower northeastern plateau area, and Chiang Mai in the northern highlands has not merely generated puzzlement but also posed an academic challenge to synthesize necessary data for further analysis. There may exist many more such "population pockets" scattered throughout leucaena growing areas which are yet to be detected. It is speculated that there exist colonizing and settling populations of psyllids, the latter forming a smaller proportion of the total population.

During the psyllid survey, collection and observation of indigenous natural enemy were also made. These natural enemies were listed in Napompeth (1987, 1988) together with some entomopathogens. These natural enemies are now being evaluated for further utilization in augmentative biological control programs. The population dynamic study was thus initiated to determine the role of these density-dependent regulatory factors versus other density-independent regulatory factors. Hopefully, some of these indigenous natural enemies may have potential for use together with the exotic natural enemies already introduced and established in Hawaii (Nakahara *et al.* 1987, Funasaki *et al.* 1988), especially the nymphal parasite, *Psyllaephagus* sp. nr. *rotundiformis* (Howard) (Hymenoptera: Encyrtidae) and the coccinellids, *Curinus coeruleus* Mulsant and *Olla abdominalis* (Say) (Coleoptera: Coccinellidae) introduced to Hawaii much earlier for other target insect species but recently found predating voraciously on the leucaena psyllid.

As an emergency measure against the psyllid, insecticide trials were also carried out by researchers from Department of Agriculture. However, this type of research is not encouraged due to its impracticability and undesirable effect to the environment because of the highly diversified leucaena ecotypes and its socioeconomic status. The recommendation of the Molokaii meeting (NFTA 1987) also stated clearly that "*not* recommended is the use of pesticides for field control of leucaena psyllids, except for nursery stock, and although many insecticides can kill psyllids, chemical control has generally proven ineffective and too expensive."

The Thailand Institute of Scientific and Technological Research (TISTR) has been conducting research on *L. leucocephala* as a multipurpose tree species since 1977 (Yantasath and Watanakul 1987). With the invasion of psyllids in Thailand, TISTR in collaboration with NFTA and F/FRED has directed its efforts to Leucaena Psyllid Trials (LPT). It is also anticipated that seed production of tolerant or resistant varieties of leucaena will be done, probably on a commercial basis.

The Department of Livestock Development also plans to evaluate farmer-generated control strategies for leucaena psyllids. Other institutions involved in leucaena psyllid research, either partially or substantially, include the Royal Forest Department, the Faculty of Forestry of Kasetsart University and several non-governmental organizations (NGOs). The Department of Agricultural Extension is involved in extension work, advising farmers on solutions of leucaena psyllid problems.

Current research activities on leucaena psyllids in Thailand are supported with grants from the National Research Council of Thailand (NRCT), the National Biological Control Research Center (NBCRC), and the Forestry/Fuelwood Research and Development Project (F/FRED). F/FRED, in affiliation with the Regional Research Program for Leucaena Psyllid Control, supports both basic and applied research together with implementation programs. The main research activities in

Thailand are in accordance with the regional research plan developed in the Manila Meeting in 1987 (Napompeth *et al.* 1987). These research projects and some of the accomplishments are as follow:

1. **Ecological investigations**

The research organizations responsible for ecological investigations are the National Biological Control Research Center (NBCRC), Department of Agriculture (DOA), Royal Forest Department (RFD), and the Faculty of Forestry, Kasetsart University (KUFF). Life history data of *H. cubana* have been obtained by Maneeratana (1989) and Winotai (1989). In their studies various stages of *H. cubana* development were described together with the growth increment using the length of metafemur of each nymphal instar as a parameter. Various nymphal instars could also be differentiated using the number of antennal segments (Winotai 1989). As far as fecundity is concerned, the numbers of eggs laid per female ranged from 53 to 444 eggs, averaging around 250 eggs in both studies The duration of incubation period, five nymphal instars and adult longevity reported were also similar. The incubation period was about 4 days, while the duration of five successive nymphal instars were approximatly 2-3, 1-3, 1-3, 1-3, and 1-3 days respectively. The total nymphal period ranged from 8-13 days. The females outlived males with the longevity ranging from 5-18 and 2-13 days for female and male adult psyllids respectively. Both studies were carried out at 25-30^{0}C and 58-72% RH under laboratory conditions.

Life tables for *H. cubana* have been constructed and analyzed under laboratory conditions and are thus termed "biological life tables". The field or ecological life tables are yet to be investigated pending acceptable standard sampling units and the practicality and time required to make absolute counts. From the life table analysis the population statistics in terms of biological attributes were obtained. In investigations by Maneeratana (1989) and Winotai (1989) the following biological attributes were calculated for *H. cubana*: the net reproductive rate of increase (R_0) = 139.179 and 183.69; the capacity for increase (r_c) = 0.298 and 0.314; the finite rate of increase (λ) = 1.348 and 1.369; the cohort generation time (Tc) = 16.544 and 16.61 days; and the population doubling time (DT) = 2.21 days.

Sampling techniques for *H. cubana* are being investigated on a provisional basis. Selection of sampling size, time of sampling, frequency of sampling and numbers of samples to be taken are theoretically not so complicated. However, the main problem is in counting numbers of psyllids present in each sample, which is laborious and time-consuming. Attempts are being made to simplify such difficulties.

2. **Determination of economic threshold levels (ETLs)**

Although it is most desirable in an integrated pest management (IPM) approach to establish an economic threshold level (ETL) for H. *cubana*, the ETL to be established must take into consideration the purposes of a leucaena plantations. Rating of leucaena psyllids and their damage has been provisionally used to obtain quick and timely data for decision-making. ETLs could not be accurately developed until satisfactory sampling techniques have been devised on a practical and economical basis. This aspect of investigation is a challenge to all researchers on leucaena psyllids in the region.

3. **Evaluation of indigenous natural enemies**

Among all indigenous natural enemies found associated with *H. cubana* in Thailand, it was obvious that they were euryphagous and considered general predators. No parasites or parasitoids have been recovered yet. From these prey-nonspecific predators, the coccinellids were the most common predators especially *Menochilus sexmaculatus* (F.) and *Menochilus discolor* (F.). Field data and observations indicated that only adults were found, not the immature stages. It is doubtful at this stage that there will exist a dominant indigenous predator having high potential for further utilization as a biological control agent. These predators may have to be treated together as a predator-complex whose role is to be determined if they could be complimentary as natural control factors to the more specific exotic natural enemies already introduced to Thailand.

4. **Introduction of exotic natural enemies**

The coccinellid, *C. coeruleus*, and the encyrtid parasite, *P.* sp. nr. *rotundiformis*, were introduced to Thailand in 1987 and 1988 respectively. After necessary quarantine screening they were released and became established in many locations. It is, however, too early to evaluate the performance of *C. coeruleus* and *P.* sp. nr. *rotundiformis* at this stage, but the fear that these control agents may not become established has been overcome. Investigations are also being made to observe the extent of hyperparasitism on *P.* sp. nr. *rotundiformis*. *C. coeruleus* cultures from Thailand were introduced to Burma, India and

Vietnam in 1987 and 1988. When fully established, *P.* sp. nr. *rotundiformis* could be made available to other countries.

5. **Search and evaluation of entomopathogens**

The entomogenous fungi found associated with leucaena psyllids in Thailand were *Conidiobolus coronatus* (Constantin) Butko, *Entomophthora* sp. and *Hirsutella thomsonii* Fischer, among the Entomophthoraceae; and *Alternaria* sp. *Aspergillus* sp., *Cladosporium* sp. and *Fusarium* sp. among the Dermatiaceae. Of these, *C. coronatus* and *Entomophthora* sp. were the most destructive on leucaena psyllids. Attempts are being made to isolate them for further possible utilization.

6. **Psyllid resistance in leucaena**

Since the use of tolerant or resistant leucaenas is unquestionably one of the main components in a leucaena psyllid management program, TISTR is devoting its efforts to the determination of the nature and effectiveness of different sources of psyllid resistance in leucaenas. Attempts are also being made to explore and evaluate psyllid resistant genotypes of *L. leucocephala* from existing stands in Thailand. It has been speculated that the combined use of resistant leucaenas and exotic natural enemies will help reduce psyllid problems.

7. **Psyllid population monitoring**

Department of Agriculture researchers are concentrating on the evaluation of various population monitoring methodologies in anticipation of a practical and timely decision-making in IPM approach and practice. This investigation will be undertaken taking into consideration economic threshold levels to be eventually developed and adopted.

8. **Farmer-generated control techniques**

Confronted with psyllid damage and a lack of appropriate control recommendations, together with the urgent need to protect their leucaena crops, farmers are forced to "invent" their own control techniques. The control techniques adopted by farmers ranges from covering young top shoots with plastic bags to keep top shoots for home consumption to abandoning the fodder fields altogether. Some farmers resort to insecticide application but to no avail. Few farmers cut down the trees and burn them, again with no success. Those farmers knowing that the coccinellid, *C. coeruleus*, is available have requested releases in their own fields.

Control techniques employed by Thai farmers to combat leucaena psyllids have yet to be explored. The Department of Livestock Development will be responsible in the evaluation of farmer-generated leucaena psyllid control techniques. Such an investigation is of importance not only for leucaena production for livestock feed and fodder but also for alley-cropping and community forestry purposes.

9. **Development of IPM prorams and Implementation**

Investigations leading to the development of IPM programs are certainly an ultimate objective in the solution of psyllid problems. However, with inadequate information such objectives will not be attainable in a short period of time. As a result, provisional ETLs may have to be used together with any available control strategy such as the release of exotic natural enemies and the substitution of tolerant or resistant varieties of *L. leucocephala* until other appropriate control measures could be made available as tools in an IPM program for leucaena psyllids.

Management and Control Strategies

Being unprepared for the sudden and unexpected outbreaks of leucaena psyllids, no management and control strategies were ready for combating them at the outset of the infestation. As a result, "no action" has been the most appropriate choice until more suitable control measures become available.

Since the selection and breeding programs to develop leucaena varieties tolerate and resistant to the leucaena psyllids will be rather time-consuming and not timely enough to help solve the confronting problems, biological control has become the only choice at present as the most appropriate management and control strategy for leucaena psyllids in Thailand. Biological control strategies were then developed by NBCRC taking into consideration the exploitation and utilization of indigenous natural enemies, especially the generalist coccinellid predators, together with classical biological control by introducing available natural enemies being used in Hawaii especially the encyrtid parasite, *P.* sp. nr. *rotundiformis* and the coccinellids, *C. coeruleus* and *O. abdominalis*. The endemic strains of the entomogenous fungi, *Entomophthora* sp., *C. coronatus* and *H. thomsonii* could also be further investigated for microbial control of the leucaena psyllids, probably in the initial stage by transferring the infected psyllids to the areas of low incidence of epidemics.

A biological control research program including releases of exotic predators and a parasitic wasp, has been established in Thailand and is described in detail elsewhere in this volume.

As far as the use of insecticides is concerned, Chawanapong (1988) of Department of Agriculture recommended the following insecticides for the control of leucaena psyllids in leucaena fodder production: carbaryl 85% WP (Sevin), carbosulfan 20% EC (Posse), cyhalothrin L 2.5% EC (Karate 2.5), dicrotophos 24% EC (Bidrin), and omethoate 80% SL (Folimat). These are to be used at the rate of 40 g, 40 ml, 10 ml, 30 ml and 15 ml per 20 l of water respectively at 60-80 l per rai (2.5 rai = 1 acre). Recommendations are for the insecticides to be applied in the evening to cover the top shoots thoroughly and the second application made 15 days later. Two applications are adequate and the fodder can be harvested 1-2 months after the last application with no residue, leaving the leucaena leafmeal safe for animal feed.

Certain plant derivatives having known insecticidal properties have also been tried. The Royal Forest Department attempted to use dry tobacco leaves at the rate of 0.25% (W/V) and dry neem seeds at the rate of 0.005% (W/V) and found that control of 90% of the *H. cubana* nymphs could be obtained at 9 and 24 hr respectively (Hutacharern 1987).

These control techniques are the only management and control strategies available for leucaena psyllids in Thailand. The use of resistant varieties, though strongly recommended, will require some time before being substantial. It is anticipated that these control strategies will remain the only available techniques until more appropriate control measures are developed for incorporation into integrated pest management programs to be developed and implemented for leucaena psyllids.

Research Collaboration

At the national level, research collaboration has been well established among universities and government agencies in various ministries collaborating under the NBCRC administration. With its headquarters in Bangkok and extended field facilities at Kampaengsaen, Nakhon Pathom together with its regional substations in Chiang Mai, Khon Kaen and Hat Yai, NBCRC and its collaborators cover research activities dealing with biological control in all important geographical regions of the country. Such collaboration has been engineered on the leucaena psyllid and strengthened with the establishment of the National *ad hoc* Committee for the Control of Leucaena Psyllid. Collaborative research other than biological control of leucaena psyllid has been made possible through this NBCRC network.

Regional collaboration on leucaena psyllid research has also been made possible under the sponsorship of the F/FRED project. The Regional Research Program for Leucaena Psyllid Control was established in 1988 and funded by F/FRED. Participating countries in the region include Indonesia, Malaysia, Philippines, Republic of China (Taiwan), Thailand and USA. In 1989, Australia and Sri Lanka have become participants. National coordinators have been selected from each participating country and the research programs and activities coordinated by a regional coordinator selected from national coordinators. From the U.S., NFTA and the State of Hawaii Department of Agriculture also collaborate with the regional research program.

Related to and connected with the regional research programs are activities supported by the International Development Research Center (IDRC), Canada for strengthening research activities on the leucaena psyllid in Indonesia and the Philippines. IDRC also supports the exploration for exotic natural enemies in the native range of the psyllid in Latin America by CAB International Institute of Biological Control (CIBC) for introduction to the leucaena psyllid affected regions in Asia and the Pacific.

The State of Hawaii Department of Agriculture (HDOA), Hawaii has also contributed greatly to the regional research program by providing consignments of the natural enemies of leucaena psyllids to other countries. The coccinellid, *C. coeruleus*, introduced to Indonesia and several countries, was obtained from Hawaii. The encyrtid parasite, *P.* sp. nr. *rotundiformis*, introduced from Trinidad and Tobago in 1985 to Hawaii, released in June 1987 and widely established in June 1988, was also made available for introduction to Thailand commencing in October 1987. Hawaii is also a good source for another coccinellid, *O. abdominalis*, which has been introduced from Tahiti to New Caledonia for the control of leucaena psyllid.

Similar regional collaboration could be expanded and strengthened within the region. Consignments of *C. coeruleus* from Thailand were sent to Vietnam in October 1987, Burma in January 1988 and India in October 1988. The cultures of the encyrtid parasite, *P.* sp. nr. *rotundiformis*, will be made available during the 1989-1990 leucaena psyllid outbreak season to other countries for introductions.

Collection, exchange and availability of psyllid-tolerant and resistant materials have

been extensively carried out by NFTA and collaborating countries in Asia and the Pacific. In addition to this cooperation, collaborative research themes are also suggested for comparative investigation in various leucaena psyllid infected countries such as the life table studies of *H. cubana* to be carried out in Australia, Thailand and other countries.

Conclusions

Current leucaena psyllid research activities should be considered as only preliminary. It is obvious that more research is needed to meet the needs for appropriate management tools for the solution of the psyllid problem. It is not possible to predict how long the country will be confronted with the psyllid problem. It is also not known if the leucaena psyllid will exhibit a highly oscillating population density during its invasion of new areas or if the populations will taper off eventually to the low levels as witnessed in some other introduced exotic insect pest species.

With timely action taken at the national and regional level, together with concerned international agencies, it is hoped that the leucaena psyllid problem will be reduced, if not totally solved. The regional research collaboration and partnership witnessed in the case of leucaena psyllid will also serve as a classical case model which will lead to pest management benefits and many other intangible benefits derived from such an effort.

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RESEARCH ON *HETEROPSYLLA CUBANA* CRAWFORD IN VIETNAM

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Abstract

The leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), was detected in Vietnam in November 1986. Since then, it has infested leucaena along the coastal areas from Hanoi to the Mekong Delta. Heavy infestation occurred from mid- October until the end of March each year. Three species of coccinellids predate on *H. cubana* in Vietnam. They are *Micraspis discolor, Menochilus sexmaculatus* and *Coccinella transversalis* but their populations are considerably low. *Curinus coeruleus* was introduced from Hawaii via Thailand in October 1987 and May 1988 for trials. Research on the biology of *H. cubana* and the role of coccinellids as biological control agents for *H. cubana* is being intensified and expanded.

Introduction

As in other Southeast Asian countries, the leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), has seriously damaged leucaena in Vietnam. The psyllid was first detected in Vietnam by Napompeth (1987). It attacked leucaena in the northern provinces of Hanoi, Nam Dinh and Thanh Hoa, in the coastal provinces of Vinh, Dong Hoi, Quang Tri, Hue, Da Nang, Quanh Ngai, Qui Nhon, Tuy Hoa, Nha Trang and Phan Rang, the southeastern provinces, Ho Chi Minh City, the Mekong Delta provinces, and An Giang along the Kampuchean border.

Damage and distribution

H. cubana occurred in large numbers and it was not unusual to find hundreds or thousands of eggs, nymphs and adults on one top shoot of the leucaena plant. Complete defoliation of the plant occurred under such heavy attacks. Such serious infestations were observed from January to March 1987, on leucaena in the suburbs of Hanoi, the Red River Delta areas in Dan Phuong and Hoai Duc (Hanoi), Dong Mo and Thuong Tin in Ha Son Binh province, Dap Cau (Ha Bac), Phu Ho (Vinh), and other areas. The infestation declined during March and April 1987. The psyllid population size was very small by May 1987. In Hanoi, *H. cubana* populations surged again in mid-October. By December, almost all of the leucaena plants withered and were completely defoliated by large psyllid populations. Similar damage and infestation occurred in other areas. In early November 1987, *H. cubana* reappeared on leucaena in Dong Mo in Ha Son Binh province and in Tam Diep. However, it was not observed during November in Phu Ly of Ha Nam Ninh province and Thoung Tin of Ha Son Binh province where severe damage occurred in the spring of 1987. The November infestation in Hue was serious.

It was obvious that the psyllid damaged leucaena plants mostly during the winter-spring season. The absence or low population size of the psyllid from May to early October probably was due to the hot and dry weather during the summer and the heavy rain during the typhoon season. However, the factors affecting the population size of *H. cubana* are not fully understood.

Biological control attempts

Researchers are seeking biological control agents for the psyllid. A number of endemic predators of *H. cubana* occur in Thailand (Napompeth 1987). Insect pathogens, such as *Beauvaria* sp. and *Metarrhizium* sp., attack the psyllid in the Philippines (Tran-Gruber *et al.* 1987). The predator *Curinus coeruleus* was introduced to the Philippines from Hawaii in March 1986. In addition, an encyrtid nymphal parasite, *Psyllaephagus* sp. nr. *rotundifomis*, was introduced to Thailand from Hawaii in 1987 and 1988 (Napompeth 1988). *C. coeruleus* was introduced to Vietnam from Hawaii via Thailand in October 1987 and May 1988.

Laboratory investigations indicated that *H.cubana* was not a suitable prey for the larvae of the endemic coccinellids, *Menochilus sexmaculatus* and *Coccinella transversalis*. Only 28.6 and 34.4 percent of the first instar, and 14.2

and 15.1 percent of the second instar larvae of *M. sexmaculatus* and *C. transversalis*, respectively, could molt when fed *H. cubana* and none of the larvae could complete their development. However, when *Aphis medicaginis* was used as prey, 60 percent of *M. sexamaculatus* and 100 percent of *C. transversalis* could complete their life cycles. When reared on *H. cubana, C. coeruleus* could complete its life cycle in 40-57 days during October which was during the winter time. Adults of *M. sexmaculata, C. transversalis* and *C. coeruleus*, however, fed voraciously on *H. cubana* under field conditions and in the laboratory.

Conclusion

Research is being expanded to evaluate the endemic and introduced coccinellids for biological control of *H. cubana* in Vietnam. More sampling of *H. cubana* populations and investigations of the ecology of *H. cubana* will be conducted.

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RESISTANCE OF LEUCAENA AND SOME OTHER TREE LEGUMES TO *HETEROPSYLLA CUBANA* IN WEST TIMOR, INDONESIA

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Abstract

Three trials were carried out in West Timor to measure the adaptation and psyllid-resistance of several varieties of leucaena and other tree legumes. All varieties of *Leucaena leucocephala* were severely damaged by the psyllid. *L. pallida* K376 and *L. diversifolia* K784 were well-adapted and psyllid-resistant. Other selections of *L. pallida*, *L. diversifolia* and *L. collinsii* are promising.

Other tree legumes not attacked by leucaena psyllids were *Acacia agustissima*, *A. villosa*, *Sesbania grandiflora*, *Gliricidia sepium* and *Calliandra calothrysus*. More work is needed on their productivity, seed production, palatability and effect on animal production, so that these alternative species can be developed for use in farming systems of Nusa Tenggara Timur.

Introduction

Leucaena leucocephala, known as "lamtoro", was probably introduced to Southeast Asia by the Spanish in the 16th Century. It was planted widely in Java and Sumatra for shade, erosion control and soil fertility in plantation crops. In 1930, leucaena was planted in the Sikka and Amarasi areas of Nusa Tenggara Timur province (Parera 1982). In Sikka, it was used mainly for erosion control, and, in Amarasi, it was used to prevent the spread of the weed *Lantana camara* in grazing land (Piggin and Parera 1985). An order from the local raja in 1932 required the people of Amarasi to plant leucaena, and, eventually, it covered about two thirds of the area of Amarasi (Metzner 1980).

Leucaena became highly regarded and was incorporated into several governmental development programs. It formed the base of the "paron" system of fattening tethered cattle, by which the income of many small farmers was increased (Jones 1983). In addition to its use for firewood production and environmental protection, it was possible to intensify land use and reduce shifting cultivation by incorporating leucaena into cropping systems.

Thus, the invasion of the leucaena psyllid (*Heteropsylla cubana*) in mid-1986 was a disaster for the province of Nusa Tenggara Timur. At the end of August 1986, it was estimated that fifty percent of the 4,300 km^2 planted to leucaena was already damaged (M'Boi 1986), and now damage is severe throughout the province. The psyllid damage to leucaena reduced farmer income from cattle fattening and cropping, hindered the land conservation and rehabilitation program, and reduced farmer confidence in leucaena (and possibly made them suspicious of new alternative species).

A strategy to alleviate the psyllid problem has been described by Piggin and Parera (1987). Part of this strategy involves the testing in Timor of the psyllid tolerance of several leucaena species and other tree legumes. Preliminary results of these trials were presented by Piggin and Mella (1987), and are updated here.

Materials and Methods

The trials were located at Besi Pae in the district of Timor Tengah Selatan (South Central Timor), situated at 10°S, 123°30'E and at 300 m elevation. The mean annual precipitation is ca. 1,000 mm, and there is an annual dry period of 7-8 months. Three trials were established on a black, light-medium clay soil with pH 7-7.5 (Aldrick 1984).

Seeds of all species were initially planted in polyethylene using soil from an established leucaena area, and, later, the seedlings were transplanted into the field. Trials were fenced to

prevent grazing, and were weeded regularly to reduce competition.

The methodology for observations was based on the guidelines issued by the Nitrogen Fixing Tree Association (NFTA) for cooperative trials. Psyllid counts (adults, nymphs and eggs) were carried out on two samples of juvenile leaves on five trees in each replication. The counts were made using scores from1 (no adults/nymphs/eggs) to 9 (50 + adults/nymphs per sample or egg masses covering leaves and stems). Psyllid damage was rated from 1 (none) to 9 (blackened stem with total leaf loss). Basal diameter at 15 cm above ground level and height were measured.

Trial 1 is part of the collaborative NFTA Leucaena Psyllid Trials (LPT). It involves evaluation of seven leucaena species or varieties and seven varieties planted for observation only (Table 1). Seeds were planted on March 6, 1987, and seedlings were transplanted June 24-25, 1987 into 5 m rows with 20 plants per row, using 3 replicates in a randomized block design. Seedlings were watered to ensure survival until the following wet season. Observations were made in July 1987 and monthly from March until December 1988. The seven varieties in the experimental plots were cut in March 1988, at 50 cm, and in June and December 1988, at 75 cm above ground level. The yields of edible dry matter and wood were measured.

Trial 2 also involves cooperation with NFTA in its Leucaena Psyllid Resistance Trial. Observations are being made on eight Hawaiian varieties or species of leucaena and five local varieties (Table 2). Seeds were planted November 21, 1986, and seedlings were transplanted January 29, 1987, into 1 m rows with 10 plants per row and 2 replicates. No cutting was carried out. Observations were

Table 1. Scores* of psyllid numbers (adults, nymphs and eggs) and damage on varieties in Trial 1- December 1988.

	Damage	Adults	Nymphs	Eggs
EXPERIMENTAL PLOTS				
L. pallida K376	1.0	1.3	1.1	1.0
L. diversifolia K784	1.0	1.4	1.2	1.0
L. diversifolia K156	4.5	5.7	5.9	5.9
L. hybrid K156 x K8	7.7	5.1	5.7	5.9
L. leucocephala K636	6.5	5.8	5.8	5.9
L. leucocephala K8	7.9	5.3	5.8	5.8
L. leucocephala K527	8.2	5.7	5.9	6.1
LSD (P = 0.05)	0.2	0.5	0.3	0.2
OBSERVATIONAL PLOTS				
L. diversifolia K785	1.0	5.8	4.4	3.9
L. leucocephala local	7.2	5.9	6.0	6.0
L. leucocephala K500	6.4	6.0	6.0	6.0
L. leucocephala K584	6.1	5.9	6.0	6.0
L. leucocephala K614	7.0	5.8	5.8	6.0
L. hybrid XK1 (K163 x K376)	1.0	1.3	1.3	1.0
L. hybrid XK2 (K8 x K376)	4.3	5.3	5.8	6.0

* See text for scoring methodology.

Table 2. Scores* of psyllid adults and damage on varieties in Trial 2-December 1988.

	Damage	Adults
L. leucocephala local	8.0	4.5
L. leucocephala K6	8.0	4.5
L. leucocephala K8	8.0	4.5
L. leucocephala K28	8.0	4.5
L. leucocephala K500	8.0	4.5
L. leucocephala K584	8.0	5.0
L. leucocephala K538	7.0	5.0
L. leucocephala K614	8.0	5.0
L. leucocephala K636	7.0	4.5
L. leucocephala K636 x *L. diversifolia* K156	8.0	5.0
L. leucocephala K341 x *L. esculenta* K138	-	5.0
L. pallida K376 x *L. diversifolia* K164	2.0	4.0
L. leucocephala K28 x L. diversifolia K156	7.0	5.0

* See text for scoring methodology.

made in June 1987, and in June and December 1988. These varieties were also evaluated at a field site at Kefamenanu, which is ca. 100 km northeast of Besi Pae in a zone of slightly higher altitude and rainfall.

Trial 3 is part of the Shrub Legume Adaptability Trial with the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Australian Center for International Agricultural Research (ACIAR). Nineteen varieties of leucaena and other tree legume genera are being observed for psyllid tolerance (Table 3). Seed was planted on October 1, 1986, and seedlings were transplanted on February 3, 1987, into 1 m rows with 10 plants per row, including 2 replicates. Observations were carried out January 9 and June 25, 1987, and in June and December 1988.

Results

Resistance: In Trial 1, there were significant differences among species in tolerance, as reflected by damage and psyllid numbers during all months. The data for December 1988, typifies these differences (Table 1). *L. diversifolia* K784 and *L. pallida* K376 showed negligible damage. *L. diversifolia* K156 was less seriously damaged than the remainder, which were all varieties of *L. leucocephala*.

There were also significant differences among varieties in monthly counts of adults, nymphs and eggs (Table 1). There was a high correlation between adult numbers and damage; the varieties with little damage harbored very low numbers of psyllids.

In the observational plots in Trial 1, the hybrids XK1 and XK2 also had some tolerance, but the sample size was limited. These plots were not cut, and, in June 1988, a small amount of seed was harvested from the XK1 variety. The other varieties have not flowered yet.

In Trial 2, all of the *L. leucocephala* varieties were severely damaged at both the Besi Pae and Kefamenanu sites, with only K376 x K164 showing some tolerance (Table 2). In Trial 3, *L. diversifolia* 46568, *L. pallida* 84581, and all of the varieties of *Acacia*, *Sesbania*, *Calliandra* and *Gliricidia* were not damaged (Table 3). *L. diversifolia* 33820, *L. collinsii* 46570 and *L. pallida* 85891 had little damage, but all of the *L. leucocephala* varieties were severely damaged.

Seasonality of psyllid numbers and damage: Psyllid numbers and damage tended to be

Table 3. Scores* of psyllid adults and damage on varieties in Trial 3-December 1988.

	Damage	Adults
L. leucocephala 85176	8.0	5.0
L. leucocephala 85929	8.0	5.0
L. leucocephala local	8.0	5.0
L. leucocephala K28	7.0	5.0
L. leucocephala 90814	7.5	5.0
L. leucocephala cv. Cunningham	8.0	5.0
L. diversifolia 33820	1.5	5.0
L. diversifolia 46568	1.0	5.0
L. collinsii 46570	3.5	5.0
L. pallida 84581	1.0	5.0
L. pallida 85891	1.5	5.0
Acacia augustissima 40175	1.0	1.0
Acacia villosa local	1.0	1.0
Acacia sp. 84998	1.0	1.0
Sesbania grandiflora local	1.0	1.0
Sesbania grandiflora 96461	1.0	1.0
Gliricidia sepium 60796	1.0	1.0
Gliricidia sp. local	1.0	1.0
Calliandra calothrysus local	1.0	1.0

* See text for scoring methodology.

greater during the early dry season months, as typified by the susceptible variety, K527, shown in Figure 1. After June, psyllid numbers decreased, but the degree of damage remained high throughout the dry season. The plants could not recover during the dry season. Damage was less in the early wet season, before psyllid numbers increased in response to new plant growth.

Plant growth: The stem diameter of *L. pallida* K376 was consistently greater than that of other varieties in Trial 1 (Table 4). By December, 1988, there was little difference among the remaining varieties, although the stem diameter of *L. diversifolia* K784 was ranked second throughout the trial.

Up to the time of the first cutting, *L. pallida* K376 and *L. diversifolia* K784 had attained a greater height (Table 4) and leaf yield (Figure 2) than the other varieties. Leaf production and height regrowth of *L pallida* K376 was greater than *L. diversifolia* K784 only in the June harvest. While the yield of *L. diversifolia* K784 was significantly better than other varieties after the first cutting, it declined in subsequent cuttings (Figure 2).

Palatability: Leaf material cut from the seven species in Trial 1 was readily eaten by Bali cattle bulls, which were receiving a base ration of grass.

Discussion

The results from these trials confirm the preliminary observations of June-July 1987 presented by Piggin and Mella (1987). The *L. leucocephala* varieties in all trials suffered severely from psyllid damage. *L. pallida* K376 is well-adapted and resistant, while *L. diversifolia* K784 is resistant but may not be as productive as *L. pallida* K376 when cut. General observations of damage indicate that other selections of *L. pallida* (e.g. 84581, 85891), *L. diversifolia* (e.g. 46568, 33820) and *L. collinsii* (e.g. 46570) may require further testing.

The productivity, seed production, palatability and animal weight gain potential of these promising species need further investigation. Preliminary observations in Timor on feeding

Table 4. Height and stem diameter of varieties in Trial 1 at cutting times in 1988.

	Plant height (cm) Mar.	June	Dec.	Stem diam. (cm) Dec.
L. *pallida* K376	192	221	177	3.60
L. diversifolia K784	189	174	145	2.90
L. diversifolia K156	125	156	124	1.97
L. hybrid K156 x K8 (K743)	130	168	142	2.47
L. leucocephala K636	108	178	138	2.60
L. leucocephala K8	121	154	143	2.57
L. leucocephala K527	100	139	119	2.20
LSD (P = 0.05)	34	38	n.s.	0.50

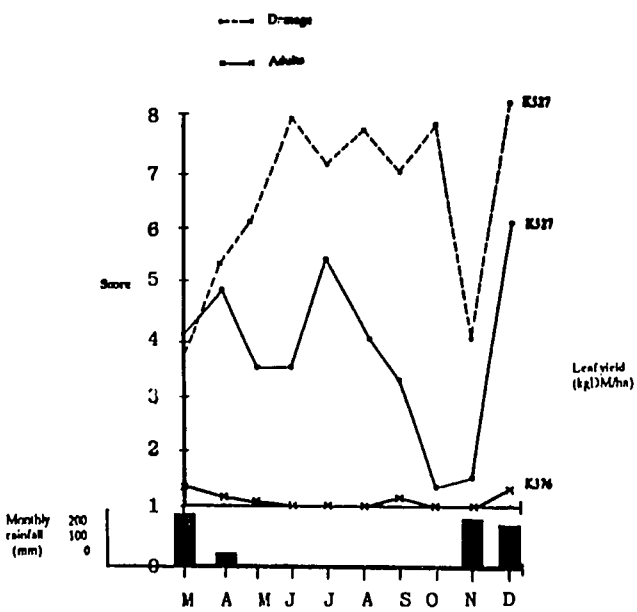

Figure 1. Seasonal variation in psyllid numbers and damage for tolerant (K376) and susceptible (K527) varieties - Trial 1.

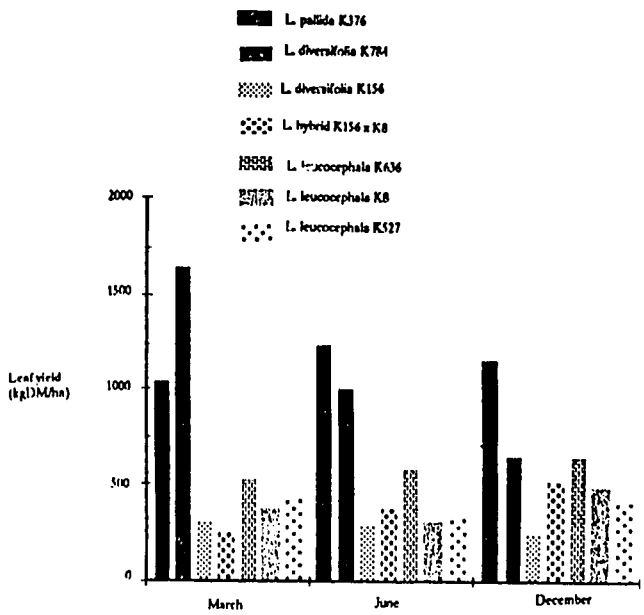

Figure 2. Leaf yield of varieties in Trial 1 at cutting in March, June and December, 1988.

some of the alternative *Leucaena* species to cattle indicate that palatability is not likely to be a major impediment to their use for forage.

Other tree legume species not attacked by the leucaena psyllid included *Acacia augustissima*, *A. villosa*, *Sesbania grandiflora*, *Gliricidia sepium* and *Calliandra calothrysus*. Of these, *S. grandiflora* is already being cultivated more widely by farmers in Timor since the devastation of leucaena. Other species, such as *A. villosa* and *G. sepium*, occur in some areas and appear to be well-adapted, but are little utilized by farmers for forage or in cropping systems. Further investigation and development for their uses are needed.

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SECONDARY METABOLITES IN LEUCAENA AFFECTING RESISTANCE TO *HETEROPSYLLA CUBANA* CRAWFORD

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Abstract

Plant secondary metabolites have a functional role in plant defense mechanisms. A study has been carried out to search for the secondary metabolite(s) that may be responsible for the resistance of some leucaena cultivars to *Heteropsylla cubana* Crawford. This report compares the contents of mimosine, total phenolics, flavonoid glycosides, tannins and "saponin" in the sap of resistant and non-resistant leucaenas. Only the compounds that are tentatively identified as saponin distinguish resistant and non-resistant leucaenas.

Introduction

The outbreak of the leucaena psyllid (*Heteropsylla cubana* Crawford) showed that resistance is a distinguishing characteristic among leucaenas. Based on the size of psyllid populations and the amount of damage, leucaenas can be classified into resistant and non-resistant groups. The classification can be based on monitoring the effect of the psyllid infestation on various leucaena accessions or, on experimental results obtained from research with a systematic design.

Whether a monitoring or a systematic research design is used, the effect of leucaena psyllids on leucaena accessions may vary with the location and the physiological states of the trees. An explanation of why certain leucaena accessions are resistant under certain conditions is lacking. Knowledge about the factor(s) that confer resistance, how the factor works and how it is expressed will enable us to understand the mechanisms underlying resistance and to exploit these mechanisms in psyllid management. The identification and quantification of chemicals that confer resistance to psyllids can be used to predict whether a leucaena accession is resistant and to substantiate results from resistance trials that monitor pest populations and damage.

The resistance of plants to pests and diseases can be related to their physical characteristics, physiological responses or biochemical properties.

Plant secondary metabolites can repel, deter, or be toxic to insect pests. Several secondary metabolites have been identified in leucaena, including mimosine, phenolics, tannins, flavonol glycosides (Lowry *et al.* 1984) and saponin (Acamovic *et al.* 1986). A comparison of the contents of these compounds in resistant and non-resistant leucaena accessions will be discussed in this paper.

Because adults of leucaena psyllids tend to congregate on non-resistant leucaenas but not on resistant leucaenas, the possibility of the presence of volatile attractants or repellents on leucaena will also be discussed.

Materials and Methods

Since leucaena psyllids are sap-suckers, the comparison is based on secondary metabolites contained in the sap, which was obtained by pinching the tip of the leucaena shoots.

Results and Discussion

Mimosine

The toxicity of leucaena was first reported by Morris (1897), who found that the ingestion of the seeds and foliage of leucaena caused hair loss, especially in the mane and tail of horses, pigs and donkeys. Mimosine, as the toxic principle, was isolated from leucaena by Kostermans (1946), who investigated the cause of hair loss in humans who ate the seeds.

The insecticidal action of mimosine was demonstrated by Mendoza and Ilag (1980) by spraying aphids with mimosine solution. In higher animals, the targets of mimosine toxicity are hair follicles and particular organs, such as the thyroid gland and the reproductive organs. Since it is poisonous to many organisms,

including plants, animals, and microbes, and it inhibits DNA, RNA and protein synthesis (Reisner *et al.* 1979), mimosine can be classified as a broad spectrum toxin. Thus, mimosine also could be deleterious to leucaena psyllids. Leucaena accessions that contain higher amounts of mimosine in the sap might be less susceptible to psyllid damage.

A comparison of mimosine content in the sap of resistant and susceptible leucaena accessions is presented in Table 1. The mimosine analyses indicate that a highly resistant accession, BPTL 003, did not contain a higher amount of mimosine in the sap than did tolerant or susceptible accessions. This suggests that mimosine is not a defensive compound against leucaena psyllids. In fact, the mimosine concentration in the sap of more than 10 percent (fresh weight) represents a concentration that is greater than its solubility in water. Such a high mimosine content has been reported previously by Tangendjaja (1983).

The ability of leucaena psyllids to flourish on sap with such high mimosine concentrations indicates that leucaena psyllids have adapted well to mimosine. Cattle can also feed on leucaena containing mimosine without toxic effects (ter Meulen *et al.* 1979) due to the rumen microorganisms, which are able to degrade mimosine efficiently and rapidly.

Mimosine degrading activity was also exhibited by leucaena psyllid extract (Figure 1). A descending mimosine concentration which evolves an ascending 3-hydroxy-4(1H)-pyridone (DHP) concentration indicates that leucaena psyllids are able to degrade mimosine to DHP. As shown in Figure 1, the leucaena sap does not demonstrate mimosine degrading activity, since mimosine solution incubated with sap did not produce higher concentrations of DHP over time.

DHP was also detected in leucaena psyllid bodies (Table 2). Since DHP is not naturally

Table 1. Mimosine content* of the sap of leucaena accessions.

No.	Accessions	Mimosine (% DW ± S.D.)	R/S
1.	*L. diversifolia* BPTL 003	51.22	R
2.	*L. diversifolia* CIAT 17388	41.34±2.09	T
3.	*L. pulverulenta* CPI 22964 x *L. leucocephala* cv Cunningham	54.49±1.78	T
4.	*L. leucocephala* K636	49.45±1.69	T
5.	*L. collinsii*	36.73±1.93	T
6.	*L. leucocephala* K8	52.29±2.67	S
7.	*L. leucocephala* cv Peru	43.55±2.32	S
8.	*L. leucocephala* K28	36.73±2.31	S
9.	*L. leucocephala* cv Cunningham	40.80±1.63	S
10.	*L. pulverulenta* CPI 23145 x *L. leucocephala* cv Cunningham	34.47±1.89	S

* Mean of 4 tree replicates, except for BPTL 003, which was unreplicated.

R = resistant, less than 5 adult psyllids per 20 cm shoot. Nymphs, if any, do not develop into late instars. Sometimes a few punctures were found on leaflets.
T = tolerant, psyllids proliferate well. Trees still retain more than 50 percent of leaves (clonally propagated K8 were heavily damaged).
S = susceptible Trees were heavily damaged.
DW = dry weight.

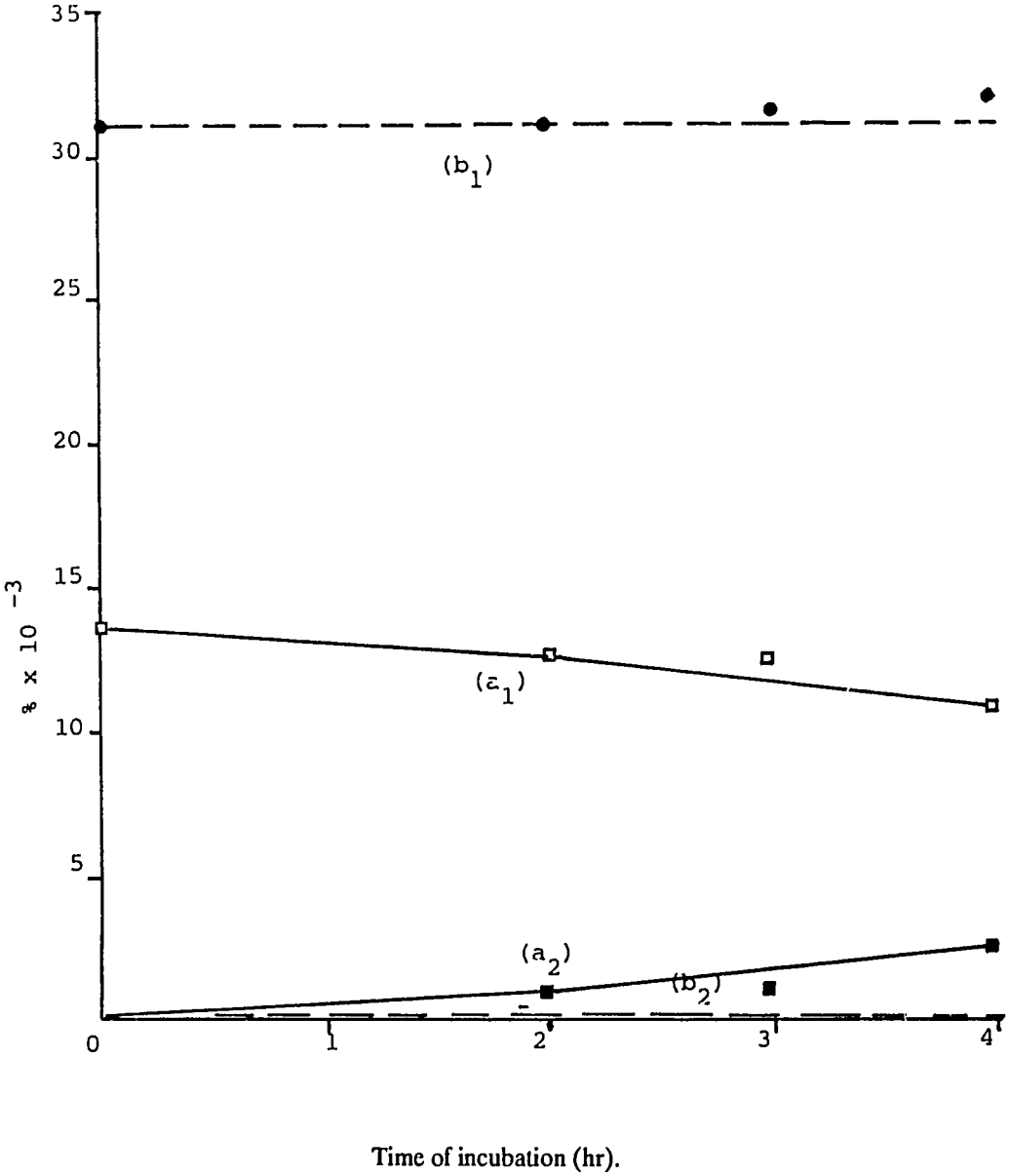

Figure 1. Mimosine degrading activity of leucaena psyllids extract.
a_1 : Mimosine incubatd with psyllids.
a_2 : Mimosine incubated with sap.
b_1 : DHP formed in a_1.
b_2 : DHP formed in a_2.

