

**EFFECT OF LEUCAENA PSYLLID ATTACK ON *Leucaena leucocephala*
SEEDLINGS GROWING UNDER DIFFERENT WATERING AND SHADING
LEVELS**

BY

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Abstract

The effect of leucaena psyllid (*Heteropsylla cubana*) (Crawford, Homoptera: psyllidae) on the growth of *Leucaena leucocephala* (Lam.) de Wit seedlings was evaluated in relation to three watering levels (every day, every other day and once a week) and three shading levels (light 10%, moderate 25% and heavy 50%). Three weeks coppices from two months pot grown leucaena seedlings in split plot design was used in the screen house.

Generally, fifteen weeks after infestation of the seedlings, infested seedlings were less vigorous, thinner and shorter than the non-infested seedlings. In addition, dry weight production (expressed as oven dry matter) was significantly reduced by the effect of psyllid attack.

The effect of attack however, varied with the treatment levels. The biomass loss was 9.7%, 18.6%, 17.2% for seedlings watered every day, after every other day, and once a week respectively. On the other hand shading contributed to respectively 15.9%, 4.8%, and 7% loss for seedlings shaded at 10% (light), 25% (moderate), and 50% (heavy). The level of damage, shoot health and nymph abundance although not significantly different among treatments were higher in the water stressed seedlings and in the lightly shaded seedlings than the other treatment levels.

Environmental factors such as drought stress and solar light intensity had an influence on the attack of the leucaena psyllid. It is therefore recommended that, leucaena planting should be confined to areas with adequate annual rains and some shade to minimize the effect of leucaena psyllid. Further work should investigate on the optimal watering and shading interaction which disfavours the performance of the leucaena psyllid and consequently use the results in Integrated Pest Management (IPM) programme.

DECLARATION

I Gisella A. Ngoo do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my original work and had not been submitted for a higher degree in any other University.

Date.....*29.06.1998*..... Signature.....*29.06.1998*.....

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LIST OF ABBREVIATION

ANOVA - Analysis of variance

ICRAF - International Centre for Research in Agroforestry

IPM - Integrated Pest Management

LSD - Least Significant Difference

NTSP - National Tree Seed Programme

SLR - Simple Linear Regression

CHAPTER ONE

1. INTRODUCTION

Tanzania has a population of about 23 million people with an increase rate of 2.8 per cent annually (1988 Census). About 80 per cent of the population are farmers, growing subsistence crops such as maize, rice, millet, sorghum, cassava, bananas, beans, vegetables and cash crops such as coffee, tea, cotton, tobacco and sugar cane. Other activities, include mining, fishing, pastoralism and agropastoralism (MDB, 1988).

The country has been facing many problems related to agricultural production particularly in the semi-arid areas. The shortage of food and fodder is partly a result of declining agricultural production associated with declining soil fertility, caused by factors such as soil erosion and degradation, little or no application of organic or inorganic fertilizer as well as erratic rainfall. The high population growth rates have also put enormous pressure on land, thereby, exacerbating the problems of land degradation through indiscriminate extensive land clearing and poor land management (MDB, 1988). Thus, land restorative fallow earlier used to sustain soil productivity under traditional shifting cultivation have become shorter and thereby ineffective or have disappeared from the farming systems altogether.

Within this broad perspective, concern grew for the sustainability of various

farming systems. The interest was developed in planting trees as a normal agricultural activity and in the potential for improving productivity and environmental protection by growing trees together with crops in different combinations. Under these combinations (namely Agroforestry), the main tree species planted are *Leucaena spp*, *Prosopis spp*, *Albizia spp*, *Cassuarina spp*, *Gliricidia sepium*, *Tephrosia volgerii*, *Cassia siamea*, etc and some of these are still under experimentation. Among these tree species *Leucaena leucocephala* (Lam.) de Wit is one of the most important exotic multipurpose tree species widely planted under agroforestry programme in tropical and sub-tropical regions.

In Tanzania, research with *L. leucocephala* started in 1970's (Lulandala, 1978), although the first plantings of this species go back to early 1950's. In spite of being very successful, during later half of 1980's a twig insect, leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae), emerged and caused defoliation, stunting growth die back and occasionally mortality to the leucaena trees (Napompeth, 1989; 1994; Palmer *et al.*, 1989; Reynolds and Bimbuzi, 1992; Ciesla, 1992; Kisaka, 1994). The spread of this insect started from Central America in 1980 when it was observed attacking leucaena in Dominican Republic, then in Florida (U.S.A) in 1983 (Brewbaker, 1987). Moving on air craft or on high altitude winds they arrived in Hawaii in 1984 (NFTH, 1988) and since then they have been detected and reported attacking leucaena trees in many tropical countries.

The insect spread rapidly west-wards through the Pacific Ocean to Taiwan in 1985, Australia in 1986, and between 1991-92 was reported in several African countries, including Madagascar, Kenya, Mauritius, Reunion, Uganda, Burundi and Tanzania (Brewbaker, 1987; Hollis, 1992; Vanden Belt and Napompeth, 1992; Reynolds and Bimbuzi, 1992; Napompeth, 1989; 1994).

The losses which are caused by this insect are both economical and socio-ecological because leucaena is used for revegetating the degraded lands and for economic purposes. For example, Funasiki *et al.* (1989), reported loss of approximately \$ 878,000 from sugar industry in Hawaii due to invasion of fields by leucaena psyllid. In Indonesia records show losses from green manure, timber, leaf as meals, shade to other crops, charcoal and fuel wood amounted to more than \$ 316 million (Oka, 1989). In Tanzania the average woman/household economy loss due to psyllid attack to pole sized leucaena trees was estimated at Tanzanian shillings 47,000 (Johansson, 1994). At the moment leucaena psyllid poses an immediate threat to all leucaena plantings all over Africa (Ciesla, 1992).

A lot of research have been done particularly in the Asian-Pacific region to find out the ultimate solution but no proper management practices have been recommended for managing leucaena trees.

In the field, leucaena psyllid population normally fluctuates quite widely over space and time (NFTH, 1988; Bray, 1992; Madoffe and Massawe, 1994; Napompeth, 1994) and seem to depend on the complex set of interactions between leucaena growth, weather conditions (particularly moisture, light intensity and temperature), psyllid mortality factor and other influences such as pruning of the leucaena trees (NFTH, 1988; Villacarlos, *et al.*, 1989; Mangoendihardjo *et al.*, 1989). It seems that the high population built up during the rain period cause severe damage during the dry season. Thus, sites with more pronounced dry season may be affected more. Factors such as light intensity which have significant effect on physiological performance of the leucaena trees could also affect population size of the psyllid as they indirectly enhance the growth survival and reproduction of the insects (Larsson, 1989). Thus, understanding of the biology and ecology of the pest could assist in developing pest management tactics and some control measures.

Despite most of leucaena plantings in this country being damaged by psyllid (Kisaka, 1994), no systematic scientific work has been done to date in Tanzania to evaluate on the impact of leucaena psyllid on plant yield. It is obvious that a number of factors (biotic, edaphic and climatic factors) are known to influence the relative abundance of this insect population (Mangoendihardjo *et al.*, 1989). A sound approach is to single out few factors for closer studies. The information so obtained will help in

developing future pest management strategies. Thus, in this study the effect of shading (light intensity) and watering (drought stress) on leucaena psyllid population and its ultimate impact on pot grown leucaena seedlings was investigated. The study was carried out at Sokoine University of Agriculture Forest nursery with the following objectives:-

Main objective

- to determine the effect of leucaena psyllid attack on *L. leucocephala* seedlings growing under different watering and shading levels;

Specific objectives

- to evaluate the intensity of psyllid attack in relation to different light and watering levels;
- to evaluate biomass loss of leucaena seedlings as a result of the psyllid attack;
- to determine an effective management option of *L. leucocephala* on the basis of light/watering relationships.
- to determine the life cycle of the psyllid in Morogoro.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 The study tree, *Leucaena leucocephala*

Leucaena leucocephala commonly known as "Leucaena" is a fast growing multipurpose tree species and the most planted species of the genus leucaena. It belongs to the Mimosoideae subfamily of the family Leguminosae. The tree is native to central America but has been widely planted throughout the tropics and sub-tropical regions. They grow best in tropical and subtropical lowlands at elevations below 100m with mean annual temperatures around 20°C, mean annual rainfall more than 600mm, and on well drained, neutral to alkaline clay soils, with pH of 5.6 to 8 (Brewbaker, 1987). But leucaena can tolerate low mean annual rainfall (250mm in parts of Hawaii) and long dry seasons (up to eight months in parts of Mexico (Tanzania Forest Division, 1983).

The spread of this tree from Central America to different parts of the world started from 1565 through the Spanish traders (Napompeth, 1994). Leucaena was introduced to the Pacific Islands, Malaysia, Northern Australia, Papua New Guinea and East and West Africa (Napompeth, 1994; Lulandala and Hall, 1994). Three types of leucaena have been recognized in different parts of introduction. These include the Hawaiian type, Peru type also known as Acapulco and Salvador type (Lulandala, 1985; Lulandala

and Hall, 1991; Napompeth, 1994). Hawaiian type which is small and bush with a rounded crown, grow to maximum height of 5 metres. Salvador type, is the tallest type reaching about 20m long and about 40cm in diameter. In Tanzania, the Hawaiian type was introduced to the Usambara mountains and Island of Zanzibar at the beginning of this century (Tanzania Forest Division, 1983; NAS, 1984). The more productive Salvador type is increasingly being planted in reforestation and agroforestry programmes throughout mainland Tanzania, especially in the low rainfall areas of the Central Northern and Western plateaus (Lulandala and Hall, 1991).

Different names have been given to this tree depending on the place of their introduction. For example in the Philippines is called ipil-ipil, lepile or bayani, lamtoro in Indonesia, kao haole in Hawaii, guaje in Latin America (NAS, 1984; Napompeth, 1994), hediondilla in Puerto Rico, tangatan in Guam and lukina or lusina in most of African countries (Tanzania Forest Division, 1983; Napompeth, 1989; 1994).

2.1.1 Worldwide Importance of *Leucaena leucocephala*

Different wonderful characteristics of leucaena has made it popular tree in agroforestry in different parts of the world. Its ability to adapt to an extremely wide range of edaphic and climatic conditions may be due in part to its symbiotic partners. Its mycorrhizal fungi provide a number of benefits

including the expansion of root-fungus absorbing area to help leucaena to avoid drought (Lulandala, 1985).

Of all the tropical legumes, probably leucaena offers the greatest assortment of uses (Napompeth, 1994). Through its many varieties leucaena have the following benefits.

2.1.1.1 Soil conservation

Leucaena produces prolific deciduous biomass (Lulandala, 1985; Lulandala and Hall, 1991). Large quantities of leaves, flowers, pods, seeds are added to the soil annually together with the dead decaying branches and roots, greatly enhancing soil organic matter and nutrient content. Besides improving the physical, chemical and biological properties of the soil, this organic matter also regulates the flow of soil nutrients thereby reducing loss due to leaching (Young, 1987). However, leucaena tree itself fixes great amount of nitrogen in the soil thereby making great potential contribution towards agricultural production. The distribution of roots laterally and downwards in the soil with abundant nitrogen fixing rhizobium nodules has the capability of fixing up to 500kg of nitrogen per hectare (equivalent of 250kg ammonium sulphate ha⁻¹ annually) (Lulandala, 1985). Those large injections of atmospheric nitrogen into the production system will largely help in enriching the soil.

Apart from maintaining soil fertility leucaena helps in controlling soil erosion especially in the hill areas. A cover of leucaena and other vegetation reduces rain drop splash and impact to soil surface, limits surface water run-off, and regulates wind speed. Deep rooting leucaena also stabilizes the soil and improves water infiltration. Sub-surface water flow, drainage and aeration of the soil foster valuable soil fauna, such as earthworms and microbial activities. The organic matter provided by the leucaena plants improves moisture-holding capacity to the soil and binds the soil together, helping to control soil erosion (Young, 1987; Otsyina and Dzowela, 1994; Chilima *et al.*, 1994; Napompeth, 1994)

2.1.1.2 Animal feed

Leucaena could provide fodder for livestock almost through out the year due to its high productivity and drought tolerance. With the absence of leucaena psyllid, leucaena pastures were among the most productive in the tropics and promise to become important source of forage and feed for livestock, poultry, wildlife (NAS, 1984) and fish (Lulandala and Hall, 1991), particularly in dry areas. It produces highly nutritious, digestible and palatable, pods, seeds, leaves, twigs and flowers for animal feed. Mashed leucaena seeds and leaves are mixed with other local materials to make cheap, high quality layer and growers feed for chickens (Lulandala, 1985).