Table 2. Mimosine and DHP contents* in Leucaena psyllids and their excreta.

Sample	% FW ± SD	
	Mimosine	DHP
Leucaena psyllids		
Adults	.050 ± .01	.010 ± .006
Nymphs	.020 ± .003	.002 ± .003
Honey dew	.070 ± .2	.001 ± .002
Solid excreta	.200 ± .08	+
Leucaena sap	7.830 ± 3.0	-

* Mean of 4 replicates
\+ = detected
\- = not detected
FW = fresh weight

found in leucaena sap, the presence of DHP in psyllid bodies indicated that mimosine degradation occurs in psyllids. The presence of mimosine and DHP in psyllid excreta indicates that the mechanism of adaptation also involves excretion of undegraded mimosine.

The ability of leucaena psyllids to thriv on high mimosine-containing sap, to degrade and to excrete this toxic amino acid suggest that it is unlikely that mimosine plays a crucial role in defensive mechanism against leucaena psyllids.

Phenolics, flavonol glycosides and tannin

Flavonol glycosides and tannin are the major constituents of leucaena leaf phenolics. The total phenolics in leucaena leaves account for 5 percent of dry weight, of which 1 percent is tannin and 3-4 percent is flavonol glycosides (Lowry *et al.* 1984).

Condensed and hydrolyzable tannins are both powerful precipitants of protein. Although there are several mechanisms to explain growth inhibition, all explanations involve protein binding. (Singleton and Kratzer 1969). By binding proteins, tannins can impair herbivore nutrition and physiological function. The astringent property of tannins may also be a deterrent to psyllids.

Like tannins, the phenolic hydroxyl group of flavonol glycosides has a strong affinity for proteins. Thus, the mechanism of toxicity to insects is indirect, through their interaction with proteins.

Tannin

The contents of total phenolics and tannins in the sap of resistant accessions were generally higher than that of non- resistant accessions Table 3. Phenolics content was available for only one resistant species, *L. diversifolia* BPTL 003(710 ppm dry weight). All non-resistant accessions contained lower amounts of phenolics ranging from 380 to 580 ppm dry weight. The tannin content of one non-resistant accession, *L. diversifolia* X, was as high as that of some resistant accessions. If this accession is ignored, resistant accessions have tannin contents ranging from 1,797-2,800 ppm dry weight, and non-resistant accessions have lower tannin contents ranging from 131 to 1,314 ppm dry weight.

To obtain more conclusive results on whether resistance is related to tannin content a further study must be carried out to compare a larger number of accessions with adequate replication. Since different types of tannin vary in toxicity,

Table 3. Total phenolics and tannin contents* in the sap of resistant and non resistant leucaenas.

No.	Accessions	ppm ± SD DW		R/S/T*
		Phenolics	Tannin	
1.	*L. diversifolia* BPTL 003	710	2,800	R
2.	*L. diversifolia* BPTL 005	-	2,435± 95	R
3.	*Leucaena* BPTL 007	-	202± 25	R
4.	*Leucaena* BPTL 010	-	1,797± 8	R
5.	*L. leucocephala* BPTL 011	-	1,854± 17	R
6.	*L. diversifolia* CIAT 17388	570±40	158 ± 16	T
7.	*L. pulverulenta* CP1 22964 x *L. leucocephala* cv Cunningham	450±30	1,142± 41	T
8.	*L. leucocephala* K636	550±90	1,056± 24	T
9.	*L. collinsii*	490±90	-	T
10.	*L. diversifolia* BPTL 001	-	596± 84	T
11.	*L. diversifolia* BPTL 002	-	131± 84	T
12.	*L. diversifolia* X	-	2,265±12	S
13.	*L. leucocephala* K8	580±50	-	S
14.	*L. leucocephala* cv Peru	450±40	732± 76	S
15.	*L. leucocephala* K28	410±40	-	S
16.	*L. leucocephala* cv Cunningham	430±60	1,314± 407	S
17.	*L. pulverulenta* CP1 23145 x *L. leucocephala* cv Cunningham	360±30	718± 66	S

* Mean of 4 replicates, except BPTL 003, which was unreplicated.
- = undetermined
* R = resistant; S = susceptible; T = tolerant;

only three closely related hexanoic acids (Kafka 1970).

That leucaena psyllids which can be found on a hidden and isolated leucaena may be related to the sensitivity of their olfactory systems to the olfactory attractants emitted by the host. Adults of leucaena psyllids congregate on the tips of shoots of non-resistant leucaenas, but not on other host species or some resistant leucaena accessions. These varied preferences may be related to the presence of olfactory attractants or repellents.

To determine whether attractants or repellents are present in resistant and non-resistant leucaenas, the volatile compounds of leucaena leaves were analyzed. Eight components were detected and designated as Component 1, Component 2 (trans-2-hexanol), Component 3, Component 4, Component 5 (1-hexanol), Component 6 (cis-3-hexenol), Component 7 (trans-2-hexenol) and Component 8 (methyl salicylate).

The number and quantify of volatile components varied among the different accessions of leucaena (Figures 2 and 3). No distinctive compound, which could be interpreted as a repellent, was found in resistant accessions. Similarly, no distinctive compound, which could be interpreted as an attractant, was found in susceptible accessions. Therefore, leucaena susceptibility or resistance to psyllids does not appear to be related to the presence or absence of attractants or repellents.

Saponins

Applebaum and Birk (1972) suggested that, in plants, saponins may impart resistance to insects. Medicagenic acid (a sapogenol) was shown to be toxic to the potato leafhopper (*Empoasca fabae*), the pea aphid (*Acyrthosiphon pisum*) and the grass grub (*Castelytra zealandica*). Soya saponin was highly toxic to *Sitophilus oryzae* and less so to the larvae of *Tribolium castaneum* (Price *et al.* 1987). Sutherland *et al.* (1975) found that crude extract of alfalfa root contains a strong feeding deterrent for the larva of *C. zealandica*. Saponin also has been reported to impair the function of the digestive tract, particularly water absorption (Applebaum and Birk 1972).

The toxicity of alfalfa saponin, however, can be reversed by incorporating appropriate amounts of cholesterol in the diet. This suggests that the detrimental effect of alfalfa saponins is due to the medicagenic acid in saponins, which complexes with sterol (Shany *et al.* 1970).

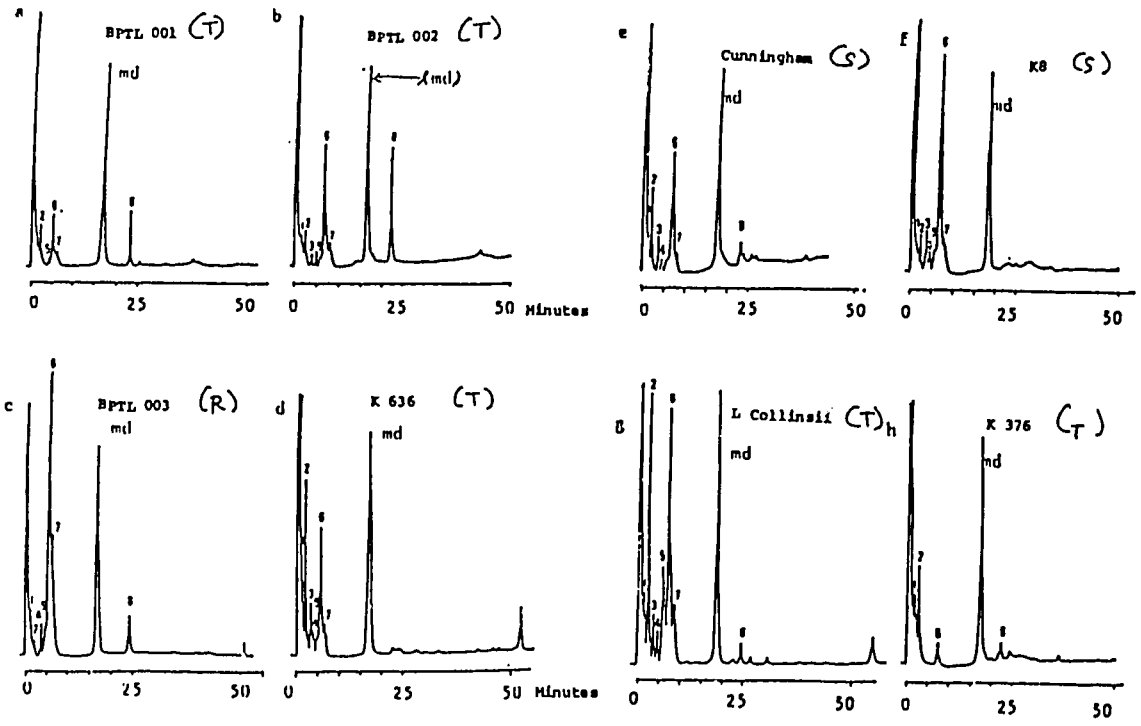

Figure 2. Chromatogram of volatile compounds of leucaenas.
Md = Methyl decanoic (internal standard).

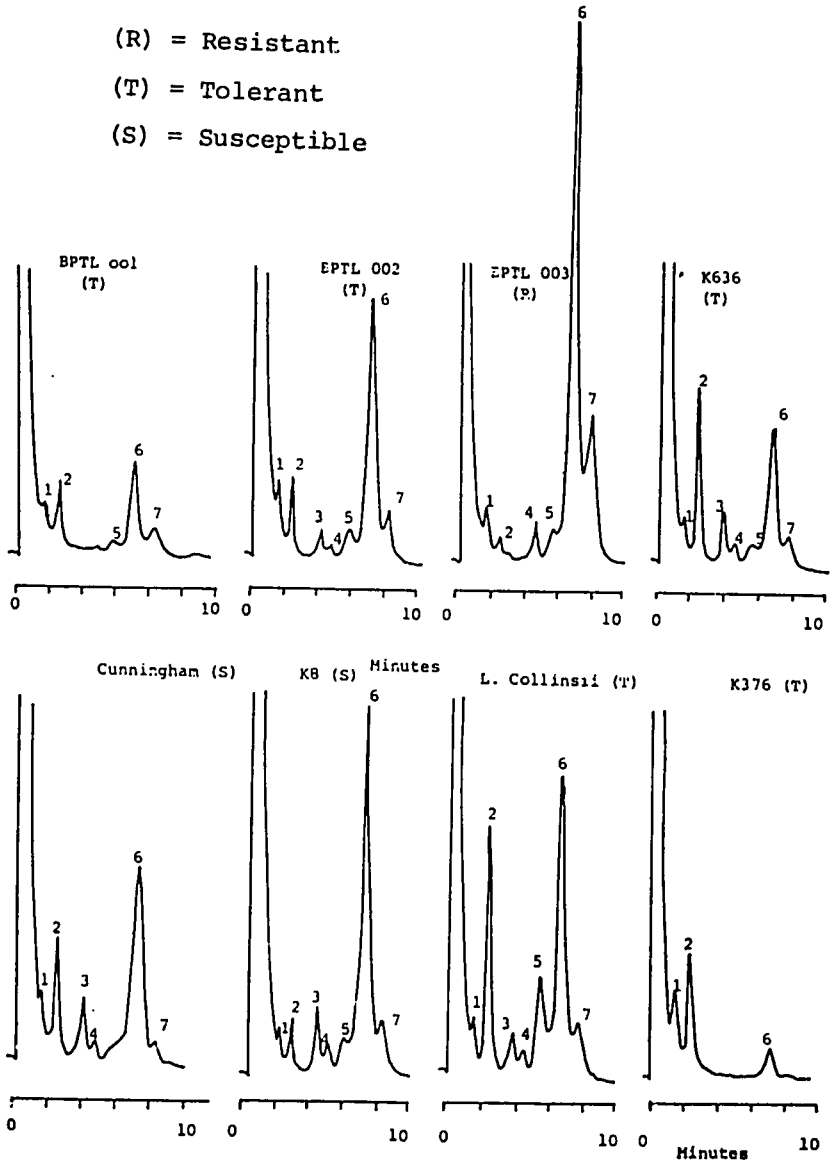

Figure 3. Chromatogram of volatile compounds of leucaenas with isothermal elution.

Insects are unable to synthesize sterols and absolutely require cholesterol or a closely related sterol in the diet.

That leucaena may contain saponins was suggested by Acamovic and D'Mello (1982), who found that chickens fed leucaena leaf meal deposit less fat than those fed on soybean

control diet. Using thin layer chromatography, one isolate, tentatively identified as saponin, has been detected (Acamovic *et al.* 1986).

Using a similar method, the saponins of our leucaena accessions were analyzed (Table 4). It appears that the number of saponin fractions and their intensities differ among resistant and non-resistant accessions. Resistant accessions possess three fractions with Rf values (n-butanol : ethanol : ammonia = 7:2:5) of fraction I = 0.24; fraction II = 0.45 and fraction III = 0.47. The Rf value of fraction I is similar to the Rf value of leucaena seed saponin (Rf = 0.26) reported by Acamovic and D'Mello (1986).

Non-resistant accessions possess only two fractions, I and II, in a lesser amounts than the resistant accessions. This difference may indicate that the saponins of leucaena may confer resistance to leucaena psyllids.

Further analytical studies are needed to confirm whether these are truly saponin and to develop a quantitative analysis. Whether leucaena saponins confer resistance can only be elucidated with bioassays. Ginseng saponins agglutinate red blood cells (Utsumi *et al.* 1984). How leucaena saponins interact with cells requires further study.

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Table 4. Saponins in the sap of resistant and non resistant leucaena accessions.

No.	Accessions	Saponin I	II	III	R/S/T*
1.	*L. diversifolia* BPTL 003	+/10	+/3	+/5	R
2.	*Leucaena* BPTL 005	+/5	+/3	+/5	R
3.	*Leucaena* BPTL 007	+/5	+/3	+/5	R
4.	*Leucaena* BPTL 010	+/5	+/3	+/5	R
5.	*Leucaena* BPTL 006	+/5	+/3	+/2	R
6.	*Leucaena* BPTL 011	+/5	+/3	+/2	R
7.	*L. diversifolia* CIAT 17388	+/3	+/2	-	T
8.	*L. leucocephala* K 636	+/3	-	-	T
9.	*L. pulverulenta* CPI 22964 x *L. leucocephala* cv Cunningham	+/3	+/2	-	T
10.	*L. diversifolia* BPTL 001	+/3	+	-	T
11.	*L. diversifolia* BPTL 002	+/3	+	-	T
12.	*L. leucocephala* cv Cunningham	+	-	-	S

\+ = present, higher quantities are represented by higher numbers.
\- = undetermined
* R = resistant; S = susceptible; T = tolerant

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FIELD OBSERVATION OF A RESISTANT *LEUCAENA* SPECIES IN BONDOWOSO, EAST JAVA

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Abstract

Leucaena leucocephala (Lam.) de Wit is an important component of the taungya system for establishing teak forest plantations in Java. Heavy psyllid infestation in early 1986 destroyed all of the leucaena plantations in the forest areas, while the forest managers were unequipped to manage the catastrophe. A psyllid-resistant species, *Leucaena pulverulenta* Benth. Both was observed in the Bondowoso Forest District of East Java. It may be a substitute for *L. leucocephala* to manage the psyllid problem in Java.

Introduction

The taungya system, a practice which combines the planting of agricultural crops with forest plantations, has been used in Java since the 1800s. In 1907, leucaena intercropping was included in the system (Becking 1928). After 40 years of development, the taungya system is the most productive and the most popular system for establishing forest plantations in Java.

The destruction of leucaena plantations by the psyllid infestation in early 1986 threatened the sustainability of the taungya system on Java. While most of the leucaena plantations in the forest areas of Java were heavily damaged, some individual leucaena trees were resistant to the psyllid infestation. A psyllid-resistant leucaena species was found in the Forest District of Bondowoso, East Java, in December 1988. This species will be studied further as part of the strategy to manage the psyllid problem (Sulthoni 1987).

Description of the Resistant Leucaena Species

Using the taxonomic key of Backer and van den Brink (1963), the species of resistant leucaena observed in the areas of the Forest District of Bondowoso is *Leucaena pulverulenta* Benth. This species is described as follows:

Leaves bipinnate, not sensitive, stem and branches unarmed, flowers in unbranched heads. Pinnae 6-16 pairs; leaflets 23-68 pairs, linear, obtuse, 3-5 mm by 0.75-1 mm; main rachis densely grey-hairy; tops of branchlets strongly angular-ribbed. Heads 2-6 in the leaf-axils; their peduncle 2-4.5 cm, thin to robust, densely grey-hairy; below the top on short lateral peduncle sometimes with a second head; interfloral bracteoles ± 1.5 mm long; calyx ± 2 mm long; petals 4.5-5 mm, rather firmly cohering; their free tops ± 1.5 mm long; filaments 7-8 mm; pod above the corolla scar on a stalk of 0.75-2.5 cm length, 10-27 cm by 1.5-2 cm; seeds 15-26, oblong or ± obovate, 6-7 mm by 2.5-4 mm. Tree, native of N. America; in 1934 introduced in Java; locally cultivated as a fertilizer.

Psyllid Resistance of *Leucaena pulverulenta* Benth

Field assessment of *L. pulverulenta*.in December 1988, indicated that no parts of the leaves were damaged, although the psyllids lived on them (Table 1). Only the nymphal and mature stages of *Heteropsylla cubana* were found on *L. pulverulenta*, while each of the life stages occurred on *L. leucocephala* growing near *L. pulverulenta*. *L. leucocepala* was totally damaged by the insects. More research and field trials are necessary to confirm that *L. pulverulenta* is highly tolerant to *H. cubana*, and may be a substitute for *L. leucocephala* to sustain the taungya system.

Table 1. *Heteropsylla cubana* populations on *Leucaena pulverulenta* in several observation plots in Bondowoso.

Location (Subdistrict)	Altitude (m)	Average number of psyllids per branchlet of *L. pulverulenta* (n = 10)	Condition of *L. leucocephala* in the surrounding area
1. Jelbuk	89	2.0	Eggs, nymphs and mature insects were observed. Leaves heavily infested.
2. Curah Dami	300	0.4	–
3. Brebes	200	9.1	Complete life stages of the psyllid were observed. Heavily damaged leaves.
4. Sumberwringin	700	7.1	(same as 3)

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EVALUATION OF LEUCAENA CULTIVARS FOR PSYLLID TOLERANCE

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Abstract

Fourteen leucaena collections from the Nitrogen Fixing Tree Association (NFTA) of Hawaii and one local leucaena collection, K28, were evaluated for psyllid tolerance and resistance. These collections were planted in June 1987, in Carranglan, Nueva Ecija. Ratings of psyllid count and psyllid damage indicate that K784 *L. diversifolia* (4N) and K785 *L. diversifolia* (4N) are resistant to psyllid. Furthermore, K785 appears to have better vegetative growth than K784.

Introduction

Cultivation of leucaena is impeded by the effects of deforestation, eroded and marginal soils, which have low organic matter content, high acidity and high aluminum content, and dominance of *Imperata* and *Themeda* grasses. Earlier attempts by both government and private sectors to reforest such areas with K8 & K28 *Leucaena leucocephala* have failed. This failure was aggravated in 1986 when the remaining leucaena stands in the North and plantations in other parts of the country were severely damaged by psyllids. In response to these problems, our office collaborated with other agencies to evaluate leucaena hybrids and varieties to determine their relative resistance to psyllid insects.

The Ecosystems Research and Development Bureau (ERDB), formerly the Forest Research Institute (FORI) under the Department of Environment and Natural Resources (DENR), conducted an evaluation trial for psyllid resistant-leucaena in cooperation with the Nitrogen Fixing Tree Association (NFTA) of Hawaii and the Rainfed Resources Development Project (RRDP) of the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD).

Materials and Methods

The resistance trial was conducted in Carranglan, Nueva Ecija, about 185 km north of Manila in June 1987. The site was selected because it is the most accessible from Manila and because the ecological constraints of leucaena cultivation are similar to other areas where fuelwood and leucaena leaf meal production are important to farmers. Fourteen leucaena collections from NFTA, Hawaii and one local collection, K28 *L. leucaena*, were used. The first seven collections, including the local K28 collection, were replicated three times while the other seven entries were unreplicated (Table 1).

Psyllid population size and damage were evaluated using the empirical rating scale (1-9) developed by the NFTA (Wheeler 1988).

Results and Discussions

The soil characteristics at the site for evaluation of leucaena entries for psyllid resistance were shown in Table 2.

Summary of Varietal Performance

Statistically significant difference in treatment means were obtained for plant height (Table 5), adults (Table 6) and egg counts (Table 8), and a highly significant difference in treatment means for damage rating (Table 9). Insignificant difference in treatment means were obtained for stem diameter (Table 4) and nymph count (Table 7).

K784 and K785 - *L. diversifolia* (4N): Both of these tetraploid leucaenas showed high resistance to the psyllid, although a few adult psyllids were occasionally observed on their shoots (Table 3). K784 flowered in November 1987, but seeds were produced only from its second flowering in March 1988. Light mealybug infestation was observed on some stems and almost all flowers. K785 grew more rapidly than K784 and other collections. This excellent growth of K785 was greatly enhanced by the termite mound in the plot.

K376A - *Leucaena pallida*: This collection was

Table 1. Leucaena collections for evaluation of resistance to psyllid.

Species	K Number	Source
1. *Leucaena diversifolia*	K156	Veracruz, Mexico
2. *Leucaena* hybrid	K743	(K28xK156) F_2
3. *Leucaena leucocephala*	K636	Coahuila, Mexico
4. *Leucaena diversifolia* (4N)	K78	Veracruz, Mexico
5. *Leucaena leucocephala*	K8	Moyahua, Zacatecas, Mexico
6. *Leucaena pallida*	K376A	Oaxaca, Mexico
7. *Leucaena leucocephala*	K527	Quintana Roo, Mexico
8. *Leucaena leucocephala*	K28	El Salvador
Unreplicated		
1. *Leucaena diversifolia* (4N)	K785	Veracruz, Mexico
2. *Leucaena leucocephala*	K584	Veracruz, Mexico
3. *Leucaena esculenta*	K897	
4. *Leucaena* hybrid	KX2	(K8 leu x K376 pal)
5. *Leucaena* hybrid	KX1	(K163 4N x K376 pal OP)
6. *Leucaena leucocephala*	K614	Tamaulipas, Mexico
7. *Leucaena leucocephala*	K600	

reported to be an excellent resistant for fodder production in Hawaii, but, in our trial, the mealybugs severely damaged the leucaena and almost killed a few plants.

KX1 - *L. diversifolia* x *L. pallida*: This hybrid consistently had a lower psyllid damage rating than KX2 and it grew taller than *L. pallida* (Table 3.)

KX2 - *L. pallida* x *L. leucocephala*: This collection was more susceptible to psyllid defoliation than KX1. It was also susceptible to mealybugs. The plant height, and leaf and tree form varied greatly. Early rouging is suggested for desired traits.

K743 - *L. leucocephala* (K8) x *L. diversifolia* (K156): This collection was susceptible to psyllid and mealybugs.

K156 - *L. diversifolia*: This collection was relatively resistant to psyllid defoliation but it was highly susceptible to mealybugs and other leaf-feeding and defoliating insects.

K500 - *L. leucocephala*: This entry surprisingly showed only slight damage to psyllid even if some psyllid adults, nymphs and eggs were found on shoots. Stem height and diameter were also found better than other entries but only second to K785 (Table 3). Like K785, K500 plot happened to be in the termite mound area.

Other *L. leucocephala* varieties, such as K636 and K614, were defoliated by psyllid and attacked by mealybugs, but they were able to recover rapidly when the psyllid population declined.

Implications

The psyllid resistance exhibited by K784 and K785 is of great significance to the fuelwood, minepole, and charcoal industries of the region.

Table 2. Soil characteristics of site for evaluation of leucaena entries for psyllid resistance.

Soil characteristics	Depth of Sampling	
	0-20 cm	20-50 cm
Physical Analysis:		
Sand	20%	12%
Silt	32%	32%
Clay	48%	55%
Textural grade	clay	clay
Chemical Analysis:		
Organic matter	1.9	1.6
pH	4.8	4.8
Percent N	0.1	
P (ppm)	2.1	1.0
K (me/100 g)	0.2	0.2
Ca (me/100 g)	14.6	13.2
Mg (me/100 g)	11.8	12.1
Na (me/100 g)	0.6	0.7

In the Philippines, before the onset of leucaena psyllid infestation, 90% of the total minepole requirement of local coal mine operators and 70% of the fuelwood and charcoal needs came from giant leucaena (Gapas 1987). Our dendrothermal plants which used to depend largely on giant leucaena for fuelwood suffered major losses from psyllid infestation. Reforestation effort of our government was also significantly hampered because leucaena which was widely used as major reforestation and nurse species as well as for erosion control cannot be used any more. Employment was also reduced especially in the leaf meal industry when our leucaena plantations were wiped out by psyllid. K784 and K785 could be one of the best answers to these problems caused by psyllid.

The contribution of termite mound on good performance of K785 and K500 could be an indication that organic matter (OM) addition to the soil can significantly enhance growth and even psyllid resistance of both *L. diversifolia* and *L. leucocephala*, thus improving further wood and leaf meal production respectively. Soil OM of 1.9 and 1.6% and pH of 4.8% at 0-20 cm and 20-50 cm sampling depth respectively of the experimental site are shown in Table 2. Most of our reforestation sites are characterized by such low soil OM and pH. Earlier tests conducted with agricultural crops revealed that crop yields, growth and resistance to pests and diseases were significantly improved by raising soil OM to 3-5% without adding lime to adjust soil pH. Although no chemical analysis of soil from termite mound was done, reports of Batra and Batra (1979) and Luscher (1961) indicated that soils within the mound area are very rich in OM, soil nutrients and has good aeration. The potential of K376A, KX1 and other hybrids for fodder or leaf meal production may be harnessed if soil OM can be increased to 3-5% or higher. Addition of OM into the soil has long been known to improve soil nutrients, water holding capacity, pH, aeration as well as soil structure.

Table 3. Summary of data after 18 months on average height, diameter insect count and damage rating of different entries.

Obs.	Rep.		Var.	Height(cm)	Diameter(cm)	No. of psyllid Adult	Nymph	Egg	Damage rating
	REPLICATED								
1	1	1	K8	202.35	2.275	2.40	1.63	1.76	8
2	1	2	K376A	168.48	2.060	1.53	1.00	1.00	8[1/]
3	1	3	K527	154.45	1.300	3.10	1.60	3.33	8
4	1	4	K28	185.60	2.035	2.47	1.97	2.43	7
5	1	5	K784	174.63	2.070	1.27	1.00	1.00	1
6	1	6	K743	229.85	2.420	2.27	1.23	1.87	8[1/]
7	1	7	K156	214.05	2.315	1.80	1.00	1.37	8[1/]
8	1	8	K636	200.70	2.130	2.97	1.93	1.93	5
9	2	1		197.05	2.140	2.43	1.77	2.07	8
10	2	3		188.60	2.060	2.73	1.67	2.47	7
11	2	2		202.10	2.080	2.20	1.20	1.57	6[1/]
13	2	7		220.05	3.195	1.87	1.13	1.40	8[1/]
14	2	6		215.35	2.200	2.67	1.37	2.03	8[1/]
15	2	4		184.05	1.985	2.60	2.13	2.47	8
16	2	8		182.90	2.040	2.23	2.00	1.50	5
17	3	1		152.80	1.860	2.73	2.00	2.27	8
18	3	3		162.50	2.040	2.37	2.13	1.90	7
19	3	8		143.75	1.725	1.53	1.13	1.37	5
20	3	7		169.60	1.920	1.50	1.40	1.50	8[1/]
21	3	4		126.80	1.360	2.10	1.93	1.80	8
22	3	2		166.30	2.040	2.17	1.70	1.63	8[1/]
23	3	6		193.20	2.300	2.87	2.70	2.77	6[1/]
24	3	5		197.25	2.000	1.87	1.50	1.77	1
	UNREPLICATED								
	1	K785		362.35	3.400	1.30	.00	1.00	1
	2	K500		283.90	2.915	2.15	2.00	2.80	3
	3	K614		247.10	2.500	2.56	2.14	1.00	7
	4	KX1		223.25	1.800	1.76	1.57	1.38	4
	5	KX2		212.30	1.600	3.00	2.80	1.90	7
	6	K584		250.00	2.400	2.86	2.18	5.00	7
	7	K897		Zero germination					

[1/] Damage was due to other insects.

Table 4. Analysis of variance for diameter.

Source	DF	Anova SS	Mean Square	F-Value	Pr F
REP	2	0.3636	0.1818	2.41^{ns}	0.126
VAR	7	0.9967	0.1424	1.89^{ns}	0.1476
Error	14	1.0560	0. 0754		
Total	23	2.4164			

Table 5. Analysis of variance for height.

Source	DF	Anova SS	Mean Square	F-Value	Pr F
REP	2	5,574.9530	2,787.4765	11.01**	0.0013
VAR	7	5,446.7101	778.1014	3.07*	0.0351
Error	14	3,545.7728	253.2695		
Total	23	14,567.4359			

Duncan's Multiple Range Test for variable: HEIGHT

Means with the same letter are not significantly different.

Duncan Grouping			Mean	VAR
	A		212.47	6 K743
B	A		201.23	7 K156
B	A	C	184.07	1 K8
B		C	178.96	2 K376A
B		C	177.64	5 K784
B		C	175.78	8 K636
		C	168.52	3 K527
		C	165.48	4 K28

Table 6. Analysis of variance for adults.

Source	DF	Anova SS	Mean Square	F-Value	Pr F
REP	2	0.0510	0.0255	0.16	0.8544
VAR	7	4.2062	0.6007	3.75*	0.017
Error	14	2.2441	0.1603		
Total	23	6.5004			

Duncan's Multiple Range Test for variable: ADULTS

Means with the same letter are not significantly different.

Duncan Grouping			Mean	VAR	
	A		2.733	3	K527
	A		2.603	6	K743
	A		2.52	1	K8
B	A		2.39	4	K28
B	A		2.43	8	K636
B	A	C	1.967	2	K376A
		C	1.723	7	K156
		C	1.47	5	K784

Table 7. Analysis of variance for nymphs.

Source	DF	Anova SS	Mean Square	F-Value	Pr F
REP	2	0.6296	0.3148	2.34^{ns}	0.1327
VAR	7	2.0609	0.2944	2.19^{ns}	0.1004
Error	14	1.8821	0.1344		
Total	23	4.5725			

Table 8. Analysis of variance for eggs

Source	DF	Anova SS	Mean Square	F-Value	Pr F
REP	2	0.0140	0.0070	0.04	0.9641
VAR	7	4.3621	0.6232	3.26*	0.0284
Error	14	2.6742	0.1910		
Total	23	7.0504			

Duncan's Multiple Range Test for variable: EGGS

Means with the same letter are not significantly different.

Duncan Grouping		Mean	VAR	
	A	2.567	3	K527
B	A	2.233	4	K28
B	A	2.223	6	K743
B	A	2.003	1	K8
B		1.6	8	K636
B		1.447	5	K784
B		1.423	7	K156
B		1.377	2	K376A

Table 9. Analysis of variance for damage.

Source	DF	Anova SS	Mean Square	F-Value	Pr F
REP	2	0.5833	0.2917	1.00	0.3927
VAR	7	129.1667	18.4524	63.27**	0.0001
Error	14	4.0833	0.2917		
Total	23	133.8333			

Duncan's Multiple Range Test for variable: DAMAGE

Means with the same letter are not significantly different.

Duncan Grouping	Means	VAR	
A	8.233	2	K376A
A	8.0	1	K8
A	8.0	7	K156
A	7.667	4	K28
A	7.333	3	K527
A	7.333	6	K743
B	5.0	8	K636
C	1.0	5	K784

Conclusions

The psyllid resistance of K784 and K785 and the outstanding growth of K785 indicate that they should be tested under a wider range of growing conditions (elevational range) and cultural management schemes for fodder, green manure and fuelwood production. In addition, the rapid growth and psyllid resistance of K785 may be combined with the mealybug resistance of KX1 through further cross breeding and selection.

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EVALUATION OF *LEUCAENA* GERMPLASM FOR PSYLLID RESISTANCE

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Abstract

In Sri Lanka, *Leucaena leucocephala* is used in agro-forestry, particularly in highland cropping, in livestock production as feed and, very commonly, as a source of energy among the rural poor. The highest constraint to its use is its susceptibility to the jumping plant lice, *Heteropsylla cubana*, which was first observed in February 1987. It has spread widely and attacks all the species of *Leucaena* grown locally.

In collaboration with the Nitrogen Fixing Tree Association (NFTA), Hawaii the evaluation of several *Leucaena* species for psyllid resistance has been undertaken. Although the trial is only six months old, we have very encouraging results. Based on preliminary information, the species may be categorized as follows:

Resistant -	*L. pallida* K376, *L. collinsii*, Hybrid KX2, *L. diversifolia* # 46568
Moderately - resistant	Hybrid KX1, *L. diversifolia* K785, *L. esculenta*
Susceptible -	*L. leucocephala* K636, *L. diversifolia* K156, *L. diversifolia* # 33820
Highly - susceptible	*L. leucocephala* K8, Hybrid KX3

Introduction

Of all fast growing legumes, *Leucaena leucocephala* offers the widest assortment of uses. The many varieties of *Leucaena* can produce highly nutritious forage, firewood, timber and rich organic manures. Its diverse uses include revegetating tropical hill slopes to prevent erosion, windbreaks, firebreaks, shade and ornamentals. In addition, it is an ideal legume for agro-forestry systems due to its rapid growth rate, high coppicing ability, quick regeneration and aggressive growth even under adverse soil and climatic conditions. Many other tree legumes fail to perform so well.

Leucaena was introduced to Sri Lanka about a decade ago, and, within this short period, it has naturalized remarkably well demonstrating wide adaptability to diverse local conditions. It has the greatest potential as the tree component in agro-forestry systems in subsistence agriculture in the dry intermediate zones of Sri Lanka. It is widely used in these systems for conservation of soil and water, and for provision of organic matter and fuelwood for subsistence farmers. In the mid-country areas, *Leucaena* is mainly used as livestock feed, primarily for cattle and small ruminants. Nestle's Ltd. planted leucaena in large plantations of over 300 ha to produce leafmeal for animal feed manufacture. This industry has kept the cost of animal feed within reasonable limits.

However, the greatest obstacle to using leucaena in agriculture and in animal husbandry is the susceptibility to the leucaena psyllid which was first observed in the mid-country around February 1987. Thereafter, the psyllid spread widely to various parts of the country where *Leucaena* has been growing. Local scientists attempted to solve this problem, but it was apparent that no quick solution could be found. A national committee was formed consisting of the Coconut Research Institute, Livestock Development Board, Department of Agriculture and the Faculty of Agriculture, University of Peradeniya. The main activity of this committee is the evaluation of psyllid resistance in different lines of *Leucaena* obtained from the Nitrogen Fixing Tree Association (NFTA), Hawaii. The results of these trials are reported in this paper.

Materials and Methods

The trial was conducted at the University Experimental Station, Dodangolla, Kundasale in the mid-country intermediate zone of Sri Lanka during June-December 1988. The altitude, latitude and longitude of the site are 367 m, 7° 15'N and 80° 45'E, respectively. The mean annual rainfall and temperature were 1,563 mm

and 31°C with major dry periods from February to March and June to September. The soil of the experimental site belonged to the reddish brown latasolic group (latosols). The pH was 6.5. The experimental design of the trial was a randomized complete block design with three replications. The 12 species/hybrids of leucaena and *Gliricidia sepium* listed below were planted 0.25 m apart two rows, 5 m in length and 1 m apart. There were 40 trees per plot with a 2 m alley separating the plots.

Leucaena species/hybrids and *Gliricidia sepium*

L. leucocephala K 636
L. pallida K 376
L. collinsii
Hybrid KX1
(L. diversifolia x
L. pallida)
Hybrid KX2
(L. leucocehala
x *L. pallida*
Hybrid KX3
(L. diversifolia x
L. leucocephala)

L. diversifolia K 156
L. diversifolia # 46568
L. diversifolia #33820
L. leucocephala K8
L. diversifolia K 785
L. esculenta
Gliricidia sepium

The seeds were treated with hot water to enhance germination and inoculated with the *Rhizobium* from NFTA, Hawaii. Seeds were first planted in seed bed nurseries and then transferred into polythene bags. After 3 months in the nursery, the seedlings were planted in the field. Germination, growth measurements, time of psyllid infestation, psyllid counts and damage and predator identification and counts were recorded during the nursery stage and in the field. Plant height and basal diameter (15 cm above ground level) of 8 trees per entry in each replication were measured on monthly basis. Psyllid count rating and psyllid damage were scored according to the instructions provided by NFTA, Hawaii.

Result and Discussion

Seedling performance in nursery

Germination

The percent germination was high in hybrid KX3 (89%), *L. esculenta* (83%), and in *L. leucocephala* (69%). In all the other entries, the rate of germination was below 40 percent. *Gliricidia sepium* also had a high germination of 83 percent (Table 1).

Psyllid infestation

The psyllid infestation was first observed in *L. leucocephala* (K8) followed by *L. leucocephala* (K636) and Hybrid KX3. Nearly 50 percent of the plants of these entries were infested 7-8 weeks after seeding (Table 2). This indicates their susceptibility to psyllids immediately after germination. However, 50 percent of the *L. diversifolia* # 46568, Hybrid KX1, *L. pallida*, *L. collinsii* and *L. esculenta* seedlings were infested at 11-12 weeks after germination, indicating their relative resistance to the psyllids in the seedling stage. *G. sepium* was free of any infestation and showed complete resistance to this insect.

Psyllid population

The observations of psyllid-infested foliage of *Leucaena* germplasm were begun six weeks after planting the seeds. The psyllid adults were 1-2 mm in length. They laid yellow eggs on the young terminal leaves, and, a few days later, nymphs of different sizes began feeding on the young leaflets. The biggest of these nymphs instars were 2-3 times small in size than that of an adult. Their color ranged from green to brown to whitish. The psyllid populations increased rapidly covering most of the terminal leaves and defoliating many entries during the nursery stage. The psyllid counts were rated 10, due to the difficulty in finding standardized samples. Psyllid populations declined rapidly as defoliation increased and leaflet availability declined. However, *L. pallida* K376, *L. collinsii*, Hybrid KX1 and *L. diversifolia* # 46568 were highly resistant even at high populations of psyllids (Table 3). No defoliation was observed in these entries.

Psyllid Damage

Psyllid nymphs and adults damage the plants by sucking the sap from young foliage. As a result of this feeding, leaflets turn yellow, then curl and wilt. In many instances, the seriously affected shoots were broken by the wind. Blackening of lower leaves and stems was also observed. This was due to the growth of sooty molds on the honeydew deposited by these insects.

Psyllid damage was highest in *L. leucocephala* K8 among all entries in the nursery (Table 3); the terminal shoots were completely defoliated. Loss of 50-75 percent of young leaves was observed in *L. leucocephala* K636, Hybrid KX3, *L. diversifolia* K156, *L. diversifolia* # 33820 and *L. diversifolia* K785. The least damage occurred in L. pallida K376, *L. collinsii*, Hybrid KX1, and *L. diversifolia* # 46568.

Table 1. Germination rates of leucaenas and *Gliricidia sepium*.

Entry	Germination (%)
1. *L. leucocephala* K636	69.3
2. *L. pallida* K376	21.3
3. *L. collinsii*	34.7
4. Hybrid KX1	20.0
5. Hybrid KX2	8.7
6. Hybrid KX3	89.3
7. *L. diversifolia* K156	38.7
8. *L. diversifolia* # 46568	12.9
9. *L. diversifolia* # 33820	5.3
10. *L. leucocephala* K8	36.7
11. *L. diversifolia* K785	20.7
12. *L. esculenta*	83.3
13. *Gliricidia sepium*	82.9

Table 2. Time at which 50 percent of plants were psyllid infested.

Entry	Time Period (weeks after planting)
1. *L. leucocephala* K636	8
2. *L. pallida* K376	11
3. *L. collinsii*	11
4. Hybrid KX1	12
5. Hybrid KX2	9
6. Hybrid KX3	8
7. *L. diversifolia* K156	9
8. *L. diversifolia* # 46568	12
9. *L. diversifolia* # 33820	10
10. *L. leucocephalu* K8	7
11. *L. diversifolia* K785	10
12. *L. esculenta*	11
13. *Gliricidia sepium*	0

Table 3. Psyllid count and damage ratings of different leucaena entries and *Gliricidia sepium* in the nursery.

Entry	Psyllid Count Rating			Psyllid Damage
	Adults	Nymphs	Eggs	Rating
1. *L. leucocephala* K636	10	10	10	7
2. *L. pallida* K376	3.0	3.3	4.6	2
3. *L. collinsii*	2.0	3.4	5.1	2
4. Hybrid KX1	2.5	2.4	3.3	2
5. Hybrid KX2	10	10	10	6
6. Hybrid KX3	10	10	10	7
7. *L. diversifolia* K156	10	10	10	7
8. *L. diversifolia* # 46568	2.9	2.8	5.5	3
9. *L. diversifolia* # 33820	10	10	10	7
10. *L. leucocephala* K8	10	10	10	10
11. *L. diversifolia* K785	10	10	10	7
12. *L. esculenta*	10	10	10	5
13. *Gliricidia sepium*	1	1	1	1

Predators

No predators of the psyllids were found during the nursery stage.

Growth of seedlings

L. pallida K376, *L. collinsii*, Hybrid KX1, Hybrid KX2 and *L. diversifolia* # 46568, and *G. sepium* grew most rapidly during the nursery period (Table 4). *L. diversifolia* K156 and *L. diversifolia* # 33820 grew very poorly. These growth rates are related to their respective abilities to overcome psyllid damage.

Field performance

Psyllid population

During the first month after field establishment, the psyllid populations declined in all entries, especially in those with extensive defoliation. This was due to a lack of young shoots for feeding. The development of new shoots was delayed because the plants were subjected to a drought during this period. When the rains came in the following months, the shoots grew and the psyllid population also increased rapidly (Table 5).

However, entries in which high psyllid populations are present before rains defoliation is low, psyllid populations first decreased and increased in following month. This temporary reduction may be due to migration of psyllids to other *Leucaena* plants in the surrounding fields. In all other entries psyllid populations increased with the formation of new shoots (Table 5).

Growth rates and psyllid damage

Because of the drought in the first month after field planting, the growth rates were very slow. When the rainfall was sufficient in the subsequent months, the *Leucaena* species grew rapidly. After three months, *L. pallida* K376, *L. collinsii*, Hybrid KX1, Hybrid KX2, and *L. diversifolia* # 46568 had the largest heights and stem diameters, while *L. leucocephala* K636 and K8, *L. diversifolia* K785, *L. diversifolia* K156 and Hybrid KX3 had the smallest heights and stem diameters (Table 6).

When the growth rates were slow due to drought in the first month, psyllid damage increased rapidly in all entries. However, as growth rates increased, the psyllid damage was very much reduced. The largest entries, *L. pallida*, Hybrid KX1, *L. diversifolia* K785, *L.*

Table 4. Growth parameters of leucaena species and *Gliricidia sepium* at the end of the nursery period.

Entry	Plant height (cm)	Stem diameter about 15 cm above ground level (cm)	No. of branches	No. of leaves
1. *L. leucocephala* K636	35.1	0.23	8.2	27.4
L. pallida K376	35.6	0.47	16.6	131.6
3. *L. collinsii*	52.0	0.39	12.2	64.8
4. Hybrid KX1	43.2	0.30	13.0	72.8
5. Hybrid KX2	37.2	0.39	13.4	66.8
6. Hybrid KX3	25.1	0.29	8.4	32.4
7. *L. diversifolia* K156	17.2	0.19	10.6	29.2
8. *L. diversifolia* # 46568	37.0	0.30	15.6	87.2
9. *L. diversifolia* # 33820	20.0	0.19	10.6	28.8
10. *L. leucocephala* K8	24.0	0.25	10.0	25.2
11. *L. diversifolia* K785	29.8	0.23	11.4	26.6
12. *L. esculenta*	30.4	0.30	13.0	56.3
13. *Gliricidia sepium*	38.0	0.58	12.0*	93.0**

* Number of compound leaves.
** Number of leaflets.

Table 5. Monthly psyllid count ratings of different leucaena entries and *Gliricidia sepium*.

Entry	Psyllid Count Rating								
	Adults			Nymphs			Eggs		
	1MAP	2MAP	3MAP	1MAP	2MAP	3MAP	1MAP	2MAP	3MAP
1. *L. leucocephala* K636	10.0	2.6	3.5	10.0	2.1	3.0	10.0	6.8	6.3
2. *L. pallida* K376	2.4	1.3	3.1	2.5	1.0	2.3	4.0	1.0	2.3
3. *L. collinsii*	2.6	1.6	3.8	3.1	1.8	2.8	4.9	1.8	3.9
4. Hybrid KX1	2.1	1.1	2.8	2.0	1.3	2.3	3.4	1.5	3.1
5. Hybrid KX2	10.0	2.3	3.5	10.0	2.1	3.0	10.0	6.5	4.8
6. Hybrid KX3	10.0	3.0	4.0	10.0	2.4	2.8	10.0	5.8	3.9
7. *L. diversifolia* K156	10.0	1.3	3.5	10.0	1.8	3.0	10.0	2.6	5.3
8. *L. diversifolia* #46568	2.6	2.1	3.4	2.9	1.9	2.3	5.0	2.3	2.8
9. *L. diversifolia* #33820	10.0	2.1	4.3	10.0	1.9	3.3	10.0	2.5	5.8
10. *L. leucocephala* K8	10.0	3.3	3.5	10.0	2.5	2.5	10.0	5.8	6.0
11. *L. diversifolia* K785	10.0	2.1	3.0	10.0	2.1	2.5	10.0	2.9	3.0
12. *L. esculenta*	10.0	1.3	3.0	10.0	1.4	2.3	10.0	1.4	2.5
13. *Gliricidia sepium*	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

* MAP = Months after planting of seedlings in the field.

diversifolia # 46568 and *L. collinsii*, had the least psyllid damage over this 3-month period (Table 7).

Predators

Only a few coccinellid beetles were preying on psyllids during the first two months after planting the seedlings. But, in the third month, they were much more common; both adults and larvae were preying on psyllids in all entries (Table 8). These beetles were found frequently on *L. leucocephala* K636, Hybrid KX3, *L. diversifolia* K156, *L. diversifolia* #33820, *L. leucocephala* K8 and *L. diversifolia* K785. This is contrary to the expectation that predators should be more abundant where psyllid damage is lowest. These entries were severely damaged by psyllids and, therefore, would be expected to harbor fewer predators. More studies are needed to determine the population dynamics of predators and prey and the effectiveness of natural enemies in controlling psyllids.

Table 6. Plant height and stem diameter of different leucaena entries and *Gliricidia sepium*.

Entry	Plant height (cm)			Stem diameter 15 cm above ground level (cm)		
	1MAP	2MAP	3MAP	1MAP	2MAP	3MAP
1. *L. leucocephala* K636	37.6	43.5	58.8	0.24	0.43	0.82
2. *L. pallida* K376	41.0	55.0	82.4	0.58	0.80	1.29
3. *L. collinsii*	58.8	82.4	108.6	0.41	0.69	1.07
4. Hybrid KX1	50.4	58.0	73.2	0.32	0.50	0.76
5. Hybrid KX2	40.4	46.2	81.0	0.41	0.76	1.22
6. Hybrid KX3	27.8	30.8	40.0	0.20	0.37	0.55
7. *L. diversifolia* K156	18.0	25.4	47.0	0.21	0.36	0.66
8. *L. diversifolia* #46568	43.4	58.4	104.2	0.39	0.87	1.42
9. *L. diversifolia* #33820	21.0	30.6	63.4	0.34	0.51	0.89
10. *L. leucocephala* K8	24.6	27.8	34.8	0.22	0.39	0.67
11. *L. diversifolia* K785	33.2	45.4	60.0	0.28	0.47	0.84
12. *L. esculenta*	34.8	42.8	-	0.32	0.53	-
13. *Gliricidia sepium*	41.2	45.2	60.6	0.66	0.82	1.21

* MAP = Months after planting of seedlings in the field.

Table 7. Monthly psyllid damage ratings of different leucaena entries and *Gliricidia sepium*.

Entry	Damage ratings		
	1MAP	2MAP	3MAP
1. *L. leucocephala* K636	7	3	3
2. *L. pallida* K376	3	1	1
3. *L. collinsii*	3	1	1
4. Hybrid KX1	3	1	1
5. Hybrid KX2	7	2	1
6. Hybrid KX3	8	4	3
7. *L. diversifolia* K156	8	2	4
8. *L. diversifolia* #46568	3	1	1
9. *L. diversifolia* #33820	7	2	2
10. *L. leucocephala* K8	9	3	4
11. *L. diversifolia* K785	8	1	1
12. *L. esculenta*	6	2	2
13. *Gliricidia sepium*	1	1	1

* MAP = Months after planting of seedlings in the field.

Table 8. Number of predators (coccinellids) found in different entries of leucaena.

Entry	No. of predators		
	Adult	Larvae	Total
1. *L. leucocephala* K636	12	5	17
2. *L. pallida* K376	4	0	04
3. *L. collinsii*	10	0	10
4. Hybrid KX1	1	2	03
5. Hybrid KX2	7	5	12
6. Hybrid KX3	18	8	26
7. *L. diversifolia* K156	8	9	17
8. *L. diversifolia* #46568	7	2	09
9. *L. diversifolia* #33820	9	4	13
10. *L. leucocephala* K8	19	6	25
11. *L. diversifolia* K785	18	8	26
12. *L. esculenta*	1	1	02

PSYLLID RESISTANCE IN FOUR LEUCAENA CROSSES

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Abstract

F_2 progenies of the crosses *Leucaena diversifolia* ssp. *diversifolia* (K156) x *L. pallida* (K376) and *L. diversifolia* ssp. *diversifolia* (K156) x *L. leucocephala* (K8) were assessed for psyllid resistance in the field during 1987 and 1988. Damage by the psyllid was rated tree by tree according to the method provided by NFTA in 1987. Among 687 one-year-old seedlings of *L. diversifolia* ssp. *diversifolia* x *L. pallida*, 6 were rated 0, similar to their parental species *L. pallida*, while the rest were rated from 1 to 4. In 2,157 progenies of *L. diversifolia* ssp. *diversifolia* x *L. leucocephala*, 32 were rated 0 while 51 were rated 5-7 as their parental species, *L. leucocephala*. The rest received intermediate ratings. Both psyllid-resistant and fast growing individuals were obtained in F_2 populations of the crosses. More selection from extant generations is needed to obtain uniform progenies for releasing.

Introduction

Many field observations indicated that several species in the genus *Leucaena* revealed resistance or high tolerance to the psyllid. These include *Leucaena diversifolia* ssp. *diversifolia* and *L pallida* (Sorensson and Brewbaker 1987, Pan 1987, Bray and Woodroffe 1988). The former displays cold and acid-soil tolerance, and has considerable potential as a source of wood or fuel (Shih *et al.* 1986). Several accessions of the latter were observed to be "immune" to the psyllids (e.g. Sorensson and Brewbaker 1987). It may be possible to incorporate psyllid- resistance genes from these species into *L. leucocephala*. Breeding programs involving interspecific hybridization and selection for the purpose are already in progress inHawaii and Taiwan. The objectives of the study were to observe F_1 and F_2 performance for psyllid resistance in some special crosses, and to search for the possibility of selecting highly resistant individuals from F_2 progenies.

Materials and Methods

F_2 seeds of the crosses of *L. diversifolia* ssp. *diversifolia* (K156) *L. pallida* (K376 and K177), by *L. leucocephala* (K8), and *L. leucocephala* (K636) *L. pallida* (K376) were sent to Taiwan by University of Hawaii. Plants were planted out on Hen-Chung, southern tip of Taiwan, and Hualien, Eastern Taiwan. Performance for psyllid resistance of the one-year-old trees was assessed, and was recorded during the period of March to June in 1987 when the psyllid damage was the most serious. An empirical 1-9 score was applied following the method provided by NFTA (Wheeler 1988). Six hundred and eighty seven trees of K156 X K376 F_2's, 2157 K156 X K8 F_2's and 434 K156 X K177 F_2's, and 20 to 40 parental trees of the crosses with the same age were observed. The cross of K636 and K376 was only assessed in F_1's.

Results

Table 1 summarizes the damage ratings of the four crosses.

1. K156 X K8

Resistance of K156 X K8 F_1 hybrids was intermediate to that of the parent species. F_2 progenies of the hybrid segregated for resistance. Of 2,157 individual trees, 12 were observed to have score of 1, i.e. 0.5% of the F_2 population with no psyllid damage. Twenty were scored 9, the rest rating from 2 to 8. Most of the trees 4 to 6 (Figure 1.) as F_1's. Of the immune F_2 progenies, most showed promise due to their psyllid resistance and vigor.

2. K156 X K177

K177 is an Oaxacan accession of *L. pallida* which usually showed high resistance to psyllid in the field. When crossed with tolerant *L. diversifolia* ssp. *diversifolia*, K156, the F_1's had only light damage with an average score of 2.6. F_2's differed in resistance, as expected from the ranges of resistance displayed within both parental species (Figure 2). Forty-three plants out of the cross appeared in rate 1 like K177.

Table 1. Psyllid damage in three leucaena species and four F_1 hybrids.

Accessions	N	Damage rating* Mean	Range
K156 (*L. diversifolia*)	40	3.4	1-6
K8 (*L. leucocephala*)	40	7.1	5-9
K636 (*L. leucocephala*)	40	4.8	3-6
K177 (*L. pallida*)	16	1.4	1-2
K376 (*L. pallida*)	20	1.2	1-2
K156 x K8	40	5.2	5-6
K156 x K177	43	2.6	2-3
K156 x K376	20	2.4	2-3
K636 x K376	20	2.4	2-3

* Psyllid damage rating scale:

1 No damage observed
2 Slight curling of leaves
3 Tips and leaves curling and yellow
4 Tips and leaves badly curled, yellowish and covered with sap.
5 Loss of up to 25% of young leaves
6 Loss of up to 50% of young leaves
7 Loss of up to 75% of young leaves
8 100% loss of leaves and blackening of lower leaves
9 Blackened stem with total leaves loss

3. K156 X K376

K376, an another accession of *L. pallida*, is highly resistant but somewhat shrubby. The average damage rate in the field observed in Taiwan was 1.2. The F_1 hybrids of K156 X K376 also appeared uniform 2-3 rates, just intermediate between their parents. The psyllid damage rating of the F_2 population was in the range of 1 to 5, mostly in 3 and 4 (Figure 3). High psyllid resistance of rate 1 was exhibited by 6 trees out of 687 F_2's.

4. K636 X K376

K636 was an accession of particularly fast growing and high resistance of giant *L. leucocephala*. In the field of southern Taiwan, damage ratings ranged from 3-6 and averaged 4.8. When crossed with the highly resistant but shrubby K376, the F_1's showed relatively uniform 2-3 ratings of psyllid damage. The hybrids seems to be superior to parents in both growth rate and acid-soil tolerance (Pan unpublished). The resistance of their F_2 progenies are being assessed. Segregation pattern of the resistance is expected to be similar to the crosses of K156 X K177 and K156 X K376.

Discussion and Conclusion

The study shows that F_1 resistance of the crosses is generally intermediate to that of the two parent accessions. F_2 differs in resistance, as expected the ranges of resistance displayed within both parents. The mechanism and genetic of resistance are not quite understood. Since 0.5%-0.05% of the F_2 progenies reveal high resistance as one of the parents, it seems that the characteristics is under multiple gene control.

Breeding programs of psyllid resistance need to consider cold tolerance and tolerance of acid soils. Of the hybrids, K156 X K177 show

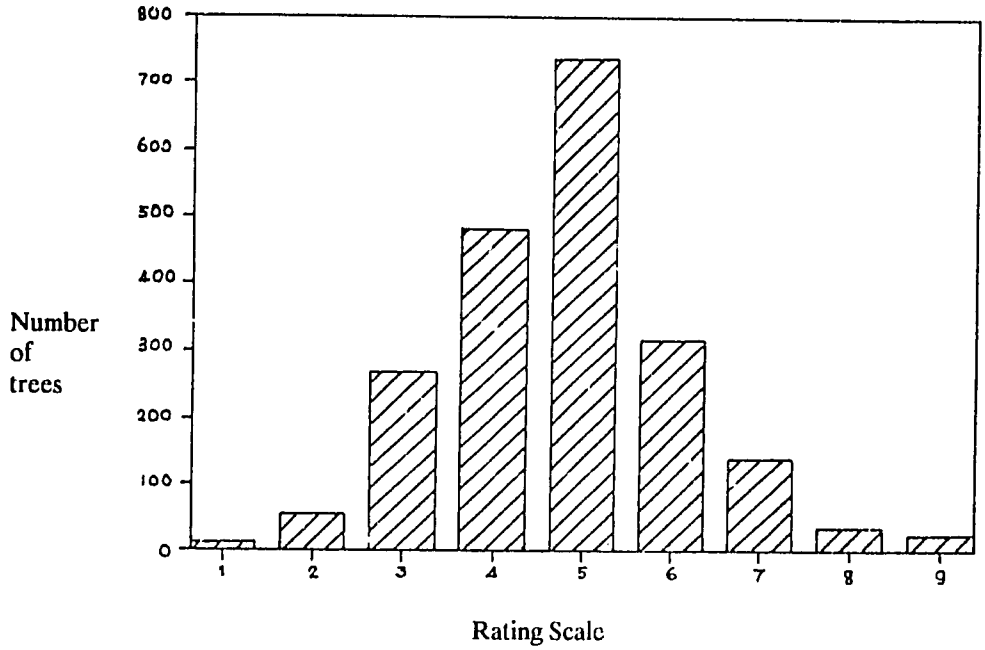

Figure 1. Psyllid damage rating scale of F2 progenies of K8 x K156.

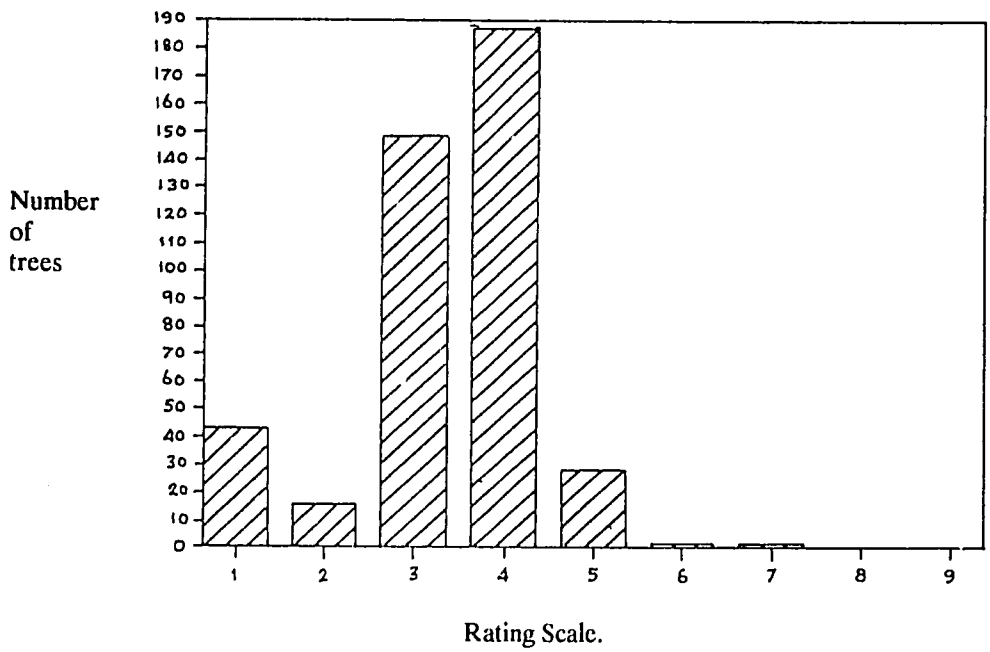

Figure 2. Psyllid damage rating scale of progenies of K156 X K177.

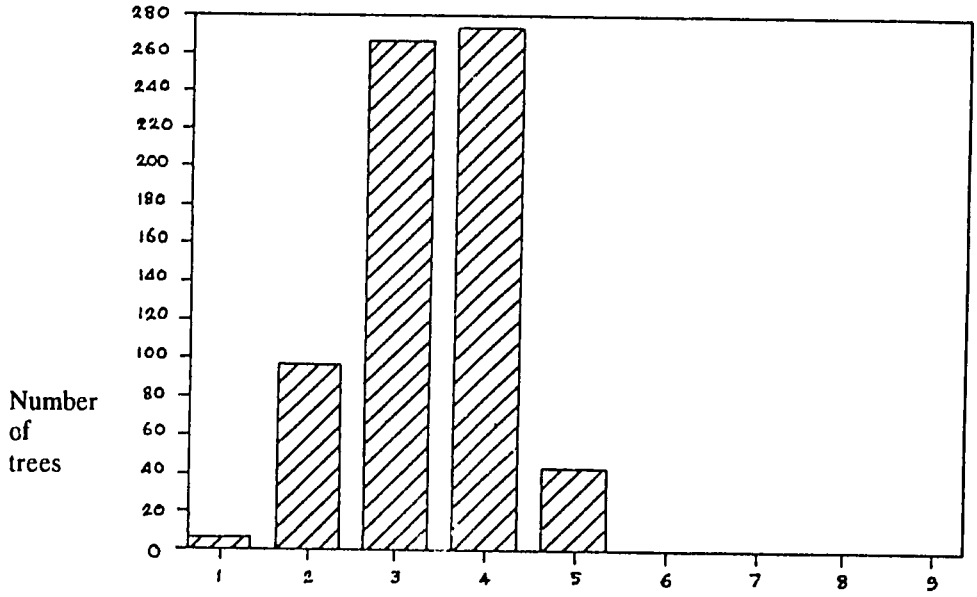

Figure 3. Psyllid damage rating scale of progenies of K156 X K376.

promise due to their high percentage of psyllid resistance and vigor in F_2 progenies, and one of the parents, K156, possesses characteristics of cold and acid-soil tolerance. It should be possible to satisfy all these requirements with one selection from the cross. Another potential cross could be K636 X K376 for the same reason.

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LEUCAENA SPP. RESISTANCE TO PSYLLID, *HETEROPSYLLA CUBANA* CRAWFORD, IN THAILAND

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Abstract

Thailand Institute of Scientific and Technological Research (TISTR) established a trial to assess psyllid resistance at Chon Buri in 1987. The eight varieties tested included 5 *Leucaena leucocephala* (K8, K28, K500, K527, K636), 2 *L. diversifolia* (K156, K784) and 1 *L. leucocephala* x *L. diversifolia* hybrid (K743). Among all of the provenances, *L. diversifolia* K784 and K156 showed the highest tolerance to psyllids. However, the of K636 and K743 coppiced rapidly after cutting and recovered most rapidly from defoliation while K784 and K156 coppiced and recovered most slowly. Therefore, K636 and K743 should be recommended for fodder production. More field trials covering larger areas will probably validate the results of this study.

Introduction

Leucaena psyllid, *Heteropsylla cubana* (Crawford) has become a serious pest of *Leucaena* spp. in Thailand since 1986 and spread throughout the country in all areas where leucaena is cultivated (Yantasath and Watanakul 1987, Napompeth 1987). The heavy infestation of psyllid caused severe damage to leucaena, especially in the livestock industries since this 'jumping plant lice' had defoliated the whole plants.

Searching for psyllid resistant leucaena genotypes and the development of resistant hybrids is one approach to the psyllid solution. Resistance to the leucaena psyllid has been reported in many countries. The resistant species were *L. collinsii*, *L. diversifolia* (K784, K785), *L. pallida* (K376), and *L. retusa*, the interspecific hybrids KX1 (*L. diversifolia* x *L. pallida*), KX2 (*L. pallida* x *L. leucocephala*), and the new hybrid between *L. leucocephala* K636 and *L. diversifolia* (4N), and most of the tetraploid hybrids (Bray 1987, Bray and Sands 1987, Brewbaker 1987, Pan 1987, Sorensson and Brewbaker 1987, Yantasath *et al.* 1987, Yantasath *et al.* 1988, Wheeler 1988).

The Thailand Institute of Scientific and Technological Research (TISTR) is participating in an International Network of Leucaena Psyllid Trials (LPT) established in 1987 by the Nitrogen Fixing Tree Association (NFTA), Hawaii, in which several *Leucaena* species and hybrids were being tested. Among these, *L. diversifolia* showed the higher degree of tolerance than *L. leucocephala* but unfortunately the yield was relatively lower. This report summarizes 15 months growth performance data on psyllid tolerance and leucaena yield of 8 leucaena accessious under trial in Thailand.

Materials and Methods

The Leucaena Psyllid Trial (LPT) being undertaken at Chon Buri Province since July 1987 consisted of eight leucaena entries, namely, *L. leucocephala* K8, K28, K500 ("Cunningham"), K527, K636 and *L. diversifolia* K156, K784 as well as the F2 hybrid K743 (K8 x K156). The experiment was a randomized complete block design with three replications. Entries were planted in two row plots with 1 m between rows, and 0.25 m spacing between plants within rows. There were 16 plants/plot. The site description is shown in Table 1. The soil was a sandy loam of moderate fertility, with pH about 5.4.

This trial has been managed as hedge lines for fodder production by cutting back the tree after 6 months of growth to 50 cm above the ground level and subsequently cut to 75 cm high every 3 months.

The measurements of the LPT trials include:

1. Psyllid counts and psyllid damage:

Psyllid populations and damage were assessed using the methods developed by the NFTA (Wheeler 1988).

Table 1. Site description.

Location of trials:	Chon Buri Province, 100 km east of Bangkok
Latitude:	13°N
Longitude:	101°E
Topography:	Flat
Elevation:	2 m
Climatological data	
Mean annual precipitation:	1,300 mm
Months with less than 50 mm of precipitation:	January, February, April and December
Mean annual temperature:	28.1°C
Minimum temperature:	17.1°C
Maximum temperature:	37.2°C

- Psyllid counts were scored empirically (1-9 rating) on monthly basis by the use of magnifying glass (8 cm in diameter) to count psyllids in all three stages (adults, nymphs and eggs) in the early morning on young leaves at the end of growing stems. Seven cm of a complete foliated juvenile leaf comprises one sample. Eight trees were scored for each entry in each replication.

- Psyllid damages were scored empirically (1-9 rating) on entire terminal shoots, which were different than those used for psyllid counts. Five trees with two samples each were scored for each leucaena entry in each replication.

2. Predator identification and counts:

At the same time of psyllid count and scoring, the number of predators was also scored empirically.

3. Growth measurement:

Height, basal diameter (at 15 cm above ground level), diameter at breast height (DBH) (130 cm above ground level) of all trees of each plot were measured before cutting. Fodder harvest data (fresh weight in kg) were recorded for all trees of each plot. The leaf and small stem fractions (animal edible fraction) were separated from wood fraction and weighed separately.

4. Climatological data:

The monthly rainfall and maximum-minimum temperatures were recorded to coincide with the time of monthly psyllid counts.

Results and Discussions

Psyllid populations and damage for the eight leucaena varieties at Chon Buri during the period from February to December 1988 are shown in Figure 1. There was one distinctive infestation period from November to April. Psyllid populations and damage increased in February, March, and April and were rarely found in May to September which was the rainy season before being recorded again in October. These events were observed in every provenance used.

Figure 2 illustrates the regrowth ability of the same varieties in term of height and biomass at 3 months after first, second, and third cutting. Humidity and rainfall were plotted with psyllid populations, but did not explain the changes in psyllid populations and damage.

L. diversifolia K784 and K156 expressed higher tolerance to psyllid than all other provenances under trials, but K636 and K743, at the same time, exhibited faster and more active regrowth after every cutting and could recover much more rapidly from defoliation. K784 and K156 performed poorest in terms of regrowth ability.

Therefore, K636 and K743 should be the acceptable lines for utilizing for fodder

production in Thailand in the future, even though they have shown less resistance than other entries in this trial. The yields of K636 and K743 may well be more seriously reduced under severe psyllid pressure.

In this trials, some of the predators have been observed, mainly the indigenous coccinellid, *Menochilus sexmaculatus* (F.) and the introduced coccinellid, *Curinus coeruleus* (Mulsant). The syrphid larvae were also detected but the number of these predators was very low.

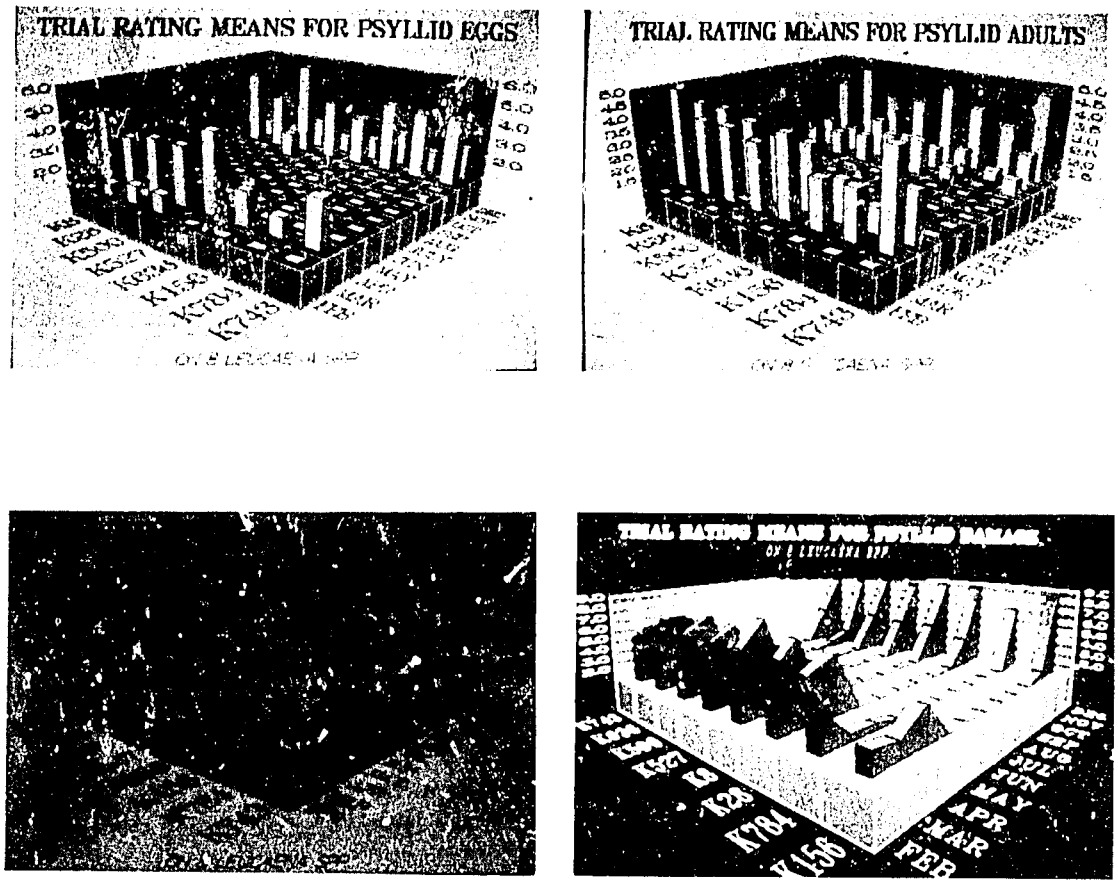

Figure1. Trial rating means for psyllid eggs, nymphs, adults, and damage on K8, K28, K500, K527, K636, K156, K784 and K743.

Acknowledgements

We thank the NFTA, Hawaii, for funding the research from 1987-1988. Thanks are also due to the F/FRED Coordinating Unit, Winrock International, Bangkok, for inviting and supporting the senior author to participate in the Regional Workshop on Leucaena Psyllid Management, and Mr. Lek Moncharoen, Soil Scientist, Department of Land Development, for his assistance in the preparation of illustrations.

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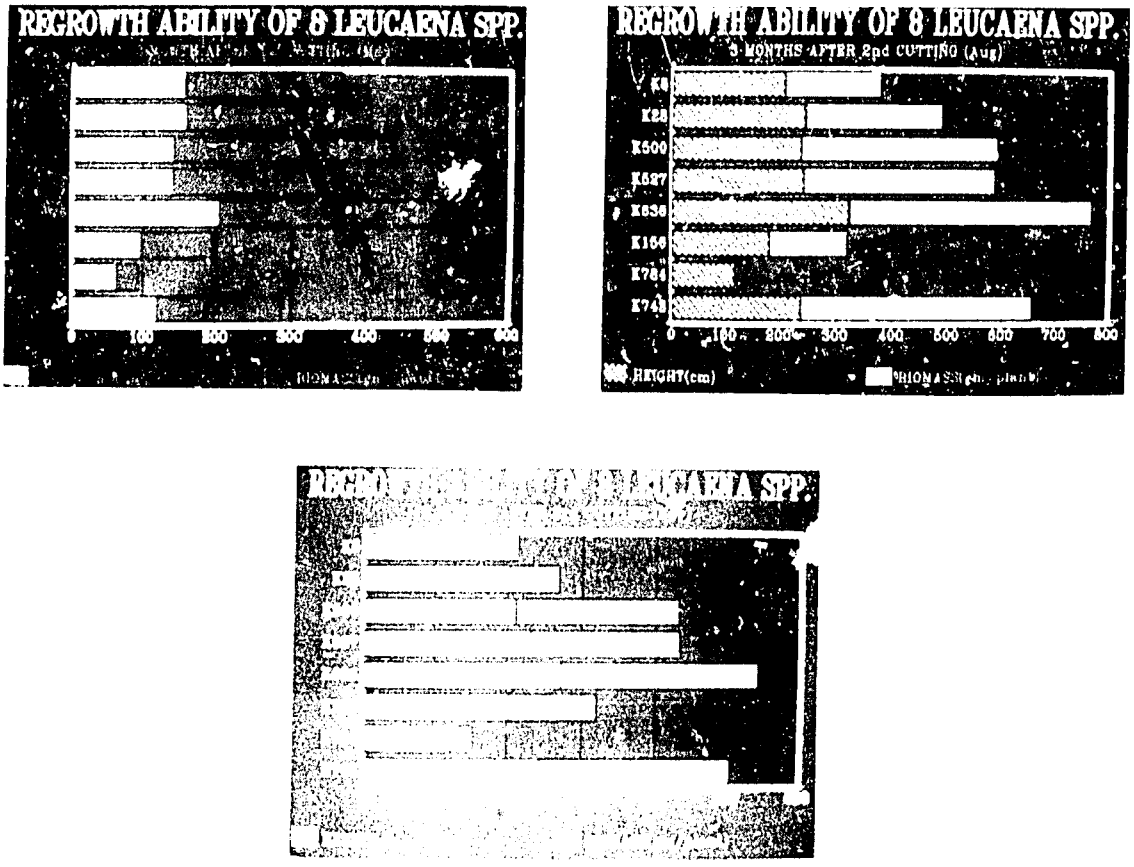

Figure 2. Regrowth ability in mean height and herbage yield of 8 leucaena species at 3 months after first, second and third cutting.

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A TWELVE WEEK STUDY OF LEUCAENA PSYLLID, *HETEROPSYLLA CUBANA* CRAWFORD, ON SEVEN LEUCAENA VARIETIES IN HAWAII[1]

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Abstract

Psyllid populations were quantified on the replicated plots within the Leucaena Psyllid Trial at Waimanalo, Hawaii during the twelve week period between August 9 and November 25, 1988. Psyllid first instar nymph populations were used as a basis for trial leucaena varietal comparisons. Resistant and semi-resistant varieties were found to have fewer first instar nymph populations than the more susceptible varieties. No significant differences in mean counts of first instar nymphs were found between K8 and K636 despite differences in total tree damage ratings. Differences between K636 and K8 in recovery from psyllid defoliation appears to be related to canopy leaf area.

Introduction

Following the invasion of the leucaena psyllid to Hawaii in 1984 (Nakahara and Lai 1984), studies were begun to determine variations among leucaena varieties for psyllid tolerance and resistance (Sorensson and Brewbaker 1987). Evaluation of the genetic resistance to the leucaena psyllid led to the establishment of the International Leucaena Psyllid Trials (LPT) Network during 1987. Entries in the 1987 LPT trials are shown in Table 1. Ten LPT international trials were established during 1987, including the trial at Waimanalo, Hawaii (Wheeler 1988). Each LPT plot was observed on a monthly basis for 12 months after establishment. These observations involved repeated estimation of psyllid population rating based on the numbers of adults, nymphs, eggs,and relative total tree damage. Following the completion of the study in June 1987, an intensive 12 week set of weekly observations was begun in August 1987. These weekly observations included replicated sampling of psyllid populations on juvenile leaves in each plot of each variety

Preliminary results of this intensive study are reported here.

Methods

Psyllid collection procedures involved the removal of five randomly selected lateral pinna per plot. A 20 cm segment of the juvenile end of the pinnae was cut from each sample tree and carefully placed in plastic bags inside an ice cooler. This procedure was repeated for each of the seven varieties in each of the three replicates on a weekly basis beginning on August 9, 1988 and ending on September 6, 1988. From September 6 through November 25, samples were collected solely from the *Leucaena leucocephala* plots (K8, K636, and K527). Nymphal instars were forcefully separated from leaf material by use of a directed spray of water. This procedure was found to be very effective to achieve total nymphl removal from the leaf material.

Results and Conclusions

The damage ratings of the LPT plots from June 1987 to June 1988 indicated that K784 and K376 had less damage than K527, K8, and K636. The psyllid counts obtained during the first five weeks of the intensive counting study indicated there were a significantly greater number of first instar psyllid nymphs on the susceptible varieties than on the less susceptible varieties (Table 2).

These first nymphal instar plot means were used to make a comparison between the seven varieties tested on a weekly basis and are summarized in Figure 1 and individually

[1]Study is supported by research funding provided to Drs. J.L. Brewbaker and J.W. Beardsley, Jr. from the United States Department of Agriculture for investigation of the biological and genetic basis of resistance to the leucaena psyllid.

Table 1. Leucaena entries used in the 1987 LPT trials at Waimanalo, Hawaii.

K Number	Species
Replicated Entries	
KX3a	*L. diversifolia* (K156) x *L. leucocephala* (K8)
K156	*L. diversifolia* 4N
K784	*L. diversifolia* 4N
K527	*L. leucocephala*
K636	*L. leucocephala*
K8	*L. leucocephala*
K376	*L. pallida*
Unreplicated Entries	
K785	*L. diversifolia* 4N
K500	*L. leucocephala* (Cunningham)
K614	*L. leucocephala*
KX1	*L. diversifolia* (K156) x *L. pallida* (K376)
KX2	*L. leucocephala* (K8) x *L. pallida* (K376)
K584	*L. leucocephala*

analyzed on Figures 2-6. Duncan's Multiple Range Test for mean separation was used with 0.05 level of significance.

First instar nymphs counts were used as the basis of varietal comparisons in this report because discontinuous nymphal mortality, caused by predators and other factors, may confound a correlation between older nymph counts and damage to trees. The decline in first nymphal instar counts for K527 during the second week was caused by the near total loss of leaves from the tree, which provided only a few pinnules for sampling. Subsequent sampling as the pinnules regrew indicated that K527 will consistently harbor higher levels of nymphs than the more resistant varieties, K784 and K376. Both K784 and K373 had consistently lower psyllid damage and lower nymphal instar counts than the other varieties in the trial and may be recommended for use as psyllid resistant varieties.

While both K8 and K636 exhibit similar levels of psyllid nymphs and defoliation, however, K636 regrows and recovers from damage more quickly, whereas heavy damage levels on K8 are sustained for much longer periods of time. K636 maintained a slightly lower average psyllid nymph count and had lower population peaks than K8 and K527. The retention of older mature leaves by K636 may be associated with its enhanced recovery after psyllid defoliation of juvenile leaves.

The damage rating observed for the varieties of K156 and KX3 were not significantly better than the *L. leucocephalas*. However, the lower damage levels observed for these two varieties with psyllid pressure under cooler conditions at the Mealani Experiment Station indicates that site/variety interactions are important factors to be considered in the interpretation of psyllid resistance trials. (Brewbaker *et al.*, 1988).

Table 2. Intensive psyllid counts on seven leucaena varieties from August 9, 1988 to September 6, 1988 at Waimanalo, Hawaii.

K Number	Damage	No. of first instar nymphs	Duncan mean separation
August 9, 1988 Mean values			
K8	4.20	11,541.0	a
K527	3.37	875.8	a
K636	2.87	460.9	ab
K156	1.07	354.1	ab
KX3	1.93	350.3	ab
K784	1.0	37.7	bc
K376	1.0	19.3	c
August 16, 1988 Mean values			
K156	1.53	348.8	a
KX3	2.53	113.6	a
K636	4.73	47.3	a
K784	1.0	37.5	a
K8	7.0	24.9	a
K527	4.73	21.4	ab
K376	1.0	.3	b
August 23, 1988 Mean values			
K527	2.47	281.6	a
K8	3.47	149.0	ab
KX3	2.87	57.0	bc
K636	2.80	56.7	bc
K156	1.0	13.0	bc
K784	1.0	3.0	c
K376	1.0	2.9	c
August 30, 1988 Mean values			
KX8	4.20	397.5	a
K527	3.40	364.1	a
KX3	1.53	171.0	a
K156	1.87	81.0	a
K636	3.33	64.2	a
K376	1.0	18.5	b
K784	1.0	.7	b
September 6, 1988 Mean Values			
K8	2.53	500.2	a
K527	2.0	256.4	a
K636	2.13	219.7	a
K156	1.80	207.5	ab
KX3	1.73	47.7	abc
K784	1.0	16.2	bc
K376	1.0	.7	c

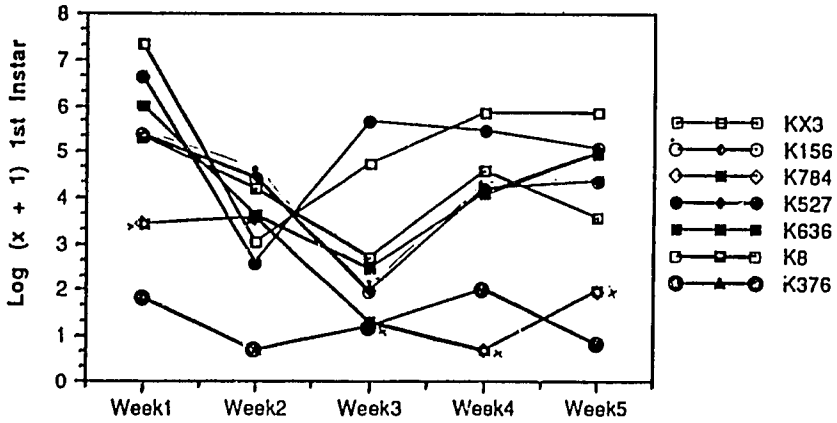

Figure 1. Weekly first instar counts on seven leucaena varieties from August 9 to September 6, 1988.

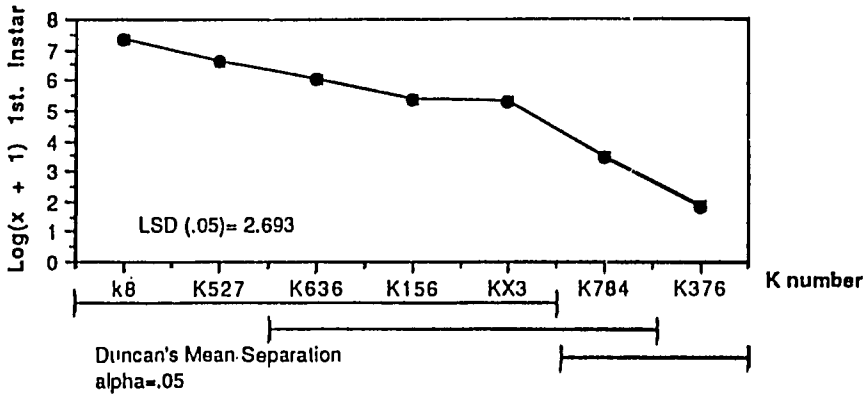

Figure 2. Week 1 first instar counts on seven leucaena varieties August 8, 1988.

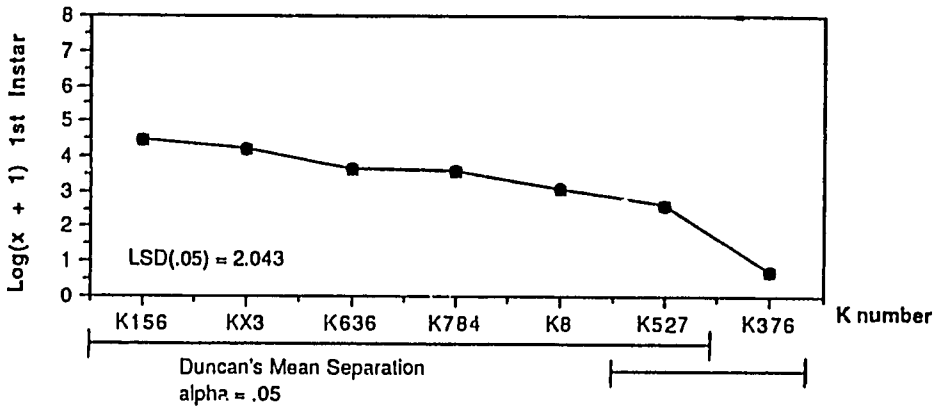

Figure 3. Week 2 first instar counts on seven leucaena varieties, August 16, 1988.

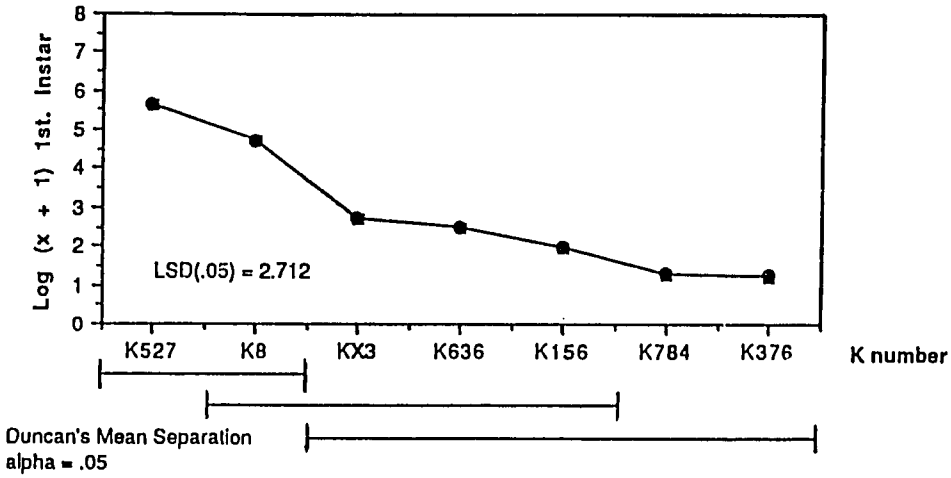

Figure 4. Week 3 first instar counts on seven leucaena varieties, August 23, 1988.

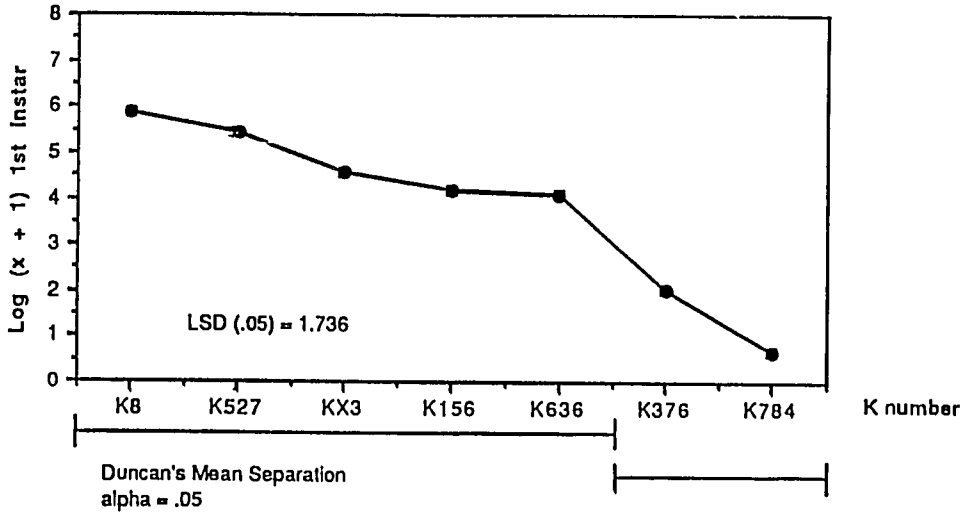

Figure 5. Week 4 first instar counts on seven leucaena varieties, August 30, 1988.