Leucaena fodder contains nutrients and roughage and makes a more less

complete feed for livestock. It contains up to 54% protein (amino acid are present in well balanced proportions) and is a rich source of carotene, vitamins and nutrients (National Academic of Science, 1977 In: Lulandala, 1985). Being used as supplement for small ruminants and cattle, very encouraging live weight gain have been obtained (Otsyina and Dzowela, 1994). Goats supplemented with leucaena and other browse species were reported to gain an average weight 12g/ head /day during wet season and 6-8g/ head/ day during the dry season in Tabora , Tanzania (Karachi per. comm; In: Otsyina and Dzowela, 1994).

2.1.1.3 Wood production

Due to its fast growth, leucaena produces large amount of wood in relatively short time. Wood production and use value depends on the species, environmental conditions and management practices. Therefore management factors could influence the morphology of the tree hence determining the use value of the tree (Lulandala, 1985).

Leucaena provide good quality wood, excellent fire wood and charcoal (Lulandala and Hall, 1991). The wood burns well with minimum smoke and the heat emitted is between 4200-4600k cal kg⁻¹ of wood. Charcoal from leucaena has heat value of about 70% of the heat value of oil (National Academic of Science, 1977; In: Lulandala, 1985). Apart from being used as fuel wood, leucaena wood is used for construction and production of

timber for industrial purposes. The properties which make leucaena wood being used for all these uses are summarized in table 1 .

Table 1 Major end uses of leucaena wood and associated properties

USES	PROPERTIES
Fuel wood (domestic)	Low smoke production Low spark production No unpleasant smell Easy drying and splitting
Fuel wood (industrial)	Good heat production
Home construction	Good compression and tensile strength Medium sized straight poles Good durability and/or ability to accept preservatives
Fence posts	Good durability Relatively straight stems
Pulp	High holocellulose content Low extractive content Bark easily removed
Charcoal	Good recovery value High heat value
Crafts	Easy to work Attractive finish Density medium to higher
Parquet flooring	Machine well Attractive finish
Furniture	Good tensile strength Attractive finish Easy to work

Source: Potlinger and Hughes (1994), In: Otsyina and Dzwowela, (1994)

2.1.1.4 Other uses

Leucaena has other miscellaneous benefits, as food, source of various medicines and amenity. In Central America, Indonesia and Thailand, leucaena is an important food source. The young leaves, shoots-tips, sprouts, young seedlings, flowers, young green pods and young seeds are eaten raw or cooked. The young seeds are also popped like popcorn (Leucaena Research in Asia Pacific region, 1982 In: Lulandala and Hall, 1991). Various parts of plants are reported to have medicinal properties ranging from control of stomach diseases to contraceptives and abortion (National Academic of Science, 1977: In Lulandala, 1985). The gum extracted from leucaena seeds can also be used in cosmetics such as hand lotion and face cream.

Leucaena is also used for ornamental purpose in some areas of south east Asia and throughout the Pacific regions (Napompeth, 1994). Leucaena shiny dark-red seeds are used to make decorative necklaces and household items. In Philippines, leucaena is widely planted for beautification, particularly in Manila. It is commonly used in Central America, Mauritius, Philippines and East Africa for hedges as living fences, to mark boundaries and protect house and fields from winds and for provision of shade (National Academic of Science, 1977 In: Lulandala, 1985).

2.2 The pest; leucaena psyllid (*Heteropsylla cubana*)

2.2.1 Taxonomic status

Within the order of Homoptera the superfamily Psylloidea has seven families, namely Liviidae, Homotomidae, Psyllidae, Spondylaspididae, Calophyidae, Carsidaridae and Triozidae (Dolling, 1992). Psyllid differ from the rest by having antennae with 5-10 (usually 10) segments; front wings often thicker than hind wings; and are jumping insects (Dolling, 1992). The adults of both sexes are winged and the beak is short and three segmented.

The genus *Heteropsylla* was first described by Crawford (1914) for a group of Central American psyllid species that lacked genal process but possessed a visible frons, a large and usually triangular, pterostigma hyaline wings and long slender antennae (Muddiman and Hodkinson, 1992; Napompeth, 1994). Basing on the head structure, nymphal morphology and antennae structure, this genus was placed in different subfamilies such as Pauropslinae and Ciriacreminae by different authors. But Crawford description has a taxonomic priority and the genus *Heteropsylla* remain broadly defined to include legume-feeding psyllid of the subfamily Ciriacreminae that posses a large, usually triangular pterostigma and a non-lobed male proctinger and which lack an r-m cross vein in the forewing and pre-ocellar tubercles on the vertex. The larvae have 9-segmented antennae and 3 + 3 or 4 + 4 prominent setae on the abdominal margin.

The insect species was named as *Heteropsylla cubana* by Crawford (1914) and as *Rhizobium incisa* by Sulc in the same year (Burdharat, 1986 In: Napompeth, 1994). Since Crawford's description has taxonomic priority, Sulc's *R. incisa* became *H.incisa* (sulc) and was later considered as synonym. In that regard, *H. cubana* remains the valid name for the species. A short taxonomic description and key to the identification of some *Heteropsylla* species , including *H. cubana* was given by Caldwell and Martorell (1951) In: Napompeth, (1994). But the most recent description and key to the identification of the *H. cubana* with a complete taxonomic account, host plant preferences and geographic distribution is given by Muddiman and Hodkinson (1992).

2.2.2 Biology, Life Cycle and Development

The female leucaena psyllid lay eggs on very young shoots. Eggs are laid singly but in dense clusters lodged between the fold of developing leaflets. The newly laid eggs are whitish with oval shape of about 0.3mm long and 0.1mm wide (Guan- soon *et al.*, 1989). In general mature eggs are orange or reddish-brown in colour. Eggs hatch in two to three days (NFTH, 1988).

Nymphs are usually very closely restricted to their food-plant source which consequently are useful guide to their identification (Dolling, 1992). Although whitish when newly hatched they change into various shade of colour ranging from yellow, green to orange or reddish-brown. Nymphs

undergo five nymphal instars to reach the adult stage (NFTH, 1988; Rauf *et al.*, 1989; Napompeth, 1989; 1994). Adults of both sexes are winged and are normally 1-2mm long with green or brown colour. There is little sexual dimorphism among adult psyllid apart from size. Males are slightly smaller than females and the obvious differences in the genitalia.

Heteropsylla cubana is a multivoltine insect with a short life cycle of about 10-20 days with several overlapping generations per year (Napompeth, 1994). However, different studies carried out to determine the life cycle of this insect found that it varies from one location to another or place to place. For example in Malaysia the psyllid takes 12-20 days to develop from egg to adult stage (Guan-soon *et al.*, 1989). In Philippines the developmental period was 11-16 days only (average 12.8 days) which was almost the same as average of 12.9 days reported by Rauf *et al.*, (1989) in Indonesia. These differences is believed to be attributed by the differences in environmental conditions especially temperature and relative humidity under which the studies were conducted.

2.2.3 Introduction and Spread

Leucaena a native of Central America, was free from significant pest in its area of introduction for over 300 years until 1984 when leucaena psyllid, a sap-sucking pest which feeds on developing leaves was found on the leucaena trees in Hawaii. In its area of origin is not known to cause

significant damage to leucaena trees because its population is held at tolerable level by natural enemies (USAID, 1991; Heynold and Affonso, 1991). Before the record of its outbreak in Hawaii in 1984, negligible attention was given to this insect (Napompeth, 1994), although it was earlier observed in Dominican Republic and Florida (U.S.A) (Brewbaker, 1987).

The psyllid probably arrived in Hawaii in aircraft. From Hawaii the insect spread rapidly through the Pacific, reaching Taiwan Australia, Japan and the South Asia mainland by 1986. Through South East Asia it arrived in India Sub-continent in 1988, and spreading throughout the sub-continent within two years (Brewbaker, 1987; NFTH, 1988; Vanden Belt and Napompeth, 1992). In September 1991 infestation was detected in Mauritius and Reunion having most likely arriving from aircrafts from Asia. In 1992 the psyllid was detected in Madagascar and coastline of Kenya and Tanzania, Uganda, and Burundi (Reynolds and Bimbuzi, 1992; Napompeth, 1994).

The mechanisms of global spread of this insect is still a controversial. Air currents are the most probable agents, Beardsley (1986), however, suggested that the rapid spread of *H. cubana* was facilitated by transportation in aircraft, the insect being attracted to aircraft lights. The insect can jump from one tree to another if they are close enough, so man

could be another possible agent through his agroforestry and or afforestation programmes.

2.2.4 Host plants

Leucaena psyllid feeds almost exclusively on *L. leucocephala* and to a lesser extent on closely related mimosoid leguminous trees. The great majority of all 39 species of the genus *Heteropsylla* are known to develop on mimosoid legumes (Muddiman and Hodkinson, 1992). The exceptions are *H. fulsa*, *H. pulchra* and *H. proximata* which were recorded from Caesalpinoids. Within the mimosoids, members of the Mimoseae, Acaciaseae, and Ingeae are known as hosts to the leucaena psyllid (Muddiman and Hodkinson, 1992). *Heteropsylla cubana* is so far the only species of *Heteropsylla* found on *Leucaena leucocephala* (Waage, 1989), although it has been reported to be found on other tree species such as *L. deversifolia* in Guatemala, *Acacia villosa* and *mimosa* in Jamaica and *Albizia quaquepele* in Cuba (Waage, 1989). This pest also appear to attack *Faidhebia albida* (Mimosoidae: Caessalpinae) in Tanzania (Madoffe, 1994).

Trials have been conducted to assess the resistance of various leucaena species and varieties to attack by *H. cubana*. In Hawaii, Taiwan and Australia, *L. leucocephala* was generally the most susceptible species, where as in Florida it had an improved resistance ratings (Brewbaker and Sorensson, 1987; Pan, 1987; Bray and Woodroffe, 1988). Species like *L.*

esculenta, *L. pallida*, *L. collinsii*, *L. salvadorensii* and *L. retusa* were consistently resistant (Muddiman and Hodkinson, 1992; NFTH, 1988). Also field observation of *L. pulverulenta* in Indonesia shows that this tree was not attacked although some psyllid were found on it (Subyanto and Wagiman, 1989). However, some lines of susceptible *L. leucocephala* reported highly resistant in some locality may become susceptible in another locality (Brewbaker and Sorensson, 1987).

2.2.5 Nature of damage

In every region that it has colonised, leucaena psyllid has caused severe damage during the initial phase of its attack. The damage to the leucaena trees could be both direct and indirect and greatest when the juvenile foliage development is rapid as on managed hedges for green manure and fodder. Both nymphs and adults are responsible for the damage due to sucking of the sap from the young shoots, leaves and inflorescence of the tree resulting in defoliation of leucaena species (Napompeth, 1989; 1994). The older leaves are in most cases not affected (Napompeth, 1989) although under heavy infestation they may be blackened by the mould from the honey dew produced by the psyllid (NFTH, 1988; Napompeth, 1994).

In the first stage of attack slight wilting of the new flushes of shoots could be observed which lose their erectness and become flaccid. With continued feeding by the psyllid the plumule lose their lustre, they later become yellow

and drop, leaving only mid rib in position. In case of heavy infestation repeated and cumulative attack cause wilting, defoliation and branch die back. Although plant can recover later, in most cases death of plant has been known to occur (Ciesla, 1992), or new flushes of shoots show some deformities and unhealthy appearance (Napompeth, 1994).

Studies of economic losses following the attack in several countries have shown psyllid as a serious economic pest in all countries studied (Heynold and Affonso, 1991; Johansson, 1994). The level of damage subsequent impact and stability of the trees vary from country to country or from place to place depending on the level of stresses the tree is exposed (Hertel *et al.*, 1994). Unhealthy and stressed trees are more susceptible than healthy and unstressed trees. Also level of damage varies with the tree age, young trees appear to suffer heavier attack than older trees.