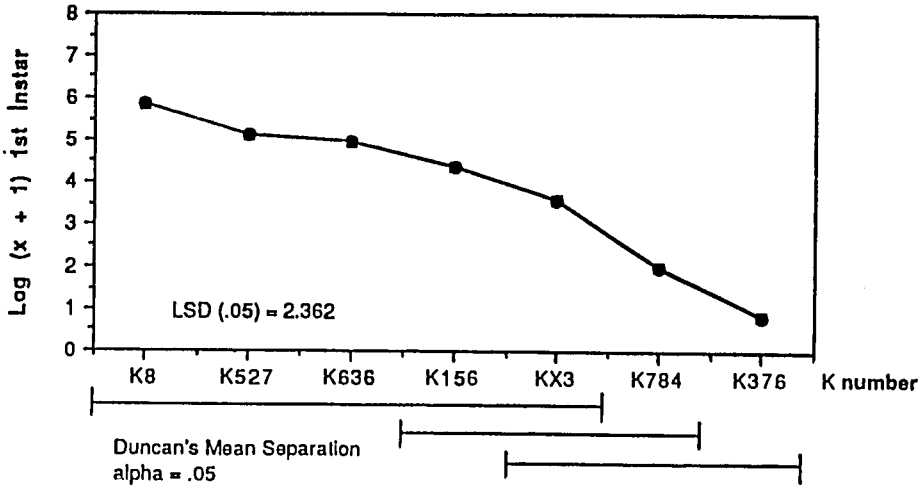

Figure 6. Week 5 first instar counts on seven leucaena varieties, September 6, 1988.

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NEW TREE CROPS FROM INTERSPECIFIC *LEUCAENA* HYBRIDS

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Abstract

The genus *Leucaena* contains a high degree of variability which remains largely unexploited. The effects of the leucaena psyllid on *Leucaena leucocephala* has encouraged research into production and use of interspecific *Leucaena* hybrids. Hand-pollinations have been done in Hawaii for ninety-four percent of all possible species hybrids, with over sixty percent of the crosses able to produce seed. Many of the new *Leucaena* hybrids such as *L. leucocephala* x *L. pallida* have shown psyllid resistance and may be useful for timber and other uses. Other hybrids show promise for timber, fodder and gum production, but are yet untested.

Introduction

Leucaenas (genus *Leucaena*, Mimosoideae: Leguminosae) are among the most versatile of tropical trees. Few tropical trees have matched leucaena's ability to provide quality fuelwood, polewood, fodder, green manure, shade, erosion control and other useful products in the tropics and subtropics. The N-fixing capability of these legumes is of great importance, particularly in low-input farming systems. Between 2 and 5 x 10^6 ha worldwide are estimated to be planted to leucaenas.

Natural evolution has created impressive variability in this genus, but the majority of leucaena production has until recently been limited to *L. leucocephala*. Both its shrubby and arboreal forms are high-yielding and coppice readily, but its heavy seed production can cause it to be weedy; additionally, it is often heavily damaged by the leucaena psyllid. Artificial hybridization has greatly expanded the way farmers can exploit these multipurpose trees by creating species hybrids with unique growth habits, ecological adaptations, pest resistance, wood and fodder quality and high productivity. The most significant of these hybrids are those that are seedless and have high psyllid resistance.

Interspecific Hybridization in the Genus Leucaena

Species intercompatibility

C.T. Sorensson, F.J. Pan and J.L. Booman have attempted since 1981 to produce seed via hand-pollination of all possible species hybrids among the 13 *Leucaena* species (182 combinations, including diploid and tetraploid *L. diversifolia*). C.T. Sorensson has completed crosses for 171 (94 percent) of these species combinations, of which 148 (87 percent) involve crosses of at least seven inflorescences (average 16.1 florets pollinated per inflorescence). A total of 2,941 inflorescences (47,102 florets) have been hand cross-pollinated.
Self-compatible species (*L. diversifolia* and *L. leucocephala*) were hand-emasculated between 3 and 5 AM on the morning of anthesis.

The ability of species to produce interspecific hybrid seed is summarized in Table 1. Hybrid verification has been morphological and/or chromosomal (Sorensson 1987). The genus is highly intercompatible (46 percent), with 79 combinations producing F1 interspecific seed, 15 producing abortive seed and 76 incompatible combinations (Table 2). Fifty-seven of the 78 combinations (74 percent) producing apparently-viable seeds were grown and verified; in addition, one more hybrid was selected among open pollinated progenies: *L. macrophylla* x *L. diversifolia*. Unverified hybrid combinations either did not germinate because of damage from seed beetles (*Araecerus levipennis* Jordan) or died a few days after germination, before verification was possible. The interspecific compatibility in the genus will increase with further testing to perhaps 70 percent (Sorensson 1987).

Table 1. Currently recognized *Leucaena* species.

Species	Chromosomes (2N or 4N)	Author	Date
1. *L. collinsii*	56*	Britton and Rose	1928
2. *L. diversifolia*	52, 104	Bentham	1842
3. *L. esculenta*	52*	(Moc & Sesse) Bentham	1875
4. *L. greggii*	56	S. Watson	1888
5. *L. lanceolata*	52	S. Watson	1886
6. *L. leucocephala*	104	(Lam.) de Wit	1842
7. *L. macrophylla*	52*	Bentham	1844
8. *L. pallida*	104	Britton and Re	1928
9. *L. pulverulenta*	56	(Schlecht) Bentham	1842
10. *L. retusa*	56	Bentham	1852
11. *L. salvadorensis*	56	Standle	1928
12. *L. shannoni*	52	Donn. Smith	1914
13. *L. trichodes*	52	(Jacq.) Bentham	1842

* Some variability exists among chromosome counts.

Table 2. F1 interspecific Leucaena Hybrid seed production, and verified species hybrids produced from hand pollinations at Waimanalo, Hawaii. species used as females are listed in the left column. I = Incompatible, CV = Compatible and verified, C = Probably compatible but, as yet, unverified.

Species	COL	DV4	DV2	ESC	GRE	LAN	LEU	MAC	PAL	PUL	RET	SAL	SHA	TRI
1. *L. collinsii*		I	I	I	I	CV	I	C	I	I	I	I	I	I
2. *L. diversifolia* (4N)	I		I	I		CV	CV	I	CV	I	I	CV	CV	I
L. diversifolia (2N)	CV	CV		CV	I	CV	CV	I	I	CV	I	I	CV	I
3. *L. esculenta*	I	I	I			I	CV	I	I	I	I	I	CV	I
4. *L. greggii*	I		I			C		I		I	I	I		
5. *L. lanceolata*	CV	C	CV	I	C		C	I	I	I	I	CV	CV	C
6. *L. leucocephala*	CV	CV	C	CV		CV		I	CV	CV	CV	C	CV	CV
7. *L. macrophylla*	C	I	CV	I	I	CV	I		I	I	I	I	I	CV
8. *L. pallida*	C	CV	I	I	I	I	CV	I			I		C	I
9. *L. pulverulenta*	CV	CV	C	C	C	CV	CV	C	C		CV	I	CV	I
10. *L. retusa*	CV	CV	I	CV	CV	CV	CV	I	CV	CV		I	CV	I
11. *L. salvadorensis*	I	I	I	I	I	CV	I	I	I		I		I	I
12. *L. shannoni*	CV	C	CV	CV		CV	C	I	CV	I	CV	CV		I
13. *L. trichodes*	C	I	CV	I		CV	I	C	I	I	I	I	C	

Table 3. F[1] pollen stainability of verified species hybrids. (NF = Not flowered yet).

Species	COL	DV4	DV2	ESC	GRE	LAN	LEU	MAC	PAL	PUL	RET	SAL	SHA	TRI
						%Pollen Stainability[1]								
1. *L. collinsii*						98								
2. *L. diversifolia* (4N)						8[2]	95		87			NF	15[2]	
L. diversifolia (2N)	97	13		NF		89	31			NF			97	
3. *L. esculenta*							9[2]						40[2]	
4. *L. greggii*														
5. *L. lanceolata*	NF		96									NF	96[2]	
6. *L. leucocephala*	NF	85		6[2]		13[2]			69	54	43		30[2]	36[2]
7. *L. macrophylla*			98			98								NF
8. *L. pallida*		69					58							
9. *L. pulverulenta*	NF	5[2]				NF	65				NF		NF	
10. *L. retusa*	64[2]	77[2]		14	NF	NF	20		86	NF			51[2]	
11. *L. salvadorensis*						NF								
12. *L. shannoni*	NF		NF	NF		94			NF		70[2]	NF		
13. *L. trichodes*			NF			88								

[1]Pollen stainability is the mean of 200+ pollen grain samples, stained in cotton blue/lactophenol, and based on grains with normal diameter and complete staining.
[2]Seedless hybrids.

Fertility and seediness of interspecific hybrids

Fifty-eight species hybrids have been grown and verified in Waimanalo, Hawaii. Their fertility status is shown in Table 3. Twenty-one (38 percent) hybrids have not yet flowered (NF); some of these were stunted in development. Twenty-six (45%) produced seeds via open pollination, and the average seed production of these is estimated to be half that of *L. leucocephala*.

Only 12 hybrids (21 percent) have flowered (F) without setting any pods (Table 3). Five of these have flowered abundantly and are represented by numerous trees, validating the sterility with certainty. The relatively low proportion of seed-sterile hybrids is probably related to the buffering effect of the generally high chromosome numbers/ploidy of the genus. Seven of the twelve seedless hybrids (58 percent) are triploids, four are diploid (33 percent) and one (8 percent) is an unusual tetraploid produced from a 2n-4n mating, *L. retusa* x *L. diversifolia* (2n = about 108).

Unpublished research by Sorensson and Nagahara suggested that irregular chromosome pairing in triploid and diploid hybrids was the basis for abnormal size and stainability of pollen whose tubes did not grow successfully *in vitro*. *L. retusa* x *L. leucocephala* (3n = 80) was striking because it produced F2 progeny from open pollination even though its pollen did not grow successfully *in vitro*. Mean pollen stainability of the 37 hybrids which have flowered is 59 ± 34 percent; mean pollen stainability of seedless hybrids is 32 ± 27 percent.

Research objectives using interspecific hybrids

Recent worldwide damage to *L. leucocephala* by psyllids attests to the probable narrow gene base of this species, and we are treating our hybrid program largely as a way to broaden the gene base of *L. leucocephala*. Because this commercial species is tetraploid (2n = 104), as are two other high-yielding species *L. diversifolia* and *L. pallida*, breeding has been at a tetraploid level. These three tetraploid species produce excellent single-cross hybrids in all combinations, and open-pollinated F2s from these planted in multinational sites have generated enormous interest (cultivars KX1, KX2 and KX3).

Research on three-way hybrids between the tetraploid species has been initiated by C.T. Sorensson, and some show promise for broadening the gene base from which breeders

can make selections. Certain three-way hybrids were self-compatible, allowing a single seed descent breeding approach. Tetraploid three-way hybrids were also derived through unreduced gametes between two tetraploid species and the frost-tolerant diploid species *L. retusa* (Sorensson and Brewbaker 1987). The use of unreduced gametes and of colchicine for chromosome doubling may facilitate gene transfer from diploid species into the *L. leucocephala* background.

Interspecific Leucaena Hybrids as New Crops

Relationships between adaptability and use

Many tropical environments are hostile to *L. leucocephala*. These include regions above 500-1,000 meters elevation, areas with mean annual temperatures below 22°C, areas where temperatures remain below freezing for more than a few hours at a time, and sites with acid and/or high aluminum soils below pH 5.5 which do not have underlying alkaline subsoils. Interspecific hybrids afford possible solutions to these problems. For example, hybrids of *L. leucocephala* x *L. diversifolia* averaged 4.5 m/year height increment in a two-year period at Waimea, Hawaii (850 m elevation, mean annual temperature 17°C). Two- and three-way hybrids involving *L. leucocephala* and frost tolerant *L. retusa* are being checked for frost resistance.

Hutton (1984) tested several species for acid soil tolerance in the Llanos of Brazil, and *L. diversifolia, L. lanceolata* and *L. shannoni* (all 2n = 52) showed potential. More recently, his program has been based on hybrids derived from the 3n = 78 triploid of *L. diversifolia* K454 x *L. leucocephala* K420. Although cultivars have not been released yet, significant advances have been made (Hutton pers. comm.).

Gum production

Legumes produce the major gums used in foods and other industries. Gum arabic from *Acacia senegal* is particularly well known. *L. leucocephala* produces a translucent tan gum under stress; this condition is called gummosis. Gummosis was first observed in India following attack by *Fusarium semitectum* and has been seen in Hawaii following attacks by *Phytophthora drechsleri* and wood-boring beetles. Gum production was sporadic and low yielding, and was often associated with wood dieback.

Analysis of several leucaena gums has revealed that they have the closest match to gum arabic of any gums tested from a hundred or so tropical trees (Anderson 1986). Although toxicity and related studies are needed, it appears that leucaena gum has good potential for use as a substitute for gum arabic.

L. leucocephala K8 x *L. esculenta* K138 (3n = 78) hybrids segregated trees that exuded gum copiously, and have not had wood dieback. Nine hybrid trees of this pedigree have been grown at Waimanalo, Hawaii for four years during which approximately a third failed to produce gum, another third exuded gums sporadically, and another third exuded gums heavily. These high gum yielders appear to outproduce the per-tree gum production of gum arabic by *Acacia senegal* of 250 gm/tree/year. Gum production is heaviest in early and late summer, appearing as gumballs or drippings from mature bark, unless washed off by heavy rains. Clonal propagation, or tree roguing at 1-2 years of age would maximize gum production. Hybrids of this species combination are seedless and have outstanding vigor and psyllid resistance.

Furniture, construction timber and polewood

Like the arboreal forms of *L. leucocephala*, a number of species hybrids appear to produce the thick straight boles required for use in furniture or construction timber. *L. pulverulenta* x *L. leucocephala* was historically about 50 years ago in Indonesia where its straight bole and fast growth at cooler upland sites made it a tree of choice. Early studies in Hawaii showed it to be a superb hybrid (Gonzalez *et al.* 1967), although its psyllid susceptibility currently limits its use in lowland sites. Hybrids that we believe to have potential to form trees with dbh of 30 cm and straight boles of 5 m include the following:

- *L. leucocephala* x *L. diversifolia* 4n 4n = 104
- *L. leucocephala* x *L. pallida* 4n = 104
- *L. pulverulenta* x *L. diversifolia* 4n 3n = 80
- *L. diversifolia* 2n x *L. diversifolia* 4n 3n = 78
- *L. diversifolia* 2n x *L. leucocephala* 3n = 78

Silvicultural practice should include dense planting with thinning (for fuelwood) at one and three years, and harvest after six to eight years.

Polewood is commonly used in the production of viny crops, where long, straight, thin poles are preferred. The hybrid *L. diversifolia* x *L. pallida* (e.g., KX1) is psyllid resistant and grows as a pseudo-shrub with many long straight branches. High-density planting of the five hybrids listed previously would also produce stems suitable

for polewood.

Fodder production

Fresh herbage yields of *L. leucocephala* (40-80 t/ha/yr) matched or exceeded those of other tropical legumes when moisture was not limiting (Brewbaker 1987). Psyllid resistance of several hybrids, such as *L. leucocephala* x *L. pallida*, is far greater than that of any *L. leucocephala*, and fodder yields of species hybrids under psyllid attack in Hawaii have exceeded those of *L. leucocephala* several-fold. *L. leucocephala* x *L. pulverulenta* (Gupta *et al.* 1987) and *L. diversifolia* x *L. leucocephala* (R.A. Bray pers. comm.) have both outyielded *L. leucocephala* cut for fodder.

Short heavily low-forked trees are preferred for herbivore browsing. Most accessions of the tetraploid species *L. pallida* are low-forking, and they confer this to some of its hybrids with *L. leucocephala*; some low shrubby dwarfs also result (Sorensson 1987). Low-forking pseudo-shrubs appropriate for browsing might also include *L. diversifolia* (2n = 52) x *L. esculenta*.

Low mimosine contents (0.5-1.0 percent) would enable leucaena fodder to be fed in higher quantities to nonruminants like chickens, horses and tilapia. Examples of *Leucaena* species and hybrids with low mimosine are *L. diversifolia* and *L. pulverulenta* and their hybrid, an attractive tall, psyllid-tolerant hybrid in the 3n = 80 version.

Shade and support

An important use of leucaenas is as a "shade" or nurse tree in plantations of coffee, cocoa, quinine or tea, or as supports for black pepper and other vine crops. *L. leucocephala*'s seediness is a major deterrent to this use, as it results in weediness and raises management costs. Some coffee and tea plantations in Indonesia graft seedless leucaena clones for use as nurse crops. Pollen analysis of two of their clones suggests that they are aneuploids derived from triploid species hybrids of *L. diversifolia* x *L. leucocephala* and *L. pulverulenta* x *L. leucocephala*.

Other uses of species hybrids

Non-seedy or seedless clones are probably attractive options for most of leucaena's uses, including pulpwood, roundwood, fuelwood, charcoal, parquet, and craftwood. Hybrids, such as *L. retusa* x *L. esculenta*, would make striking home ornamentals. Vegetatively-propagated clones of self-incompatible species that are attractive to honeybees, like *L. lanceolata* (2n = 52) or *L. shannoni (2n = 52)*, should have long flowering seasons due to inhibition of seed set. Non-seedy interspecific hybrids could also be produced with extended flowering periods.

Production of Seedless Hybrids

Commercialization of seedless leucaenas requires economic methods of production by vegetative or seed propagules. Rooting of vegetative cuttings of leucaenas has only been notably successful in temperate greenhouses. Mericlone and other tissue culture techniques have similarly succeeded only with juvenile tissues in the laboratory (Brewbaker 1987). Grafting has been used with some success in cooler regions of Indonesia. These methods must be adapted to the economic demands of large-scale use. Such methodologies could produce seedless leucaenas by exploiting leucaena's self-incompatibility as well as hybrid sterility (triploids, aneuploids).

A second method of producing seedless leucaenas exploits the self-incompatibility (SI) of the diploid species and *L. pallida* (4n = 104). A single tree of the SI species would be cloned or grafted and used as a female to hybridize with self-compatible (SC) species. Species would be interplanted at an appropriate ratio of female to pollen-parent and allowed to produce interspecific hybrid seed through open-pollination. Promising hybrids that lend themselves to this approach include (*L. diversifolia* and *L. esculenta*) x *L. leucocephala*, and *L. pulverulenta* x *L. diversifolia*.

A third method to produce seedless leucaenas would involve the self-incompatibility system. Inbreds would be produced through "pseudo-self-fertility" treatments, not yet known to work in leucaena (although rare selfs have been identified, Sorensson 1987), and S allele homozygotes identified. When two such homozygotes are planted in isolation, all seeds produced by both parents are of a single S allele heterozygote, e.g., S1S2. When these seeds are grown in isolation as a plantation, seedless progeny will result. Gamete sterility of the triploid type is not required, thus enlarging the number of species and species hybrids that could be exploited commercially.

Marketing of hybrid seeds is a prerequisite for a successful leucaena seed industry. *L. leucocephala* and other species have not attracted seed industries because heavy and early seeding limits profitability. Our proposed

technologies to produce seed of seedless hybrids have the double benefit of providing both the profit incentive needed to spur a hybrid seed industry, and providing high-yielding, ecologically attractive, well-adapted hybrids with unique and useful properties.

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SEASONAL ABUNDANCE OF LEUCAENA PSYLLID POPULATIONS IN YOGYAKARTA, INDONESIA

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Abstract

Fluctuation of leucaena psyllid populations were analyzed with changes in physical conditions, mainly rainfall, and solar light intensity. Populations of nymphs and adults were higher during the dry season than during the rainy season when a fungus disease was observed to infect psyllid populations. The disease may be an important regulating factor.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford, was first recorded in Bogor in Indonesia in March 1986 and an outbreak occurred during the dry season of 1986 (Anonymous 1986, Wardoyo and Sudarmadji 1986). The psyllid was detected in Yogyakarta by the end of April 1986.

A population dynamics study was initiated in May 1986 and fluctuations of psyllid populations were studied during 1986 to 1987 by Sudjono *et al.* (1987), and during 1987 to 1988 by Mangoendihardjo *et al.* (1988).

Materials and Methods

Nymph and adult populations were assessed at a trial site located about 120 m above sea level near the meteorological station at the Faculty of Animal Husbandry, University of Gadjah Mada, Yogyakarta. The populations were sampled every two weeks by shaking and removing the shoot tip carefully so that all nymphs and adults were caught in a plastic bag. Some droplets of chloroform on cotton were put into the plastic bag to kill the psyllids. Later the nymphs and adults were counted.

Rainfall and solar light intensity measurements were collected from the meteorological station. Regression analysis was used to explore the relationship between psyllid population size and these physical factors.

Biotic factors, especially natural enemies, were observed in some localities in Yogyakarta Special Territory.

Results and Discussion

Populations of nymphs and adults fluctuated over time, apparently in response to physical and biotic factors. Sudjono *et al.* (1987) reported that psyllid populations were much higher during the dry season than during the rainy season in the study made from June 1986 to May 1987. A similar pattern of lower populations during the rainy season and higher populations during the dry season was observed in this study.

Psyllid population size, rainfall, solar light intensity and wind velocity are presented in Figure 1. There is a significant negative relationship between population size and rainfall ($r = -0.715$, $Y = 98.55 - 0.442X$). Rainfall may suppress populations of the psyllid, as observed during November to December 1987, and January 1988.

There are positive relationships between the physical factors of solar light intensity, wind velocity and population size of the psyllid. The coefficient of correlation between psyllid population size and solar light intensity was + 0.724 ($Y = -161.69 + 4.299X$). The coefficient of correlation for wind velocity and psyllid populations was + 0.826 ($Y = -375.807 + 8.727X$). Perhaps the reason for the population increase during the dry season was that higher wind velocities encouraged the spread of the

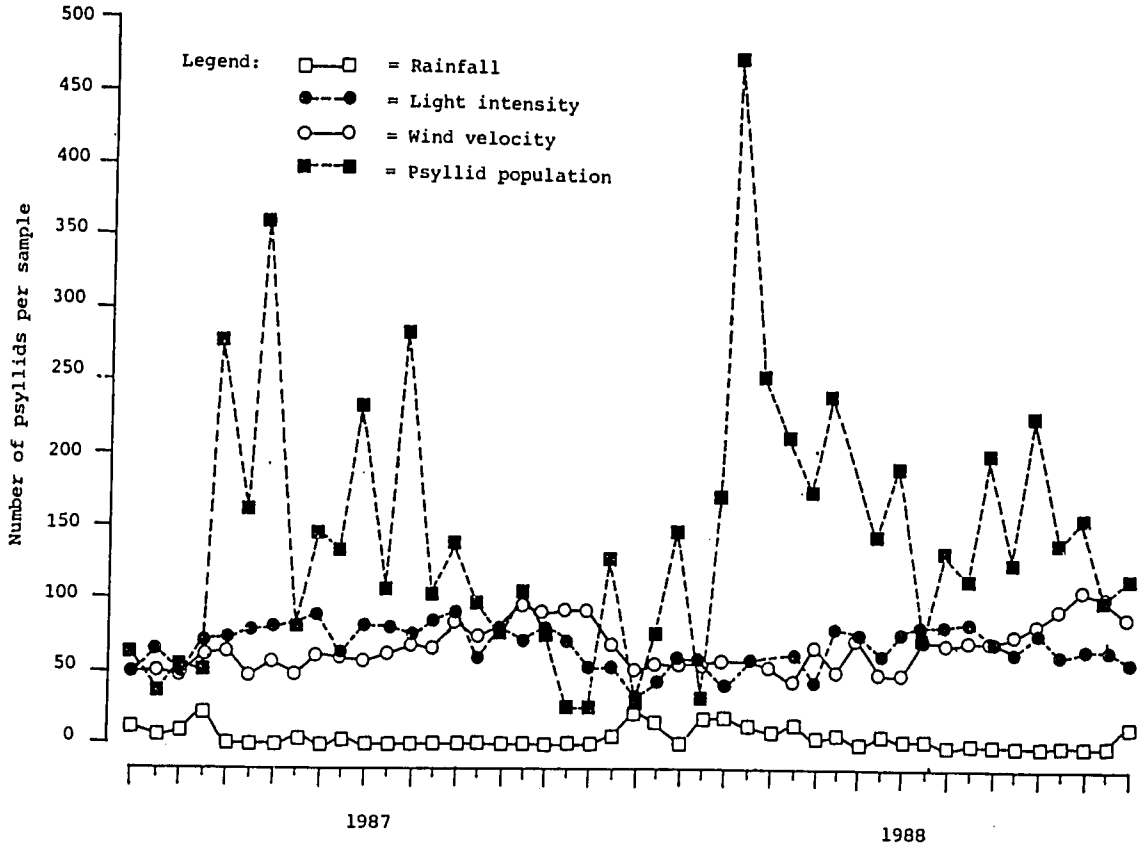

Figure 1. The relationship between leucaena psyllid population, rainfall, solar light intensity and wind velocity.

psyllid.

When all physical factors in relation to the population were analyzed using multiple linear regression analysis, there was no significant interaction which is characteristic of density-independent factors. Further studies on whether physical factors or other biological factors are regulating psyllid population size should be continued and determined.

An unidentified fungus was also observed attacking the psyllid. From 60 to 80 percent of the adults were killed by this fungus during the rainy season in Yogyakarta. One of the dominant pathogens found on adults was *Fusarium* (Christanti Sumardiyono, pers. comm.). Further investigation on these entomopathogen is needed.

Conclusion

Seasonal abundance of the psyllid was negatively correlated with rainfall and positively correlated with solar light intensity and wind velocity. The interaction of these physical factors was, however, not significant. An unidentified fungus may play an important role in suppressing populations of the psyllid in nature.

Acknowledgements

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University for their assistance in collecting data.

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BIOLOGY AND DEMOGRAPHY OF *HETEROPSYLLA CUBANA* CRAWFORD (HOMOPTERA: PSYLLIDAE)

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Abstract

The biology and reproductive potential of *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) were studied in the laboratory. Eggs hatched in 3.0 days and the nymphal period required 7.9 days. Female adults lived an average of 14.5 days, while males lived 9.7 days. A life table of *H. cubana* was constructed and the intrinsic rate (r_m) was 0.264. The mean generation time (T) was 14.92 days, the net reproductive rate (R_o) was 51.35, and the finite rate of increase (λ) = 1.305. The highest reproductive value was attained on day 3 of female's adult life. The theoretical stable stage distribution was 58.3% eggs, 38.7% nymphs and 3% adults.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), was first detected in Indonesia near Bogor, West Java, in March 1986. By August almost all provinces reported the pest (Oka *et al.* 1987). Both adults and mostly nymphs feed on the developing shoots of the host plant, *Leucaena leucocephala*. Feeding caused stunting and rosetting of new growths. Repeated attacks lead to severe defoliation. Additionally, their excessive sucking of plant sap results in the excretion of copious honeydew which sticks on the terminals and falls onto lower older leaves, encouraging growth of sooty molds. Little is known about the biology of this new pest.

The ecosystem approach to the management of insect pests requires careful biological and ecological studies (Chant 1963). Thus this study was conducted to determine the life history and population parameters of *H. cubana*, which are essential constituents in formulating management strategies for this insect pest species.

Materials and Methods

Several aspects of *H. cubana* life history were studied both in the laboratory and under the field condition. For life cycle study, insects were caged individually on 37 potted leucaena seedlings. Observations included the duration of each developmental stage and fecundity. Mating and oviposition behavior were studied under field conditions.

Adult flight activity was monitored using sticky traps (10 x 16 cm) tied to leucaena branches. The traps were installed in a heavily attacked leucaena plantation at four consecutive times: 06:00-10:00, 10:00-14:00, 14:00-18:00, and 18:00-06:00 hr. The traps installed at 06:00 were removed at 10:00 and so on. Each treatment consisted of 8 traps. The number of adults catches were counted in the laboratory.

The sex ratio was determined by slipping large plastic bags over 87 infested small leucaena twigs before being cut off. Adult counts were made in the laboratory.

Eggs to initiate the life table experiment were obtained by placing two pairs of *H. cubana* adults into 10 plastic cages (diameter 15 cm and height 30 cm), with one leucaena seedling per cage, for 24 hours. Adults were then removed, and eggs were counted. For each cage, all eggs were removed except 20 eggs. Cages were checked daily for egg and nymphal mortality.

When adults emerged, the surviving individuals were paired. For the age-specific fecundity study, 35 pairs of *H. cubana* were used. Cages were checked daily for the number of eggs laid and female mortality.

A table of age-specific survival (l_x) and age-specific fecundity (m_x) was constructed, and life table parameters were calculated as in Birch (1948). The net reproductive rate (R_o), intrinsic rate of increase (r_m), finite rate of increase (λ), mean generation time (T), and stable age distribution (p_x) were estimated.

The r_m was calculated with a computer program that used iterative substitution. The reproductive value was calculated as defined by Fisher (1930).

Results and Discussion

Biology

Life cycle

H. cubana is a multivoltine insect with a short life cycle (12.9 days). The eggs hatched 3.0 days after being deposited. The nymphs passed through five instars within 7.9 days. The duration of each instar was 1.0, 1.0, 1.0, 1.6 and 3.3 days, respectively. Total longevity of female adults averaged 14.5 days and of male adults 9.7 days.

Sex ratio

Based on 1,807 adults collected, the sex ratio was 1.46:1. The slightly favored females might due to that females live longer than males.

Mating

Both males and females tended to aggregate on the new shoots. Females tended to sit quietly, while males moved about more actively on the shoots. When a female was encountered the male approached rapidly, and took up a position closely behind or slightly to one side of the female. The male's genitalia were then thrusted toward the tip of female abdomen. At the same time, the tip of female abdomen was flexed. They remained in copulation for about 0.5-2.0 minutes. Both males and females mated more than once, and often the interval between two consecutive matings was several minutes. Mating occurred as early as 7:00 until 17:00 hr.

Oviposition

Eggs were mostly laid on the upper surface of unfolded leaflets, and were attached into the leaf tissue by a posterior pedicel. The number of eggs found per leaflet were 4-5, and could reach 16 eggs on one leaflet if the population density was high. In the laboratory, the number of eggs laid by a female throughout her life ranged from 176 to 338, with an average of 241.4 eggs. A female was observed to lay as many as 60 eggs a day.

Adult Flight Activity

H. cubana is a diurnal insect. Adults flights occurred in the morning as well as in the afternoon. The number of adult catches per trap averaged 94.37 at 6:00 - 10:00, 138.63 at 10:00 - 14:00; and 78.00 at 14:00 - 18:00 hr. Almost no flights occurred during night. The higher flight activities during noon probably related to high temperature and light intensity.

Demography

Age-Specific Fecundity and Survivorship

Mean daily survivorship (l_x) and fecundity (m_x) patterns are illustrated in Figure 1. Survivorship curve exhibited a Type I pattern, in which mortality rate increases with age. This type of survivorship curve is usually found when insects are caged and thus protected from various hazard (Hutchinson and Hogg 1984). Mortality during the egg stage was 2.5% and during the nymphal stage was 26%.

Mean daily fecundity was defined as the numbers of females born per female per day. Since the sex ratio was 1:1, m_x was 1/2 of the daily egg production. m_x curve peaked at the adult age of 4 days, and then gradually declined.

Life-table statistics

Life-table statistics were calculated for *H. cubana* on an initial cohort of 200 eggs. The results are presented in Table 1. Both r_m and λ refer to rates of increase for a population with a stable age distribution (Birch 1948). r_m is the continuous form and λ is the multiplication rate for discrete unit of time (1 day). GRR (Gross reproductive rate) equals the average gross number of female progeny per female per generation, whereas R_o incorporates 1_x as well as m_x to provide a measure of net female progeny per female per generation. T, the average period between birth of the parents to 50% of net reproduction (R_o), is a reflection of both the prereproductive period and fecundity (m_x) pattern.

Once the intrinsic rate of increase was determined, the mortality and fecundity age-specific tables were used to calculate the age-specific reproductive value. According to Fisher (1930) the reproductive value measures the relative contribution of age x to future generations. The result of the calculation of the age-specific reproductive values is given in Figure 2. The area below curve, which represents summing up the age-specific reproductive values over all ages, was 317.5. It can be seen from Figure 2 that the most important reproductive age period is 13 days (adult aged 3 days), or one day before the

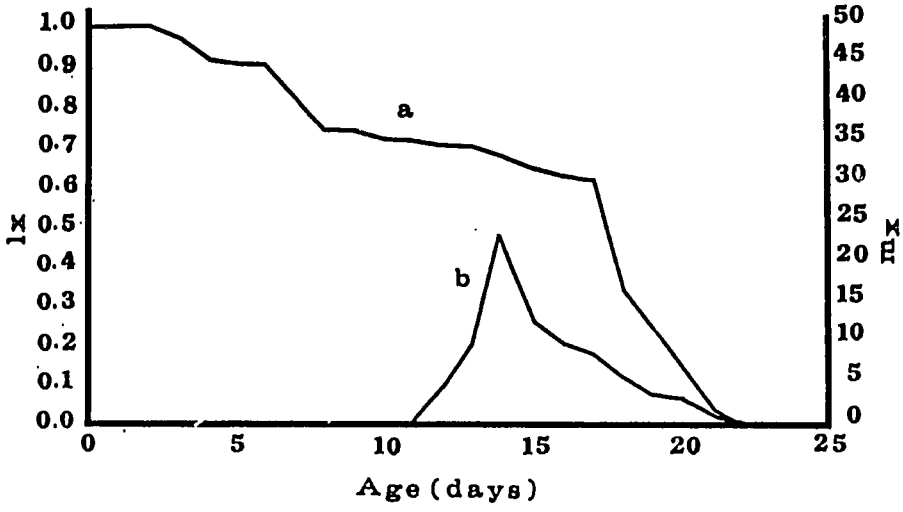

Figure 1. Age-specific survivorship (a) and daily egg production per female (b) for *Heteropsylla cubana*.

Table 1. Demographic statistics for *Heteropsylla cubana*.

Statistic	Value
GRR (Gross reproductive rate)	86.55
R_o (Net reproductive rate of increase)	51.35
r_m (Intrinsic rate of increase)	0.264
T (Mean generation time) (days)	14.92
λ (Finite rate of increase)	1.305

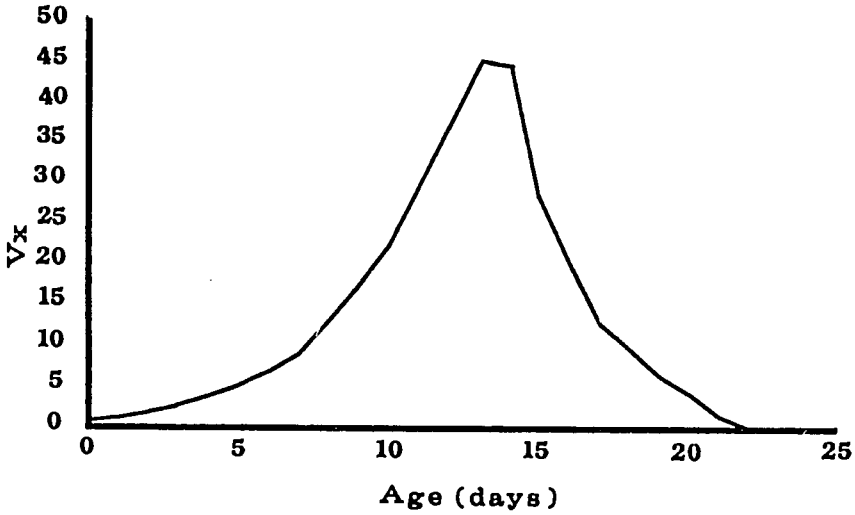

Figure 2. Reproductive value of each age class for *Heteropsylla cubana*.

number of eggs laid by a female reached maximum.

An ecological implication of the reproductive value is to colonizing ability (Wilson and Bossert 1971). A founder population should consist of individuals with the highest V_x. Therefore, it was assumed that the initial population of *H. cubana* arrived in this country have both high dispersal rate and reproductive value.

Stable Age Distribution

The stable age distribution (p_x) represents the proportion of individuals aged x in a population that is increasing at a constant rate. This parameter was computed, and for easier interpretation, was translated into stable stage distribution. The stage proportions in a stable age distribution was 58.3% eggs, 38.7% nymphs and 3% adults.

Daily changes in age structure were examined using computer simulations with the Leslie matrix model. Simulation was run for 270 days. Simulated stage structure (Figure 3) showed considerable variability, starting with a narrow age structure. However, this variability decreased with time, and there was convergence toward the stable stage distribution (last histogram). Adult proportion stabilized sooner than nymph and egg proportions. Convergence to the stable age distribution, regardless of the initial age distribution, is a well known property of the Leslie matrix model (Leslie 1945).

Divergence from the mentioned stable stage distribution can provide valuable insight into dynamics of population that have overlapping generation such as *H. cubana*. For example, increasingly low proportions of egg yet consistent (unchanging) proportions of nymph and adult in the population is an indication of a declining birth rate or a change in stage-specific mortality (Carey 1983). As pointed out by Cole (1954), knowledge of stage-structure dynamics can provide clues concerning the fate of a population before actual changes in population density are observed.

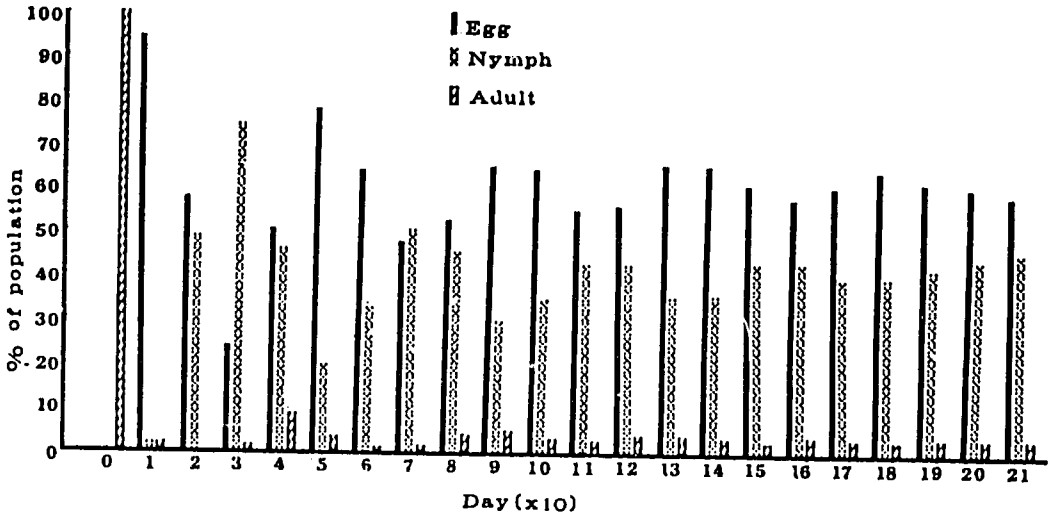

Figure 3. Changes in population stage structure for *Heteropsylla cubana*.

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LABORATORY LIFE TABLE OF *CURINUS COERULEUS* MULSANT (COLEOPTERA: COCCINELLIDAE), AN INTRODUCED PREDATOR FOR CONTROLLING *HETEROPSYLLA CUBANA* CRAWFORD (HOMOPTERA: PSYLLIDAE)

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Abstract

Development and population parameters of *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae) were estimated from a laboratory cohort. The eggs hatched 6.45 days after oviposition. The larval period lasted on average 14.82 days, with four instars. The mean pre-pupal and pupal times were 2.13 and 6.07 days respectively. Adult longevity was 65.86 days for females and 97.64 days for males. The intrinsic rate of increase (r_m) was 0.103 female offspring per female per day. The mean generation time (T) was 51.0 days and the net reproductive rate (R_o) during this period was 189.74 eggs per generation. The theoretical stable age distribution of the laboratory population was 97.9 percent immature stages and 2.1 percent adults.

Introduction

The coccinellid, *Curinus coeruleus* Mulsant, was introduced into Indonesia from Hawaii in August, 1986 to control *Heteropsylla cubana* Crawford, a new pest attacking *Leucaena leucocephala*. The predator was successfully mass reared in the laboratory (Sudarmadji 1987) and, eventually, released in the field. The establishment of *C. coeruleus* in many areas in Indonesia has been reported (Sudarmadji 1988, Mangoendihardjo 1988, Darma 1988, Bahagiawati *et al.* 1988).

Oka *et al.* (1987), Mahrub and Hartanti (1987), and Irianti and Mangoendihardjo (1987) studied the life cycle and behavior of the species. The present article adds to our knowledge about the population parameters of *C. coeruleus*.

Materials and Methods

The population analysis was based upon the study of a cohort - a group of individuals of exactly the same age. The individuals comprising the cohort were obtained from a group of eggs deposited within a 24-hr period.

One cohort of 100 individuals was prepared by collecting 100 eggs deposited in a 24-hr period in rearing cages. Each egg was placed in a plastic cup (160 ml). The mouth of the cup was covered with muslin cloth. When the first instar larva emerged, a small leucaena shoot with *H. cubana* nymphs and eggs on it was placed in the cup. The prey and its host plant was replaced at daily intervals until larvae reached the pre-pupal stage. The cups were checked daily to register the mortality of the larvae and pupae.

When the adults emerged, the surviving individuals were paired. The males were replaced if mortality occurred, thus making it possible for mating to occur continuously. *H. cubana* nymphs and eggs were replaced in the cups at 24-hr intervals. Mortality by sexes and fecundity, defined as number of eggs per day, were measured daily. These observations were continued until the last individual died.

A life table with age-specific survival (l_x) and age-specific fecundity (m_x) was constructed using the methods described by Birch (1948). For any particular age group of pivotal age x, l_x is the survival rate (proportion of individuals alive) at the beginning of the interval and m_x is the mean number of female eggs produced.

Results and Discussion

Developmental times

The duration of egg stage was 6.45 $\pm$ 0.68 days (x $\pm$ sd). The first, second, third, and fourth larval instars lasted 3.12 $\pm$ 0.51, 2.69 $\pm$ 0.49, 3.27 $\pm$ 0.52 and 5.74 $\pm$ 0.60 days respectively. The pre-pupal and pupal stages lasted 2.13 $\pm$ 0.39 and 6.07 + 0.53 days. The duration of the adult preoviposition period was about 12 days. The total longevity of female adults was 65.86 $\pm$ 23.33 days and of male adults was 97.64 $\pm$ 39.69 days.

Survivorship (l_x)

Daily counts of the number of living individuals in the cohort provided information about survival in the different stages of the life cycle. Figure 1 shows the survivorship curve (l_x). There was a high mortality (14%) in the egg stage, a lowmortality (2.3%) in the larval and pupal stages, and almost a constant mortality for the rest of the life cycle. The cohort was reduced to one half of its original number after 79 days.

Daughter production (m_x)

The number of female eggs laid daily were counted and divided by the number of surviving females. Since the sex ratio of the newly emerged adults was about 1:1 (36 females and 47 males), it was assumed that the number of females born per female per day (m_x) was 0.5 of the daily egg production. Fecundity peaked early then erratically declined as adults aged (Figure 1).

Life-table statistics

C. coeruleus in the laboratory had a mean generation time (T) of 51.0 days, during which the net reproductive rate (R_o) was 189.74 eggs per generation. The intrinsic rate of increase (r_m) was 0.103 female/female/day, and the finite rate of increase (λ) was 1.108 per day. The stable age distribution (Birch, 1948) revealed

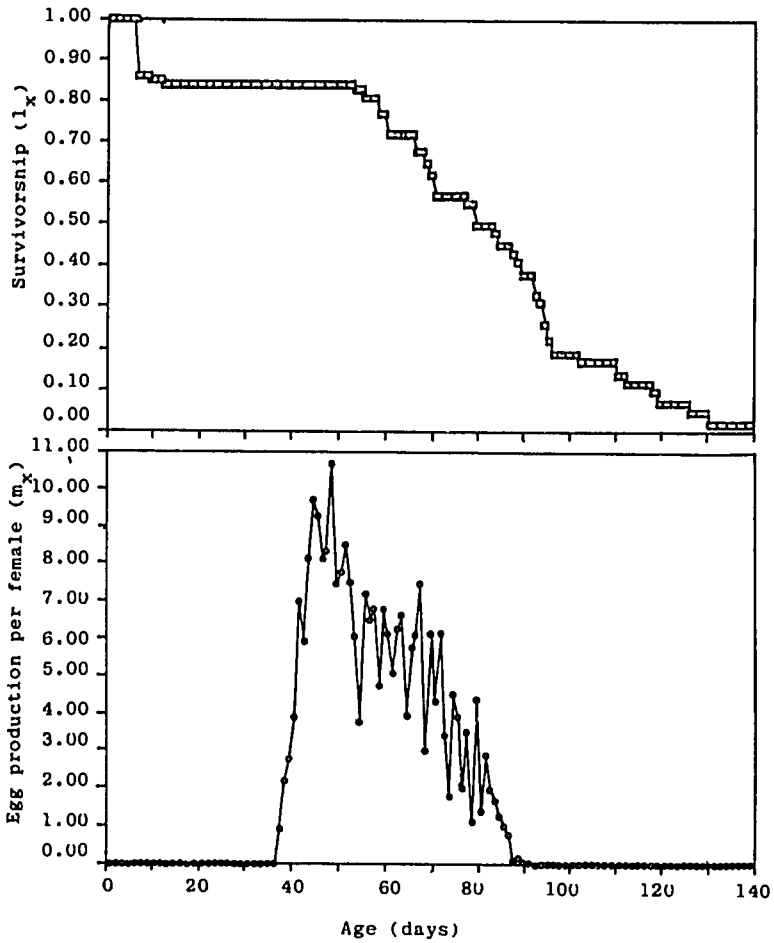

Figure 1. Age-specific survivorship (top) and daily egg production per female (bottom) of *Curinus coeruleus*.

that 97.9 percent of the population were immature stages while 2.1 percent were adults. The birth rate (B) was 0.147, the instantaneous birth rate (b) was 0.140, and the instantaneous death rate (d) was 0.037.

This laboratory study does not account for the biotic or abiotic factors that influence field populations. Therefore, it is improbable that the population parameters of the field populations of C. coeruleus would be the same as of the laboratory estimates. However, the population growth of the species in Indonesia since its introduction clearly indicates that *C. coeruleus* is capable of achieving a finite rate of increase (λ) greater than one.

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FACTORS AFFECTING LEUCAENA PSYLLID POPULATIONS IN LEYTE, PHILIPPINES

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Abstract

Monthly fluctuations of psyllid, *Heteropsylla cubana* Crawford, populations and the abiotic and biotic factors likely to affect them were monitored in five towns of Leyte from February 1986 to December 1988. Extreme wet and dry periods reduced psyllid numbers on leucaena hedgerows in Babatngon, Baybay, Bontoc and Villaba, but not in the mountainous area of Naval. Initially the psyllid population declined after pollarding, but the population increased rapidly with the development of new shoots. Several biotic agents may regulate psyllid populations on the island. Among these were spiders in the families Araneidae, Clubionidae, Oxyopidae, Salticidae and Thomisidae. The most common species were *Araneus* sp., *Misumena* sp., *Liocranum* sp., *Oxyopes javanus* Thorell and *Cyclosa mulmeinensis* (Thorell). The predominant entomophagous insects were the mirids, *Campylomma livida* Reuter and *Deraeocoris* sp., the reduviid, *Scipinia horrida* (Stal), and a coccinellid, *Menochilus sexmaculatus* (F). In Baybay, Bontoc and Babatngon, epizootics, mainly due to *Entomophthora* sp., were frequently observed. *Fusarium* sp., *Paecilomyces farinosus* and *Hirsutella citriformis* also infected adult psyllids in these areas.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford, was first noticed in Leyte in early 1985, when it was also reported in other South Pacific countries (ACIAR 1986, Aloalii 1987, and Stechman *et al.* 1987). Heavy infestation by the pest caused the defoliation of leucaena hedgerows trees in some areas of the island until early 1986. However, by September 1986, the defoliated plants started to recover and remained lush and green up to the present. Some natural mortality factors have apparently reduced the psyllid population to a tolerable level. This study examines the biotic and abiotic factors that may have affected the pest in the island from 1986 to 1988.

Materials and Methods

Psyllid populations and natural enemies were sampled biweekly in the Visayas State College of Agriculture (ViSCA) Campus, Baybay, and monthly in Villaba, Biliran, Babatngon and Bontoc. Twenty samples were taken randomly from each site. Each sample consisted of 15-20 cm of terminal shoot having three opened and some unopened leaves. The shoot was carefully cut and sealed in a size 10 brown paper bag and placed inside a refrigerator until they could be counted. Psyllid nymphs and adults, and predators were counted. In Villaba, where there was a high density of orb spiders, a 15-sec. visual count of these spiders was taken for each sample. Diseased insects were also counted and entomopathogenic fungi were isolated. Weather data were gathered from stations where they were available.

Results

From the five stations (Table 1), two ecologically and climatically distinct areas were chosen to focus the contrast investigation on psyllid ecology. The climate at ViSCA is generally moist and humid, and the climate at Villaba is hot and dry.

Three important factors affected psyllid populations in Leyte. First, psyllid populations decrease during extreme wet and dry periods. There was a drastic reduction in numbers of psyllids in August, 1986 in ViSCA and Villaba (Figures 1 and 2). This was due to heavy rains brought by a typhoon. During 1987, the lowest insect populations were recorded in June at ViSCA, Villaba and Bontoc (Figure 3), and in July at Babatngon (Figure 4). These population reductions occurred during a 4-month (March-June) dry spell. In Biliran, where it is normally cool and moist, the psyllid population declined only slightly in July.

A second factor, the regular cutting of hedgerows, resulted in psyllid population increases. Because psyllids feed preferentially on young shoots, increases in psyllid populations soon followed the appearance of new growth on recently cut leucaena. There was usually a drastic reduction in the psyllid population a few days after pollarding because most of the immature psyllids living on young foliage were killed. However, the survivors rapidly repopulated the new shoot growth especially if the cutting was done at the onset of the rainy period.

The method of cutting also seems to affect psyllid populations. Regular cutting of the hedgerows at 3-6 month intervals was done at ViSCA. The cut foliage was used as mulch for crops growing in the area. From May to August 1988, staggered pollarding was done monthly; alternate hedgerows were cut each month. This practice apparently provided a continuous supply of new shoots for insect development. Thus, even with the presence of the entomopathogens, there were slightly higher psyllid populations in ViSCA than in Villaba towards the end of 1988. In Villaba, the hedgerows were not cut at regular intervals. This may explain the more severe oscillation of psyllid populations there.

The third factor affecting psyllid populations was natural enemies. There were two kinds of beneficial organisms collected during our survey. One group consisted of predatory arthropods, predominantly spiders (Tables 2

Table 1. Description of the different sampling stations in Leyte.

Location	Distance from ViSCA/Area/Terrain	Relative Weather Condition
ViSCA, Baybay	Main station, ca. 0.5 ha hilly area with leucaena as hedgerows	Moist and humid
Cagnocot, Villaba	100 km NW, ca. 5 ha hilly area with mainly leucaena as hedgerows	Dry and hot
San Ricardo, Babatngon	148 km NE, ca. 2 ha slightly elevated area, leucaena as shade and hedgerows	Slightly moist and humid
Naval, Biliran	162 km N, mountain area, sampling site at ca. 800 m above sea level with old leucaena trees	Moist and cool
Buenavista, Bontoc	91 km SE, ca. 1 ha, slightly hilly, leucaena and madre de cocoa as hedgerows	Moist and humid

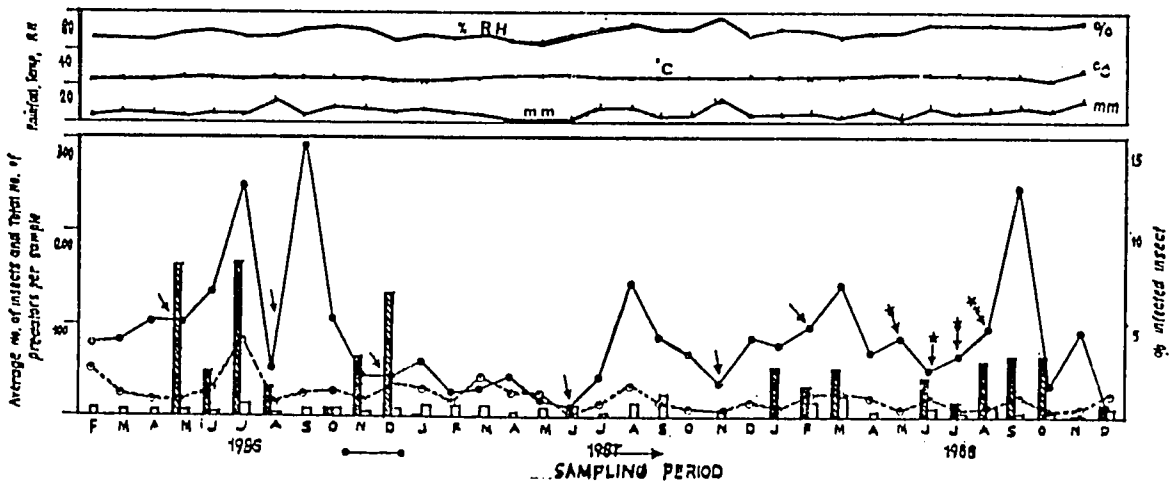

Figure 1. Number of *Heteropsylla cubana* Crawford, its natural enemies and % infected insect in relation to mean daily rainfall, temperature and relative humidity in ViSCA, Baybay, Leyte. (------ nymphs, - - - adults, predators, entomopathogens, ——> pollarded • ——> staggered pollarding).

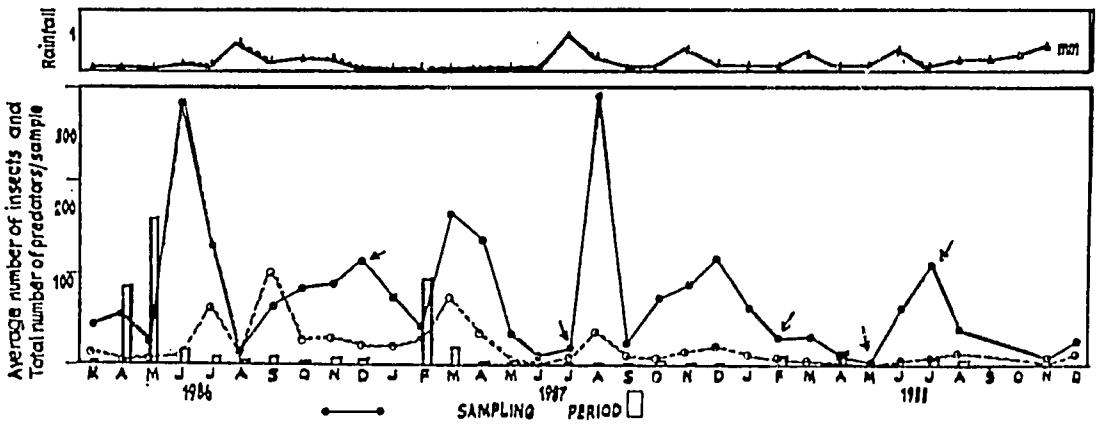

Figure 2. Number of *Heteropsylla cubana* Crawford, its natural enemies in relation to mean daily rainfall in Cagnocot, Villaba, Leyte. (— nymphs, - - - adults, predators —> pollarded).

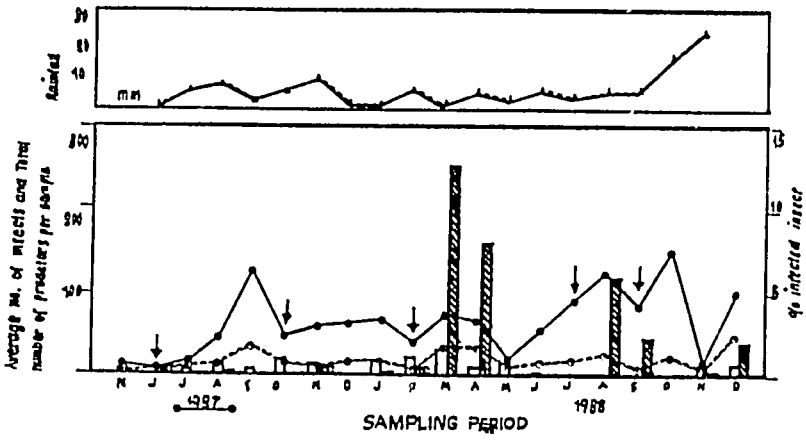

Figure 3. Number of *Heteropsylla cubana* Crawford its natural enemies and % infection in relation to mean daily rainfall in Buenavista, Bontoc, South Leyte. (——nymphs - - - - adutls, ▭ predators, ▨ entomopathogens ⟶ pollarded).

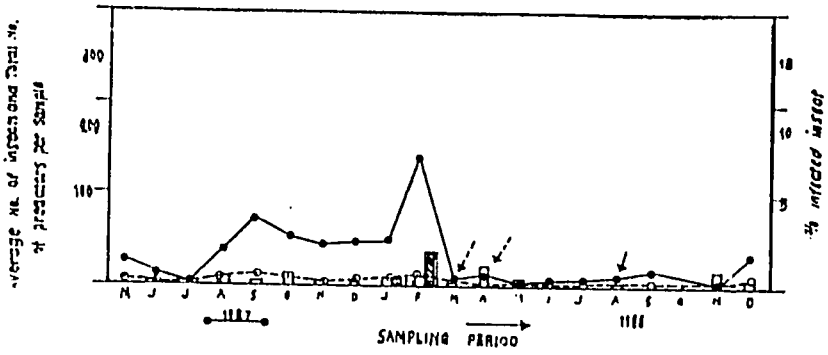

Figure 4. Number of *Heteropsylla cubana* Crawford, its natural enemies in San Ricardo, Babatngon, Leyte. (----- nymphs - - - adults ▭ predators ▨ entomopathogens ⟶ pollarded ⟶ trimmed).

Table 2. Spiders collected from psyllid-infested leucaena stands in Leyte[1].

Species[2]	Relative Occurrence[3]				
	Babatngon	Biliran	Bontoc	Villaba	ViSCA
Araneus sp.	+ +	+ +	+ + +	+ +	+
Clubiona sp.				+	
Coleosoma blandum				+	
Cyclosa mulmeinensis (Thorell)	+	+ + +	+	+ + +	+
Dexippus sp.				+	
Diaea xanthogaster	+		+	+	+
Hasarius sp.		+ +	+ + +	+	+ +
Leucauge decorata				+	
Liocranum sp.	+ + +	+ + +	+ + +	+ + +	+ + +
Marpissa calcutaensis		+ +	+ +	+	
Misumena sp.	+ + +	+ + +	+ + +	+ + +	+ + +
Misumenops sp.					+
Oxyopes javanus (Thorell)	+ +	+ + +	+ + +	+ + +	+ + +
Tetragnatha sp.				+	
Thomisus sp.	+ +		+ +	+	+ +
Xysticus sp.	+ +		+	+	+
Unidentified species	+ + +	+ +	+	+ +	+ +

[1]Babatngon, Biliran and Bontoc data from May 1987 to December 1988; ViSCA and Villaba = data from February 1986 to December 1988.
[2]Identified by Mr. A.T. Barrion, Research Associate, International Rice Research Institute, Los Banos, Laguna.
[3]Scale: + = rare, + + = common, + + + = very common, blank = no record.

and 3). The other group consisted of four species of entomogenous fungi: *Entomophthora* sp., *Paecilomyces farinosus, Hirsutella citriformis* and *Fusarium* sp. The occurrence of these natural enemies depended on local weather conditions. For instance, epizootics caused by entomogenous fungi were common in moist, humid sites like ViSCA, Bontoc and Babatngon (Figures 1, 3 and 4). Epizootics were never recorded in Villaba. However, the orb spider, *Cyclosa mulmeinensis* (Thorell), was commonly found in Villaba and sometimes in Biliran and Babatngon, but rare in Bontoc and ViSCA. There was a noticeably lower number of psyllids in Babatngon and Bontoc. In Babatngon, leucaena is mainly used as a shade tree. The limited number of developing shoots, in addition to the presence of entomopathogens and some predators limited the rapid increase of psyllids in that area (Figure 4). The high incidence of entomopathogens in Bontoc apparently kept the psyllid population at a low level (Figure 3). Limited data from Biliran also indicated the presence of entomopathogens. However, it was

Table 3. Entomophagous insects collected from psyllid-infested leucaena stands in Leyte[1].

Species	Relative Occurrence[2]				
	Babatngon	Biliran	Bontoc	Villaba	ViSCA
Coleoptera					
Coelophora inaequalis	+				
Formicomus sp.[3]		+	+ +	+ +	+ +
Menochilus sexmaculatus	+ + +	+ +	+ + +	+ + +	+ + +
Micraspis sp.			+ +	+ +	+ +
Hemiptera					
Campylomma livida[3]	+ + +	+	+ + +	+ + +	+ + +
Deraecoris sp.[4]	+ + +	+ +	+ + +	+ + +	+ + +
Geocoris flaviceps[3]			+ +	+	+ +
Philophorus sp.[3]				+ +	+ +
Scipinia horrida [5]	+ + +	+ + +	+ + +	+ + +	+ + +
Hymenoptera					
Ropalidia flavopicta flavobrunnea [6]	+ +	+ +	+ + +	+ +	+ + +

[1]Babatngon, Biliran and Bontoc data from May 1, 1987 to December 1988, ViSCA and Villaba data from February 1986 to December 1988.

[2]Scale: + = rare, + + = common, + + + = very common, blank = no record.

[3]Identified by Dr. V.P. Gapud, Taxonomist, Museum of Natural History, UPLB, College, Laguna, Philippines.

[4]Identified by Dr. R.T. Schuh, Curator, American Museum of Natural History, Central Park West at 79th St. New York, NY 10024-5192, USA.

[5]Identified by Mr. A.T. Barrion, Research Associate, International Rice Research Institute, Los Banos, Laguna, Philippines.

[6]Identified by Dr. C.R. Baltazar, Taxonomist, Museum of Natural History, UPLB, College, Laguna, Philippines.

impossible to monitor them closely because of the difficulty in taking samples from tall trees.

Discussion

When the survey began in February 1986, the psyllid outbreak was at its peak, causing widespread defoliation of leucaena trees in Villaba (Villacarlos *et al.* 1988). As a consequence, a low number of psyllids was recorded in the succeeding months because of the depletion of leaves and shoots where psyllids could feed and oviposit. However, there was a high population of the orb spider, *C. mulmeinensis*. Its webs interlocked among dry twigs where hundreds of psyllid adults had been trapped. However, a slight rain in June 1986, triggered shoot development resulting in rapid increase of the insect. The reason for the simultaneous decrease in the number of orb spiders during the following months is uncertain. It is possible that this species is sensitive to rain. A large number of spiders was again recorded in February 1987, when it was relatively dry, and a few appeared in January to April 1988, when there was very little rain. Although we were not able to quantify the proportion of the psyllid populations that had been removed by *C. mulmeinensis*, this species and other predatory arthropods may be important mortality factors of psyllids at this station. From May 1986, to December 1988, no further severe defoliation of leucaena in Villaba was recorded in spite of the relatively high psyllid population.

A completely different situation was observed in ViSCA. Although the psyllid population in the area was also high, there was only sporadic defoliation of trees. The greater oscillations in insect number in Villaba than in ViSCA can partly be attributed to the difference in the amount of rainfall in the two areas. In ViSCA, the total precipitation in 1986, 1987 and 1988 was 2,641, 1,794 and 1,961 mm respectively, while in Villaba, the precipitation was only 99, 104 and 96 mm for the same years. The amount of moisture may affect the insect population indirectly in two ways. First, water stress may reduce the pest population. If plants are under stress, they become more susceptible to other pressures in the environment, such as psyllid feeding. Since psyllids feed by sucking the sap from the shoots and young leaves of leucaena, a tremendous number of them can withdraw a great amount of moisture that can further weaken the plant. We observed in early 1986 that leucaena trees planted near water sources, such as rice paddies, were not defoliated, unlike trees along highways far from water sources. But even plants that get enough water can become defoliated if they are exposed to heavy psyllid infestation. We observed severe defoliation of leucaena trees in Biliran when we first visited the area in April 1987, but these also recovered after a few months. As mentioned earlier, the station is in a mountainous area ca. 800 m above sea level, where it is normally moist. A study conducted by Burdeos (1986) also showed that 4-month-old leucaena seedlings planted in pots of moist soil cannot tolerate the feeding of 100 adults allowed to infest the plants for 21 days. There was 40 percent defoliation of the plant after this period. One hundred nymphs can also cause 36 percent defoliation during the same exposure period. Although most plants can tolerate 30-40 percent defoliation without serious loss to the crop (Price 1984), a longer exposure to high numbers of psyllids can be devastating, especially if the plants are under water stress.

Secondly, psyllid populations may be affected negatively by high moisture conditions. Adequate moisture in the environment encourages new shoot development in leucaena, but moisture also encourages psyllid reproduction and also its pathogens. In ViSCA, where it is normally moist, epizootics due to entomogenous fungi may explain the gradual decrease in the psyllid population from May 1986 to May 1987 (Figure 1). Villacarlos and Robin (1989) indicated that disease incidence was high from May to July 1986, when moisture was consistently available and the psyllid population was high. Moisture and the incidence of entomopathogens was also high between November 1986 and January 1987, when the temperature was lower (26.6°C) than the average of 28.4°C during other months. They found a significant negative correlation between temperature and the occurrence of *P. farinosus* and *H. citriformis*, which may explain why these species were not as common as *Entomophthora* sp.

There are four major implications of our findings. First, the niche created by the newly introduced pest is now gradually being occupied by other organisms, such as predators and entomopathogens. In late 1988, we collected an unidentified species of mirid bug feeding on psyllid eggs. Previously, we encountered only *Campylomma livida* (Reuter). In early 1988, we collected adults and nymphs infected with apparently another species of *Entomophthora*. The first species that we observed usually infected only the adults. With time, the third trophic level may be filled and brings about

stability in the psyllid population.

Second, although some entomopathogens appeared in the dry, hot environment of Villaba, disease development and spread cannot be sustained because of the dry condition in the area. Thus, in this situation, augmentation with other more efficient predators is needed to reduce the oscillation of the psyllid population. This is particularly important when regular pollarding is being practiced.

Third, it was shown that in moist, humid areas, entomopathogens were the major mortality factors of the psyllid. Thus, species that can grow on locally available substrate could be mass-cultured and used as spray material a few days after pollarding to hasten disease spread and to prevent damage on the developing shoots. Since leaves become more resistant to the insect feeding as they mature, one application may be sufficient to keep the psyllid population down.

Fourth, since we know very little about the contribution of common spiders and predatory insects to the control of the pest, there is a need to look more closely at the predators and study the factors that affect their irregular existence in the field.

Acknowledgements

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BIOLOGICAL AND PARTIAL ECOLOGICAL LIFE TABLES OF *HETEROPSYLLA CUBANA* CRAWFORD AND ITS PREDATOR, *CURINUS COERULEUS* MULSANT IN THAILAND

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Abstract

Biological and partial ecological life tables were constructed and analyzed under laboratory conditions for the leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), and its predator, *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae). In addition to using *H. cubana* as prey in the construction of life tables for *C. coeruleus* comparative life tables were also constructed using cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphidae) as prey. The population statistics obtained for biological attributes of *H. cubana* were: net reproductive rate of increase (R_o) = 139.179, the capacity for increase (r_c) = 0.275, the finite rate of increase (λ) = 1.316, the cohort generation time (T_c) = 17.95 days and the population doubling time (DT) = 2.52 days. The partial ecological life table revealed heavy mortality during the egg stage and the first nymphal instar. The population parameters obtained from the analysis of biological life tables of *C. coeruleus* constructed by using leucaena psyllid and cotton aphids as prey were: net reproductive rate of increase (R_o) = 26.384 and 16.929, the capacity for increase (r_c) = 0.054 and 0.044, the finite rate of increase (λ) = 1.055 and 1.045, the cohort generation time (T_c) = 61.02 and 63.88 days, and the population doubling time (DT) = 12.84 and 15.75 days respectively. The analysis of partial ecological life tables also revealed relatively higher mortality during the egg stage and the first larval instar of *C. coeruleus* when fed on either *H. cubana* or *A. gossypii*.

Introduction

Life table studies introduced by Deevey (1947) have long been employed by entomologists to analyze insect populations in a quantitative manner. Yet it is surprising that some entomologists are still not convinced of the importance of life table studies and engage in only life cycle or life history studies. Life tables of insects and insect pests could be classified as "biological" and "ecological" life tables. Data obtained from the "biological" life tables could be used to construct "partial" ecological life tables (Napompeth 1973). Data for the construction and analysis of biological life tables are normally generated under laboratory or quasi-field conditions while ecological life table data are, as a rule, obtained under field conditions where normal regulatory or mortality factors could be detected and quantified. Studies and data generation for ecological life table studies in the temperate region are relatively less complicated because of the simple voltinism of insect species. Under tropical conditions insect species exhibit a more complicated voltinism, termed "cryptovoltinism" by Napompeth (1973). Thus most life table studies of insect species under the tropical condition are confined to biological life tables and partial life tables. Other difficulties encountered in the ecological life table studies are the time required for proper quantitative analysis in addition to the selection of suitable sampling units and sample size.

The objectives of this investigation were to construct and analyze biological and partial ecological life tables of the leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), and its introduced predator, *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae). The intent is to determine the biological attributes of these insects on an ecological basis for further utilization in an integrated pest management program for the leucaena psyllid in Thailand.

Materials and Methods

Laboratory cultures of *H. cubana* maintained on 3-month old leucaena (K8) seedlings kept in the NBCRC insectary greenhouse were used as stock culture for this study. Cultures of *C. coeruleus* introduced from Hawaii and maintained by using *H. cubana* eggs, and young instar nymphs as prey were used. However, in the construction of the biological life tables of *C. coeruleus*, the prey used were *H. cubana* in one set of experiment and the cotton aphid,

Aphis gossypii Glover (Homoptera: Aphidae), in another set for comparative analysis.

The life table studies of *H. cubana* were carried out at the NBCRC Central Laboratories at Kasetsart University, Bangkhen, Bangkok from January to March, 1988 covering the declining period of the annual seasonal peak of leucaena psyllid populations in the field. During this period the temperature ranged from 24-35°C, averaging 30±2°C and the relative humidity ranged from 55-75%, averaging 65±7%.

Life table studies of *C. coeruleus* were carried out at NBCRC Northern Regional Substation at Mae Jo Institute of Agricultural Technology (MIAT), Mae Jo, Chiang Mai from April to July, 1988 covering the period of total disappearance of leucaena psyllid populations. During this period, the temperature ranged from 28-36°C, averaging 31±2°C while the relative humidity ranged from 57-75%, averaging 65±7%.

The preys used for life table studies of *C. coeruleus* were eggs and young instar nymphs of *H. cubana* collected from an alley-cropping farm at Pong Yang Nai of Samoeng district and nymphs and adults of *A. gossypii* collected from siam weed, *Chromolaena odorata* (L.) and other host plants.

Leucaena seedlings grown in vermiculite were used for rearing psyllids in the life table studies. Young seedlings with fully emerged cotyledon and unfurled secondary leaves were used. Each seedling was kept in a glass vial, 2.5 cm in diameter and 12 cm in length, filled loosely with vermiculite and water with a solution of Bifolan. The seedling stem was then wrapped with an absorbent cotton wad and plugged into the vial allowing the roots to be kept inside the vial. Vials with seedlings were kept in a clear cylindrical plastic cage, 13.5 cm in diameter and 20.5 cm in height, with a circular screen window of 5.0 cm diameter on four sides as a rearing container.

Two cohorts of 95 and 246 eggs of *H. cubana* were used, all laid on the same day. Upon hatching, ten 1st instar nymphs were transferred to each seedling. Numbers of surviving nymphs were recorded daily until the 5th instar when 20 nymphs were kept in one container for recording the number of eggs laid. Data thus obtained were used in the construction of life table and analysis carried out using methods modified by Loughlin (1965) and Napompeth (1973). A cohort of 246 eggs was used to construct the partial ecological life table of Napompeth (1973).

In a similar way, life tables of *C. coeruleus* were carried out using two cohorts of 103 and 105 newly laid eggs of uniform age. The first cohort of 103 *C. coeruleus* eggs was used with cotton aphids as prey while the second cohort of 105 eggs was used with leucaena psyllids as prey. For each cohort the eggs laid in folded tissue paper were kept in a plastic cup, 6.5 cm in diameter and 4.0 cm in height. Upon hatching a single larva was transferred to a new cup of the same size covered with thin cheese cloth fastened to the cup with a rubber band. They were prepared and kept separately in two batches of 103 and 105 cups for using aphids and psyllids as prey respectively.

The larvae in each cup were fed daily and the number of surviving larvae for each batch recorded through each larval instar until pupation. Pupae from each batch were then kept in a plastic container, 17.5x25.0x9.0 cm in size, lined at the bottom with tissue paper with a lid of nylon screen 12 cm in diameter. Emergent adults were fed with either cotton aphids or psyllids but not both prey. A few drops of water were added to the rearing container to keep it from dehydration. An ample amount of bee pollen was also provided in a small aluminum foil cup as a food supplement for adult *C. coeruleus*. Daily observations and records were made on the numbers of eggs laid and surviving adults in each batch until all adults died of old age. Data thus obtained were used for the construction and analysis of life tables of *C. coeruleus* fed with aphids and leucaena psyllids respectively using the same technique as for *H. cubana*.

Results and Discussion

Life table of *H. cubana*

The biological life table of *H. cubana* showing proportion or probability at birth of female psyllids being alive at age x, is given in Table 1. From this life table the net reproductive rate of increase (R_o) was obtained from $l_x m_x$. From the R_o value thus obtained the cohort generation time (T_c), the capacity for increase (r_c) and the finite rate of increase (λ) and the population doubling time (DT) were calculated and are given in Table 2.

As a result of biological life table construction and analysis quantitative interpretation of *H. cubana* population characteristics and dynamics become obvious for further use in population criteria and management. The net reproductive

Table 1. Biological life table, age-specific fecundity rate, and net reproductive rate (R_o) of *Heteropsylla cubana* Crawford under laboratory conditions (30±2°C and 65±7% RH).

Pivotal age in days (x)	Proportion at birth[1] of female being alive at age x (l_x)	Age-specific[2] fecundity (female eggs/female/x) (m_x)	Egg curve ($l_x m_x$)
1.5	1.0	-	-
3.5	0.7684	-	-
6.5	0.7263	-	-
9.5	0.7263	-	-
12.5	0.7263	3.8696	2.8105
15.5	0.5895	85.4286	50.3602
18.5	0.4	144.9737	57.9895
21.5	0.2632	96.64	25.4357
24.5	0.0105	246.0	2.583
			$R_o = \Sigma\, l_x m_x = 139.179$

[1] l_x = The probability of individuals being alive at the beginning of age-interval (x).

[2] m_x = The number of female eggs for each age-interval (x).

Table 2. Population statistics expressed as biological attributes of *Heteropsylla cubana* Crawford.

Biological attributes	Values
Net reproductive rate of increase (R_o)	139.179
Cohort generation time (T_c) (days)	17.95
Capacity for increase (r_c)	0.275
Finite rate of increase (λ)	1.316
Population doubling time (DT) (days)	2.52

rate of increase (R_o) indicated the rate of multiplication in one generation, i.e., *H. cubana* could multiply almost 140 times in each generation expressed as cohort generation time (T_c) which is the mean age of female *H. cubana* in the cohort at birth averaging about 18 days. The innate capacity for increase (r_m) could be approximated by calculating r_c (Laughlin 1965) which is relatively much easier but equally accurate. An instantaneous growth coefficient, or growth increment in Malthusian population growth, of 0.275 was obtained for *H. cubana* in this preliminary investigation. The finite rate of increase (λ) expressed the number of times *H. cubana* population could multiply itself during each time interval (x) which is 1.3 times every three days. The population doubling time (DT) indicated that *H. cubana* would be capable of doubling its population size in 2.5 days.

The egg curve ($l_x m_x$) of *H. cubana* indicated that the oviposition period of *H. cubana* lasted for about 12 days with relatively low numbers of eggs laid during the first few days. The highest numbers of eggs laid were between the fourth and the sixth day of the oviposition period.

The partial ecological life table of *H. cubana*, shown in Table 3, indicated that within each generation the percent mortality (100 q_x) and generation mortality (100 d_x/n) were high during the egg and first nymphal instar of *H. cubana* accounting for about 27 and 26% mortality and 27 and 19% generation mortality. Taking into consideration all nymphal stages the percent mortality and the generation mortality were 42.28 and 27.24% respectively.

Life tables of *C. coeruleus*

The construction of life tables of the coccinellid predator, *C. coeruleus*, was carried out using psyllids, *H. cubana*, and aphids, *A. gossypii*, as prey. The purpose of this design was to determine population statistics when the "preferred" prey or leucaena psyllids were available and abundant, and when the leucaena psyllids were absent (e.g. survival on "less-preferred" prey). The investigation was carried out during the absence of leucaena psyllids using psyllids from a "population pocket" at Samoeng District of Chiang Mai. It is suggested that other prey could and should be investigated further during the non-outbreak season of leucaena psyllids.

The life tables of *C. coeruleus* using *H. cubana* and *A. gossypii* as prey are presented in Tables 4 and 5 respectively. Similarly the population statistics of *C. coeruleus* analyzed as biological attributes on its respective prey are given in Table 6.

It is quite obvious from the comparative population statistics of *C. coeruleus* that *H. cubana* was a more suitable prey while *C. coeruleus* could survive well on non-psyllid prey such as aphids. While the cohort generation

Table 3. Partial ecological life table of *Heteropsylla cubana* Crawford under laboratory condition (30±2°C and 65±7%RH).

Stage of development (x)	No. surviving in x (l_x)	No. dying in x (d_x)	Percent mortality (100 q_x)	Generation mortality (100 d_x/n)
Egg:	246	66	26.8293	26.8293
Nymph:				
- Instar I	180	47	26.1111	19.1057
- Instar II	133	9	6.767	3.6585
- Instar III	124	3	2.4194	1.2195
- Instar IV	121	5	4.1322	2.0325
- Instar V	116	3	2.8562	1.2195
Adult:	113			

Table 4. Life table, age-specific fecundity rate, and net reproductive rate (R_o) of *Curinus coeruleus* Mulsant when fed with *Heteropsylla cubana* Crawford under laboratory condition (31±2°C and 65±7% RH).

Pivotal age in days (x)	Proportion at birth of female being alive at age x (l_x)	Age-specific fecundity (female eggs/female/x) (m_x)	Egg curve ($l_x m_x$) (x)
1.5	1.0	-	-
4.5	1.0	-	-
7.5	0.6826	-	-
10.5	0.5928	-	-
13.5	0.5629	-	-
16.5	0.527	-	-
19.5	0.527	-	-
22.5	0.521	-	-
25.5	0.503	-	-
28.5	0.503	-	-
31.5	0.503	-	-
34.5	0.503	-	-
37.5	0.503	-	-
40.5	0.503	-	-
43.5	0.4731	2.5317	1.1977
46.5	0.4491	11.9467	5.3653
49.5	0.4491	5.12	2.2994
52.5	0.4371	6.1918	2.7064
55.5	0.4371	3.3151	1.449
58.5	0.4072	2.8235	1.1497
61.5	0.4072	0.5588	0.2276
64.5	0.3892	8.5077	3.3112
67.5	0.3892	3.7539	1.461
70.5	0.3892	1.6769	0.6527
73.5	0.3892	3.0	1.1676
76.5	0.3653	2.7705	1.0121
79.5	0.3653	2.459	0.8983
82.5	0.1677	6.6429	1.114
85.5	0.1138	11.7895	1.3416
88.5	0.0539	19.1111	1.0301

$R_o = \Sigma\, l_x m_x = 26.3837$

Table 5. Life table, age-specific fecundity rate, and net reproductive rate (R_o) of *Curinus coeruleus* Mulsant when fed with *Aphis gossypii* Glover under laboratory condition (31±2°C and 65±7% RH)

Pivotal age in days (x)	Proportion at birth of female being alive at age x (l_x)	Age-specific fecundity (female eggs/female/x) (m_x)	Egg curve ($l_x m_x$)
1.5	1.0	-	-
4.5	1.0	-	-
7.5	0.8058	-	-
10.5	0.6408	-	-
13.5	0.5631	-	-
16.5	0.534	-	-
19.5	0.534	-	-
22.5	0.5049	-	-
25.5	0.5049	-	-
28.5	0.5049	-	-
31.5	0.5049	-	-
34.5	0.5049	-	-
37.5	0.5049	-	-
40.5	0.5049	1.2692	0.6408
43.5	0.4757	0.9184	0.4369
46.5	0.466	3.1667	1.4757
49.5	0.466	2.1875	1.0194
52.5	0.466	0.0208	0.9417
55.5	0.4078	2.1191	0.8642
58.5	0.3592	2.2432	0.8058
61.5	0.2913	5.1333	1.4953
64.5	0.2621	2.7407	0.7183
67.5	0.2427	8.9600	2.1746
70.5	0.233	10.2083	2.3785
73.5	0.233	9.0417	0.2107
76.5	0.2136	5.8182	1.2428
79.5	0.1845	5.9474	1.0973
82.5	0.1845	2.4737	0.4564
85.5	0.1262	3.5385	0.4466
88.5	0.1262	4.1539	0.5242

$R_o = \Sigma\, l_x m_x = 16.9292$

Table 6. Population statistics of *C. trinus coeruleus* Mulsant expressed as biological attributes when *Heteropsylla cubana* Crawford and *Apnis gossypii* Glover were used as prey.

Biological attributes	*H. cubana*	*A. gossypii*
Net reproductive rate of increase (R_o)	26.384	16.929
Cohort generation time (T_c) (days)	61.02	63.88
Capacity for increase (r_c)	0.054	0.044
Finite rate of increase (λ)	1.055	1.045
Population doubling time (DT) (days)	12.84	15.75

Table 7. Partial ecological life tables of *Curinus coeruleus* Mulsant when fed on *Heteropsylla cubana* Crawford under laboratory condition (31± 2°C and 65±7% RH).

Stage of development (x)	No. surviving in x (l_x)	No. dying in x (d_x)	Percent mortality (100 q_x)	Generation mortality (100 d_x/n)
Egg:	105	33	31.4286	31.4286
Larva:				
- Instar I	72	8	11.1111	7.619
- Instar II	64	5	7.8125	4.7619
- Instar III	59	4	6.7797	3.8095
- Instar IV	55	2	3.6364	1.9048
Prepupa:	55	0	-	-
Pupa:	53	1	1.8868	0.9524
Adult:	52	-	-	-

time (T_c) was about the same, 61 and 64 days respectively, the net reproductive rate of increase (R_o) or the number of times *C. coeruleus* could multiply in one generation was obviously much higher (i.e. 26 times on leucaena psyllid but only 17 times on aphids). The capacity for increase (r_c), the finite rate of increase (λ), and the population doubling time (DT) were similar. A similar value of population doubling time of approximately 13 and 16 days on both prey should not pose any question because *C. coeruleus* under investigation was feeding on its prey under confinement and provided with no choice, a situation which may not be so under natural conditions. Thus, the population parameters obtained were similar in quantitative values. Under field conditions during the leucaena psyllid-free period, *C. coeruleus* may have to thrive on any prey available and such prey-complex may give rise to much lower biological attribute values leading to a much lower density of *C. coeruleus* during the absence of *H. cubana*. The data lead to the conclusion that although *C. coeruleus* could survive on other prey it would be more specific in its predation on *H. cubana*.

The egg curves (l_xm_x) of *C. coeruleus* when fed with *H. cubana* in comparison with *A. gossypii* were similar with oviposition periods of 48 to 50 days. While the numbers of eggs laid when fed with *H. cubana* were higher during the beginning of the oviposition period followed by a gradual decline, those fed with *A. gossypii* indicated a lower but relatively constant number of eggs during the oviposition period. Prey suitability may be important in determining reproductivity of *C. coeruleus* which could be explained by the significant difference in the net reproductive rate of increase (R_o) which were 26 and 17 times when *H. cubana* and *A. gossypii* were used as preys respectively. Other population parameters remained similar.

The partial ecological life tables of *C. coeruleus* when *H. cubana* was used as prey in comparison with *A. gossypii* as prey are given in Tables 7 and 8. While high percent mortality ($100q_x$) and generation mortality ($100q_x/n$) were observed during the egg and first larval instars in both cases, these were probably normal in *C. coeruleus* and other insect species which in most

Table 8. Partial ecological life table of *Curinus coeruleus* Mulsant when fed on *Aphis gossypii* Glover under laboratory condition (31±2°C and 65±7% RH).

Stage of development (x)	No. surviving in x (l_x)	No. dying in x (d_x)	Percent mortality ($100\ q_x$)	Generation mortality ($100\ d_x/n$)
Egg:	103	20	19.4175	19.4175
Larva:				
- Instar I	83	10	12.0482	9.7087
- Instar II	73	5	6.8493	4.8544
- Instar III	68	4	5.8824	3.8835
- Instar IV	64	2	3.125	1.9418
Prepupa:	62	2	3.2258	1.9412
Pupa:	62	0	-	-
Adult:	62	-	-	-

cases assumed the survivorship curve Type III of Deevey (1947) and Type IV of Slobodkin (1961) as explained in Napompeth (1973). However, the higher mortality during the egg stage of *C. coeruleus* when fed on *H. cubana* in comparison to those fed on *A. gossypii* could not be explained. This discrepancy could be because there was no replication in the experiment. With adequate replication a more representative estimate would be possible.

Conclusions

In most ecological investigations of insect pest species and their natural enemies it is generally true that the construction and analysis of life tables, are needed but usually lacking. Without such basic research it will be difficult to provide a sound basis for the development of an integrated pest management program for the target pest species. The same obvious deficiency was evident in ecological investigations of the leucaena psyllid and many other well known insect pest species. This is largely due to the preoccupation of using a single-component control strategy, especially the use of pesticides. As far as the leucaena psyllid is concerned, it is relatively a "new" insect pest and the lack of life table investigation is justifiable. Other life table work on the leucaena psyllid has been done in Hawaii by Takara *et al.* (1987).

Life table studies could also be used for screening leucaena varieties and provenances for psyllid tolerance and/or resistance. Rearing leucaena psyllids on different varieties would certainly yield differing values of biological attributes. R_o, r_c, λ, T_c and DT values obtained would differ from one leucaena variety to another, thus enabling quantitative comparison of the degree of psyllid tolerance or resistance among various varieties. No matter how cumbersome the methods may seem, such research could be highly complimentary to the existing traditional methods of screening for psyllid resistance.

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DISTRIBUTION OF LEUCAENA PSYLLID AND ITS NATURAL ENEMIES IN MEXICO: IMPLICATIONS FOR BIOLOGICAL CONTROL

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Abstract

The leucaena psyllid is believed to have originated in Mexico, the native range of its host plant *Leucaena leucocephala*. Exploration in this region is an important step in finding the most effective biological control agents for this pest. During a visit to Mexico in October - December 1988, observations were made on the ecology and distribution of *Heteropsylla cubana* and its natural enemies. *H. cubana* is widespread in Mexico and was often abundant, but it was absent from certain areas where *L. leucocephala* was common, such as the Yucatan peninsula.

Populations were never heavy enough to defoliate the trees. *H. cubana* is rare during the wet summer season and increases at the end of the wet or beginning of the dry season (September -October). It was also found on *Leucaena pulverulenta*.

H. cubana is attacked in Mexico by a range of predators including syrphids, spiders, chrysopids, reduviids, anthocorids and coccinellids. None of these appear to be specialized psyllid predators. It is also parasitized by two main parasitic hymenoptera, *Tamarixia leucaenae* and *Psyllaephagus* sp. nr. *rotundiformis*. Both occur throughout the range of *H. cubana* in Mexico, but parasitism by *Tamarixia* is generally much higher than by *Psyllaephagus*. Samples of both of these species were sent to the CIBC laboratory in Trinidad for rearing and study.

A foliar pathogen, *Camptomeris leucaenae*, caused severe damage to the leucaenas. It will be important to ensure that biocontrol agents for leucaena psyllid introduced into Asia are free from spores of this pathogen.

Introduction

To assess the prospects for biological control of an introduced pest, it is important to know something about its ecology in its area of origin. In particular, experience with biological control has shown that the most effective biological control agents are usually specialized natural enemies from the area of origin of the pest. The leucaena psyllid, *Heteropsylla cubana*, is native to the neotropics and most likely originated in Mexico, where its host *Leucaena leucocephala* is native. However, little information has been available on the ecology of *H. cubana* in this region. The observations presented in this paper were made during a visit to Trinidad and Mexico, from October to December 1988, as part of the CAB International Institute of Biological Control (CIBC)'s program on the biological control of the leucaena psyllid. Although these observations cover only a limited time period, I hope that, in conjunction with other data on the leucaena psyllid to be presented at this workshop, they will provide some insight into the possibilities of biological control of this pest.