2.2.6 Population dynamics

Population of insects are never truly stable but often raise from low level to high densities and then fall approximately to their original size (Wallner, 1987). On global scale, seasonal rainfall and temperature patterns constitute the major factors that determine the distribution and abundance of organisms in space and time (Wallner, 1987). However, the cause of herbivorous insects outbreak on trees is a controversial and unresolved (Barbosa and Schultz, 1987), although the phenotypic condition of the host

tree has been hypothesized to have an important effect on the performance of the phytophagous insects (Craig *et al.*, 1987). Thus, the implication is this, factors (rainfall and temperature) do not only affect directly the population of insects but on the extreme cases affect the physiological status of the host tree thereby making them more vulnerable to insect attack.

Observation from many areas shows that leucaena psyllid exhibit season abundance with higher populations coinciding with the dry and cooler period of the year and development of the new shoots from the pruned trees (Bray and Woodroffe, 1991; Mangoendihardjo *et al.*, 1989; Madoffe and Massawe, 1994; Napompeth, 1994). This has implication on the leucaena psyllid attack on leucaena seedlings which become more severe when young shoots emerge. During the rain period population of leucaena psyllid could drop to low level as a result of the rain period most adults and nymphs being washed away by the rain (Villacarlos *et al.*, 1989; Madoffe and Massawe, 1994). Other factors which are known to affect leucaena psyllid population are solar light intensity, wind velocity (Mangoendihardjo *et al.*, 1989), and natural enemies (Villacarlos *et al.*, 1989).

2.2.6.1 Drought effect

Insect densities often increase under stressful environmental conditions (Speight and Wainhouse, 1986; Mattson and Haack, 1987). Drought is one

of the major environmental factor that has been associated with subsequent insect outbreaks (Wagner and Frantz, 1990; Tisdale and Wagner, 1991). However, the evidence that moisture stress improves the suitability of a host for attack is largely circumstantial although improved food quality, less efficient natural enemies (Mattson and Haack, 1987) and effect of the abiotic environment (Mangoendihardjo *et al.*, 1989) have been proposed to be the cause.

Association between drought and leucaena psyllid attack has been observed repeatedly. Psyllid population fluctuations and damage is more severe at the sites with more pronounced dry season (NFTH, 1988). In a study of two sites in Philippines Villacarlos *et al.* (1989), observed that psyllid populations built up during the rainy season, but when growth is slowed down in the dry season, the already high populations cause the most severe damage. This effect was also observed in the Southern part of India which is drier than the Northern part of the country (Krishnamurthy *et al.*, 1989).

According to the food quality hypothesis biochemical changes leading to enhance insect performance take place under abiotic stress e.g increase in concentration of soluble amino acids (White, 1974) and/or changes in concentrations (Rhodes, 1983). However, the result of experimental tests have been mixed (Larsson, 1989). Among the possible explanations for these inconsistency findings as explained by Mattson and Haack (1987) and

Larsson (1989) is that; insects that differ in their feeding modes probably respond differently to changes in food quality. Larsson (1989) proposed that insect groups could be ranked as follows in terms of sensitivity to stress induced changes in the host plants: cambium feeders > sucking insects > mining insects > chewing insects > gall forming insects.

2.2.6.2 Shading effect

Changes in the environment factor results into inadequate performance of the plants roles with consequent reduction in growth rate, survival, reproductive success and/or defense against herbivores insect (Rhodes, 1983). For example height and dry matter production of *L. leucocephala* were greatly reduced when grown with annual weed grass *Eleusine indica* (Jones and Aliyu, 1976). The very marked depression in the growth of leucaena associated with the grass could be due to shading or due to below ground competition or to both.

Some insects respond positively towards solar light intensity, while other don't show any responses due to change in light intensity. For instance *H. cubana*, *Curinus coeruleus* and *Korscheltellus gracilis* (Mangoendihardjo *et al.*, 1989; Diravian and Viraktamath, 1992; Kuenen *et al.*, 1994) have been found to respond positively towards light intensity. The reason behind this positive response is still unknown but it is probably related to changes of food qualities caused by the decreased or increased solar light intensity.

Basset (1992) in his experiment on the influence of leaf traits on spatial distribution of arboreal arthropods within an overstorey rain forest trees, found that, local illumination regime for host young leaf production and its indirect effects on the spatial distribution of arboreal arthropods is an important factor in the determination of food quality especially phloem feeding insects.

2.2.6.3 Natural enemies

Parasites, predators, and pathogens have been important mortality factors in regulating the psyllid population. Different species of coccinellids, larvae of syrphid flies, wasps, dragon flies, predator bugs, spiders, ants, and parasitic hymenopteran (*Psyllaephagus* and *Tamarixia*) are associated with leucaena psyllid (Krishnamurthy *et al.*, 1989; Waage, 1989; Veeresh, 1989; Madoffe and Massawe, 1994). Hyperparasitoids have also been detected parasiting on the psyllid, but according to Waage (1989) this is not common. Presence of these factors in the field could check the population to a level which is tolerable, but this level has not yet been attained.

2.2.6.4 Other factors

Other factors which are known to affect the psyllid population include wind velocity and pruning of the leucaena trees. Wind is probably the most important mechanism in the dispersion of the psyllid while pruning of trees encourage growth of the new shoots which are the sites for oviposition and

food source for the psyllid

2.2.7 Management and control strategies

Since leucaena is a multipurpose plant grown in different environmental conditions it inevitably requires different management and control strategies (Napompeth, 1989). Leucaena managed for different purposes such as firewood, fodder or hedgerows suffer from different levels of damage (Bray, 1992) which could make it difficult to have a single control method, thus an integrated pest management approach could be the only alternative solution. Further, the selected control strategy could also face another challenge in terms of time, practicability, and economic feasibility.

2.2.7.1 Biological control

Biological control has been suggested as one of the best options for the control of the psyllid (Napompeth, 1989). Classical biological control is widely used against this pest and some successful examples from Asia and Central America include the use of predators *Curinus coeruleus* *Olla v-nigrum* (Funasaki *et al.*, 1989). These two species have been introduced in Hawaii and proved to be effective in controlling the psyllid, although not to the extent of eliminating the problem (Oka, 1989). From Hawaii they were also introduced into Indonesia, Philippines, and Vietnam (Napompeth, 1994). An encyrtid nymphal parasite, *Psyllaephagus yaseenii* and *Tamarixia leucaenae* have also been used successfully in these regions

(Funasiki *et al.*, 1989). The two parasitoids were introduced in Eastern Africa in 1995 and spread and establishment have been recorded from Tanzania and Kenya (Madoffe *pers comm.*, 1996). Some local predators; spiders, lance wings, dragon flies and lady-bird beetles have been recorded in Tanzania (Madoffe *pers communication.*, 1996). There is also a potential use of entomopathogenic fungi against the leucaena psyllid (Napompeth, 1994).

2.2.7.2 Chemical control

In the short term, chemical control (mostly systemic chemicals) has been proven effective against leucaena psyllid (Oka and Bahagiawati 1988; Palmer *et al.*, 1989; Ciesla, 1992). These include diazium, dimethote and acephate. But chemicals must be applied at frequent intervals, and their use is not considered to be economically feasible at the farm level (USAID, 1991).

Chemical insecticides are potentially hazardous to the environment and to human health and animals as well (Ciesla, 1992). In addition repeated applications of chemicals against insects could lead to the development of strains which are resistant (Speight and Wainhouse, 1986). Therefore chemical control is not recommended as a proper means of controlling insects in agroforestry programs, instead is only recommended for seedlings, demonstration trials, seed production nurseries or experimental

leucaena plots (Heynold and Affonso, 1991; USAID, 1991).

2.2.7.3 Genetic tactics

The conditions under which trees are grown have an important influence on their resistance to pests. But some tree species are inherently more resistant than others (Speight and Wainhouse, 1986). This genetic variation could potentially be exploited in the long term program and breeding for more resistant leucaena tree genotypes (Brewbaker and Sorensson, 1987). The possible approaches in breeding for more resistant leucaena genotypes is to use either psyllid tolerant species of leucaena (Bray, 1992) or other species of leucaena, for example, *L. diversifolia*, *L. collinsii* and *L. pallida* to breed for high resistant species (Bray and Woodroffe, 1988; Bray, 1992; Wheeler *et al.*, 1988; Napompeth, 1994). Of the hybrid proven to be more resistant include hybrids of *L. diversifolia* x *L. pallida*, *L. diversifolia* x *L. leucocephala* and *L. leucocephala* x *L. pallida* (Napompeth, 1994). Some of these hybrids are now being tried in Kenya and Tanzania (Hertel *et al.*, 1994).

2.2.7.4 Cultural tactics

Currently ICRAF (International Center for Research in Agroforestry) and agroforestry extension services have stopped promoting *Leucaena leucocephala* as an agroforestry tree species, while awaiting for effective pest management measures (Chilima *et al.*, 1994). The available practical

cultural tactics, for managing leucaena psyllid is planting of alternative multipurpose tree species which are not or less damaged by this insect (Napompeth, 1994). Tree species such as *Gliricidia sepium*, *Senna siamea* and *Sesbania sesban* could be used (Chilima *et al.*, 1994; Napompeth, 1994).

However, the main problem with this approach is that trees which would be used to substitute leucaena might not have many beneficial uses as leucaena, and farmers may therefore not easily be persuaded to take up the replacement.

2.2.7.5 Regulatory tactics

There is continuing risk from exotic pests and diseases, particularly with the much increase in international trade and traffic, and also the prevailing winds. Although it is still believed that the spread of leucaena psyllid is caused by wind currents and air drifts, the rapid invasion to different parts of the world especially in Africa indicates that this spread has a combination of extremely efficient dispersal mechanisms (Napompeth, 1994). Based on experiences in Asian-Pacific regions, attempts to limit the rate of spread through increased plant inspection and quarantine procedures, could also be used to slow down the rate of spread in Africa (Napompeth, 1994).

2.2.8 Sampling techniques for assessing psyllid populations

Sampling techniques can be designed to estimate the total population in a given area, or can be designed to indicate comparative population level. However, many pest management programs do not require exact estimates of population densities, but rather require that pest populations are categorized into density classes which are related to predictable levels of crop loss (Southwood, 1987). As it is normally impossible to count all individuals in a population, most field studies involve some methods of estimating the populations from samples. Sampling of a particular insect population must be based on the distribution and life cycle of the insect involved. If life cycle is known, preliminary work is necessary to gain some knowledge of the distribution of the insects and work involved in sampling.

There are several methods of assessing the number of psyllid population (Bray, 1992), but two methods are widely used (Bray *et al.*, 1989). These are counting of the psyllid populations and censuring methods. The censuring method which is primarily designed to determine much more clearly the relationship between the plant shoot phenology and psyllid abundance, is non-destructive and the sampler returns to the same tree on subsequent occasions (Guan-soon *et al.*, 1989). In this method, the subjective damage ratings developed by Bray and Woodroffe (1988) and Wheeler (1988), is widely used. It can be modified for convenience of the research (Madoffe and Massawe 1994; Hertel *et al.*, 1994). This method

has been quite effective, but it gives no indication of the real loss due to psyllid infestation (Bray, 1992).

The counting method is destructive to the trees and has some effect on the population. Elder and Mayer (1990) suggests that this method gives gross under estimation of the eggs present and is unable to distinguish between levels of nymph infestation. However, accurate estimation of eggs and nymphs number must apparently involve time consuming laboratory counts (Bray, 1992).

CHAPTER THREE**3 MATERIALS AND METHODS****3.1 Site description****3.1.1 Location of the experimental site**

The experiment was carried out in one of the crop science screen houses, located within the main campus of Sokoine University of Agriculture at 6°50'27'' and 37°38'59'' at about 530m above sea level. The campus is about 3.5km. from Morogoro town.

3.1.2 Climate

The area experiences a bimodal rainfall regime (Table 2), with short and long rains during November to December and February to May respectively. The annual rainfall ranges from 600-1000mm with peak rains in April. The area experiences semi humid type of climate with most rains falling within a period of seven months from November to May.

Mean monthly temperature ranges from 15-35°C with hottest period between October and January, while June and July are usually the coldest months in a normal year.

Table 2 The mean annual rainfall (mm) for 1985 - 1995 at Morogoro region.