The purpose of my visit was to survey populations of *H. cubana* in Mexico, collect data on its natural enemies, and collect material of natural enemies for culturing and further study at the CIBC Caribbean and Latin American Station (CLAS) in Trinidad. During my visit I looked at *L. leucocephala* and psyllid populations in southern Veracruz state, Tabasco and the Yucatan peninsula; along the Pacific coast from Tehuantepec, Oax., to Acapulco, Gro.; and along the Gulf coast from Veracruz north to Tampico, Tamps., and inland to Monterrey, N.L. My visit occurred towards the end of the wet season; in an earlier exploration in July and August (the rainy season in most areas), Dr. R.G. Brown, CIBC's leucaena psyllid project entomologist, had found the psyllid to be very scarce or absent in most of the same areas I surveyed.

The localities referred to are indicated in Figure 1. Identifications are not yet available for all

Figure 1. Mexico, showing localitis under the present survey and exploration .

plant and insect material collected.

Host Plant Distribution

L. leucocephala occurs widely in lowland Mexico. Through most of this area, the climate is characterized by a dry winter season and summer rains; however, the relative duration of these seasons and the total amounts of rainfall vary widely. Over much of its range *L. leucocephala* is not abundant, occurring as scattered plants or small patches mainly around houses and villages. This pattern was observed in southern Veracruz, and along the Pacific coast from Tehuantepec to Acapulco. In many such sites it appears to have been deliberately planted, and in most of the areas I surveyed, it is well known to local people for its edible seeds, which are eaten green as a vegetable. Between Villahermosa, Tab., and Escarcega, Camp., there is a gap in the distribution of *L. leucocephala*. North of Escarcega it is abundant and widespread over most of the Yucatan peninsula, often forming the dominant shrubby roadside vegetation. In this area it is not consistently associated with settlements, but occurs for long distances along roadsides. From Veracruz city north to approximately Tuxpan, Ver., *L. leucocephala* is somewhat scarce and continues to be associated with settlements. In the region around Tampico, Tamps., (from approximately Tempoal, Ver.,to Llera, Tamps.) it again becomes more abundant and occurs along roadsides in open country.

However, it does not grow as densely here as in the Yucatan peninsula. In the area from Ciudad Victoria, Tamps., to Monterrey, it is common around towns and in fence lines. In this area it appears mainly to be deliberately planted.

Psyllid Abundance and Distribution

H. cubana was common on *L. leucocephala* in southern Veracruz, and often occurred at quite high densities. Some young trees at the Campo Experimental Cotaxtla, near Veracruz city, had quite heavy infestations.

In the Yucatan peninsula, most of the *L. leucocephala* appeared to be in ideal condition for psyllid attack, with abundant fresh growth. However, no psyllids were found on it anywhere in the peninsula, despite searches at approximately 40 separate sites. A possible exception was the collection of five early-instar nymphs from a single shoot near Chetumal, Q.R. Searching revealed no other psyllids on *L. leucocephala* in this area. Other legumes in the vicinity had colonies of other psyllid species, and it is possible that the nymphs collected on *L. leucocephala* were strays from these other colonies.

No psyllids were seen on *L. leucocephala* along the Pacific coast from Tehuantepec to Huatulco, Oax. From Huatulco to Acapulco psyllids were found, varying in density from a few individuals to heavy infestations. Some of these psyllid colonies seemed relatively long-established; the plants were heavily coated with honeydew, and high numbers of all stages of the psyllid were present. Other psyllid infestations in this region appeared more recent.

Psyllids were found frequently and often at high density as far north as Tempoal, in northern Veracruz state, and from Ciudad Victoria to Monterrey. However, none were found in the coastal region around Tampico. It was interesting to find abundant psyllids around Monterrey, a region with a strongly seasonal climate where frost occurs regularly in winter. This indicates a fairly wide range of climatic tolerance by *H. cubana*.

Near Ciudad Victoria and south of Tantoyuca, Ver., psyllids resembling *H. cubana* were collected on another *Leucaena* sp., probably *L. pulverulenta*.

A number of other phytophagous insects were also collected on *L. leucocephala* in southern Veracruz, including larvae of Arctiidae (Lepidoptera), nymphs of Coreidae (Heteroptera) which feed gregariously on the shoot tips causing them to wilt and die, and Membracidae (Homoptera). The general level of insect attack on *L. leucocephala* in the Yucatan was much lower than in southern Veracruz. The only insect commonly observed was a thrips feeding on the young leaves. Some necrosis and loss of young leaflets seen at a number of sites in this area may have been due to thrips attack.

Diseased leaves of *L. leucocephala* were collected at La Mancha, on the Gulf coast a short distance north of Veracruz city. These were examined by Dr. H. Evans, CIBC, and found to be attacked by an ascomycete later identified as *Camptomeris leucaena*. These trees were also attacked by psyllids, and appeared to be under heavy stress from the combined effects of insect and pathogen attack.

Psyllids, apparently *Heteropsylla* spp., were collected from several other mimosoid legumes in southern Veracruz, Tabasco and the Yucatan peninsula. Host plant material was collected for identification and probably includes species of *Acacia*, *Mimosa* and *Calliandra*. At the Chichen Itza archaeological site, Yucatan, dense psyllid colonies were found on two shrubby legumes superficially resembling *L. leucocephala*, but none were found on *L. leucecephala* itself. This may explain an earlier report of leucaena psyllid from this site (J. Waage pers.comm.).

Natural Enemies

General predators, particularly spiders, syrphid larvae, and a nabid were common on the psyllid colonies in all areas. Chrysopid larvae, coccinellids and predatory Hemiptera were also collected. Coccinellids were not generally abundant, and no single coccinellid species seemed to be strongly associated with *H. cubana* at any site surveyed. A possible exception was a pale green coccinellid, of which several adults with associated eggs and larvae were collected on psyllid-infested *L.pulverulenta* at Tantoyuca, Ver. The identification of this insect is not yet available. *Curinus coeruleus* was collected only once.

Rates of parasitism were low in most areas, but *Tamarixia leucaenae* (Eulophidae) and *Psyllaephagus* sp. nr. *rotundiformis* (Encyrtidae) were found in all areas. *Tamarixia* was always the more abundant of the two. Parasitism was heavier on some apparently older colonies at Puerto Angel, Oaxaca, on the Pacific coast. Mummified psyllid nymphs caused by *Tamarixia*

and *Psyllaephagus* were collected from this site for shipment to Trinidad. Both parasitoids were also collected from small psyllid colonies in this area which seemed to be more recently established.

Tamarixia and *Psyllaephagus* were also collected from other *Heteropsylla* spp. on other mimosoid legumes in southern Veracruz and the Yucatan peninsula (identifications not yet available).

One adult of *Sectiliclava* sp. (Encyrtidae) was collected in association with *H. cubana*. This genus is known as a parasitoid of adult psyllids. Further details of natural enemies collected on this visit, and by other collaborators with the CIBC leucaena psyllid program, are given in the paper by Dr. J. Waage in this workshop.

Discussion

Comparing my findings on this visit with those of Dr. R.G. Brown earlier in 1988, it is clear that populations of *H. cubana* in Mexico fluctuate widely in space and time. Population levels were generally much higher in November, but there was often wide variation in density over fairly small spatial scales. The relationship of *H. cubana* phenology to rainfall is not clear, although it would appear that populations tend to increase at the end of the wet season. Studies presently being conducted by Dr. R.G. Brown in Trinidad should clarify this. Populations of *H. cubana* appeared to be growing rapidly at many sites and without heavy mortality from natural enemies. Parasitism rates were not estimated precisely, but in general they were very low. Even at the Puerto Angel site there were many more unparasitized nymphs than mummies. General predators were common but did not usually appear to be abundant enough to cause heavy mortality. However, damage from the psyllids was never as severe as reported from Asia and was always confined to the younger leaves. General defoliation with the loss of older foliage was never observed. A good illustration of the relative lack of impact of *H. cubana* in Mexico was seen at experimental plots of the University of Nuevo Leon at Linares, N.L., where insect pests on *L. leucocephala* were under study. The investigators were not aware of the presence of *H. cubana* until we went out into the plots and found it during my visit.

An intriguing feature of the distribution of *H. cubana* in Mexico is the presence of large "holes" where the insect is absent (or so rare as to be undetectable) in spite of apparently suitable host plant and climatic conditions. The most prominent of these is the Yucatan peninsula, but the insect was also conspicuously absent in the areas around Tehuantepec and Tampico. The Tampico "hole" is particularly strange as there is no break in the distribution of *L. leucocephala* southwards to Tempoal and Tantoyuca where the psyllid was present. From the information available at present we cannot say if these "holes" are permanent or temporary.

It seems certain that factors other than natural enemies must be responsible for the absence or extreme rarity of *H. cubana* in these areas. If generalist natural enemies were responsible, they should be equally effective against other *Heteropsylla* spp. However, several of these were common in the Yucatan and did not appear to be suffering heavy predation. If natural enemies specific to *H. cubana* were responsible, it is hard to imagine how they could avoid local extinction and keep the host population stable at such extremely low densities. Thus, although the absence of *H. cubana* in these areas poses an intriguing problem, I do not believe they are promising areas in which to search for biocontrol agents.

To maximize the effectiveness of the search for biocontrol agents for *H. cubana*, it is important to search in the area of origin of the species. This is probably (although not necessarily) the same as the area of origin of the host plant *L. leucocephala*. I believe that the question of where these species originated is still open. Most treatments of the genus *Leucaena* suggest that *L. leucocephala* is native to Yucatan. Despite its abundance there, I have doubts about this, mainly because of the poverty of its phytophagous insect fauna in that area. It is possible that it was introduced to Yucatan from central Mexico as a food crop by the Maya and later became naturalized. In support of this, its Maya names "xaxim" or "guaxin" are clearly derived from the Aztec name "guaje". I believe further study aimed at determining the exact centre of origin of *L. leucocephala* and *H. cubana* might be useful in suggesting areas to survey for biocontrol agents. The suggestion of Dr. J.L. Brewbaker (pers. comm.) that *L. leucocephala* is of hybrid origin, and that it may be possible to identify the parent species, may be useful in this connection. Studies on isozymes or mitochondrial DNA polymorphism (e.g. Powers *et al.* 1989) of *H. cubana* might also be useful in identifying its area of origin.

It would have been pleasing to report that *H. cubana* populations in Mexico are tightly controlled at low levels by natural enemies, and that outbreaks never occur. However, this is not

the case. Populations in Mexico are capable of quite rapid increase under suitable host-plant conditions, and can cause some stress to the plant. Natural enemies are clearly not maintaining them at a very low, stable equilibrium level. Nonetheless, it is encouraging that levels of damage from *H. cubana* in Mexico are never as severe as reported from Asia. The general predator fauna found in Mexico is similar in composition to that reported from Asia (C.R. Baltazar, pers. comm., L.T. Villacarlos, pers. comm., and A.L. Yao, pers. comm.). Possibly the additional impact of parasitism in Mexico may reduce the rate of increase to the extent that outbreaks do not have time to become as widespread and devastating as in Asia.

Tamarixia appears to be more important in the population dynamics of the psyllid than *Psyllaephagus*; it was commoner in all areas of Mexico surveyed, and casual observations suggest that it has a shorter generation time. Both parasitoids were found associated with what appeared to be comparatively recent infestations of *H. cubana*, suggesting that their host-finding powers are good. Both parasitoids should be well adapted to climates with a distinct dry season; this may be useful as these are the types of areas in which *Curinus coeruleus* has so far been less successful in Indonesia and the Philippines (I. N. Oka, pers. comm.).

The presence of a damaging foliar pathogen, *Camptomeris leucaenae*, on *L. leucocephala* in Mexico points up the need to take careful quarantine precautions against the introduction of pathogens to Asia with biocontrol agents for *H. cubana*.

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EXPLORATION FOR BIOLOGICAL CONTROL AGENTS OF LEUCAENA PSYLLID IN TROPICAL AMERICA

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Abstract

In 1988, a research and exploration program was initiated by CAB International Institute of Biological Control (CIBC) with the support of International Development Research Center (IDRC), Australian Center for International Agricultural Research (ACIAR) and U.S. Agency for International Development (USAID) to study *Heteropsylla cubana* Crawford in its neotropical region of origin and to characterize and screen important natural enemies for introduction into Asia and the Pacific. To date, ten exploratory missions and collections have been made in thirteen countries in the Caribbean, Central and South America. *H. cubana* was highly seasonal in its occurrence and usually extremely rare. Population studies are underway in Trinidad to determine important mortality factors.

Two parasitoid genera, *Psyllaephagus* and *Tamarixia*, the beetle *Curinus coeruleus* (= *colombianus*) Mulsant and a number of other generalists predators appear to be associated with *H. cubana* over a broad region. An *Entomophthora* sp. has been isolated on *H. cubana* in Trinidad. The new parasitoid species, *Tamarixia leucaenae* Boucek has been described and may be a promising agent for introduction. Present laboratory research focuses on specificity screening of this and other agents to determine whether they will attack the *Heteropsylla* sp. developed for biological control of the weed, *Mimosa invisa* (Mart. ex Colla), in the Pacific and Australia.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford, appeared in Hawaii in 1984 and has since spread westward at an unprecedented rate to infest *Leucaena leucocephala* (Lam.) de Wit plantings in the Pacific, Asia and Australia. Its westward front is presently in Western India and its eventual appearance in Africa is likely.

In its westward movement, leucaena psyllid has severely damaged *L. leucocephala* planted for cover crops, often killing trees over large areas, and has drastically reduced the productivity of leucaena for use as fodder and fuelwood by small farmers and for commercial leucaena production for leafmeal, timber and pulp. Development projects employing leucaena for these purposes and for land reclamation, erosion control and soil improvement have been affected, and a shift away from the use of leucaena in new programs has begun. Thus, the psyllid threatens existing investment in leucaena and the future use of this valuable tree in farming systems in the Pacific, Asia and Africa.

A range of methods for control of the leucaena psyllid are presently being explored, primarily by the research groups coordinated through the Regional Research Program for Leucaena Psyllid Control in Southeast Asia, which is supported by USAID through Forestry/Fuelwood Research and Development (F/FRED) Project of Winrock International. Of the various control options, only breeding for psyllid resistance and biological control are economically viable on a broad scale.

With respect to biological control, the establishment of exotic biological control agents from the tropical American region of origin of the pest is a particularly promising approach. *H. cubana* does not attain the population levels in tropical America that have been observed in Asia and the Pacific, possibly due, in part, to a diverse indigenous complex of natural enemies. Where successful, the introduction of specialized and safe exotic control agents from this natural enemy complex, called "classical biological control", has the advantage of continuous control at no recurrent cost. The pest is controlled in both deliberate leucaena plantings and on wild scrub leucaena, which is a constant reservoir for the reinvasion of the pest into agroforestry systems. The precedent for biological control of Homopteran pests, to which group the psyllid belongs, has been well established in many biological control programs,

and the prospects for control of these pests are greater than those for any other insect group. Accordingly, an exploration program for natural enemies of *H. cubana* was initiated in 1988 by the CAB International Institute of Biological Control (CIBC).

The CIBC exploratory program is based at its Central and Latin American Station (CLAS) in Trinidad and Tobago and administrated from CIBC Headquarters in the United Kingdom. This program consists of two phases, each of 18 months. Phase 1 began in February 1988, and involves exploration for the psyllid and its natural enemies in tropical America, where both are virtually unstudied, identification of promising control agents and biological studies. In Phase 2, the exploratory component will be reduced and effort will concentrate on the selection and quarantine screening of potential agents, and their introduction into affected countries in Asia and the Pacific.

Project Support

Phase 1 of the exploratory program is supported by three donor agencies: USAID, IDRC and ACIAR. Each agency contributes an important component to the overall program. Besides this financial support, the CIBC program has benefitted substantially from the assistance of other CABI Institutes, particularly the CAB International Institute of Entomology (CIE), the CAB International Mycological Institute (CMI), the CAB International Development Services (CDS), and from exploratory work carried out in the course of other projects in Bermuda, Trinidad, Honduras, and Mexico. Also collaboration and assistance with exploration and research has come from a number of other institutions.

Exploratory work to date

By the end of the first year of the exploratory program in February 1989, CIBC staff and collaborating institutions have made collections and surveys in 13 countries in the suspected Caribbean/Central American region of origin of *H. cubana*, including Trinidad and Tobago, Barbados, Dominican Republic, Haiti, Cuba, Jamaica, Mexico, Belize, Guatemala, Honduras, Costa Rica, Colombia and Guyana. Repeated and extensive surveys have focused on Mexico, the likely area of origin of the host plant, *L. leucocephala*, and the Caribbean, which is the source of the natural enemies of *H. cubana* currently being used in Asia and the Pacific (i.e., *Curinus coeruleus* Mulsant, *Olla abdominalis* (Say) and *Psyllaephagus* sp. nr. *rotundiformis* (Howard)*). These major surveys are listed in Table 1.

During exploratory studies, psyllids on all mimosoid legumes were collected, along with natural enemies and information on the plant, habitat and climate. Attention was also paid to other pests on *L. leucocephala*, including insects and diseases. Herbarium specimens were kept of plants from which psyllids were collected, and, where possible, these were accompanied by color slides of plant growth patterns. Dr. Colin Hughes and colleagues at the Oxford Forestry Institute are providing plant identifications.

Much of this taxonomic material is still being processed and identified. This is a lengthy process: taxonomic difficulties surround the identification of the natural enemies, psyllids and plants, requiring considerable coordination between entomologists and botanists. A summary of the results found to date is given, but it must be borne in mind that further identifications and exploration may change this picture.

Patterns of distribution and abundance of *H. cubana*

Distribution records of *H. cubana* have been assembled from present surveys and material in the U.S. National Museum (USNM), British Museum (Natural History) (BMNH) and elsewhere. These indicate a range for *H. cubana* from Florida and Mexico to Argentina and Peru and throughout the Caribbean. However, it is thought that much of this distribution has accompanied the propagation and spread of *L. leucocephala* from its native Mexico. The capacity of this insect to disperse in the New World was demonstrated by its discovery in Bermuda in 1988 by CIE taxonomists. Museum specimens indicate its presence there on introduced *L. leucocephala* since 1967.

Due to delays in the confirmation of support from some donor agencies, the first surveys could not begin until the end of the dry season in June 1988. Exploration between June and August, in both the Caribbean and Central America revealed very low populations of *H. cubana*. Where found, colonies were associated

*Robert Burkhart of the State of Hawaii Department of Agriculture carried out exploration in Trinidad and Tobago in 1984, obtained Tetrastichus triozae Burks, (= Tamarixia leucaenae Boucek), Psyllaephagus sp. nr. rotundiformis (Howard) and Cycloneda conjugata Mulsant and shipped them to Hawaii. See Nakahara et al. 1987. Leucaena Research Reports 7(2):40. - Editors

Table 1. Major exploratory surveys in tropical America.

Dates	Countries (Provinces)	Explorer(s)
Jun-Aug 1988	Mexico (Tamaulipas, Veracruz, Tabasco, Campeche Yucatan, Quintana Roo, Pueblas, Guerrero, Oaxaca), Belize	Brown (CIBC) Segura (CSIRO/ACIAR)
Jul-Aug 1988	Jamaica, Haiti, Dominican Republic, Cuba	Hollis (BMNH) Broomfield (BMNH)
Oct-Dec 1988	Mexico (Nuevo Leon Tamaulipas, Campeche, Yucatan, Quintana Roo Oaxaca)	McClay (AEC) Abraham, Evans (CIBC)
Feb-Mar 1989	Mexico (various states) Costa Rica, Guyana, Barbados	Hollis (BMNH) Hodkinson (Liverpool) Brown (CIBC)

with expanding leaves on growing shoots as in Asia. Infested plants were extremely rare: in July in Yucatan, Mexico, an estimated 10,000 young shoots were examined without finding a single psyllid. When found, populations of *H. cubana* were usually restricted to only one *L. leucocephala* plant in a population of many healthy and apparently identical individuals. Interestingly, psyllid species on other legumes were not uncommon during this period, suggesting that seasonal climate was not the explanation for *H. cubana*'s scarcity on *L. leucocephala*.

By contrast, Mexican surveys in November 1989, at the start of the dry season, revealed the psyllid to be widespread, both between sites and between trees within sites. Surprisingly, even in this period, no psyllids were found on the extensive wild *L. leucocephala* populations in Yucatan, even though this is a suspected region of origin of the plant.

The emerging pattern is one of a very seasonal insect, as in Southeast Asia and the Pacific. The exact cause of fluctuations in psyllid populations in tropical America remains unclear, and is the subject of ecological studies in Trinidad by CIBC.

Psyllid-plant associations

Surveys in tropical America to date reveal a number of interesting points. First, *H. cubana* in its native range is not restricted to *L. leucocephala*. Populations have been recovered from *L. diversifolia* in Guatemala, *Acacia villosa* and *Mimosa* sp. in Jamaica, and *Albizia guachepele* in Cuba. These associations may be casual, but the possibility of specialized races of *H. cubana* on different legume species cannot be excluded.

At present, the genus *Heteropsylla* contains 19 known species. A survey of recorded host associations of these psyllid species indicates that they are primarily associated with bush or tree legumes, including such genera as *Prosopis, Acacia, Cassia, Albizia, Mimosa, Samanea, Desmanthus* and *Calliandra*. Records suggest that most species are host genus- if not species-specific.

H. cubana is so far the only species of *Heteropsylla* found on *L. leucocephala*. Other *Heteropsylla* found during exploration include *H. distincta* on *Pithecellobium* sp. *H. reducta* on *Prosopis juliflora, H. mimosae* on *Acacia*

farnesiana, and *H. crawfordi* and *H. huasachae* on *Acacia villosa, A. macrocantha, Zapoteca (Calliandra) formosa, Desmanthus virgatus* and *Albizia guachepele*. This latter psyllid may prove to be a complex of up to four species.

A taxonomic revision of the genus *Heteropsylla* is underway at Liverpool Polytechnic and the BMNH, supported by the Natural Environment Research Council of the UK government.

Natural enemies of psyllid

Before the CIBC exploration program commenced, only a few species of natural enemies of the leucaena psyllid had been recorded from tropical America. A diverse natural enemy complex has since been found associated with *H. cubana* and related psyllids in the region and this work is by no means finished. The structure of this complex is similar in all regions, although not all taxa are present at all sites. The complex includes predatory spiders, coccinellids, bugs (mirids, phymatids, reduviids), wasps, ants and syrphids, and parasitic Hymenoptera in two main genera, *Psyllaephagus* (Encyrtidae) and *Tamarixia* (Eulophidae). Hyperparasitoids have been detected but are not common. *Entomophthora* sp. has been recorded from Trinidad; this is the only fungus recorded so far. CIBC staff are comparing this taxonomically with isolates from Thailand.

Predatory beetles collected to date are listed in Table 2. Among the coccinellids, it is particularly interesting to note that the two exotic species that have moved on to *H. cubana* in Hawaii, *C. coeruleus* and *O. abdominalis*, are natural predators of this species in tropical America (although they were not originally released in Hawaii against psyllids). Research on material from CIBC and elsewhere by Dr. R.G. Booth of CIE reveals that the largely South American *Curinus colombianus*, is in fact a smaller race of *C. coeruleus*. Other predators are listed in Table 3.

Among the parasitoids (Table 4), closer examination of CIBC material by the BMNH reveals that the *Psyllaephagus* sp. nr. *rotundiformis* (Howard) provisionally identified by Dr. John Noyes, and introduced into Hawaii and Thailand, and now recorded from a number of localities in tropical America, is probably a new species. This is presently being described by Dr. John Noyes as part of the CIBC project.

More exciting is the discovery of a new species of *H. cubana* parasitoid, *Tamarixia leucaenae* Boucek. It is likely that this is the same parasitoid as the eulophid collected with *P.* sp. nr. *rotundiformis* in 1985 by Robert Burkhart of the Hawaii Department of Agriculture, then based at CIBC's Caribbean and Latin American Station in Trinidad. *T. leucaenae* was misidentified then as the generalized psyllid parasitoid, *Tetrastichus triozae* Burks, and was not maintainable in culture. The true identity of this species was determined by Dr. Z. Boucek of CIE, and a description was published in 1988. This species appears to have thelyotokous (all female) races in the Caribbean, but bisexual races in Mexico. It has been recorded from other *Heteropsylla* spp. (Table 4). Another *Tamarixia* sp, possibly two, have been found which may be hyperparasitic. More taxonomic work is necessary before it can be said how many species of *Psyllaephagus* and *Tamarixia* there are in this complex.

Finally, the encyrtid *Sectiliclava* sp. has been found associated with *H. cubana* in Mexico. Some species of this genus are known to be parasitoids of adult psyllids.

Surveys do not provide a reliable indication of the impact of different natural enemies on *H. cubana*. However, it is fair to say that predatory coccinellids can be locally abundant but do not appear to be an important and widespread limiting factor of *H. cubana* populations. Predatory syrphids, wasps and ants may play an important role in some areas. Parasitoids are regularly associated with psyllid colonies, and of the two genera, *Tamarixia* appears both more widespread and causes generally higher levels of parasitism than *Psyllaephagus* during the survey period.

Other Observations

A number of insect pests of *L. leucocephala* have been recorded in surveys by CIBC and by Dr. C. Hughes of the Oxford Forestry Institute. These include various Homoptera, Thysanoptera, Lepidoptera Coleoptera (bruchid seed beetles) and leaf and pod galling insects. Of perhaps greater interest is the identification of the fungus, *Camptomerus leucaenae*, by Dr. Harry Evans, CIBC pathologist exploring in Mexico. Experts at CIBC suspect that this little known disease is quite specific to *L. leucocephala* and potentially very damaging. The symptoms of the disease are not distinctive, which may account for its infrequent reporting. Surveys in Mexico found it to be widespread and damaging. Its existence has a bearing on the quarantine of psyllid control agents for Asia.

Table 2. Predatory Coleoptera associated with *Heteropsylla cubana* on *Leucaena leucocephala*.

Species	Countries
Coccinellidae:	
Curinus coeruleus	Trinidad, Colombia
Cycloneda sanguinea	Mexico, Haiti
Olla V-nigrum (= *abdominalis*)	Mexico, Trinidad
Olla sp. nr. *v-nigrum*	Trinidad
Hippodamia convergens	Mexico
Coleomegilla maculata	Mexico, Cuba
Brachiacantha laevis	Mexico
Procula douei	Jamaica
Chilocorus cacti	Jamaica
Exochomus jamaicensis	Jamaica
Hyperaspis sp. ?*distinguenda*	Trinidad
Hyperaspis sp	Trinidad
Coccinella emarginata	Trinidad
Chnoodes terminalis	Trinidad
Nephus sp. nr. *flavifrons*	Trinidad
Nephus spp	Trinidad, Mexico
Diomus spp	Trinidad, Jamaica
Scymnus sp.	Jamaica
Staphylinidae:	
Euvira sp.	Mexico

Biological Studies

At CIBC's Central and Latin American Station (CLAS) in Trinidad and Tobago, culturing methods have been developed for the production of leucaena psyllids on leucaena seedlings, both in outdoor screen cages and in indoor perspex cages. In the latter, colonies of *Psyllaephagus* and *Tamarixia* species/races from the Caribbean and Central America are presently maintained for biological studies. *Mimosa invisa* and its *Heteropsylla* sp. from Australian cultures is also maintained for host specificity studies. Studies have begun on the Trinidad syrphid, *Allograpta exotica* (Say). Larvae are general feeders and will eat aphids, but oviposition studies are planned to determine adult specificity, which is usually more important in Syrphidae.

Preliminary studies on the Trinidad *T. leucaenae* reveal it to be thelyotokous (all female producing) and to attack a later nymphal stage than *P.* sp. nr. *rotundiformis*. These may prove desirable qualities with respect to *T. leucaenae*'s potential as a biocontrol agent.

Table 3. Other predatory taxa associated with *Heteropsylla cubana* on *Leucaena leucocephala*.

Species	Country
Syrphidae	
Allograpta exotica	Trinidad
Gen. and sp. indet.	Mexico
Chrysopidae	
Ceraeochrysa sp.	Trinidad
Gen. and sp. indet.	Mexico
Miridae	
Neurocolpus sp.	Mexico
Rhinacloa forticornis	Mexico
Gen. and sp. indet.	Trinidad
Anthocoridae	
Orius ?tristicolor	Mexico
Phymatidae	
Phymata parva	Mexico
Reduviidae	
Sinea undulata	Mexico
Araneidae	
Araneus theisi	Mexico
Thomisidae	
Misumenops sp.	Mexico
Salticidae	
Gen. and sp. indet.	Mexico

Research on the biology of these and other natural enemies is being undertaken by CIBC staff and Mr. N.G. Patil of the Mahatma Phule Agricultural University, India, who is collaborating with the research program as part of a study period at the University of West Indies.

A program of *H. cubana* population studies has been initiated to determine the factors affecting its abundance in tropical America, for comparison with studies presently underway by participating countries in the Regional Research Program for Leucaena Psyllid Control in Asia and the Pacific.

These studies are made on leucaena plantings at the University of West Indies Field Station. Observations on psyllid populations commenced there in June 1987, but intensive ecological studies began only in the summer of 1988 during the present program.

This program consists of intensive weekly sampling and censuses of marked plants. The research methods have been designed to complement those used in Asia and the Pacific. For census shoots, the appearance and growth of every leaf is recorded along with the numbers

Table 4. Parasitoids associated with *Heteropsylla cubana* on *Leucaena leucocephala*.

Species	Countries	Comments
Encyrtidae		
Psyllaephagus sp. nov.	Trinidad, Mexico, Cuba, Haiti, Jamaica,Puerto Rico(1), Barbados	P
Sectiliclava sp. nov.	Mexico	P
Eulophidae		
Tamarixia leucaenae(2)	Trinidad, Mexico, Barbados Florida(1), Puerto Rico(1)	P
Tamarixia sp. indet.	Cuba, Jamaica, Haiti, Costa Rica	P
Tamarixia sp. A	Puerto Rico(1), Mexico	H?
Signiphoridae		
Signiphora ?unifasciata	Mexico, Puerto Rico(1)	H

Comment codes: P-primary parasitoid, H-hyperparasitoid.

(1) Collected by Dr. F.D. Bennett of the University of Florida.

(2) *T. leucaenae* also associated with *H. reducta* on *Prosopis juliflora* (Jam) and *H. huasachae* and *H. crawfordi* on *Acacia* sp.

and age structure of the psyllid population and the activities of any natural enemies. This gives a very detailed picture of seasonal variation in the abundance of the psyllid and its relationship to plant phenology, environmental parameters and natural enemies.

L. leucocephala, H. cubana and its natural enemies all show extensive seasonality. As there is less than a year's data, a full analysis would be premature at this time. Nonetheless, certain features are already apparent. The study plot shows strong seasonality and synchrony in the reproductive behavior of the plants. At the time of flowering and fruiting, the numbers of new flushing leaves and growing shoots is depressed and this appears to reduce the number of psyllid at these times. The psyllid depends on young leaves for its development here as at other sites. Rainfall and other environmental factors have not had any marked direct effect on psyllid populations. Three species of ants, the syrphid, *A. exotica* and the parasitoid, *Tamarixia*, are all significant causes of mortality at certain times of the year. At the

highest population levels of *H. cubana*, an *Entomophthora* fungus is also a significant cause of mortality.

Associated studies

In the UK, a project was undertaken with the Overseas Development and Natural Resources Institute (ODNRI) to study the means of dispersal of *H. cubana* across the Pacific and Asia, as a basis for predicting the rate of future spread and the time of its probable arrival in Africa. Meteorological calculations and methods developed to study the dispersal of rice brown planthopper were used to calculate the likely distance of aerial dispersal over water by *H. cubana*. This revealed that its dispersal to Hawaii and from Hawaii west to Guam and south to Samoa was almost certainly aircraft assisted, but that the dispersal through Southeast Asia, Australia and into Sri Lanka and India was probably on monsoon winds. Dispersal of *H. cubana* to Africa in this manner will be difficult.

In Africa, CIBC and the International Center for Research on Agroforestry (ICRAF) are organizing an "early warning system" for the appearance of the psyllid on that continent. This would involve cooperation of national programs, the International Livestock Center for Africa (ILCA) and the International Institute of Tropical Agriculture (IITA).

In July, CABI held a joint workshop with ICRAF on the pest problems associated with multipurpose tree crops in agroforestry, from which priorities for future research have been identified to reduce the risk of future problems like leucaena psyllid.

In 1989-1990, CABI Development Services hope to begin an assessment of the economic impact of leucaena psyllid on leucaena production and use in Asia.

Future work plan

In Phase 1 of the CIBC program, three priorities remain for the work period before its termination in August 1989. First, exploration will continue, along with associated studies to establish more clearly the identity and distribution of the psyllid associated with *L. leucocephala* and their natural enemies. Second, biological studies on key natural enemies, particularly species of *Psyllaephagus*, *Tamarixia* and important predators, will be undertaken to determine their potential value and to develop methods for their production and assessment. Third, host specificity studies will be undertaken to determine the general safety of introducing exotic natural enemies of *H. cubana* in Asia, including species already introduced (i.e. *C. coeruleus*, *O. abdominalis*, *P.* sp. nr. *rotundiformis*) and with particular reference to the potential conflict of interest with the biological control of *M. invisa* and the conservation of rare vertebrates which specialize on psyllids (e.g. the Australasian bell miner). It is not expected that all of these studies will be completed in Phase 1.

The ultimate aim of these studies is the introduction of safe and effective natural enemies to depress and regulate populations of *H. cubana* and to reduce the chance of its westward spread. It is premature at this point to suggest which new agents may be prioritized for introduction, but of those available, *Tamarixia* spp., if safe, are of particular interest.

Before any agents are introduced into Asia, the governments and quarantine authorities of Asian countries must be aware of any potential risks or conflicts of interest with such introduction (e.g. with weed control programs). In other words, a policy of "prior informed consent (PIC)" is recommended in the movement of natural enemies from tropical America to the Pacific and Asia, or between countries in this region.

The issue of quarantine is of particular importance. The Association of Southeast Asian Nations (ASEAN) Ministerial Understanding on Plant Quarantine Ring (October 1982) stipulates that the quarantine services of these countries will cooperate in procedures for the introduction of plant materials into ASEAN countries, such that quarantine authorities of one country will not allow introductions without consultation with other ASEAN countries. Specific recommendations are made by some ASEAN countries (i.e. Malaysia and Indonesia) regarding introduction of plant material from tropical America because of the particular risk of the introduction of damaging pests, including leaf blight of rubber. These recommendations include "third country quarantine" in a country (preferably temperate) between tropical America and Asia. CIBC presently operates such a third country quarantine center in UK, officially recognized by the Inter-African Phytosanitary Commission and other national and regional quarantine bodies.

The discovery during the present exploratory program of a common and potentially serious plant disease of *L. leucocephala* in tropical America, whose spores could survive on plant

or insect material transmitted directly to Pacific or Asian countries, makes this kind of quarantine particularly important. Furthermore, the likely existence of different biotypes of *H. cubana* on different *Leucaena* spp., as well as other *Heteropsylla* spp. on multipurpose tree legumes, makes essential the prevention of shipments of any live psyllid material out of tropical America, including "presumably parasitized" individuals. It is noteworthy that another exotic neotropical psyllid, *H. huasachae* Caldwell, has recently reached the Mariana Islands, spreading westward from Hawaii in the same manner as *H. cubana*. Furthermore, CIE scientists have now documented the recent rapid spread across the Pacific and into Southeast Asia of an exotic lepidopteran pest of *Leucaena* spp. and other tree legumes from tropical America, *Semiothisa abydata*.

Thus, third country quarantine and very careful screening of control agents is recommended to satisfy standard quarantine practices and regional agreements relevant to the introduction of new plant materials into the Pacific and Asia. This is in addition, of course, to the routine procedures of removing diseases and hyperparasites.

STATUS OF NATURAL ENEMIES OF *HETEROPSYLLA CUBANA* CRAWFORD (HOMOPTERA: PSYLLIDAE) IN HAWAII

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Abstract

Curinus coeruleus Mulsant (Coleoptera: Coccinellidae), a long established but previously rare and difficult to find species, has become the dominant predator of *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) on all major islands of Hawaii. *Psyllaephagus* sp. nr. *rotundiformis* (Howard) (Hymenoptera: Encyrtidae) was purposely introduced from the West Indies and was released statewide in June 1987 to aid in the biological control of *H. cubana*. By June 1988, it became widely established throughout the State of Hawaii. *C. coeruleus* and *P.* sp. nr. *rotundiformis* are expected to significantly reduce damage by *H. cubana* to terminal growth of *Leucaena leucocephala* (Lam.) de Wit on all islands.

Introduction

The leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), was discovered infesting *Leucaena leucocephala* (Lam.) de Wit in April 1984 on the island of Oahu. Within two months, *H. cubana* was found on *L. leucocephala* on all six of the major Hawaiian islands (Nakahara and Lai 1984). The population increased rapidly throughout the state and heavy infestations (1,500 to 3,000 nymphs and adults per 15 cm terminal growth) occurred on *L. leucocephala* during the remainder of 1984 and early 1985. *H. cubana* caused defoliation of entire *L. leucocephala* plants in many areas by repeatedly feeding on young terminal leaves and, in some cases, caused the death of plants

In Hawaii, *L. leucocephala* is considered to be a weed by some people and a desirable plant by others. It is common along roadsides and forms dense thickets in vacant lowlands and lower mountain slopes (Neal 1965). It occurs from sea level to 760 m elevation.

L. leucocephala has been credited with reducing soil erosion and retarding fires by competing with fire-prone grasses in the drier areas of the islands (Nakahara and Funasaki 1986, C.W. Smith, pers. comm.).

Ranchers utilize *L. leucocephala* for cattle forage on all islands but mostly on the islands of Kauai, Oahu, and Hawaii. There are an estimated 22,000 ha of *L. leucocephala* pastures (Nakahara and Lai 1984) primarily in dry lowland areas on the leeward side of the islands.

Beekeepers on the Kona Coast of the island of Hawaii depend on *L. leucocephala* flowers as the main source of pollen for the production of queen honey bees (G. Rouse, pers. comm.).

The Agricultural Experiment Stations of the University of Hawaii have large plantings of *L. leucocephala* and other species and crosses of *Leucaena* on Oahu and other islands for research purposes (D. Withington, pers. comm.).

L. leucocephala is an undesirable plant in some areas, such as in sugarcane lands, where it is considered to be the most difficult to control of the dicotyledonous plants infesting sugarcane fields. The sugar industry's annual loss due to *L. leucocephala* infestations is approximately $878,000 (Osgood 1985).

The Hawaii Department of Agriculture (HDOA) weighed the advantages and disadvantages of *L. leucocephala* and reached a decision to pursue a classical biological control program for *H. cubana*. The decision was made primarily because of the economic impact on the cattle industry, which depends on *L. leucocephala* pastures for cattle forage. The HDOA contacted its exploratory entomologist, who was on assignment in Trinidad, West Indies in 1984 and 1985, to pursue investigations on natural enemies of *H. cubana* in that area.

This paper reports on the predators of *H. cubana* in the State of Hawaii and on the purposeful introduction of additional natural

enemies to aid in the biological control of *H. cubana.*

Predators of *H. cubana* in Hawaii

Field investigations were initiated in 1984 to evaluate the effectiveness of locally established natural enemies that had begun to prey on *H. cubana*. Early observations of *H. cubana* outbreaks indicated predation by a wide variety of arthropods (Table 1).

Other possible predators of *H. cubana*, such as: *Allograpta obliqua* (Say) (Syrphidae); *Azya orbigera* Mulsant, *Coelophora inaequalis* (F.), *Coccinella septempunctata brucki* Mulsant and *Hippodamia convergens* (Guerin) (Coccinellidae); also have been found in association with *H. cubana* infestations but their significance as natural enemies of *H. cubana* has been determined to be of minor importance.

Despite the presence of the predators listed in Table 1, extremely high *H. cubana* populations, combined with an unusually dry year, resulted in severe damage to *L. leucocephala* on all major islands. From March 1985, however, the predator complex on *L. leucocephala* changed considerably. *H. cubana* infestations substantially declined as populations of two species of coccinellids, primarily *Curinus coeruleus* Mulsant and to a lesser degree *Olla abdominalis* (Say), increased significantly. *C. coeruleus* has subsequently become the dominant predator of *H. cubana* on all islands and is commonly observed on *L. leucocephala*

Table 1. Predators of *Heteropsylla cubana* in Hawaii.

COLEOPTERA	
Coccinellidae	Coelophora pupillata (Swartz)
	Curinus coeruleus Mulsant
	Olla abdominalis (Say)
EMIPTERA	
Anthocoridae	*Paratriphleps laevisculus* Champion
Miridae	*Rhinacloa forticornis* Reuter
Reduviidae	*Zelus renardii* Kolenati*
NEUROPTERA	
Chrysopidae	*Chrysopa comanche* Banks
ARACHNIDA	Various species of spiders

* *Zelus renardii* Kolenati is commonly known as the coccinellid predator. It also preys on predatory coccinellids. - Editors

plants (Figure 1).

C. coeruleus was purposely introduced into the State of Hawaii from Mexico in 1922 for the biological control of the coconut mealybug, *Nipaecoccus nipae* Maskell. Subsequent to its introduction, *C. coeruleus* was rare and difficult to find. In the past, only a few adults of *C. coeruleus* were reported occasionally in association with *N. nipae, Chrysomphalus aonidum* (L.) (Diaspididae), *Aphis nerii* Boyer de Fonscolombe (Aphididae) and *Aleurodicus dispersus* Russell (Aleyrodidae) (Funasaki *et al.* 1988). However, after the arrival of *H. cubana* in 1984, *C. coeruleus* became the most abundant of all species of coccinellids in the State of Hawaii and this status has persisted to the present time. This strongly indicates that the primary or preferred prey finally became available to *C. coeruleus*.

C. coeruleus was able to reduce high populations of *H. cubana*, but it was not able to disperse fast enough into areas of rapid *H. cubana* population increase to prevent early damage to *L. leucocephala*. *H. cubana* has a high biotic potential and can increase to large numbers rapidly when situations become favorable, such as when *L. leucocephala* produces new growth after rains following a dry period. Laboratory studies indicated that the life cycle of *H. cubana* is about 10.4 days (Takara *et al.* in press). Its short life cycle and a female's potential of depositing a total of about 395 eggs on new growth during the ovipositional period account for the periodic rapid population buildup of *H. cubana*. In comparison, the life cycle of *C. coeruleus* is 30.5 days (Nagamine 1986). The longer development time for *C. coeruleus* accounts for the lag in the predator's ability to increase in sufficient numbers quickly enough to prevent or retard the rapid *H. cubana* population buildup. To prevent this buildup, an effective parasite was needed to fill the void during periods of low *H. cubana* density.

Additional natural enemies from West Indies

Two species of parasitic hymenoptera and one species of coccinellid were collected in the West Indies by HDOA exploratory entomologist, Robert Burkhart, from *H. cubana* infestations on *L. leucocephala*. All were previously unrecorded on *H. cubana*. One species of parasite, *Tetrastichus* (= *Tamarixia*) *triozae* Burks (Eulophidae) and the coccinellid, *Cycloneda conjugata* Mulsant were collected from *Leucaena* variety test plots on Trinidad. The other parasite, *Psyllaephagus* sp. nr. *rotundiformis* (Howard) (Encyrtidae), was collected from *L. leucocephala* on Tobago.

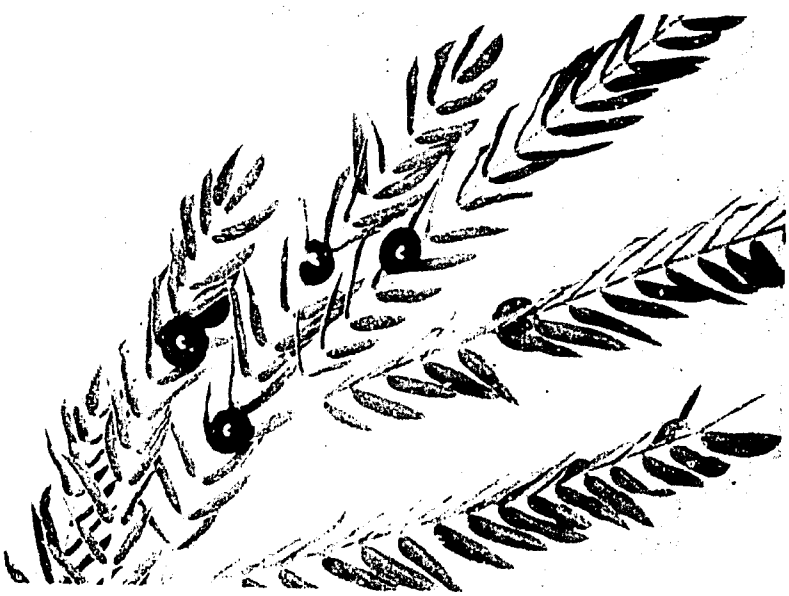

Figure 1. Adults of *Curinus coeruleus* on *Leucaena leucocephala* foliage. (Photo by W. Nagamine).

Beginning in September 1985, shipments of all three species were made to the HDOA Insect Quarantine Laboratory in Honolulu, Oahu for screening and host-specificity studies.

Attempts to propagate *T. triozae* in the quarantine facility were unsuccessful and the colony eventually died out. Primarily a North American species, *T. triozae* has a wide host range and is known to parasitize 12 species of psyllids in seven genera (Burks 1943, Jensen 1957).

Propagation of the other two species, *C. conjugata* and *P.* sp. nr. *rotundiformis*, was more successful and host range studies were initiated when sufficient numbers of each species became available for testing. *C. conjugata* has previously been recorded from *Psylla* sp. on leguminous trees in Brazil and is also found in Mexico, Central America and eastern South America to Argentina (Machado 1982, N.J. Vandenberg, pers. comm.). The colony of *C. conjugata* was destroyed in the quarantine facility in October 1986 because, in host range tests, it readily preyed on several species of endemic Hawaiian psyllids.

P. sp. nr. *rotundiformis* was successfully reared on *H. cubana* in the quarantine facility and host range studies were conducted until December 1986. The studies indicated that *P.* sp. nr. *rotundiformis* would restrict its host range to psyllids in the genus *Heteropsylla* (Murai 1986). It successfully developed on *H. cubana* and two other species of *Heteropsylla* which occur in the State of Hawaii (*H. huasachae* Caldwell and *H. fusca* Crawford). However, it did not parasitize four native Hawaiian psyllid species (*Trioza ohiacola* Crawford, *Kuwayama minuta* Crawford, *Hevaheva* sp., and *Megatrioza* sp.) and two other non-native psyllid species (*Leptynoptera sulfurae* Crawford and *Psylla uncatoides* (Ferris and Klyver). Except for the gall-forming *T. ohiacola*, all other test species were free-living forms, similar to *H. cubana*.

The Board of Agriculture's Advisory Subcommittee on Entomology and Advisory Committee on Plants and Animals reviewed the host specificity studies and recommended approval to release *P.* sp. nr. *rotundiformis* in the State of Hawaii. Permission to release the parasite from the HDOA Insect Quarantine Laboratory for mass propagation was granted by the Board on April 15, 1987. In April 1988, the parasite was introduced from Hawaii to Thailand through the National Biological Control Research Center (NBCRC).

P. sp. nr. *rotundiformis* is an internal, solitary parasite. Females oviposit in the first and second instar nymphs of *H. cubana* (Figure 2). A parasitized nymph continues to feed and develop until it reaches its fifth instar, when it becomes affixed to older foliage, mummifies, and turns brown (Figure 3). This mummified stage lasts for eight to nine days. The adult parasite emerges from the mummified nymph by cutting a circular hole in the dorsum of the host's abdomen. The total development time for the parasite is 15-17 days. The life cycle of *P.* sp. nr. *rotundiformis* was determined while developing rearing methods for the host specificity studies (Murai 1986).

Field releases and establishment of *Psyllaephagus* sp. nr. *rotundiformis*

In April 1987, mass rearing of *P.* sp. nr. *rotundiformis* was initiated according to techniques developed by Nagamine and Murai (1988).

Mass production of the parasite was conducted in the Honolulu insectary on Oahu and the Hilo insectary on the island of Hawaii.

Weekly inoculative releases of *P.* sp. nr. *rotundiformis* adults began on June 3, 1987 and continued to June 1988. Liberations were initially concentrated in *L. leucocephala* pastures on the islands of Hawaii, Kauai and Oahu. Subsequent releases were made at other areas on these islands and on the islands of Maui, Lanai and Molokai. A total of 31,000 parasite adults was disseminated throughout the State. The establishment of *P.* sp. nr. *rotundiformis* was apparent in February 1988, when numerous mummified *H. cubana* nymphs appeared on Oahu at several release sites, and also in areas where no releases were made.

Subsequent surveys on other islands revealed the presence of mummified *H. cubana* nymphs in many *L. leucocephala* localities. By June 1988, mummified *H. cubana* nymphs were common in all *L. leucocephala* sites from sea level to 760 m elevation. Mummified *H. cubana* nymphs also were present in areas with trace levels of *H. cubana*. With its establishment on all islands, propagation of *P.* sp. nr. *rotundiformis* was terminated at the Honolulu insectary. However, the Hilo insectary continued to propagate the parasite for periodic releases in *L. leucocephala* pastures on the island of Hawaii.

Recent discoveries, which hopefully will not be an impediment to the effectiveness of *P.* sp. nr. *rotundiformis*, are the emergences of three immigrant species of hyperparasites, *Pachyneuron siphonophorae* (Ashmead)

Figure 2. Female *Psyllaephagus* sp. nr. *rotundiformis* parasitizing Heteropsylla cubana nymphs. (Photo by W. Nagamine).

Figure 3. Mummified *Heteropsylla cubana* nymphs (arrows). (Photo by W. Nagamine).

(Hymenoptera: Pteromalidae); *Syrphophagus* (=*Aphidencyrtus*) *aphidivorus* (Mayr) and *Syrphophagus* sp. (Hymenoptera: Encyrtidae); from mummified *H. cubana* nymphs. Adults of *P. siphonophorae* emerged from *H. cubana* mummies collected on Oahu. It has been present in the State of Hawaii since 1914 and previously attacked only aphid parasites in the family Aphidiidae (formerly a subfamily of Braconidae). *S. aphidivorus* adults emerged

from *H. cubana* mummies collected from several areas on the islands of Oahu, Hawaii and Kauai. This species was found in Hawaii in 1906 and has previously been recorded from aphid parasites in the families Aphidiidae and Aphelinidae. *Syrphophagus* sp. adults emerged from *H. cubana* mummies collected on Oahu. This hyperparasite apparently is a recent immigrant to Hawaii.

Discussion

C. coeruleus has become the dominant predator of *H. cubana* in the Hawaiian Islands. It has reduced high populations of *H. cubana* in *L. leucocephala* pastures and other localities. By doing so, it has prevented severe dieback, stunting and defoliation of *L. leucocephala* in many areas. However, because of its longer development time, *C. coeruleus* did not increase in sufficient numbers quickly enough to prevent or retard rapid *H. cubana* population buildup. *H. cubana* has a high biotic potential and can increase to large numbers rapidly when circumstances become favorable, such as when *L. leucocephala* produces new growth after rains. In order to prevent or suppress this rapid *H. cubana* buildup, a parasite was needed to fill the void during periods of low *H. cubana* density.

It appears that *P.* sp. nr. *rotundiformis* is this needed parasite. *P.* sp. nr. *rotundiformis* seems to possess the attributes of an effective natural enemy of *H. cubana*. The parasite has a narrow host range, occupies all host-inhabited sites in a short period of time, and finds its host when the host is scarce. *P.* sp. nr. *rotundiformis* is expected to complement the activity of *C. coeruleus* in the control of *H. cubana* in the State of Hawaii. However, it is not yet known to what extent hyperparasites may limit the effectiveness of *P.* sp. nr. *rotundiformis*.

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ENDEMIC NATURAL ENEMIES OF THE LEUCAENA PSYLLID IN INDONESIA

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Abstract

Several species of endemic natural enemies of the leucaena psyllid have been found in Indonesia. Some specialist predators are promising control agents, but the generalist predators are not. The most common predators are dragonflies, which captured about 114 individuals per day. Eight species of coccinellids consumed from 19 to 50 psyllid nymphs and adults per day. A web spider could consume only nine adults per day, but may trap up to 300 individuals per day. A red ant colony, *Oecophyla smaragdina*, may kill about 2,000 psyllids per day. Some species of predacious birds, including collibri, are also reported as common predator. The most effective pathogen is an entomogenous fungus which may kill 60 to 80 percent of adult psyllids during the rainy season.

Introduction

The leucaena psyllid has a high rate of reproduction, and can be classified as an r-strategist (K. Untung, pers. comm.). A female oviposits 33-129 eggs among the young folded leaves of leucaena. Eggs hatch in 3-6 days, and the five nymphal instars last eight days each. The psyllid takes about 112 days to complete its life cycle (Daryati and Mangoendihardjo 1987).

An outbreak of the leucaena psyllid, *Heteropsylla cubana* Crawford, commonly called the *lantoro* jumping plant-lice in Indonesia, was recorded in the dry season of 1986. Since then population and infestation levels have decreased intermittently due to stress by either physical or biotic environmental factors. The most important physical factor is probably rainfall (Sudjono *et al.* 1987) while the important biotic factors are natural enemies (Mangoendihardjo *et al.* 1988).

Several species of endemic natural enemies, including general predators and an unidentified fungus, were reported in Indonesia by Karsono *et al.* (1987), Mangoendihardjo (1987), Notosoedarmo *et al.* (1987) and South (1988). The preying capacity of some predator species was tested by Mangoendihardjo *et al.* (1988) and the results indicated that dragonflies and red ants were effective predators.

Materials and Methods

Studies were carried out in the laboratory and field from 1986 to 1988. Laboratory studies emphasized identification of the species and determination of predation capacity. The field studies were designed to investigate the distribution, population, predation capacity and incidence of pathogen infection.

A. Laboratory Studies

The predation capacity of the coccinellids, *Coccinella arcuata* and *Coccinella repanda*, were studied over 24 hr. Fifty nymphs and adults of the psyllid were offered to an adult coccinellid in a cage. Observations were made for ten days to determine the number of nymphs and adults consumed by the predators per day.

B. Field Studies

Observations were made in some provinces of Java, Sumatra, Bali, Sulawesi and the eastern part of the Southeast Indonesian Islands. Predation capacity of dragonflies, the red ant *Oecophylla smaragdina*, and a web spider were investigated in Yogyakarta. The number of nymphs and adult psyllids taken by the predators were counted in the morning at 6.00-9.00 hr, around noon at 11.00-13.00 hr and in the afternoon at 15.00-18.00 hr. The observations were made for three days.

Rough observations on the incidence of fungal disease among adult psyllids and the abundance of predators were made in some localities in Central Java.

Results and Discussion

The predation capacity of the coccinellids was low. In a day, *C. arcuata* could consume only 22 nymphs and 10 adults, while *C. repanda* could consume only 11 nymphs and eight adults. The beetles did not feed on the psyllid eggs. Kalshoven (1981) observed that these coccinellids are general predators of aphids whose nymphs and adults, but not eggs, are present in the field. This behavior may explain why both predators prefer nymphs and adults, not the eggs, of the psyllids.

Other coccinellids found in North Sulawesi, *Coelophora inaequalis, Chilocorus politus, Cryptogenus orbiculus, Menochilus sexmaculatus,* and *Heteroneda reticulata* consumed 50, 19, 29, 49 and 26 nymphs and adults per day respectively.

The aesnid dragonflies were more effective predators, capturing on average 106 adults in the morning, five adults at noon and three adults in the afternoon or 114 adults per day. Ninety two percent of their prey were captured in the morning.

The predatory activity of individual red ants was very difficult to determine. Therefore, the number of psyllids killed by a colony was observed. The ant colony captured on average 865 psyllid nymphs and adults in the morning, 493 at noon, and 635 in the afternoon: a total of 1,194 psyllids per day. The predation capacity at different time of the day by dragonflies, web spider and red ant is shown in Table 1.

Other predacious insects observed in Central Java were *Chrysopa* sp. and an unidentified coccinellid (yellow with rectangular lines on its forewings), but their predation capacity was very low.

The predation of the web spider was the lowest among predator species, only nine adults per day. However, 25-300 adult psyllids were caught in one web in a day. A number of web spiders were observed during the dry season of 1986, but were rare in 1987 and 1988. The reason for the rapid decline of the spider population after the outbreak of the psyllids is unknown.

Birds, especially the collibri, may be general predators. However, only two persons have verified that the collibri eat psyllids (Soetoyo and Arif Budiman, pers. comm.). The birds were shot accidentally at Assinan and Jollong Coffee Estate in Central Java and psyllids were found in the gut. Another bird "preci," *Prenia familiarise*, may be a predator, but no one has verified that it eats psyllids.

A fungus that infects adult psyllids was found in Central Java and Timor Islands. In Central Java and Yogyakarta Special Territory, the fungus infected 60 to 80 percent of the psyllid population, but it was found only in the rainy season in 1986 and 1987. The fungus has not infected the psyllid during the 1988 rainy season.

Table 1. The average number of psyllids preyed by dragonflies, red ant, and spider per day in the field.

Species of predators	Observation tims		
	6.00-9.00 hr	11.00-13.00 hr	5.00-18.00 hr
Dragonflies	106	5	3
Web spider	8	0	0
Red ants (colony)	865	493	635

Conclusion

There were eight species of coccinellids, *Coccinella arcuata* (= *Harmonia octomaculata*), *C. repanda* (= *C. transversalis*), *Coelophora inaequalis*, *Chilocorus politus*, *Cryptogenus orbiculus*, *Heteroneda reticulata*, *Menochilus (Chilomenes) sexmaculatus* and an unidentified species, with predation capacity ranging from 19 to 50 individuals per day. Dragonflies consumed 114 psyllids per day and a red ant colony consumed 1,994 individuals per day. *Chrysopa* sp. was not an effective predator. A web spider could consume nine adults per day, but 25-300 adult psyllids per day were caught in its web. An unidentified entomogenous fungus infected 60-80 percent of the adult psyllids during the rainy seasons in 1986 and 1987 in Central Java and Timor.

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NATURAL ENEMIES AND BIOLOGICAL CONTROL OF *HETEROPSYLLA CUBANA* ON *LEUCAENA LEUCOCEPHALA* IN TAIWAN

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Survey of the natural enemies of *Heteropsylla cubana* on *Leucaena leucocephala* in the eastern and southern Taiwan has been carried out since July 1988 over the wild and giant varieties of *L. leucocephala*. Six species of Coccinellidae (Coleoptera), one species of Reduviidae (Hemiptera), one species of Miridae (Hemiptera) and one species of Pteromalidae (Hymenoptera) were obtained. The entomogenous fungi *Beauveria bassiana, Metarhizium anisopliae* var. *anisopliae* and *Paecilomyces javanicus* were tested on a small scale field trial. Infected psyllids could be found ten days after fungus spray and *P. javanicus* gave a better control than the other two fungi.

Field surveys were initiated to determine the natural enemy complex associated with the leucaena psyllid in Taiwan, and to evaluate the impact of these native natural enemies on psyllid populations. Monthly surveys of the natural enemies of *Heteropsylla cubana* on *Leucaena leucocephala* in eastern and southern Taiwan have been started since July 1988 over the wild and giant varieties of *L. leucocephala*. To date, several species of Coccinellidae, Miridae, Syrphidae, Chrysopidae, Reduviidae and spiders were found associated with leucaena psyllid. The more important one were six species of Coccinellidae: *Menochilus sexmaculatus* (F.), *Coccinella septempunctata, Coccinella transversalis* F., *Synonycha grandis* Thunberg, *Micraspis discolor* (F.) and *Harmonia octomaculata* F.; one reduviid, *Euagoras plagiatus* Burm. and an undescribed species of *Helopeltis*. They were identified by Bernarr Kumashiro, Department of Agriculture, Hawaii, and C.T. Yang, Department of Entomology, National Chung-Hsin University, Taiwan. Most of these predators are known general predators and are not host-specific. W.Y. Wang is looking for some serological evidence to see which of these species are feeding on leucaena psyllids. The conventional study of feeding habits of those species will also be carried out in the laboratory. An undetermined pteromalid parasitoid has been recovered from leucaena psyllid. However, its role as a biocontrol agent of the psyllid is unknown at this stage.

Entomogenous fungi infecting psyllids were also collected in Taiwan. *Beauveria bassiana, Metarhizium anisopliae* var. *anisopliae* and *Paecilomyces javanicus* have been isolated and cultured on potato agar and cooked rice media successfully. These fungi were also subjected to small scale field trials to determine their effectiveness. The infected psyllids could be found on leucaena shoot tips ten days after the spray and *P. javanicus* gave a better control than the other two fungi. But, according to Y.S. Hwang, the last spray of *P. javanicus* in April 1988 resulted in not too many diseased psyllids until late September after a heavy rain. A large number of diseased psyllids was found on old leaves and the leucaena trees recovered. It was suspected that the heavy rain could probably revive the fungi. However, before drawing any conclusion, further study of these candidate biocontrol agents and their roles in the suppression of leucaena psyllid are needed.

PERFORMANCE OF *CURINUS COERULEUS* MULSANT AS A PREDATOR AGAINST LEUCAENA PSYLLID

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Abstract

Curinus coeruleus Mulsant (Coleoptera: Coccinellida), a predator of leucaena psyllid, was introduced from Hawaii to Indonesia in August 1986. It has been released and established in some localities. Although its dispersal was slow, the predator suppressed the psyllid population and restored the function of leucaena as a shade tree for coffee. Forty *C. coeruleus* individuals per leucaena plant, with a vigorous canopy of about 180 sprouts, reduced the psyllid population and the damage to leucaena. The predator developed well at elevations between 400 and 800 m. In addition, the predator may suppress the citrus mealybug, which attacks coffee. However, *C. coeruleus* was attacked by several species of predators, such as the chameleon, birds and the red ant.

Introduction

Heteropsylla cubana Crawford (Homoptera: Psyllidae), locally known as lamtoro jumping-lice, is incriminated as the world's most feared leucaena pest due to its destructive feeding habit. One natural enemy of the leucaena psyllid is the predator, *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae). It was introduced and became established in Hawaii in 1922 (Wardojo 1986), and was introduced from Hawaii to Indonesia in 1986.

Adults of the predator could be reared equally well on the eggs and nymphs of the leucaena psyllid, or on artificial diets consisting of pure honey and raisin (Irianti and Mangoendihardjo 1987). The mated adults were the most effective stage for release. First and second larval instars could be found in the release sites two weeks after the adults were released. (Wijayanti and Mangoendihardjo 1987). The National Team of Leucaena Psyllid Control recommended the release of 50 predators per leucaena plant (Anon. 1987).

Materials and Methods

Releases of *C. coeruleus* were carried out by staff of the Estate Crops Extension Service of Yogyakarta Special Territory and Jollong Coffee Estate, Pati, Central Java, from November 1986 to October 1988. About 131,000 individuals were released in some localities in Yogyakarta and Central Java.

The *C. coeruleus* populations were monitored mainly at the coffee estates in Central Java during the dry season of 1988. The predator population, leucaena growth and damage to leucaena by the psyllids were surveyed. At Jollong Coffee Estate, 810 out of 219,024 leucaena plants were sampled.

In addition, *C. coeruleus* was monitored on coffee to assess its role as a predator of the citrus mealybug. At Jollong Coffee Estate, 810 out of 605,236 coffee plants were sampled. To verify that *C. coeruleus* preys on mealybugs, the predator was successfully reared on citrus mealybug in the laboratory. Finally, the local natural enemies of *C. coeruleus* were also surveyed in the field.

Results and Discussion

After the predator was released in 1986, damage to leucaena by the psyllid decreased at the Jollong Coffee Estate (Table 1). The leucaena trees at the coffee estate regrew during the dry season of 1988 and insecticide applications were stopped. The predator population increased gradually and by the end of 1987, the mass rearing program was terminated because the predator was well-established in the field (Table 2).

The growth of the predator population fluctuated during the dry season (Table 2). The lowest growth increment was 4.42 percent in May 1988 when the leucaena leaves were cut to increase light intensity in the whole estate. The average population growth rate was 19.91 percent per month. There were more than 18 million predators in 400 ha at Jollong in August 1988. In this 400 ha area, 19.70 percent of the predator population was found on the coffee,

Table 1. Size of the introduced *Curinus coeruleus* population and the decreasing damage to leucaena at Jollong Coffee Estate from 1986 to 1988.

Year	No. of *C. coeruleus*			Source	Damage level of leucaena (%)
	Larvae	Adults	Total		
1986	4,273	1,710	5,983	Laboratory	100
1987	16,935	6,865	23,800	Laboratory	90
1988*	-	66,227	66,227	Mainly from nursery and coffee harvested	20

* Data until August 30, 1988

while 80.30 percent was found on the leucaena.

The level of damage to sprouts (43 percent) was low enough for leucaena to provide adequate shade to the coffee. On a plant with a vigorous canopy producing 180 sprouts, 40 individuals of *C. coeruleus* were needed to control the psyllids. This number was consistent with the recommendation of releasing 50 individuals per plant (Anon. 1987).

In addition, population of the citrus mealybugs on coffee at Jollong Coffee Estate was lower after the release of *C. coeruleus*. Laboratory studies showed that the predator could develop well on a mealybug diet. In the field, *C. coeruleus* also preyed on the green scale, *Coccus viridis*, which attacks coffee, but further investigation of this relationship is needed.

Table 2. The population of *Curinus coeruleus* on leucaena and coffee in the Coffee Estate of Jollong at the PTP XVIII in Central Java during the dry season of 1988.

Month	Average size of *C. coeruleus* pop. (indiv./plant)		Estimated population of *C. coeruleus* in the whole estate			Pop. growth estimated (%)	Sprout damage (%)
	Leucaena	Coffee	Leucaena	Coffee	Total		
Feb	20.50	1.22	4,529,003	778,306	5,307,309	-	47.89
Mar	22.86	1.95	5,080,458	1,181,513	6,261,970	15.25	44.53
Apr	40.57	3.77	7,305,651	1,648,043	8,989,693	30.34	47.38
May	35.86	2.90	7,700,582	1,704,601	9,405,183	4.42	39.45
Jun	47.32	4.02	9,778,850	2,439,244	12,218,094	23.02	41.61
Jul	49.66	4.73	10,346,315	2,854,773	13,201,088	8.05	44.61
Aug	65.56	8.02	13,494,349	4,770,047	18,264,396	38.36	36.56
Mean	40.33	3.80	8,319,315	2,196,647	10,521,105	19.90	43.14

C. coeruleus appeared in other places, such as the Coffee Estate of Assinan and Tlogo in Central Java and Samigaluh in Yogyakarta. There was an indication that the predator could not develop well in a habitat where leucaena was planted with other crops, especially in the lowlands. The predator developed well at elevations between 400 and 800 m.

A disadvantage of the predator was its low dispersal capacity. During three years, it dispersed about 5 km from the release sites. In addition, the field chameleon, birds and the red ant, *Oecophylla smaragdina*, fed on *C. coeruleus* and may reduce its populatic Further studies on the population dynamics and impact of these predators of *C. coeruleus* are needed.

Conclusion

C. coeruleus reduced damage to leucaena by the psyllid in some localities in Yogyakarta and Central Java. As a result, the leucaena plants regrew and provided adequate shade to the coffee. Forty predator individuals per leucaena plant (with a vigorous canopy of about 180 sprouts) minimized damage by the psyllid. In the laboratory, *C. coeruleus* could be reared on the citrus mealybug, which attacks coffee. *C. coeruleus* may suppress the mealybug population in the field. In the field *C. coeruleus* dispersed slowly and was attacked by the chameleon, birds and a red ant.

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SOME EXPERIENCES IN MASS BREEDING, RELEASE AND EVALUATING THE ESTABLISHMENT OF *CURINUS COERULEUS* MULSANT IN YOGYAKARTA AND CENTRAL JAVA

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Abstract

Curinus coeruleus Mulsant has been mass produced, released and evaluated since 1986. The results varied over time and in different locations in Central Java and Yogyakarta. Laboratories from eight stations in both provinces have mass-produced 350,000 adults during the last two years. Mated adults were the most suitable stage for release and the beginning of the dry season, coincided with the increase of the psyllid population, was the most favorable time for releases. After periodic releases from 1987, it was estimated that 30-40 million eggs, larvae, pupae and adults occupied the areas in the release sites and its vicinities by the beginning of 1989. When laboratory mass-production programs end, *C. coeruleus* will be field collected and released in certain locations to accelerate its dispersal and to ensure the establishment of the predator.

Introduction

Curinus coeruleus Mulsant was introduced to Indonesia to control leucaena psyllid because the pest is of exotic origin. About 8,300 adults of the predator *C. coeruleus* were imported from Hawaii in July-August 1986 to control the leucaena psyllid. Some of them and their progeny were subsequently distributed to North Sumatra, Yogyakarta, Semarang, Surabaya, Denpasar and Kupang to be mass-reared. One hundred and ninety seven adults were brought to the Laboratory of Biological Control in the Faculty of Agriculture at the Gadjah Mada University (UGM) in Yogyakarta in August 1986. These were used to set up a mass rearing program in the laboratory with some modification of existing rearing techniques. A portion of the larvae and adults produced were then delivered to the Laboratory of Estate Crops Extension Service in Yogyakarta and Jollong Coffee Estate for a mass-rearing program under the supervision of UGM entomologists (Managoendihardjo 1986).

C coeruleus was released periodically in rural areas of Yogyakarta and Central Java, and continuously in Jollong and Assinan Coffee Estate in Central Java. Official releases were made by the Vice Governor of Yogyakarta Special Territory on May 9, 1987 and by the Governor of Central Java Province on May 22, 1987. The techniques of release and evaluation were described by Mangoendihardjo (1987).

Mass breeding

Generally mass-rearing of the predator has been successful in Indonesia. Most laboratory staff under the Directorate of Plant Protection for Estate Crops and Estate Crop Enterprise used the guidelines in the booklet issued by the National Team For Lamtoro Jumping Plant Lice, while the staffs in the Jollong and Assinan Coffee Estates followed the guidance of UGM entomologists.

Modifications of equipment and techniques

The equipment and rearing techniques recommended by the National Team (Figure 1) were modified in one laboratory of the Estate Crops Extension Service in Yogyakarta. The leucaena twigs, which carry the eggs and nymphs of the psyllid, were not thrown away after replacing them with new twigs. They were kept in plastic baskets (Figure 2) and allowed to dry. The dried materials were covered with white muslin and tied with string to prevent the escape of newly hatched predator larvae. Usually the larvae were found crawling on the underside of the muslin where they could easily be collected and transferred to plastic jars. More than 200 larvae could be collected in 2-4 days.

The recommended material for predator oviposition sites was also modified. Knotted bamboo sticks were preferable to pleated plastic or notched bamboo sticks (Figure 3). The number of eggs laid in knotted bamboo sticks and notched bamboo sticks was nearly equal, but egg mortality on the knotted bamboo was

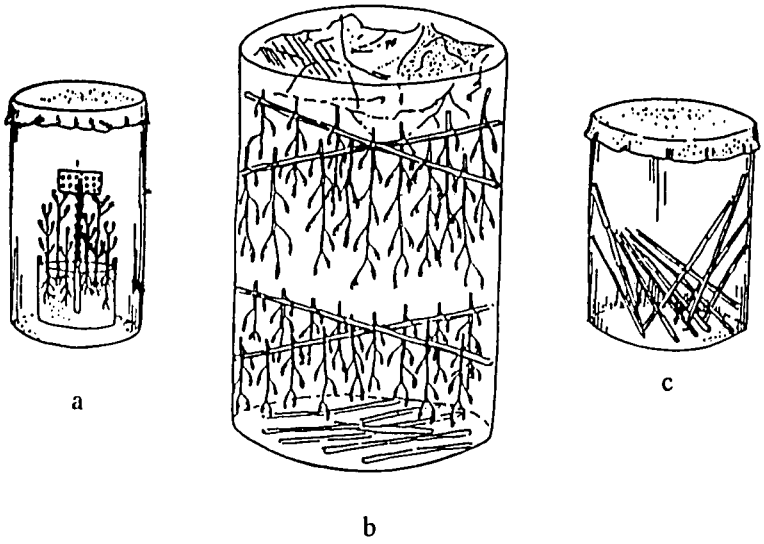

Figure 1. Mass breeding equipment for *Curinus coeruleus* Mulsant. a. Plastic cage with a notched bamboo stick as an oviposition site stuck into a plastic pot planted with leucaena seedlings and a piece of carton dropped with pure honey. b. Plastic cage or basket with 4 bamboo sticks as hangers of leucaena shoots infested by the jumping lice, and c. Bamboo sticks containing eggs of *C. coeruleus* kept in the plastic jar.

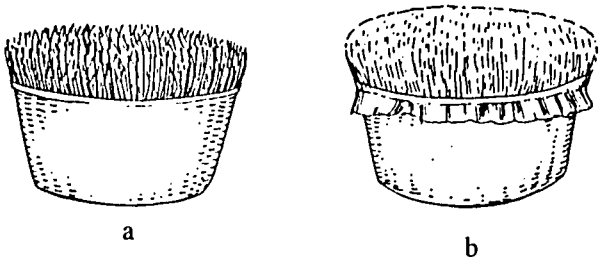

Figure 2. Baskets used for drying leucaena shoots after use as sources of psyllid eggs for rearing adults of *Curinus* a. Uncovered, b. Covered with muslin.

lower (67%) than on the notched bamboo (83%).

The plastic baskets used for rearing larvae were also modified. Plastic baskets with four screened windows on the side and one on the bottom were stored on racks made of perforated materials to reduce humidity in the rearing chambers. In the well-aerated baskets, 30-40 percent of the eggs developed into the last instar, while in the non-aerated baskets, only 10-20 percent of the larvae survived due to a fungal attack (Yuniastuti and Mahrub 1987).

Handling of eggs and larvae

The most critical factor in mass-rearing of *C. coeruleus* is the handling of eggs and young larvae. Oviposition sites should be handled carefully, especially when the knotted bamboo sticks are used. A dry environment is essential because many eggs did not hatch in damp jars. Eggs and larvae of different ages should be placed in separate jars, because the older larvae prey on younger ones and eggs (Irianti 1980). Cannibalism may occur at all larval instars and adult stages, and at all population densities. Transferring first and second instar larvae using a brush may injure the larvae; allowing the larvae to move by themselves reduced larval mortality.

Production

Production of adults varied from about 10,000 to almost 100,000 individuals per mass-rearing station, depending on staff skill, equipment, and availability of food for the predators. Development and production of the predators were much better at higher elevations (400-800 m) than at lower elevations. By the end of 1988, about 350,000 adults had been produced and released from the stations in Yogyakarta and Central Java.

Release

Optimal stage for release

Trials to determine the optimal stage to be released were conducted in Jollong Coffee Estate by Wijayanti (1988). Mated adults were more successful in becoming established than third and fourth instar larvae. After release, mated females soon laid their eggs and new progenies were rapidly found. Larvae require time to develop into pupae and adults after release and since adults emerge at different times, they may not find mates.

Environmental conditions

Certain environmental conditions retard development of *C. coeruleus*. Windy or extremely hot, dry, or humid conditions, the isolation of leucaena among other crops or natural vegetation, and frequent insecticide applications by spraying discourage reproduction, survival, and dispersal of the predator. In extreme conditions of drought and very wet weather, the psyllid population is low and establishment of the predator can fail. The predator should be released when eggs and young nymphs of the psyllid are abundant. *C. coeruleus* should not be released at night, because they are inactive and other predators, such as ants and lizards can prey on them.

Evaluation

The evaluation should be based on the recovery, reproduction and effectiveness of the predator.

Recovery

Larvae, pupae and adults of *C. coeruleus* are usually easy to find. The adults are active in seeking prey. Since adults may survive for 1-4 months, recovery of adults is not the most important indicator of predator establishment. However, recovery of adults one or two months after release is a good indicator of predator survival.

Reproduction

Recovery of larvae and pupae in the field reflects successful reproduction of *C. coeruleus*. Eggs and newly hatched larvae were difficult to observe; older instars, pupae and adults could be found more easily. The population in an area near a release site was estimated by counting larvae, pupae, and adults collected from twigs sampled at the height of the observer. This per twig count multiplied by the average total number of twigs on each stem of leucaena and the number of leucaena plants in the area provided an estimate of the total population. *C. coeruleus* should be counted between 8.00 and 10.00 hr in the morning when its vertical and horizontal distribution on the plant is observed to be nearly even.

Using this procedure, it was estimated that at Jollong Coffee Estate in Central Java, at an

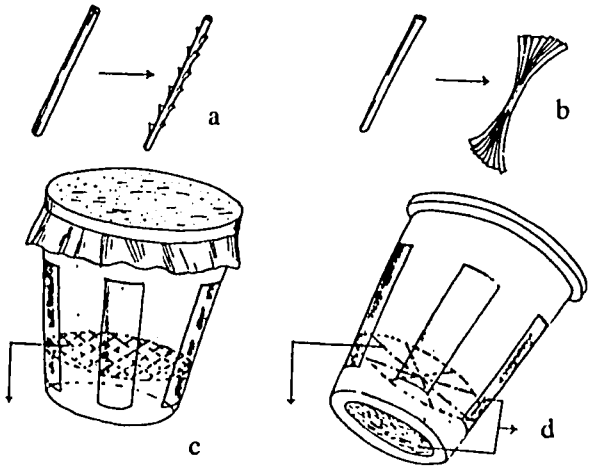

Figure 3. Bamboo sticks as oviposition sites and plastic baskets with 5 screened windows. a. Notched bamboo stick, b. Knotted bamboo stick, c. and d. Plastic baskets with different bamboo stick arrangements.

elevation of 500 to 900 m., the *C. coeruleus* population gradually increased from about 100 individuals in December 1986 to 25,000 in March 1987, 250,000 in June 1987, 600,000 in September 1987, 1.5 million in December 1987, 6.3 million in March 1988, 12.2 million in June 1988, 19.0 million in September 1988, and 25.0 million in December 1988. In Yogyakarta and Central Java, there were 30-40 million *C. coeruleus* at various life stages in January 1989 (Wagiman *et al.* 1988, Suparman, pers. comm.).

Efficacy

Finally, efficacy of the predator was evaluated by monitoring psyllid populations and recovery of leucaena.

Reduction of psyllid populations

Nymphs and adults of the psyllid were sampled periodically before and after release of the predator. The psyllids were collected by enclosing the tip of a leucaena shoot in a plastic bag, tapping the plastic bag and removing the tip carefully. Chloroform dropped on a piece of cotton killed the psyllids in the bag. The psyllids were counted using a hand counter and a piece of paper marked with a grid (Figure 4).

Suparman (pers. comm.) found no significant relationship between population density, of the psyllid and *C. coeruleus*; the correlation coefficient was only -0.2. Perhaps a higher population of the predator is needed to control the psyllid or perhaps other environmental conditions override the effect of the predator on the psyllids.

Recovery of leucaena

Although there was no significant correlation between the populations of *C. coeruleus* and psyllids per twig, *C. coeruleus* population growth was followed by the recovery of the leucaena trees. Recovery of leucaena was documented by taking photographs of damaged leucaena plants before the release of the predator and several months after the release during the dry season.

Another indicator reflecting the degree of control by *C. coeruleus* was the production of estate crops with leucaena as shade trees. Data collected during 1986 - 1988 by Mangoendihardjo *et al.* (1988) showed that at Jollong Coffee Estate, where *C. coeruleus* was released and became established in 1986, there

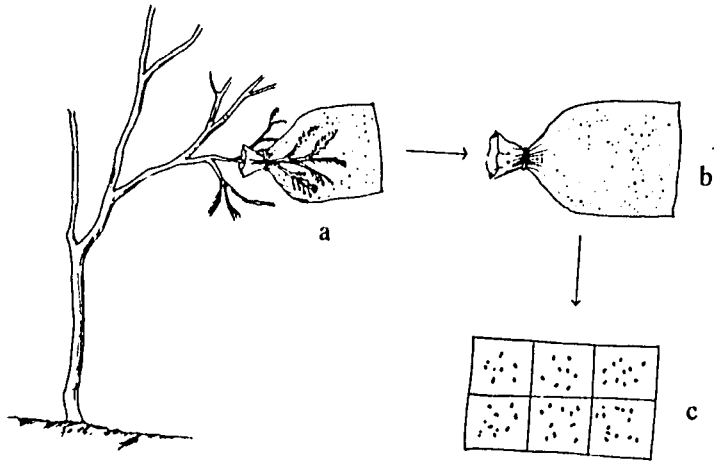

Figure 4. Plastic bag and paper used for collecting and counting the population of nymphs and adults of leucaena psyllid. a. Plastic bag used for snarling at the tip of leucaena, b. Plastic bag and a piece of cotton dropped with chloroform to kill the psyllid, and c. Paper with grid to spread the psyllids before counting.

collected during 1986 - 1988 by Mangoendihardjo *et al.* (1988) showed that at Jollong Coffee Estate, where *C. coeruleus* was released and became established in 1986, there was no reduction in coffee production. In the Public Coffee Estate near Jollong Coffee Estate, where no *C. coeruleus* was released, coffee production in 1987 and 1988 was only 50 percent of the production in 1986.

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STUDY ON ARTIFICIAL DIET FOR THE REARING OF *CURINUS COERULEUS* MULSANT

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Abstract

Four formulae of artificial diet consisting of chicken egg or chicken liver were tested on the larval instars of *Curinus coeruleus* Mulsant. The development of the third and fourth instar larvae into adults ranged from 24 to 40 percent, and the females produced fertile eggs. A dough consisting of the powder of egg white or chicken liver, sugar, yeast, pure honey, vitamin C, agar, and aquadest was a good artificial diet. However, the developmental period of the larval instars was longer and the adults that emerged were smaller for larvae fed the artificial diet than for the larvae fed with natural prey.

Introduction

Curinus coeruleus Mulsant (Coleoptera: Coccinellidae) has been easily reared on its natural prey, the eggs and young nymphs of leucaena psyllid, *Heteropsylla cubana* Crawford (Anon. 1987). While producing eggs, the adult predator could be reared on artificial diets, such as raisin and pure honey. It has also been reared on a diet of natural prey and pure honey and females produced 957 eggs (maximum 2,159 eggs), about 6 times as many eggs as the females fed eggs and nymphs without honey (Irianti 1988).

At some *C. coeruleus* mass rearing centers in Central Java and Yogyakarta Special Territory, the mass rearing failed because of the lack of natural prey during the rainy season. Preliminary studies showed that older instar larvae of *C. coeruleus* could be reared on an artificial diet consisting of raisins and a dough made of fruits and pure honey (Mangoendihardjo 1987). This result encouraged the investigators to develop artificial diets which could be produced easily and cheaply. Preliminary results of the study are presented in this paper.

Materials and Methods

Four formulae of artificial diet made of chicken eggs or chicken liver were tested. The primary ingredients, (1) egg white, (2) egg white and yolk, (3) yolk, and (4) chicken liver, were steamed, dried and ground. A dough was prepared consisting of 5 g of the protein powder, 5 g of cane sugar, 5 g of yeast, 2.5 ml of honey, one tablet of vitamin C, 0.1 g of agar, and 18 ml aquadest.

The diets were placed in a petri dish lined with paper to prevent dampness on the bottom. Five larvae of each instar were released in each petri dish. The dishes were arranged in a completely randomized design and replicated five times. The parameters were larval, prepupal and pupal period, percentage of adults emerged and egg production.

Results and Discussion

The percentage of larvae that developed into adults ranged from 0 to 40 percent (Table 1). In general, older instars developed better than younger instars. No first instar larvae fed with artificial diet developed into adults, and no second instar larvae fed with egg yolk or chicken liver developed into adults. Four to 40 percent of third and fourth instar larvae developed into adults.

Larval, prepupal and pupal periods were longer for larvae fed with artificial diets than for larvae fed with natural prey (Table 2). Adults of *C coeruleus* reared on artificial diets were smaller than adults reared on natural diets (Table 3).

Adults that were fed artificial diet produced eggs (Table 4) and some eggs hatched. Further investigation of egg viability is still needed. The highest number of eggs produced was from females fed with chicken liver or egg white and yolk. Females fed with yolk alone produced the lowest number of eggs (Table 4).

Irianti (1988) reported that the total number of eggs and nymphs of leucaena psyllid consumed by the first to third instars of *C. coeruleus* was

Table 1. The average percentage of larvae that developed into adults when fed with artificial diets.

Artificial diets	Larval instar			
	L1 (%)	L2 (%)	L3 (%)	L4 (%)
1. Egg white	0	8	20	36
2. Egg white mixed with yolk	0	16	8	32
3. Egg yolk	0	0	4	20
4. Liver	0	0	4	40

Table 2. Larval, prepupal and pupal periods of larvae fed with various artificial diets (days).

Larval diets		Stages					Total
		L1	L2	L3	L4	PP	P	
L1	Egg white	3.75	-	-	-	-	-	-
	White egg + Egg yolk	-	-	-	-	-	-	-
	Egg yolk	2.0	-	-	-	-	-	-
	Liver	2.0	-	-	-	-	-	-
	Natural prey	2.9	2.2	3.2	5.1	1.7	4.7	19.8
L2	Egg white	-	6.38	21.5	14.0	2.0	7.0	50.88
	White egg + Egg yolk	-	3.09	12.75	8.5	2.0	7.0	33.34
	Egg yolk	-	3.3	-	-	-	-	-
	Liver	-	6.3	10.0	-	-	-	-
	Natural prey	-	2.2	3.2	5.1	1.7	4.7	17.6
L3	Egg white	-	-	8.63	16.0	2.6	7.0	34.23
	White egg + Egg yolk	-	-	10.67	11.5	1.5	8.5	32.17
	Egg yolk	-	-	10.67	11.0	4.0	5.0	30.67
	Liver	-	-	10.33	10.0	1.0	7.0	28.33
	Natural prey	-	-	3.2	5.1	1.7	4.7	14.7
L4	Egg white	-	-	-	12.1	2.0	6.9	21.0
	White egg + Egg yolk	-	-	-	12.3	1.9	7.9	22.1
	Egg yolk	-	-	-	10.0	2.17	8.0	20.17
	Liver	-	-	-	13.83	2.25	7.8	23.88
	Natural prey	-	-	-	5.1	1.7	4.7	11.5

Table 3. The size of adult *Curinus coeruleus* fed with various artificial diets.

Diets	Male			Female		
	length (mm)	width (mm)	n	length (mm)	width (mm)	n
1. Egg white	4.75	4.11	8	4.8	4.06	7
2. Egg white + yolk	4.86	4.22	8	4.9	4.17	9
3. Egg yolk	4.6	4.25	2	4.4	3.9	1
4. Liver	4.58	3.98	6	4.58	3.88	5
5. Natural prey	5.09	4.46	10	5.35	4.63	10

Table 4. Egg productivity of *Curinus coeruleus* fed with various artificial diets for 70 days.

Artificial diets	Number of females	Total number of eggs produced	Number of eggs per female
1. Egg white	7	536	76
2. Egg white + yolk	9	1,112	123
3. Egg yolk	1	2	2
4. Liver	5	731	146

lower than that of fourth instar larvae and adults. When offered psyllids eggs only, the first to third instar larvae of *C. coeruleus* consumed 511 eggs per individual, while fourth instar larvae and adults consumed 536 eggs per individual. If eggs and nymphs were offered together, the number of individuals consumed by younger and older stages were 391 and 474 respectively.

When psyllid nymphs were offered alone, the number of individuals consumed by the younger and older stages were 111 and 232 respectively. This means that we can reduce the number of psyllid eggs and nymphs by more than one half by substituting artificial diet at the fourth instar larvae and adult stages. During the rainy season, when the population of the psyllid was low and sometimes quite difficult to obtain, this procedure would be more economical.

Conclusion

Artificial diets consisting of chicken egg or chicken liver powders, sugar, honey, yeast, vitamin C, agar and aquadest, can be used to rear 4th instar larvae and adults of *C. coeruleus*. About 20-40 percent of the larvae developed into adults and the females produced fertile eggs.