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1985	11	159	107	135	118	1	17	10	1	14	59	43
1986	135	70	157	143	158	11	2	7	1	38	176	156
1987	109	75	66	108	133	0	4	9	0	44	36	29
1988	94	34	192	87	13	45	0	18	33	28	58	170
1989	229	7	146	250	113	12	4	7	0	72	86	103
1990	84	180	229	194	57	10	9	7	31	7	159	68
1991	85	1	95	212	66	3	27	3	10	7	18	184
1992	13	46	85	240	87	22	5	0	2	0	118	111
1993	32	167	118	296	101	13	5	3	5	46	37	1
1994	54	135	77	169	88	8	37	19	6	26	43	49
1995	142	99	202	247	134	0	1	29	13	65	1	73

Source: Sokoine University of Agriculture weather station.

Mean monthly relative humidity vary from 40% to 70% with absolute relative humidity varying from 28% to 100%. Usually the values are at maximum in April and minimum in October.

3.2 Experimental material

3.2.1 Seedlings

Leucaena leucocephala seeds were obtained from National Tree seed Programme (NTSP) situated in Morogoro region. Treated by hot wire, the seeds were directly sown in 10cm layflat diameter and 24cm long polythene tube each field with 1884cm³ of potting mixture. The potting mixture was made up of three parts of forest top soil (collected from leucaena plantation), two parts of river sand and two parts of animal manure. Fifteen weeks after sowing the seedlings were severed at 10cm from the pot mixture and grown for another two weeks period in order to coppice. The seedlings were watered on daily basis at early mornings. Weeds were removed (uprooted) once spotted.

3.2.4 Shades

Local shades made of sisal threads and pieces of timber were used over the shading treatments (Plate 1).



Plate 1 Local shades made of sisal threads and pieces of timber.

3.2.3 *Leucaena* psyllid

Psyllid infested shoots were collected at Melela farm and around Departmental of Forest Biology nursery at the University. Shoots were closely examined for the presence (psyllid parasitoid) *Tamarixia leucaenae* and any other possible predator and/or parasitoids before cutting. Shoots

with signs of, or any natural enemies were rejected or the infested part or the natural enemy was removed before cutting. The shoots were directly cut into polythene bags early in the morning and put in a refrigerator before psyllid counting.

3.3 Experimental design

A split plot experiment arranged in complete randomized block design was used, with three replications. Two different experiments, one with three subjective levels of shading (light, moderate, and heavy) and the other with three levels of watering (daily, after every other day, and once a week) were used as split plots while two level of infestation (infested and non-infested seedlings) formed the main plots. The main plots were screened from psyllid by using fine netting material. The whole experiment was housed under a transparent roofed house with wire mesh and glass enclosure. Each units included 16 seedlings (4 x 4 seedling plot) placed 30 cm apart with 10 cm between plants. Therefore, total number of seedlings per experiment were 288 (that is 16 seedlings/unit x 3 units/block x 3 blocks x 2 plots (main plots)). In the infested plots, each seedling were loosely tied with a single infested leucaena shoot collected from the field.

3.4 Life cycle determination

Three cages (made of fine netting materials) each containing uninfested leucaena seedlings were used for the study. Each seedling was infested

with six adult psyllids. All adults were removed from the cages immediately after depositing some eggs on the shoots. Hand lens (x10 magnification) was used to monitor daily changes from eggs to adult.

3.5 Data collection

3.5.1 Seedling diameter and height determination

These variables were measured at the start of the experiment and thereafter fortnightly. Vernier calliper and a ruler were used for diameter and height measurements respectively. All measurements were taken on 4 cm mark measured from the pot soil mixture level.

3.5.2 Biomass production

At the beginning of the experiment, twenty seedlings randomly selected from the same nursery stock were uprooted and roots were carefully washed to remove soil material. Green weight of roots and shoots were determined separately, and then oven dried at 80°C to constant weight for determination of plant dry weight as representative for the whole plant material of the experiment. At the end of the experiment dry weight of two randomly picked seedlings per plot was determined. For the infested seedlings, psyllid (eggs, nymphs and adults) were removed before oven drying.

3.5.3 Psyllid counts, damage level and shoot health

Psyllid population (Nymphs), damage level and shoot health were recorded fortnightly using empirical scores of 0 to 4, 1 to 9, and 1 to 5, respectively (Table 3).

3.6.4 Life cycle

The duration for each developmental stage from egg through adult was recorded.

3.7 Data analysis

Data were analyzed by using SAS software (SAS Institute, 1985). Analysis of variance (ANOVA) was performed on the effect of leucaena psyllid on mean height, diameter and weight production to test the differences between these variables among the main plots (infested and uninfested seedlings) and the split plots (watering and shading levels). Descriptive statistics was used to test the rate of defoliation, shoot health and nymph population counts. Correlation between nymph counts to level of damage and shoot health were determined by using simple linear regression (SLR). Least significant difference (LSD) was used to separate differing means.

Table 3 The mean scores for damage ratings, shoot health and nymph population counts

Damage ratings	Nymph population count	Shoot health score
1 - No damage	0 - None	1 - No damage
2 - Slight curling of leaves	1 - 1-5 nymphs	2 - Slight damage
3 - Tips and leaves curled and yellowish	2 - 6-30 nymphs	3 - Heavy damage
4 - Tips and leaves badly curled and yellowish	3 - 31-100 nymphs	4 - Dead
5 - Loss of up to 25 percent of young leaves	4 - >100 nymphs	
6 - Loss of 26 to 50 per cent of young leaves	5 - >100 nymphs extends to the stems	
7 - Loss 51 to 75 per cent of young leaves		
8 - Loss of 100 per cent of leaves and blackening of lower leaves		
9 - Blackening stem with total leave loss		

Source: Bray and Woodroffe, (1988)

CHAPTER FOUR

4 RESULTS

4.1 Performance of the seedlings

Germination started three days after seed sowing. Seedling growth was rapid. Six weeks after sowing, the mean seedling height and diameter was about 65cm and 0.4cm respectively. At about two weeks after shoot pruning, the mean height for the seedlings was about 15.5cm mean diameter was about 0.43cm. Most infested seedlings were severely defoliated between the eighth and tenth week of infestation. On the tenth week after infestation, non-infested seedlings looked healthier than infested seedlings (Plates 2(i) and (ii)). Some shoots were also covered with honey dew and mold (blackish substance). On the twelfth week some of the heavily defoliated seedlings started to sprout, however, most sprouting shoots were quickly covered by psyllid eggs and nymphs.



ii



Plate 2 Appearance of non-infested (i) and infested (ii) seedlings on the tenth week of infestation.

4.2 Watering Experiment

4.2.1 Height and diameter

Height and diameter growth for both infested and non-infested seedlings increased throughout the experimental period, however the growth rates for the former seedlings were highly affected by leucaena psyllid attack (Figs. 1 and 2). Overall seedlings in the infested plots were shorter and thinner than in the non-infested plots and height was the most affected variable. Growth rate (Height growth rate) of the infested seedlings started to slow down on the fourth week after the infestation and after the ninth week growth was almost constant for all watering treatments. The growth rate (height) for the non-infested seedlings also declined, (at smaller rates) with time. Diameter growth for infested seedlings started to decline in the twelfth week of infestation while the growth was almost constant for the uninfested seedlings. Height and diameter growth for (the weekly watered) infested seedlings were more affected than the daily watered seedlings.

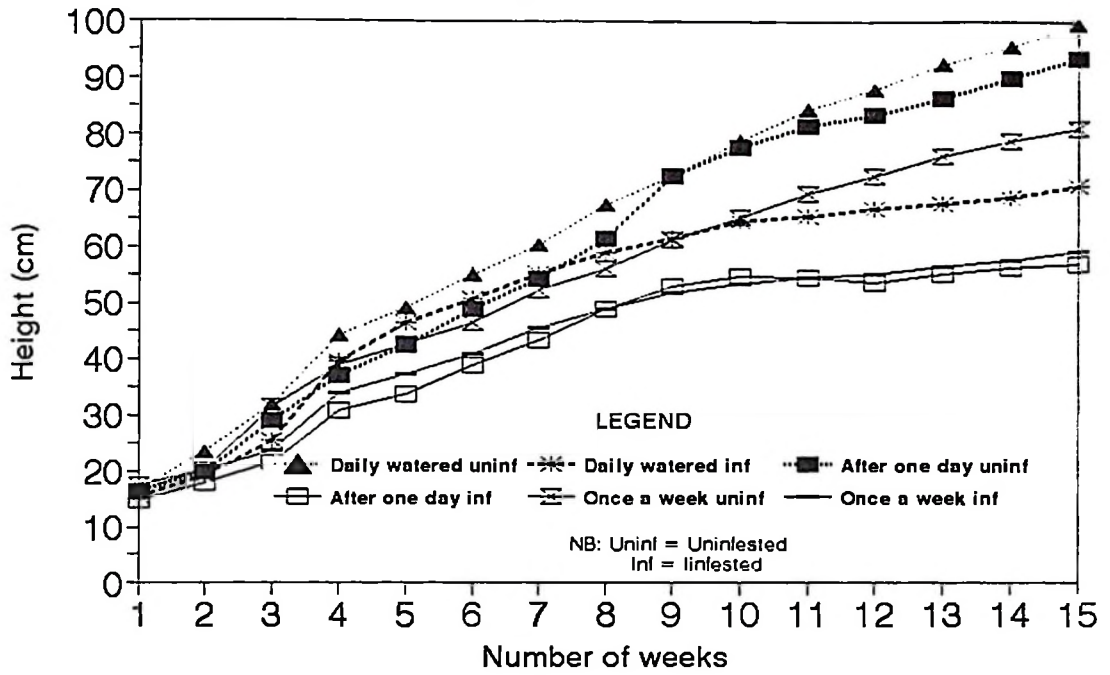


Fig. 1 The mean height growth over fifteen weeks for infested and non-infested leucaena seedlings watered at different levels.

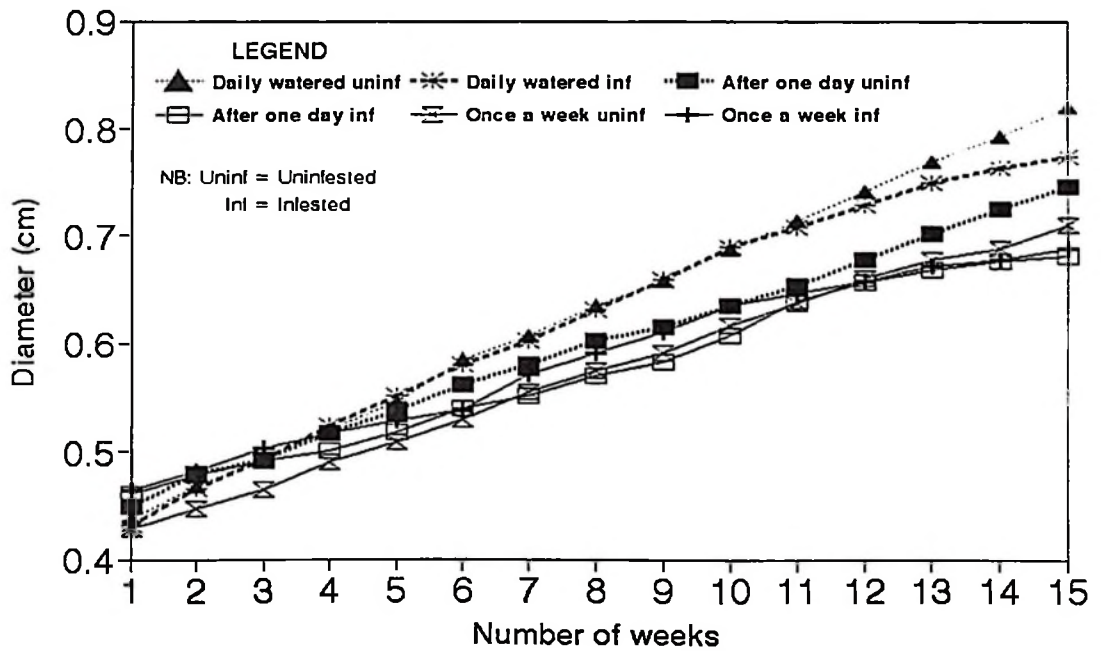


Fig.2 The mean diameter growth over fifteen weeks for infested and non-infested leucaena seedlings watered at different levels.

Height growth was significantly different ($p < 0.05$) between infestation and watering levels (Table 4). On the other hand, diameter growth was significantly different ($p < 0.05$) among watering levels and not significant between infestations. Mean values for height and diameter growth, showed that, infested seedlings watered daily, was significantly different ($p < 0.05$) from those watered every other day and weekly. The later two treatments were not significantly different (Table 6).

Table 4 Height and diameter growth for leucaena seedlings growing under different watering regimes for fifteen weeks with and without psyllid.

Source	Df	F-ratio	
		Diameter (cm)	Height (cm)
Infestation	1	0.02	48.00*
Watering levels	2	6.96*	4.51*
Infestation x Watering	2	1.38	0.58

* Significant at $p < 0.05$

4.2.2 Shoot and root biomass production

Figures 3, 4, and 5 show the mean biomass production (expressed as oven dry weight) for different watering levels after fifteen weeks growth. It is evidently shown that the infested seedlings produced lower biomass compared to non-infested seedlings (Fig. 3). Seedlings watered once a week

produced shoot biomass of 4.5g (infested) and 6.0g (non-infested). Conversely, seedlings watered daily produced 9.0g and 13.5g for infested and non-infested respectively. On the other hand infestation did not appear to have a serious impact on the root biomass production (Fig. 4). Seedlings watered daily produced root biomass of 8.4g (infested) and 8.7g (non-infested) while seedlings watered once a week produced 5.2g and 4.7g respectively. Psyllid attack reduced the whole plant biomass production for all the watering treatments (Fig. 5). Seedlings watered once a week produced 9.8g (infested) and 11.2g (uninfested) while those watered daily produced 17.8g and 22.3g respectively.

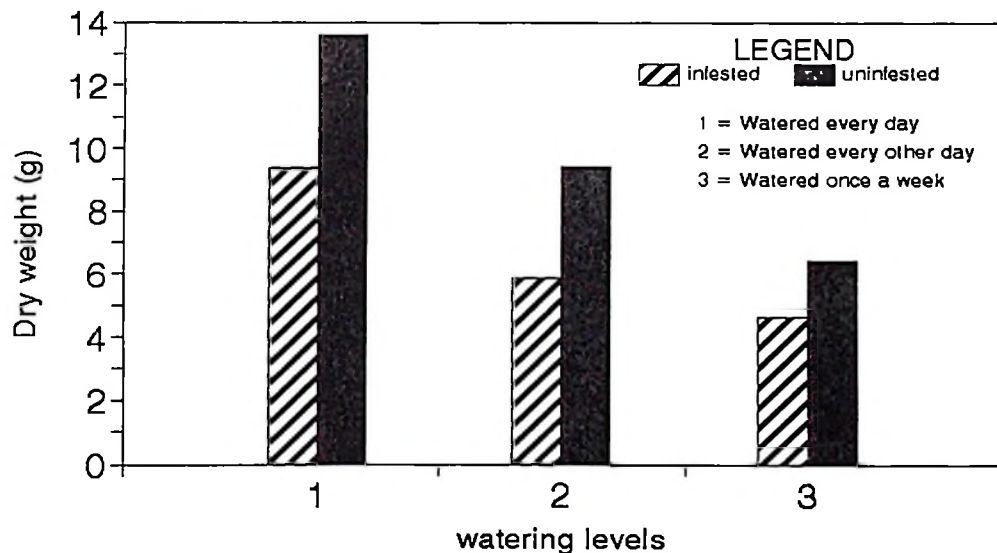


Fig. 3 Mean shoot dry weight production(g) between infested and non-infested seedlings growing at different watering levels at the fifteenth week of infestation.

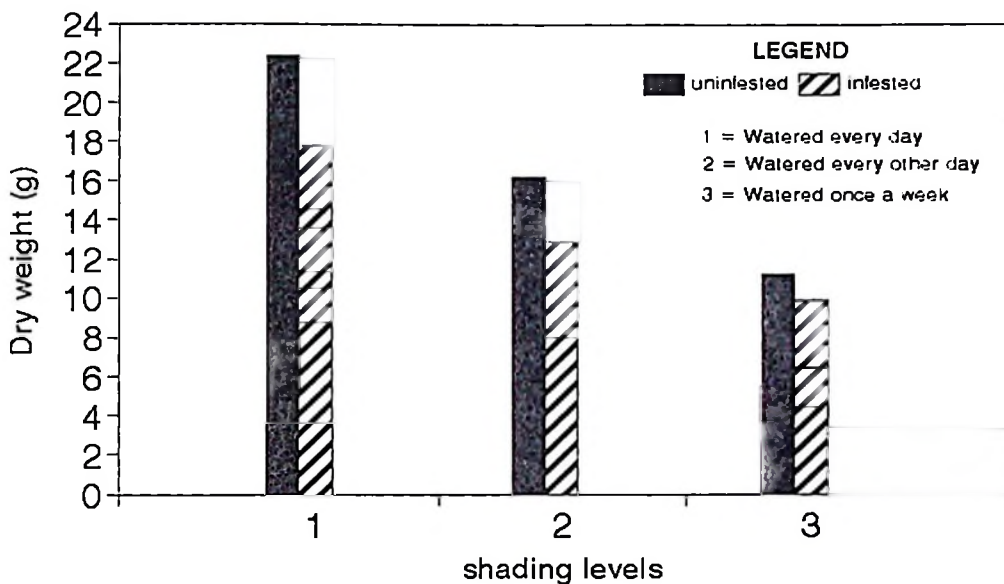


Fig. 5 The overall mean biomass production(g) for infested and non-infested seedlings growing at different watering levels at the fifteenth week of infestation.

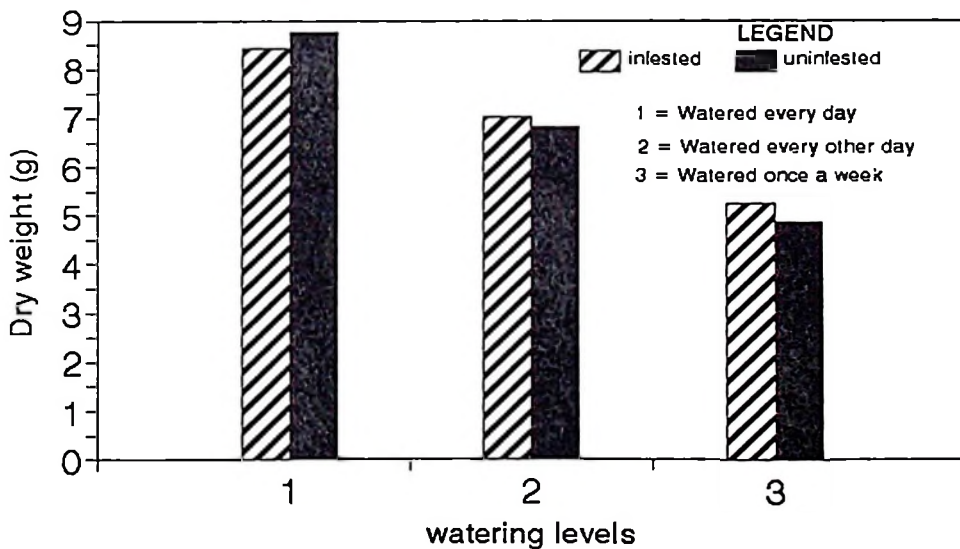


Fig. 4 Mean root dry weight production(g) between infested and non-infested seedlings growing at different watering levels at the fifteenth week of infestation.

Mean shoot dry weight production (g) were significantly different ($p < 0.05$) between infestation and watering levels. Root biomass differed significantly ($p < 0.05$) among treatments but not between infestations (Table 5). Similarly, the whole plant biomass production was significantly different ($p < 0.05$) among treatments and not significantly different between infestations.

Table 5. Mean biomass production for infested and non-infested leucaena seedlings growing under different watering levels after fifteen weeks.

Source	DF	F - ratio		
		Root dry weight	shoot dry weight	Total plant weight
Infestation	1	0.03	50.53*	4.44
Watering levels	2	40.05*	18.42*	7.81*
Infestation x Watering levels	2	0.33	0.83	0.06

* Significant at $p < 0.05$

Separating the mean values for total biomass production by Least Significant difference (LSD) infested seedlings watered daily were significantly different ($p < 0.05$) between seedlings watered every other day and once a week (Table 6). Seedlings watered after every other day were not significantly different from those watered on weekly basis.

Table 6. Mean growth for leucaena seedlings watered at different levels after fifteen weeks of infestation.

Watering Treatments	Height (cm)	Diameter (cm)	Dry weight (g)
Every day	57.71a	0.63a	18.95a
Every other day	50.79b	0.59b	14.31b
Once a week	48.67b	0.58b	11.32b

Values followed by different letters in a given column are significantly different ($p < 0.05$); Least Significant Difference (LSD)).

Considering the shoot biomass weight production there is an indication of the seedlings watered after every other day being more attacked by the psyllid (Table 7). At the termination of the experiment, yield loss due to psyllid attack was 9.7%, 18.6%, and 17.2% for watered seedlings daily, after every other day, and weekly, respectively. The losses here were consistent with figures for the whole plant where the overall percentage weight was 3.3%, 4.6%, and 3.3% respectively for seedling watered daily, twice a week and once a week (Table 8).

Table 7. The effect of *Leucaena psyllid* attack on shoot biomass production(g)of dry weight of seedlings growing under different watering levels.

Watering treatments	Yield increment (g)		Yield reduction (%)
	Non-infested	Infested	
Daily	10.68	6.45	9.7
Every other day	6.48	2.96	18.6
Once a week	3.50	1.74	17.2

Table 8. The effect of psyllid attack on the whole plant dry matter production (g) for seedlings growing under different watering levels.

Watering treatments	Yield increment (g)		Yield reduction (%)
	Uninfested	Infested	
Daily	19.42	14.87	3.3
Every other day	13.29	9.97	4.6
once a week	8.32	6.95	3.6

4.2.3 Damage level

Nearly all seedlings in the infested plots were attacked by psyllid in all assessment occasions. The intensity however, varied between the seedlings and assessment periods, with damage increasing with time (Fig. 6). In nearly all the assessment occasions, damage was more severe on seedlings watered once a week and least for those watered after every other day. In

spite of this there was no significant damage differences among the watering levels. Generally, the rate of defoliation was very high from the eleventh week, and at the termination of the experiment nearly all seedlings had lost up to 100 per cent of the young leaves (Plate 9). In addition blackening of the lower leaves and stems was common on most infested seedlings.

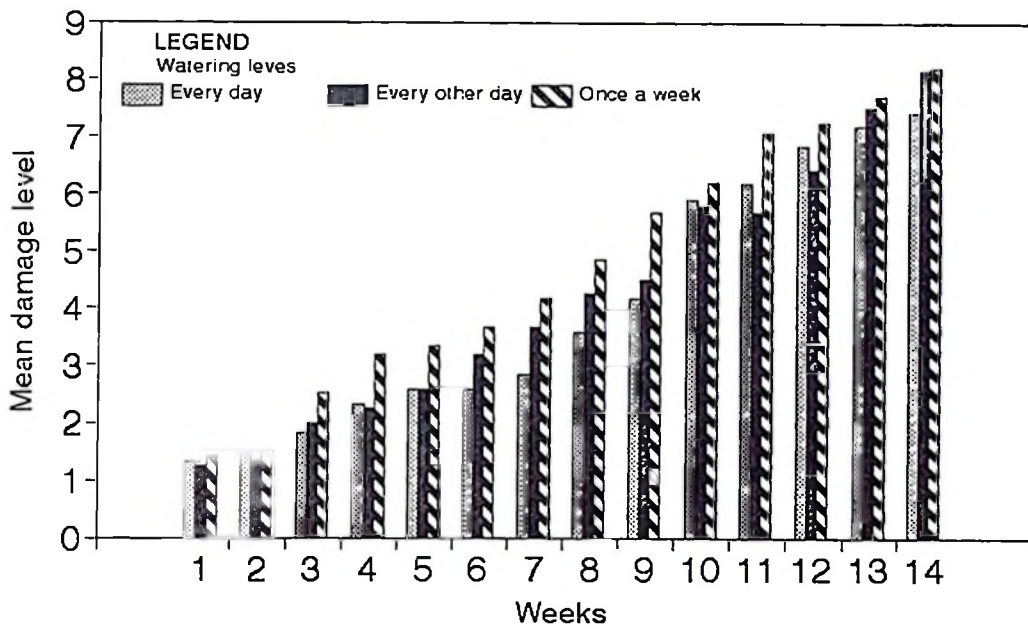


Fig. 6 Weekly mean damage for infested seedlings watered at different levels.