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UTILIZATION OF NATURAL ENEMIES FOR BIOLOGICAL CONTROL OF THE LEUCAENA PSYLLID IN THAILAND

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Abstract

Accounts are given of the attempts to utilize various natural enemies for biological control of leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), in Thailand. No endemic parasites were available but an encyrtid nymphal parasite, *Psyllaephagus* sp. nr. *rotundiformis* (Howard) (Hymenoptera: Encyrtidae), was introduced from Hawaii in October 1987 and 1988. The parasites are now established at several release sites and their efficiency is being evaluated. Several endemic predators are also being evaluated for their potentials in augmentative biological control. They included *Menochilus sexmaculatus* (F.), *Micraspis discolor* (F.), *Coelophora inaequalis var. novemmaculata* (F.), *Chilocorus circumdatus* Schonken and *Synonycha grandis* (Thunberg) among the coccinellids. Other predators were found too euryphagous to warrant further evaluation. Among the introduced predators, the coccinellid *Curinus coeruleus* Mulsant, introduced from Saipan and Hawaii in April and October 1987, was investigated in detail after its release and establishment. The role of some coccinellids reported to predate on *H. cubana* in Hawaii and Australia, earlier introduced to Thailand for other target pest species in 1970s, was not obvious. These coccinellids are *Azya orbigera* Mulsant, *Coelophora pupillata* (Swartz) and *Cryptolaemus montrouzieri* Mulsant. Among the entomopathogens, field populations of *H. cubana* were extensively infected by several fungi including *Entomophthora* sp. and *Conidiobolus coronatus* (Constantin) Butko in the Entomophthorales group, and *Fusarium* sp., *Aspergillus* sp., *Alternaria sp.* and *Cladosporium* sp. in the Deuteromycetes group. Of these fungi, *C. coronatus* and *Entomophthora* sp. were found most promising.

Introduction

As an exotic insect pest unintentionally introduced to Thailand, the leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), is considered a most suitable target for classical biological control in which introductions of natural enemies from the native range are made. Introduction of such exotic natural enemies have been further simplified when the coccinellid *Curinus coeruleus* Mulsant and *Olla abdominalis* (Say) (Coleoptera: Coccinellidae) introduced to Hawaii much earlier for other target pest species were found effectively predating on *H. cubana* after its invasion of *Leucaena leucocephala* (Lam). de Wit, in April 1984. The timely exploration by a Hawaiian exploratory entomologist in Trinidad and Tobago has resulted in the introduction of an encyrtid nymphal parasite, *Psyllaephagus* sp. nr. *rotundiformis* (Howard) (Hymenoptera: Encyrtidae) to Hawaii in September 1985, with field releases in June 1987 and field establishment in February 1988. These exotic natural enemies were introduced into Thailand through collaboration between the State of Hawaii Department of Agriculture (HDOA) and the National Biological Control Research Center (NBCRC). Other exotic natural enemies of *H. cubana* were also introduced to Hawaii but were not released. These were *Tamarixia leucaena* Boucek (= *Tetrastichus triozae* Burk) (Hymenoptera: Eulophidae) and the coccinellid *Cycloneda conjugata* Mulsant (Coleoptera: Coccinellidae). *T. leucaena* could not be further propagated while *C. conjugata* was destroyed in quarantine because it readily preyed on several species of endemic Hawaiian psyllid (Nakahara *et al.* 1987).

After the invasion of *H. cubana* in Thailand several indigenous predators and entomogenous fungi were found associated with this exotic insect pest (Napompeth 1987). Preliminary attempts to use biological control of *H. cubana* using these indigenous beneficial natural enemies, entomogenous fungi and introduced exotic natural enemies are described in Napompeth (1988), Maneeratana (1989), and Winotai (1989).

The purpose of this paper is to describe biological control efforts on *H. cubana* in Thailand. It will cover the survey and evaluation of indigenous natural enemies found associated with *H. cubana* in Thailand and their potential for augmentative biological control, the introduction of exotic natural enemies of *H. cubana* for classical biological control, and the survey and evaluation of entomogenous pathogens associated and infective on *H. cubana* populations.

Survey and Evaluation of Indigenous Natural Enemies.

In a survey and evaluation of indigenous natural enemies associated with *H. cubana* in Thailand, only predatory species were found. No parasitic species have been encountered or recovered so far. The major indigenous predators found, including spiders, are listed in Table 1.

Of these insect predators and spiders, very few exhibited obvious potential for further utilization in an augmentative program except the two coccinellids, *Memochilus sexmaculatus* (F.) and *Micraspis discolor* (F.) (Coleoptera: Coccinellidae). Others were found only sporadically.

It has been very interesting to observe distinctive associations of these predators in the field. During the initial stage of reinfestation or new seasonal occurrences when colonizing populations of *H. cubana* are still confined to a small number of leucaena plants, swarms of dragonflies in hundreds would be seen hovering over leucaena canopies. The swarms are always seen with the infested plants. This incidence has been used for field monitoring in August and September each year in a quick nationwide survey of psyllid occurrence by NBCRC researchers. When psyllid populations are low, the common red ants, *Oecophylla smaragdina* (F.) (Hymenoptera: Formicidae), is found instead. Occasionally observed are solitary praying mantids. A tiny mantid-like neuropteran mantispid is always found as a gregarious feeder numbering from a few individuals to almost a hundred at times. Due to their mimicry and relatively small size (body length of about 10 mm) they have been mistakenly identified as mantids, which are orthopterans. Both nymphs and adults of an anthocorid, *Campylomma* sp. (Hemiptera: Anthocoridae), and an assassin bug, *Scipinia horrida* (Stal) (Hemiptera: Reduviidae), have been observed, but with population densities too low to be of any significant contribution to natural control. Low population densities of other predators, such as a syrphid fly, *Allograpta* sp. (Diptera: Syrphidae), whose larvae are predatory on the leucaena psyllid; a chrysopid, *Chrysoperla* sp. (Neuroptera: Chrysopidae); an unidentified robber fly (Diptera: Asilidae); and coccinellids other than *M. sexmaculatus* and *M. discolor*, are also commonly encountered. Spider fauna consisting of *Araneus inustus* (Koch), *Neoscona theisi* (Walckenaer) (Araneae: Araneidae), and *Oxyopes javanus* Thorell (Araneae: Oxyopidae) are also observed at significant levels of abundance in association with the leucaena psyllid.

Of great interest among all the indigenous predators of leucaena psyllid encountered in Thailand is the coccinellid complex consisting of *M. sexmaculata, M. discolor, Coccinella transversalis* F. (= *Coccinella repanda* Thunberg), *Coelophora inaequalis* var. *novemmaculata* (F.), *Chilocorus circumdatus* Schonken, *Harmonia* sp., *Oenopia zausetti* Mulsant, and *Synonycha grandis* (Thunberg). They have been observed frequently in association with leucaena psyllid in the field. Their role as individual species or as a species complex regulating the psyllid population is worth a thorough investigation and evaluation. This is also the only predator group likely to have some potential in augmentative program for biological control of leucaena psyllid using indigenous natural enemies in Thailand. At this time an extensive field survey of these coccinellids indicated that only adults are associated with psyllid populations while their larval stages are rarely observed. Further investigation is needed to confirm such observation. If positive, further efforts to use these indigenous coccinellids may have to be reduced, and emphasis given to the exotic coccinellids with known efficiency in the regulation of psyllid populations.

Introduction of Exotic Natural Enemies for Classical Biological Control.

Two coccinellids, *Olla abdominalis* (Say) and *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae), were found to be dominant predators of the leucaena psyllid in Hawaii (Nakahara *et al.* 1987). They were introduced from Mexico in 1908 and 1922 for the scale insect, *Saissetia oleae* (Olivier) (Homoptera: Coccidae) and the coconut mealy bug, *Nipaecoccus nipae* (Maskell) (Homoptera: Pseudococidae) respectively (Funasaki *et al.* 1988). *C. coeruleus* has been introduced for biological control of *H. cubana* in several Pacific Islands and countries (NFTA 1987). More recent were introductions of a predatory coccinellid *Cycloneda conjugata* Mulsant

Table 1. Indigenous predators found associated with *Heteropsylla cubana* Crawford in Thailand.

Insect Predators:	
Odonata:	Several species of dragonflies*
Orthoptera:	
Mantidae:	Unidentified mantid
Hemiptera:	
Anthocoridae:	*Campylomma* sp.
	Orius sp.
Nabidae:	*Nabis* sp.
Lygaeidae:	*Geocoris* sp.
Reduviidae:	*Scipinia horrida* (Stal)
Diptera:	
Asilidae:	Unidentified robber fly
Syrphidae:	*Allograpta* sp.
Coleoptera:	
Coccinellidae:	*Chilocorus circumdatus* Schonherr
	Coccinella transversalis F.
	(= *Coccinella repanda* Thunberg)
	Coelophora inaequalis var. *novemmaculata* (F.)
	Harmonia sp.
	Menochilus sexmaculatus (F.)**
	Micraspis discolor (F.)**
	Oenopia zausetti Mulsant
	Synonycha grandis (Thunberg)
Endomychidae:	Unidentified endomychid
Neuroptera:	
Chrysopidae:	*Chrysoperla* sp.
Mantispidae:	Unidentified mantispid
Hymenoptera:	
Formicidae:	*Oecophylla smaragdina* (F.)*
Vespidae:	*Polistes* sp.
Spiders:	
Araneae:	
Araneidae:	*Araneus inustus* (Koch)
	Neoscona theisi (Walckenaer)
Oxyopidae:	*Oxyopes javanus* Thorell

*Used for monitoring of early infestation by leucaena psyllid.
**Of potential for augmentative use.
Adapted from Napompeth (1987, 1988)

(Coleoptera: Coccinellidae), and two parasitic hymenopterous insects *Tetrastichus trichilae* Burks (= *Tamarixia leucaenae* Boucek) (Hymenoptera: Eulophidae) and *Psyllaephagus* sp. nr. *rotundiformis* (Howard) (Hymenoptera: Encyrtidae) from the Caribbean area (Nakahara 1987). Of these exotic natural enemies only *P.* sp. nr. *rotundiformis* has been released and utilized in Hawaii.

The first shipment of *C. coeruleus* from Saipan was received in April 1987 (Napompeth 1988) with two additional shipments from Hawaii during 1987-1988. The coccinellid predators were mass-reared at NBCRC headquarters post quarantine laboratory for field releases in psyllid-infested areas all over the country as well as for distribution to other countries interested in using them. The first field release of *C. coeruleus* was made in September 1987 and are still continuing. Cultures of *C. coeruleus* ranging from 100 eggs, 10 larvae, 20 adults upwards to a few thousand were made available to researchers and farmers. Among the recipients of *C. coeruleus* cultures in Thailand other than NBCRC Field Facilities at Kampaengsaen, Nakhon Pathom and the NBCRC Regional Substation in Chiang Mai, were the Department of Agriculture, Royal Forest Department, Thailand Institute of Scientific and Technological Research (TISTR), Chulalongkorn University in Bangkok, Plant Protection Unit under the Department of Agricultural Extension at Phitsanuloke; Northeastern Agricultural Office, Khon Kaen, the Ecological Recovery Project in Chiang Mai, and leucaena farmers in Phetchabun as a few examples. Two shipments of *C. coeruleus* were made to Vietnam, in 1987 to the Plant Protection Research Institute in Hanoi in the north and in 1988 to Nha Ho Cotton Research Center in Phan Rang in the South. Consignments were also sent to Burma in January 1988 and to India in October 1988.

C. coeruleus has become firmly established in several areas in Thailand. It is not known how well they are doing in Burma, India and Vietnam. With adequate effort on a regional basis, it is speculated that *C. coeruleus* will soon become widely established in continental Southeast Asia and the Indian Subcontinent.

The introduction of *P.* sp. nr. *rotundiformis* from Hawaii commenced in October 1987. A total of five consignments totalling 2,124 adults of *P.* sp. nr. *rotundiformis* was received from Hawaii Department of Agriculture, Honolulu. The first field release was made in Chiang Mai in April 1988 followed by subsequent releases concentrated in the northern highland areas of Chiang Mai and the lower northeastern plateau areas of Muak Lek, Saraburi, Pak Chong and Kao Yai, Nakhon Ratchasima. The encyrtid parasite has become established in the release sites and has spread satisfactorily. When *P.* sp. nr. *rotundiformis* has become firmly established in Thailand, NBCRC will make cultures available for introductions to other countries participating in the regional research program as well as other countries interested in receiving the cultures.

A number of other coccinellids are reported to predate on *H. cubana* in Hawaii (Nakahara *et al.* 1987) and Australia (Bray and Sands 1987), including *Azya orbigera* Mulsant, *Coelophora pupillata* (Swartz) and *Cryptolaemus montrozieri* Mulsant (Coleoptera: Coccinellidae). These coccinellids were earlier introduced to Thailand in the 1970s (Napompeth 1982, Napompeth and Charernsom 1978) but were not observed predating on *H. cubana* probably due to their limited, localized and sporadic distribution.

Survey and Evaluation of Entomogenous Pathogens of Leucaena Psyllid.

A number of entomogenous pathogens, especially fungi in the Entomophthorales and Deuteromycetes groups, were reported from other countries such as Taiwan by Hsieh *et al.* (1987) and the Philippines by DeGuzman (1987) and Escalada (1987). A survey of entomogenous pathogens associated with the leucaena psyllid by NBCRC in collaboration with Xenova Ltd. during 1987-1988 yielded the entomogenous fungi given in Table 2. Of these entomopathogens most of them may be either secondary or saprophytic but not primary causal agents. Although confined to some localities, the most dominant fungi found attacking leucaena psyllid nymphs and adults were *Entomophthora* sp. and *Conidiobolus coronatus* (Constantin) Butko.

Present investigations on these microbial control agents are confined to recording the extent of epidemics and areas of occurrence. Being faced with the known difficulties of further development of these agents, attempts to use them were confined to disseminating infected and diseased psyllids to other areas where the disease incidence is low or nonexistent.

Plans are also being made to test the commercially available formulation of *Hirsutella thomsonii* Fischer, especially Mylar, and other available fungi isolates such as those of

Table 2. Entomogenous fungi found associated with *Heteropsylla cubana* Crawford in Thailand.

Entomophthorales:	
Entomophthoraceae:	*Conidiobolus coronatus* (Constantin) Butko
	Entomophthora sp.
Moniliales:	
Dermatiaceae:	*Alternaria* sp.
	Aspergillus sp.
	Cladosporium sp.
	Fusarium sp.
	Hirsutella thomsonii Fischer

Beauvaria bassiana (Balsamo) Vuillemin for microbial control of leucaena psyllid.

Conclusion

The utilization of natural enemies for biological control of leucaena psyllid in Thailand is only in the beginning stage. The use of indigenous natural enemies is not very promising due to their non-specificity and tendency to be euryphagous and general feeders. However, when taken as a whole these indigenous natural enemies could be considered as a regulating factor of leucaena psyllid populations. Coccinellids introduced from Hawaii to Thailand earlier and reported to predate on leucaena psyllid in Hawaii and Australia do not seem to contribute much to compliment indigenous natural enemies. *Curinus coeruleus* Mulsant (Coleoptera: Coccinellidae) and *Psyllaephagus* sp. nr. *rotundiformis* (Howard) (Hymenoptera: Encyrtidae) are very promising and show encouraging contributions although only recently introduced from Hawaii. It is anticipated that the introduced coccinellids and encyrtid will contribute greatly to the regulation of psyllid populations in Thailand complimented by a complex of indigenous natural enemies and entomogenous fungi especially *Conidiobolus coronatus* (Constantin) Butko and *Entomophthora* sp. The utilization of these biological control agents should be considered as one of the main components of an integrated pest management program to be developed for the leucaena psyllid in Thailand, if not elsewhere in the infested areas.

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OTHER MANAGEMENT STRATEGIES

TRANSFER OF TECHNOLOGY IN THE UTILIZATION OF *CURINUS COERULEUS* Mulsant

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Indonesia

Abstract

Training courses were conducted to transfer the technology of mass production and release of *Curinus coeruleus* to control the leucaena psyllid. After the training, each trainee was given 150 eggs, 110 larvae and 50 adults of the predator to carry with them to their respective stations. Through these trained personnel and scientists, a total of 257 training courses were conducted in the provinces. Within one year, 4,036 persons were trained. These trainees, mass produced *C. coeruleus* in the provinces. Eighty eight laboratories for mass production have been developed for small land holder plantations. Out of these laboratories, at least 355,000 predators have been produced within one year. Although the mass production is satisfactory, the adequate supply of psyllid as predator food has been the constraint. The predator has become successfully established in most plantations. However, since predator dispersal is low, the small land holder should distribute the predator to areas where it is not found.

Introduction

Leucaena leucocephala, commonly called "lamtoro" in Indonesia, is a very important multi, purpose tropical legume. In the Estate Crop Subsector, leucaena is used as a shade tree for coffee, cocoa, tea, vanilla and some other spices and medicinal crops. Leucaena is also used for animal feed, firewood, soil conservation, wind break, timber, pulp, and traditional medicine; the young leaves and small pods are used for human food and dry seeds for ornamentation.

The leucaena psyllid, *Heteropsylla cubana* Crawford, was first observed in Bogor, Indonesia in March 1986 and, subsequently, was observed in most Indonesian Provinces by June 1986. The psyllid causes defoliation, deformation, stunting and die-back of the new growth of leucaena.

This damage to leucaena greatly reduced estate crop production, especially in the dry areas of the country and during a long dry season. Field observations showed that, in the areas with heavy rainfall, damage to leucaena was lower than in the areas with low rainfall. The psyllid population increased during the dry season and decreased during the rainy season.

The Government of Indonesia has set up a national committee and three action programs: 1) a short-term program using insecticides, 2) a medium-term program using natural enemies, and 3) a long-term program using psyllid-resistant leucaena varieties.

At first, insecticides were used to reduce psyllid infestation. Later, the predator, *Curinus coeruleus*, was introduced from Hawaii. In August 1986, the first batch of 1,300 *Curinus* was consigned to Indonesia through quarantine procedures and mass reared in Bogor in three institutes: 1) Bogor Research Institute for Food Crops, 2) Bogor Research Institute for Estate Crops, and 3) Spices and Medicinal Crop Research Institute. The mass production and releases of *Curinus* on large estate crop plantations was guided by the Bogor Research Institute for Estate Crops. By September 1986, 8,300 *Curinus* individuals had been introduced.

To speed up the mass production, distribution and field release of *Curinus*, a series of training courses were held. This paper emphasizes the transfer of technology to small land holders using short training courses.

Training

In the beginning, two training courses were conducted simultaneously. One training course

in Bogor was sponsored by three Institutes: the Bogor Research Institute for Food Crops, the Bogor Research Institute for Estate Crops, and the Spices and Medicinal Crop Research Institute. The training course lasted 10 days and the trainees came from nine provinces. The second training course was conducted at the University of Gadjah Mada, Yogyakarta.

When the trainees returned to their provinces, they were each given 150 eggs in a petri dish, 100 larvae and 50 adults in a plastic container.

In their respective provinces, these trainees held 2-day courses with 15 to 45 participants per course. The educational level of the trainees ranged from a high school diploma to a university degree. They were mostly from government agencies, and a few were from private institutes. Within one year, 4,036 persons were trained.

At the provincial level, the training courses were supported by the local government, which provided training and operational facilities. This support was mobilized by the National Team, which visited the provinces and collaborated with the provincial leaders.

Radio and television programs have disseminated information on this predator, and leaflets and other materials were distributed to small land holders and crop protection staff in the provinces.

Distribution of the predator

The first generation of the predator was mass produced in the Bogor Food Crop Research Institute, the Bogor Estate Crop Research Institute and the Spices and Medicinal Crop Research Institute. A total of 240 predators were sent to the University of Gadjah Mada, 250 to the Jember Estate Crop Research Institute (East Java), 250 to the Medan Estate Crop Research Institute (North Sumatra), and 250 to the University of Cendana (East Nusa Tenggara).

The second generation of the predators was distributed to nine Provincial Estate Crop Services: Aceh, Lampung, Central Java, East Java, South Sulawesi, Bali, West Nusa Tenggara, East Nusa Tenggara, and Irian Jaya. The selection of these locations was based on the availability of laboratory facilities and the severity of the psyllid infestation.

The predator is now being mass produced in 14 provinces and in 88 smaller substations throughout the country.

Mass production and release

Researchers have developed two methods to guide the trainers.

1. Mass rearing

Curinus coeruleus adults were put into plastic jars containing some leucaena tips along with psyllid nymphs and eggs for food. A small piece of folded black plastic was added for egg laying. Eggs were removed from the black plastic fold everyday by brushing them onto wet tissue paper. After hatching, the *Curinus* larvae were transferred to a plastic box containing leucaena tips with psyllid nymphs and eggs. The leucaena tips were replaced daily with fresh ones. After pupation all leucaena tips were taken out of the plastic box. Pupae were kept in the box until the adult stage.

2. Mass production

Bamboo sticks with splits on the side were provided for egg laying. Once a day the bamboo sticks were removed from the plastic jar and placed in a large bucket or container with leucaena tips infested with psyllid nymphs and eggs. Fresh food was hung on the wooden sticks. Pupae were removed and put in a plastic box until the adult stage.

This method has been practiced in the Provincial Estate Crop Services. The predators developed well in all of the laboratories. However, due to insufficient psyllids in the field, the production of *Curinus* in the laboratories was less than expected. To overcome this, some of the predators produced in the laboratories were released. The remaining predators produced in one year (October 1986 - October 1987) totalled 355,808 individuals (Table 1).

Field Release

Two hundred second generation adults were released in an isolated area at Pasir Sarongge, Tea Research Station, West Java in October 1986. Thirty days after the release, many larvae were observed. This release was repeated in 12 locations in East Java in November 1986. The predator reproduced well in all of the plantations but its dispersal was slow.

Due to the limited number of predators relative to the psyllid, the researchers suggested a field release of 200 adults per hectare. To facilitate dispersal, the transfer of predators from one

Table 1. Number of predators produced by various provinces (October 1987 - October 1988).

Province	Number
Aceh	64,841
North Sumatra	11,480
South Sumatra	1,800*
Bengkulu	378*
Lampung	4,753*
West Java	60,840
Central Java	52,330
East Java	42,608
Yogyakarta	26,835
Bali	14,864
West Nusa Tenggara	13,857
East Nusa Tenggara	7,426
South Sulawesi	6,640
South - East Sulawesi	566*
Irian Jaya	46,590
Total	355,808

* Data from 6 months.

field to another was suggested. In areas where *Curinus* has successfully reproduced, farmers were encouraged to collect them and distribute them to other fields. This procedure has been practiced nationwide.

Acknowledgements

I would like to thank the former DECP Director, Ir. Samino, who organized the activities of the Disbun in the different provinces, which made possible the production and distribution of *Curinus coeruleus*. Thanks are also due to Ir. Siti Nuraini for collecting the data for this paper.

ECONOMIC IMPACT OF LEUCAENA PSYLLID INFESTATION ON ESTATE CROPS AND TEAK FOREST PLANTATION

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Abstract

The leucaena psyllid, *Heteropsylla cubana* Crawford, invaded Indonesia during the dry season of 1986 and defoliated almost all of the leucaena stands. Estate crop production, such as coffee, vanilla and round cardamom (*Amomum kepulaga* Sprague & Burkill, decreased about 55 percent in the following years in two regions of Central Java. Due to the heavy psyllid infestation, leucaena seed could not be collected from the teak forest in Central and East Java. Losses in both the agriculture and forestry sectors in those areas was estimated at Rp 4.5 billion, but this value should be confirmed with further studies.

Introduction

The leucaena psyllid, locally called "lamtoro" jumping plant lice and scientifically named *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) (Wardoyo and Sudarmadji 1986) was first observed in Indonesia by Dharma and Kompiang (1986). By the end of 1987, 343,329 ha out of 1,214,837 ha of leucaena were infested. Leucaena continues to be infested by the pest especially in dry areas in the eastern part of Indonesia (Perhutani 1988).

Leucaena leucocephala (Lam.) de Wit has played an important role in forestry in Java since 1907 as a component of the taungya silvicultural system for establishing teak plantations (Oemi Haniin *et al.* 1987). It has been intercropped between the rows of the teak stands because of its good survival in poor soil, deep rooting system, evergreen, sprouting capability, and relatively dense canopy (Coster 1934). Other advantages of leucaena include its use as green manure and fodder, erosion control by terrace planting, the high caloric value of the timber, and its potential as a bee forage plant in apiaries in the rural villages bordering the forest areas (Sulthoni 1986).

When the pest broke out in the dry season of 1986, there was limited data on losses for consideration in implementing chemical control. Perum Perhutani (State Forest Corporation) (1988) in Central Java documented the Rp 63,000,000, loss to the forestry sector due to the psyllid infestation. This was estimated from the failure of leucaena seed production (Anon. 1986a). In the absence of an economic analysis, chemical control was implemented by notching the stem using a machete and brushing the injury with a systemic insecticide, such as monocrotophos (Anon. 1986b).

Alternative plant species, such as *Cassia siamea* Lam., *Acacia vilosa* Willd., *Glericidia* sp., and *Tephorosia* sp., have been substituted for leucaena in intercrops. Whether they will function as well as leucaena is questionable because they were substituted without preliminary evaluation.

Since 1987, more attention has been paid to the bioecology of the leucaena psyllid and its natural enemies. Some data on economic losses due to the psyllid infestation in agriculture and forestry have also been collected. This paper documents the economic losses in coffee, vanilla and round cardamom as estate crops, where leucaena has been used as a shade tree, and in the teak forests where leucaena has been planted as a component of the taungya silvicultural system in Central and East Java.

The economic impact of the leucaena psyllid infestation was recorded at the Jollong Coffee Estate and its surroundings, the Tlogo Coffee Estate, the vanilla and round cardamom plantations in Central Java, and in the teak forest plantations in Central and East Java.

A. Estate Crops

The economic impact of the leucaena psyllid infestation was reflected in both yield losses and the cost of insecticides to control the pest.

1. Yield losses

Some data from the public and private estate indicated that the production of coffee, vanilla and round cardamom decreased from 10-93 percent. The losses due to the psyllid are based on prices at the time the commodities were harvested (Table 1).

The greatest losses to vanilla production occurred in 1986,when the price was Rp 32,500/kg; the smallest losses occurred in 1988, when the price was Rp 17,500/kg. The price of coffee and round cardamom remained stable.

In Siluwok Sawangan and Assinan/Banaran, the reduction of coffee production in 1987 and 1988 was 49.96 and 35.26 percent respectively. Intensive chemical control of the psyllid was practiced in both estates. If the budget for control of the psyllid is included and considered as loss, the total loss was about Rp 532.50 millions. In Tlogo Coffee Estate, the loss was about Rp 4.07 millions. The hectarage of the Tlogo estate was only 1/7 of the Siluwok Sawangan and Assinan/Banaran estates.

2. Cost of insecticides

Insecticides were used to control the psyllid by spraying or notching and brushing with monocrotophos and other systemic insecticides. The cost of chemical control and biological control using *Curinus coeruleus* Mulsant is compared in Table 2.

The cost of chemical control was an unwanted additional cost, which was considered as "loss" due to the psyllid infestation.

It is important to note that the total cost of implementing biological control was about 4.5 times lower than chemical control. Also, there were no harmful effects in using biological control agents.

B. Teak Forest Plantation

Perhutani has suffered from the psyllid outbreak in terms of destruction of leucaena plantations and the impossibility of maintaining the traditional taungya system to establish teak plantations. The psyllid outbreak in the forest areas of Central Java cost Rp 535,808,010 or U.S.$ 310,613 (Table 3).

The necessity of having leucaena seeds to maintain the taungya system in establishing forest plantations is illustrated by the data from East Java's Perhutani (Table 4).

Before the psyllid outbreak in 1986, about 86 percent of the annual leucaena seed consumption in East Java was produced by its own plantation. Therefore, the Perhutani of East Java lost its annual income of 80% x 1,173,821 kg x Rp 300/kg = Rp 281,717,040 (= US$163,314) due to the annual loss of leucaena seed production.

Table 1. Losses of coffee, vanilla and round cardamom in some localities in Central Java from 1986 to 1988.

Location	Estate crops	Losses in million rupiahs			
		1986	1987	1988	Total
Pati	Coffee	-	-	80.14	80.14
Magelang	Vanilla	72.15	45.73	22.40	140.28
Magelang	Round cardamom	449.93	1,264.10	1,915.89	3,629.92
Total		552.08	1,309.83	2,018.43	3,850.34

Conclusion

From the information and analysis in this paper, it can be concluded that losses due to the

Table 2. The cost of the implementation of chemical and biological control of the leucaena psyllid in Central Java.

Location	Year	Methods	
		Biological control	Chemical control
1. Assinan/Banaran	1986	Rp -	Rp 13,951,185
	1987	Rp 2,404,487	Rp 20,263,638
	1988	Rp 2,141,601	Rp 13,812,367
		Rp 4,546,088	Rp 48,027,190
2. Jollong	1986	Rp -	Rp 12,881,871
	1987	Rp 10,255,500	Rp 4,458,632
	1988	Rp -	Rp -
		Rp 10,255,500	Rp 17,340,503
3. Tlogo	1986	Rp -	Rp 2,398,590
	1987	Rp 139,100	Rp 845,910
	1988	Rp 361,820	Rp 327,035
		Rp 500,920	Rp 3,571,535
Total		Rp 15,302,508	Rp 68,939,228

Table 3. Damaged leucaena plantations in the forest areas of Central Java in 1986.

Forest district	Damaged leucaena plantation (ha)	Financial loss (Rp)
1. Balapulang	1,241.40	21,103,800
2. Blora	505.00	8,755,000
3. West Banyumas	3,528.18	59,979,060
4. East Banyumas	1,103.10	18,752,700
5. Cepu	1,942.41	46,465,170
6. Gundih	1,035.45	17,602,650
7. Kebonharjo	745.40	12,671,800
8. South Kedu	1,987.30	33,784,100
9. Kendal	1,414.01	24,038,170
10. Magelang	9.50	161,500
11. Mantingan	1,185.95	20,161,150
12. Pati	2,185.70	37,156,900
13. West Pekalongan	2,715.68	46,166,560
14. East Pekalongan	895.70	15,226,900
15. Pemalang	619.20	10,526,400
16. Purwodadi	2,137.40	36,335,800
17. Randublatung	1,504.00	25,568,000
18. Semarang	2,517.00	42,789,000
19. Surakarta	1,654.65	33,138,450
20. Telawa	1,349.80	25,424,900
Total	30,286.83 ha	Rp535,808,010 (US$ 310,613)

Source: State Forest Corporation Perhutani, Central Java, 1988.

Table 4. Leucaena seed consumption to support the establishment of forest plantation in East Java during 5 years.

Year	Establishment of forest plantation (ha)	Leucaena seed consumption for taungya system (kg)	Self support of leucaena seeds	
			(kg)	(%)
1983	12,357	745,130	447,927	61
1984	14,513	859,546	621,385	70
1985	17,829	849,633	857,043	101
1986	19,645	1,326,278	479,157	36
1987	23,509	1,711,831	150,144	9
Average	17,571	1,173,821	574,759	51

Source: Sri Murtiningsih 1987.

leucaena psyllid outbreak in some localities in Central and East Java, especially in coffee, vanilla and round cardamom where leucaena is used as a shade tree and in teak forest plantations during 1986 - 1988, was about Rp 4.5 billion equal to about U.S. $ 2.8 million.

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COOPERATIVE STRATEGIES FOR LEUCAENA PSYLLID RESEARCH

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Abstract

The rapid spread of the leucaena psyllid in Asia and the Pacific has resulted in widespread economic damage. The input of this pest on leucaena production and use has resulted in leucaena psyllid research programs in at least ten countries in the region. Common interest in finding solutions to the psyllid has led to cooperative planning of research, increased communication and coordination between researchers and additional funding by institutions such as IDRC, USAID and ADB. With the spread of the psyllid to South Asia and the potential for outbreaks in East Africa, new strategies for increased cooperation must be explored.

Introduction

The economic damage to leucaena by the psyllid has caused enough alarm in many countries in Asia and the Pacific for governments to assign significant manpower and financial resources to solving the problem. Research interest in the psyllid has resulted in the production of a regional research plan and regular communications between national programs (Napompeth *et al.* 1987, MacDicken 1988).

The process of regional research cooperation on the psyllid can be described as a five stage process:

1. Diagnosis of the problem

The identification of the psyllid as a serious economic pest demonstrated the existence of "crisis-driven" communications among researchers in many countries. Organizations such as the Nitrogen Fixing Tree Association (NFTA) and Canadian Undergraduate Service Organization (CUSO) have provided valuable services in publishing updates on psyllid damage and the range of the insect's spread.

Since *Leucaena leucocephala* presently has few serious insect pests, none of which resemble the leucaena psyllid, field identification of the pest has not been difficult. The only remaining questions in problem diagnosis of the leucaena psyllid relate to economic impacts. Donor agencies such as the Asian Development Bank (ADB) have sought to determine the economic impact of the psyllid through a regional study (C. Codrington pers. comm). These however are difficult questions which will likely require more effort to answer accurately than that currently planned.

Leucaena remains one of the most important multipurpose tree species in agroforestry practices in Asia and the Pacific. It follows that any pest which causes significant damage to growth and yield is worthy of serious collaborative research efforts.

2. Planning for research collaboration

National psyllid research programs began independently in Asia and the Pacific as the infestation reached Australia, Indonesia, Malaysia, the Philippines, Taiwan, Thailand and the United States between 1983-86. This initially led to communication between a few researchers on potential control measures. Notable among these early efforts were introduction of the predatory coccinellid *Curinus coeruleus* from Hawaii to Saipan, Indonesia, Philippines and Thailand. Seed of leucaenas with potential sources of resistance were also exchanged among researchers during these early years.

In November 1986 an international workshop was organized by the Nitrogen Fixing Tree Association in Hawaii to summarize research and develop a general action plan for future psyllid research. The meeting produced a proceedings which is a valuable reference to the early research on the psyllid and its control.

In early 1987 national research meetings were held in Thailand and the Philippines with support from the Forestry/Fuelwood Research and Development Project (F/FRED) to further

define leucaena production objectives and psyllid research priorities. These national objectives and priorities were assembled during a meeting of national psyllid research coordinators in Manila in June 1987. The output from this meeting was a regional plan which summarized the national programs and recommended the support of research in seven general areas. The plan was an important step in identifying researchers and gaps in the range of topics which needed attention.

The plan and the recommendations it contained were circulated widely among the research and donor communities. The Asian Development Bank expressed interest in funding some form of psyllid research, but ultimately decided not to provide funding. However, the plan provides useful information which was used by the F/FRED Project, USAID and IDRC in their decisions to fund psyllid research.

The plan was also a useful document in other ways. Winrock International received many requests from researchers and research institutions for copies of the plan.

As part of the planning process, a Psyllid Advisory Team was formed and is presently comprised of

Max W. McFadden	USDA Forest Service
Banpot Napompeth	National Biological Control Research Center
James L. Brewbaker	Nitrogen Fixing Tree Association
K.G. MacDicken	Winrock International

The participation of these individuals in this group is supported primarily by their own institution, with only travel support provided through the F/FRED Project. The role of the advisory group has been to help stimulate the planning process and to recommend means of enhancing cooperation and collaboration in psyllid research.

3. Experimentation

Virtually all of the research conducted on the leucaena psyllid up to 1988 was funded by national or local sources. Some of this work continues, although no current summary of national program research projects exists for all of the countries involved in the regional program. In 1988, the International Development Research Center of Canada (IDRC) and the U.S. Agency for International Development (USAID) provided support for research on leucaena psyllid in the affected region. Development of studies with support from these two sources was done under direction of national psyllid research coordinators and resulted in a series of projects in Indonesia, Malaysia, Philippines, Republic of China and Thailand.

Topics were identified from the Regional Plan by national coordinators in collaboration with donor representatives and the psyllid advisory team. Proposals were discussed during a meeting of national coordinators in April 1988 in Bangkok. Externally funded research with funds from the F/FRED Project has begun under eight grant/contract arrangements in Indonesia, Malaysia, Philippines, Republic of China and Thailand.

In addition, national program funding of psyllid research has continued in all of the participating countries.

4. Assessment

Assessment of psyllid research has to date been done solely by individual researchers and research institutions. The national psyllid research coordinators and the Psyllid Advisory Team who jointly drafted the regional program for leucaena psyllid research will be the most likely group to evaluate outputs and suggest revisions for the future.

5. Recommendations and dissemination

To date, recommendations for leucaena producers have come both through national programs and regional meetings. Nearly all of the psyllid-affected countries have produced recommendations of some kind for farmers. Control measures such as spraying, species replacement and introduction and release of parasite and predators have been recommended.

The two regional scientific meetings on the psyllid (November 1986 and January 1989) in Hawaii and Indonesia, both provided widely-distributed recommendations for leucaena researchers and producers. In addition, the NFTA and CUSO have also published newsletters and brief summaries of the psyllid situation and possible control strategies.

Conclusion

Organizations such as NFTA and CUSO have provided critical services in summarizing and disseminating information on the leucaena psyllid and its control. Communication and information sharing among national programs in

Southeast Asia and parts of the Pacific has been useful to a number of national and international research and development organizations. Some of this exchange, much of it between individual scientists, has already resulted in substantial exchange of biological control agents, seed of resistant leucaenas and information on research methods. It is too early to tell how effectively new research results will be shared and communicated.

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RECOMMENDATIONS

THE PROBLEM

Leucaena leucocephala (Lam.) de Wit is an important multipurpose tree species throughout much of the tropics. It has been widely grown in a variety of plantations and agroforestry systems for fodder, fuel, timber, food, green manure and other uses.

A destructive insect pest called the leucaena psyllid (jumping plant lice) has spread rapidly to Asia and the Pacific in the past few years, often causing serious economic damage. The species is identified as *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), also synonymously called *H. incisa*. *Heteropsylla* spp. are tiny (usually 1-2 mm) insects of the family Psyllidae. The insects undergo five instars, all of which can cause damage to susceptible leucaena.

Psyllids have long been known to feed on leucaena in the Caribbean islands. In late 1983, they were discovered defoliating leucaena in Florida. In April 1984, the psyllid was found in Hawaii and later caused serious defoliation there. In 1985-1986 the insects arrived in the South Pacific, Australia and Southeast Asia. In 1987-1988 they were found in parts of south Asia. It is anticipated the psyllid will eventually spread to Africa.

EXISTING KNOWLEDGE OF PSYLLID PROBLEM

1. The longevity, survivorship and fecundity of *H. cubana* have been measured at approx. 27°C in the laboratory in Hawaii, Thailand and Indonesia.

2. The host range of *H. cubana* is restricted to species in the genus *Leucaena* and very few other plants that have been less studied, including *Albizia saman*.

3. Apparently there are no simple relationships between *H. cubana* population dynamics and weather.

4. Native predators, parasites and pathogens of *H. cubana* have been identified in several countries in Asia and the Pacif

5. Natural enemies of *H. cubana*, namely *Curinus coeruleus* and *Psyllaephagus* sp. nr. *rotundiformis*, have been introduced in several countries and appear to be making a substantial contribution in some areas.

6. The search for natural enemies in the native range of *H. cubana* has been initiated.

7. Surveys for and identification of additional natural enemies (including pathogens) attacking *H. cubana* have been conducted in a number of countries within the region. The potential of some of these agents is being evaluated.

8. Among the 13 species of *Leucaena*, three show no significant damage from the psyllid-*L. collinsii*, *L. esculenta* and *L. pallida*. Four other species appear to be highly resistant. All have been successfully crossed with the commercially important *L. leucocephala*.

9. Progress has been substantial in assessing biomass yield and relative damage levels in the Leucaena Psyllid Trials (LPT), but very limited progress can be reported in wood or fodder quality evaluations.

10. The results from trials in 10 countries suggest that resistance is highly stable, but that yields can be highly variable in relation to location (notably, temperature). The psyllid tolerance of some varieties such as K156 and K743 was reported in 1986 but has since been shown to be inadequate, particularly for fodder production.

11. Progress has been made in research-quantity seed multiplication from resistant or tolerant varieties and accessions. Leucaena seed orchards have been started for multiplication of resistant sources.

12. Limited research has been conducted on the genetic and biochemical basis for resistance. Mimosine has been excluded as basis for resistance, and genetic control is believed to be polygenic and lacking dominance.

POLICY RECOMMENDATIONS

* The psyllid infestation problem can be contained only over a period of several years and will require international cooperation.

* Biological control and planting of resistant varieties should form the basis for leucaena psyllid management.

* Considering that leucaena is an important multipurpose tree species, it should be the focus of further improvement, and resistant varieties sought in preference to replacement with other species.

* Research and development efforts on other multipurpose tree species with production and use characteristics similar to *L. leucocephala* should be intensified.

* Networks for research, monitoring and technology transfer systems on leucaena psyllid should be strengthened.

* Monoculture tree stands be avoided if a compatible species mix is available.

* Sources of funding should be sought first from national entities, either government or private, and then from international groups and agencies.

* Linkages among international donors and development agencies to improve research and development of leucaena and other multipurpose tree species should be closely coordinated.

RESEARCH RECOMMENDATIONS

PSYLLID ECOBIOLOGY

* Prepare and publish a synthesis of current knowledge of *H. cubana* biology and ecology.

* Decide on a standard minimum data set for field investigations and devise an inexpensive, quick and reliable method for estimating population densities of all psyllid life stages in the field.

* Carry out field life table studies using a standardized protocol.

* Develop a conceptual model of the psyllid life system.

* Study movement and distribution of *H. cubana* (i.e., plant to plant, country to country, etc.).

* Prepare damage functions by relating population density of *H. cubana* to damage caused.

* Measure longevity, survivorship and fecundity at a range of temperatures, humidities and plant nutrient status in controlled environment chambers.

GENETIC IMPROVEMENT AND NETWORK TRIALS

* Local breeders are encouraged to select trees with apparent resistance, and to increase seed for entry into cooperative trials. They are also encouraged to select resistant trees from segregating populations that are becoming available.

* Composites developed by intercrossing accessions within *L. pallida* and *L. diversifolia* should be developed and widely distributed for selection. Such broadly based composites will ensure that the genetic base of resistant varieties does not become too narrow.

* The genetic integrity of existing leucaena collections must be conserved, to ensure that valuable genes present in original accessions are not lost.

* Fertile interspecific hybrids (e.g., KX1) should be widely distributed for selection in specific environments.

* The techniques for developing seedless interspecific hybrids need to be refined, both with respect to the making of the hybrids (e.g., synchronizing flowering) and their propagation (e.g., grafting, tissue culture).

* Present selection techniques are effective, but can be time-consuming and expensive. There is a need for a method to screen large numbers of trees for resistance in the seedling stage.

* There are important selection objectives to be combined with that of psyllid resistance. These include suitability for wood production or shade, tolerance to cold and acid sites, and forage yield and quality. Particularly urgent is the need for data on forage digestibility and quality of psyllid-resistant germplasm.

* Network experiments should be expanded to include 3 stages: resistance verification, varietal yield trials, and management x variety trials.

* The study of mechanisms and biochemistry of resistance should be continued and expanded to cover most resistant species, with full collaboration of entomologist and breeder. A search should be made for physical and morphological factors related to resistance. It is also important to ascertain the effects of environmental factors such as nutrition, light and moisture on resistance.

* The genetics of resistance is not known, although dominance is not observed. Polygenic control is inferred for segregating populations of the polyploid species hybrids studied. Research is especially needed on the patterns of inheritance at the diploid level, to include all major species sources *L. collinsii*, *L. diversifolia*, *L. esculenta*, *L. greggii*, *L. retusa* and *L. salvadorensis*.

* Leucaena seed orchards for production of foundation seed of psyllid-resistant composites should be established at as many locations as possible. Careful rogueing must be maintained in order to produce suitable populations.

* A description of leucaena seed storage requirements should be prepared, to include recommendations for labelling and storage conditions for maximizing seed viability. Permanent storage should be considered for selected seedstocks in existing (available) long-term storage facilities.

* A document for training seed orchard managers should be prepared. This should address problems related to orchard establishment, controlled and open pollination, identification of seed contamination by other varieties, and germplasm preservation.

* A document outlining procedures for successful grafting and vegetative propagation is needed. Research is recommended to determine whether rejection or growth reduction is associated with some of the interspecific grafts.

BIOLOGICAL CONTROL

* Biological control should be emphasized as one of the main components in management strategies to control *H. cubana*.

* Continue to identify and evaluate the natural enemies existing in the region (including pathogens that are attacking the psyllid). A country by country inventory of these natural enemies should be made available.

* Where acceptable, further utilize the available exotic enemies, especially *Curinus coeruleus* and *Psyllaephagus* sp. nr. *rotundiformis*.

* Continue the search for natural enemies in the native range of the leucaena psyllid until additional effective natural enemies become available for introduction into the region.

* New biological control agents originating from the Americas to be introduced into the region should be screened for contaminating organisms in a quarantine facility in a temperate region country.

* Monitoring of the psyllid populations and evaluation of the effectiveness of natural enemies should be undertaken.

* The introduction and release of biological control organisms between countries should only be undertaken after consultation with neighboring countries.

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