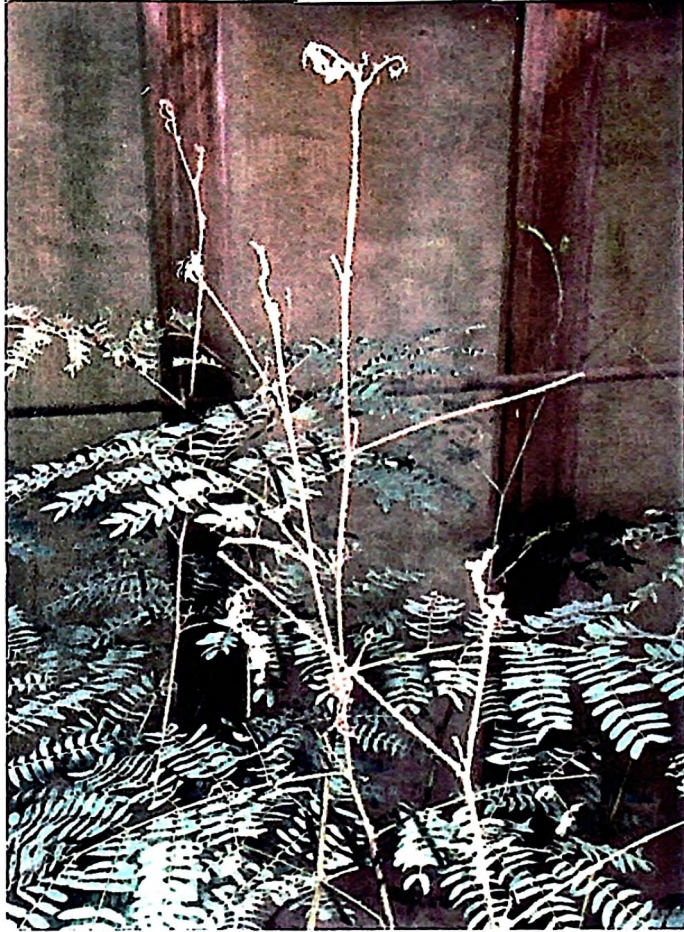


Plate 3 Seedlings defoliation as recorded on the twelfth week of infestation

4.2.4 Shoot health

Results from the infested seedlings showed poor shoot health in all treatment levels (Fig. 7). Shoot health deteriorated with time (between first and ninth week) and after the ninth week, seedlings were heavily damaged and this level remained constant to the end of the experiment. Generally seedlings watered once a week appeared to be unhealthy compared to seedlings in the other two treatments. In spite of this, health score did not demonstrate significant differences between the three treatments. No seedling mortality was observed in all assessment occasions. Conversely, the non-infested seedlings remained healthy for the whole experimental period.

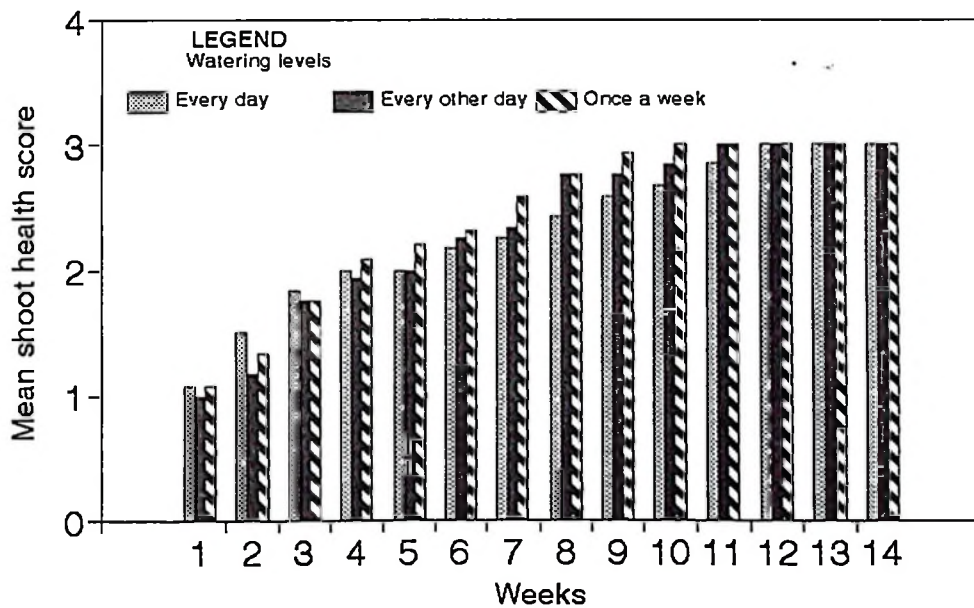


Fig.7 Weekly shoot health score for infested seedlings watered at different levels.

4.2.5 Nymph counts

Population of leucaena psyllid nymph fluctuated throughout the assessment period and treatment levels (Fig. 8). The increase was fairly fast (1-4 count levels) for the first eight weeks and thereafter declined gradually towards the end of the experiment. The count was 1-5 nymphs during the first week, and at the eighth week, population was about 30-100 nymphs for seedlings watered daily and every other day, and more than 100 for seedlings watered once a week. On the average, water stressed plants had higher records of nymph than in the unstressed seedlings for the first ten weeks. Conversely, there was an indication of declining population in the stressed seedlings between the eleventh and fourteenth week.

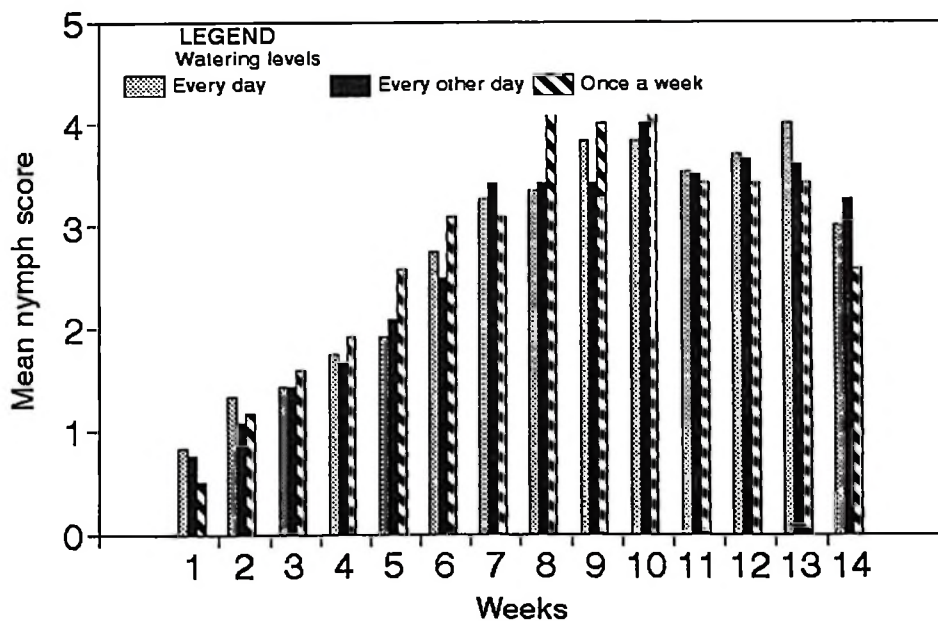


Fig. 8 Weekly mean nymph score for infested seedlings watered at different levels.

4.3 Shading Experiment

4.3.1 Height and Diameter growth

Figures 9 and 10 show the effect of shading on height and diameter growth for the infested and non-infested seedlings. There was gradual height increase for the first eight weeks for both infested and non-infested seedlings (Fig. 9). The non-infested seedlings continued to grow at a decreasing rate. The heavily shaded seedlings were more affected. Conversely, infestation affected height growth, the heavily shaded seedlings (50%) suffering more. From the fourth to the eighth week, there was a remarkable declining height growth for the infested seedlings. From the ninth week, height remained almost ceased (on average 64cm) to the end of the experiment. Diameter growth appeared to be less affected by the psyllid for infested seedlings. There was however, an indication that diameter growth suffered more for the heavily shaded (50%) seedlings.

Height growth was significantly different ($p < 0.05$) between infestations and was not significant between shading levels. Diameter growth was significantly different ($p < 0.05$) between shading levels and not significantly different between infestations (Table 9). Separating the mean values for height and diameter growth, infested seedlings shaded at 10% were significantly different ($p < 0.05$) from those shaded at 25% and at 50%. The later two treatments were not significantly different (Table 11).

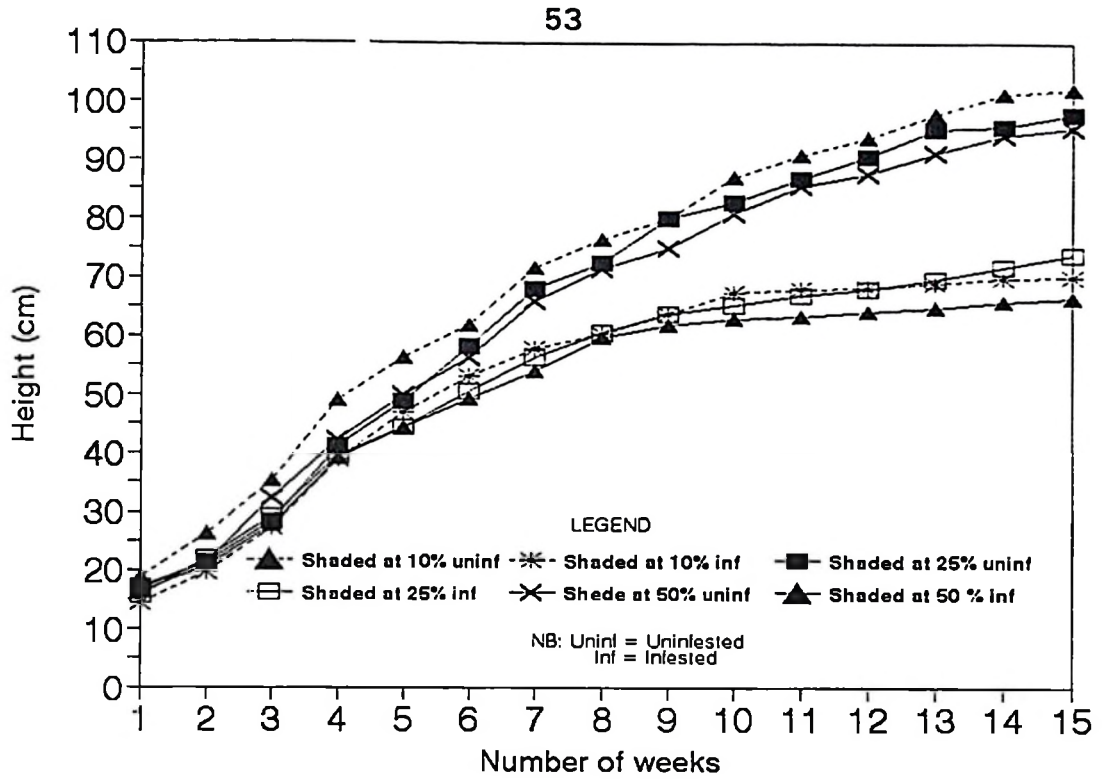


Fig. 9 The mean height growth over fifteen weeks for infested and non-infested leucaena seedlings shaded at different levels

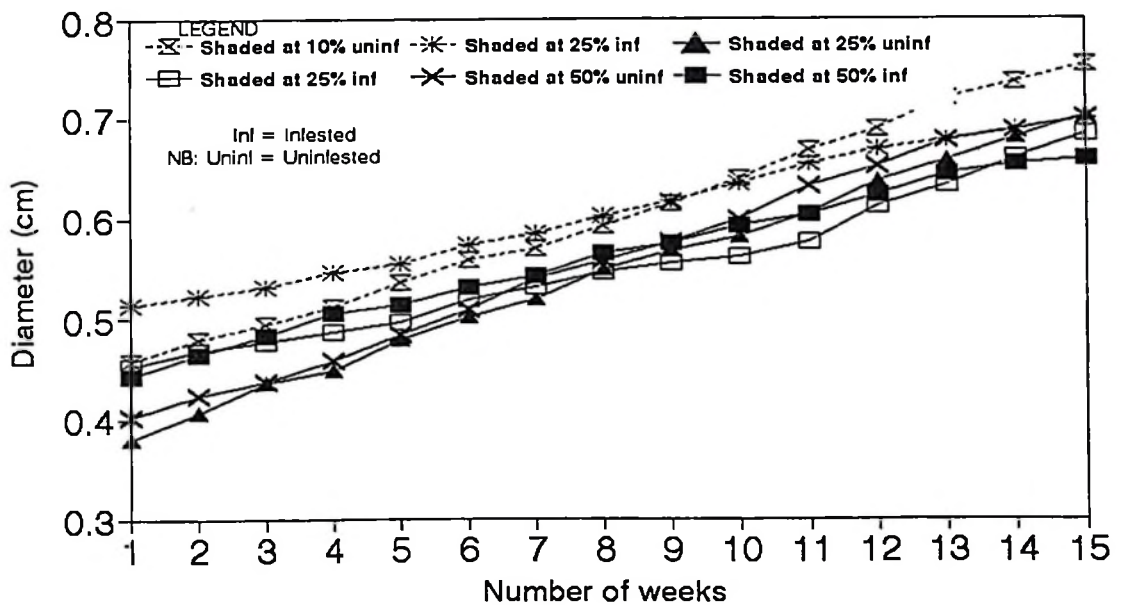


Fig. 10 The mean diameter growth over fifteen weeks for infested and non-infested leucaena seedlings shaded at different levels.

Table 9 Height and Diameter growth for seedlings growing under different shading levels.

Source	Df	F-ratio	
		Diameter (cm)	Height (cm)
Infestation	1	4.15	108.19*
Shading level	2	6.43*	0.49
Shading level x Infestation	2	0.07	0.25

* Significant at $p < 0.05$

4.3.2 Shoot and root biomass production

Figures 11, 12 and 13 shows mean biomass production (expressed as oven dry weight) for three shading levels after fifteen weeks growth. The infested seedlings produced lower shoot biomass compared to non-infested seedlings for all treatments (Fig. 11). Seedlings shaded at 50% produced shoot biomass of 6.5g (infested) and 10.5g (non-infested). Seedlings shaded at 10% produced 5.0g (infested) and 11.5g (non-infested). On the other hand infestation did not appear to have a serious impact on the root biomass production (Fig. 12). Seedlings shaded at 10% produced root biomass of 4.2g (infested) and 6.0g (non-infested) while those shaded at 50% produced 6.7g and 7.5g respectively. Psyllid attack reduced the whole plant biomass production for all the shading treatments (Fig. 13). Seedlings shaded at 50% produced 14.1g (non-infested) and 9.3g

(infested), while those shaded at 10% produced 14.57g and 6.03g for non-infested and infested respectively.

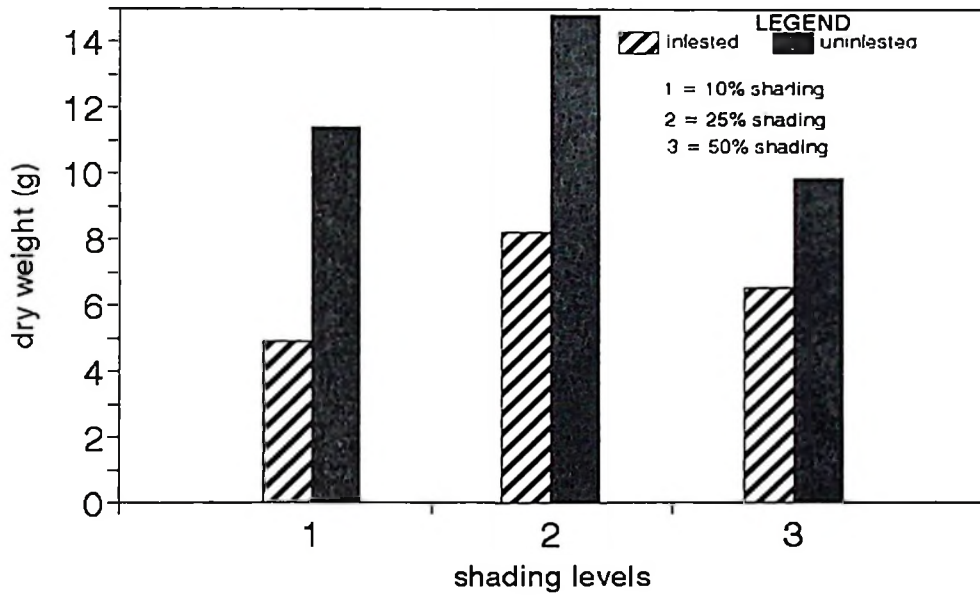


Fig. 11 Mean shoot dry weight production(g) between infested and non-infested seedlings growing at different shading levels at the fifteenth week of infestation.

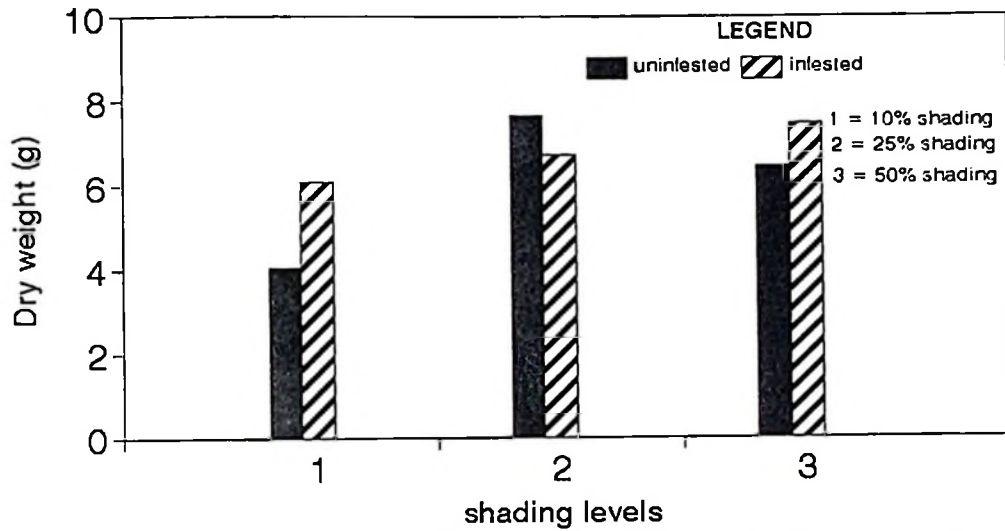


Fig. 12 Mean root dry weight production(g) between infested and non-infested seedlings growing at different shading levels at the fifteenth week of infestation.

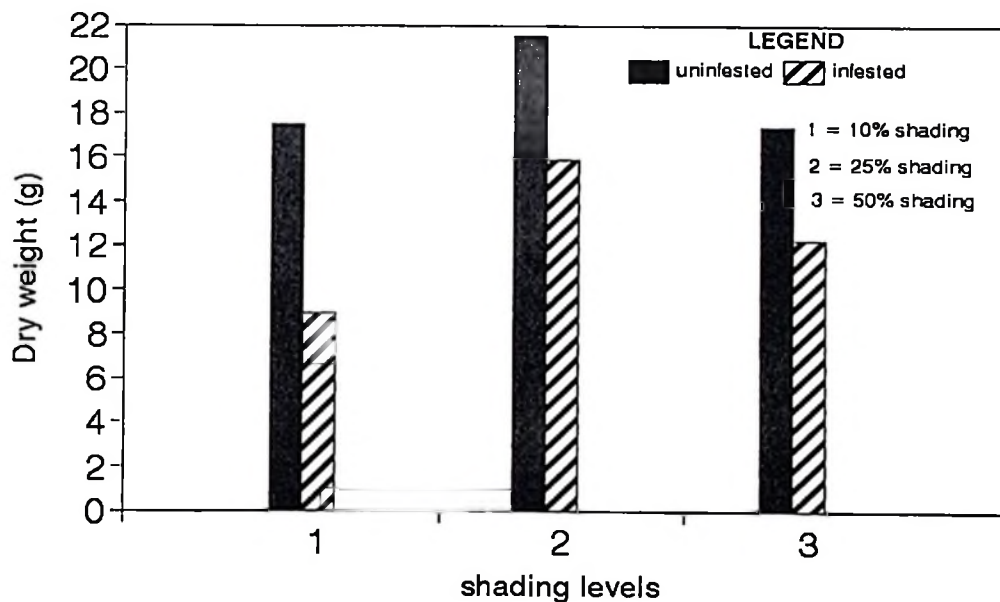


Fig. 13 The overall mean biomass production(g) between infested and non-infested seedlings growing at different shading levels at the fifteenth week of infestation.

Statistically, the mean shoot dry weight production were significantly different ($p < 0.05$) among infestation and shading levels, while root biomass production were not significantly different ($p < 0.05$) between treatments and between infestations (Table 10). Further more, the whole plant biomass production was significantly different ($p < 0.05$) between treatments and between infestations.

Table 10. Mean biomass production(g) for infested and non-infested leucaena seedlings growing under different shading levels.

Source	DF	F - ratio		
		Root dry weight	Shoot dry weight	Total plant weight
Infestation	1	0.25	68.27*	20.62*
Shading level	2	2.19	13.47*	8.66*
Infestation x Shading level	2	3.28	2.97	1.52

* Significant at $p < 0.05$

Separating the mean values for total biomass production, infested seedlings shaded at 25% were significantly different ($p < 0.05$) from those shaded at 10% and at 50% (Table 11). Seedlings shaded at 10% were not significantly different from those shaded at 50%.

Table 11. Mean growth for leucaena seedlings shaded at different levels after fifteen weeks of infestation.

Treatments	Height	Diameter	Dry weight
Shaded at 10%	61.09a	0.60a	15.33b
Shaded at 25%	59.22b	0.56b	18.67a
Shaded at 50%	57.66b	0.56b	13.20b

Values with different letters in a give column are significantly different ($p < 0.05$); Least significant difference (LSD)).

Considering the shoot biomass weight production there is an indication of the seedlings shaded at 10% being more affected by psyllid attack (Table 12). At the termination of the experiment yield loss due to psyllid attack was 20.1%, 6.1% and 9.1% for seedlings shaded at 10%, 25% and 50% respectively. The loses here was consistent with figures for the whole plant where the percentage weight loss expressed as oven dry weight was 15.9%, 4.8%, and 7.0% for seedlings shaded at 10%, 25%, and 50% respectively (Table 13).

Table 12. The effect of leucaena psyllid attack on shoot biomass production of seedlings growing under different shading levels.

Shading treatments	Yield increment (g)		Yield reduction (%)
	Non-infested	Infested	
Shading to 10%	9.64	3.15	20.1
Shading to 25%	13.25	6.50	6.1
Shading to 50%	8.13	4.76	9.1

Table 13. The effect of leucaena psyllid on the whole plant dry matter production for seedlings shaded at different levels.

Shading treatments	Yield increment (g)		Yield reduction (%)
	Non-infested	Infested	
Shading at 10%	14.57	6.03	15.87
Shading at 25%	18.58	12.94	4.79
Shading at 50%	14.41	9.31	6.98

4.3.3 Damage level

The rate of seedling damage on the shading experiment increased slowly for the first seven weeks and thereafter increased gradually towards the thirteenth week before declining again (Fig. 14). The highest damage (7-8 damage level) was recorded between 11 and 13. Seedlings shaded at 10 per cent appeared to be the most affected by the attack, followed by 25 per cent shaded seedlings. The mean damage level for all treatment levels was

approximately 8 (loss of 100 percent of the young leaves plus blackening of lower leaves).

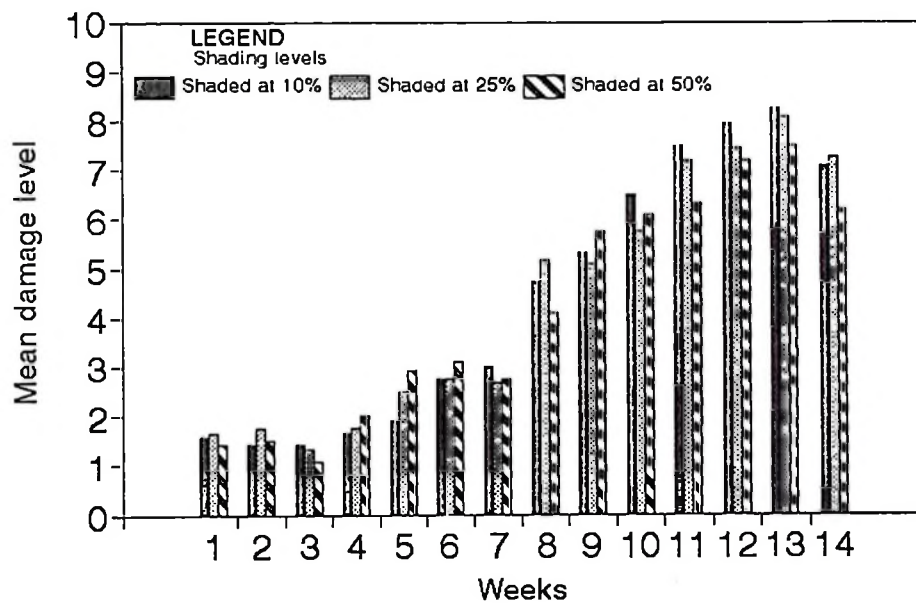


Fig. 14 The mean damage for infested seedlings shaded at different levels.

4.3.4 Shoot health

Fig. 15 represents the mean shoot health for seedlings shaded at different levels. The rate of damage seemed to increase with the assessment occasions, and from the eighth week to the end of the experiment, shoot health remained almost constant (3 = heavy damage). Seedlings shaded at 10 per cent appeared unhealthier than seedlings at other shading levels. In this experiment, seedling shoot health was not significantly different ($p < 0.05$) among shading levels.

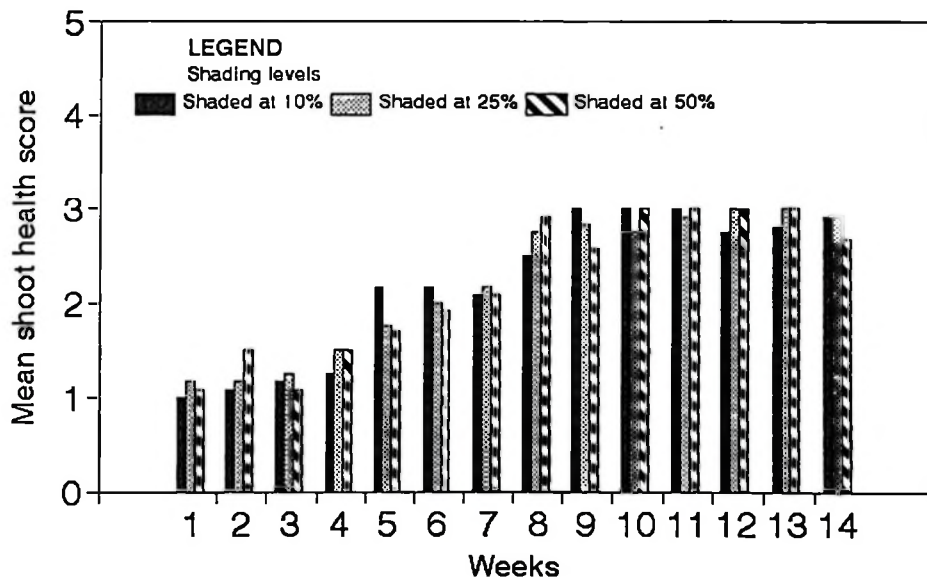


Fig. 15 Weekly mean shoot health score for infested seedlings shaded at different levels.

4.3.5 Nymph count

Leucaena psyllid nymph counts fluctuated with the assessment period (Fig. 16). The increase was fairly low (1-2) in the first six weeks of infestation and more or less constant (3-4) for the rest of the assessment period. Generally, lightly shaded seedlings (10%) had higher records of nymph than other shading levels in the first nine weeks. The mild shaded seedlings (25%) appeared to be less favoured to the psyllid than the other two treatments.

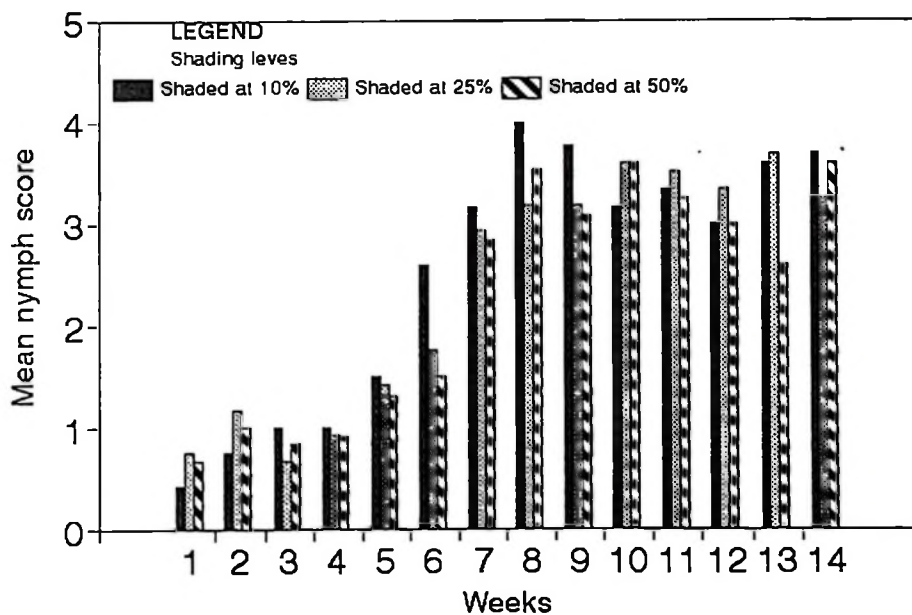


Fig. 16 Weekly mean nymph score for infested seedlings shaded at different levels

4.4 The relationship between psyllid nymph counts to damage level and shoot health

Table 12 show the relationship between psyllid nymph population to damage level and seedlings shoot health for both experiments (watering and shading experiments). In both variables (damage level and shoot health) showed strong correlation to nymph counts. However, the relationship was stronger for shoot health than to damage level (Table 14).

Table 14. Regression equations relating psyllid nymph population to rate of damage and seedlings shoot health.

Type of experiment	Variables	Equations	r-value
Watering experiment	Damage level	$Y = -0.5 + 1.74x$	0.71
	Shoot health	$Y = 0.72 + 0.59x$	0.90
Shading experiment	Damage level	$Y = -0.25 + 1.92x$	0.81
	Shoot health	$Y = 0.79 + 0.61x$	0.94

4.5 Life cycle determination

Eggs were laid on a very young, just expanding leucaena leaves. The newly laid eggs were whitish in colour, and two days after deposition they changed into light yellow. Eggs hatched to nymph between the fourth and fifth day on the same depositing site. Nymph development was consistent

with the leave opening. The duration of each instar stage was 3, 2.5, 2.5, and 3 days for four instars respectively, and the life cycle from the egg stage to adult stage was found to be ranging from 16-19 days. Each instar differed from the other in colour and size. The first instar was yellow, followed by orange for second instar, green for third instar, light green with almost full development for the fourth instar and the adults were orange and bigger than the nymphal instars.

CHAPTER FIVE

5 DISCUSSION

5.1 Watering experiment

5.1.1 Effect of *Leucaena psyllid* attack on *leucaena*

Drought treatment suppressed tree growth, as indicated by consistently lower height, and diameter as well as biomass shoot weight production, in both infested and non-infested seedlings. However, decreased weight, height and diameter in the infested seedlings was more serious than in uninfested seedlings, due to the effect of psyllid attack. High defoliation rate and blackening of lower leaves due to secretion of honeydew by the *leucaena psyllid* was probably the main cause of the effect mentioned above. However, the effect seem to be limited to the shoot growth more than in the root growth.

Results from this study have demonstrate growth loss of the *leucaena* trees most likely as a result of *leucaena psyllid* attack. The effect observed in this study after fifteen weeks of infestation indicate that water stressed seedlings have low defensive mechanisms (Rhodes, 1985) making them more prone to attack by the psyllid than healthy and non-stressed seedlings (NFTH, 1988; Villacarlos *et al.*, 1989).

Growth differences for height and diameter started to manifest from the

fourth week of infestation in the infested seedlings while, in the uninfested seedlings started from the seventh week. The gap between infested and uninfested seedlings was getting wider towards the end of the experiment. This gap would probably increase with time. Bray and Woodroffe (1991) showed that infested coppices of leucaena plants had 47% fresh weight loss in growth after seven months. Further they demonstrated that after another seven months fresh weight loss increased to 80%. This is consistent with the assumption in this study that the difference in growth would have increased with time.

In another study Lapis and Borden (1992) found low weight and diameter growth leucaena seedlings infested for fourteen weeks than in uninfested seedlings. Palmer *et al.*, (1989) also observed reduction of 45% of leucaena plants due to psyllid attack. These observations concur with the results from this study and clearly indicate that, leucaena psyllid infestation does seedlings reduce growth and yield. Thus it is possible that there are long term effects of psyllid infestation in depressing yield especially for leucaena trees managed for timber or wood production.

Based on the literature comparing the effect of leucaena psyllid attack on different water stressed seedlings, more effect was expected on the highly stressed seedlings (Mattson and Haack, 1987). In contrast to this more effect was observed on the moderately stressed seedling (watered after

every other day). This results did not consistently support the hypothesis advanced by White (1974; 1976) and Mattson and Haack (1987) that, herbivores insects perform well on highly stressed seedlings. On the other hand an alternative hypothesis that insects may perform better on less-stressed plants was supported (Craig *et al.*, 1987).

It has long been recognised that drought stress leads to high psyllid infestations by the psyllid on the leucaena plants (Mangoendihardjo *et al.*, 1989; Villacarlos *et al.*, 1989; Napompeth 1989, 1994 Madoffe and Massawe, 1994). Larsson (1989) ranked sucking insects as highly sensitive in response to drought stress, but levels of stress induced is important to evoke the insects. Larsson and Bjorkman (1993) found no significant difference on the performance of phloem feeding insects (*Cinara costata*) between infested and non-infested plants. On the other hand Craig *et al.* (1987) found that *Neodiprion* sp sawflies perform better on non-stressed plants. The probable reason for the above contrary observation is either plants were too stressed or too little stressed to influence the performance of insects.

There are several factors that could contributed to the results recorded in this study. Water stress affects oviposition and subsequent egg survival of the herbivore insects (Wagner and Frantz, 1990). Thus as stress increases a threshold is reached at which herbivore performance is optimum. A plant

under moderate water stress may provide conditions for optimum psyllid survival and reproduction. Hence, providing better site for oviposition and survival of the eggs. Bearing in mind that psyllid feed by sucking sap from the host tree it is possible for moderately stressed seedlings to experience more effect as compared to highly stressed seedlings (Napompeth, 1994).

Report by Mangoendihardjo *et al.* (1989) Villacarlos *et al.* (1989) Madoffe and Massawe (1994) on the psyllid population dynamics show that extreme drought influences psyllid populations. More severe drought may deteriorate the quality of the plant to a point where food is of poorer quality to psyllid than either a more moderately or even vigorous grown seedlings. Therefore it is possible that the level of drought induced in the seedlings watered once a week was too high, hence affecting the quality of the food provided by those seedlings to the insects.

A third assumption to explain the observed results is that period of exposure to high leucaena psyllid population might have contributed to a large extent to the high loss in the seedlings watered every other day. It is known that even if trees are not stressed long period of exposure to high psyllid population may cause severe damage to the seedlings (Bray and Woodroffe, 1991).

5.1.2 Intensity of leucaena psyllid

Psyllid population increased continuously from the initial infestation to the eighth week and thereafter declined towards the end of the experiment. However, rates of damage increased with higher psyllid density partly because of psyllid number. The magnitude of attack was more pronounced in stressed seedlings than in unstressed seedlings and also varied within the sampled seedlings. It has been suggested that, in spite of varying degree of resistant also stressed seedlings are weaker to attack than health seedlings (Mattson and Haack, 1987; NFTH, 1988; Napompeth, 1994).

The differences in the magnitude of attack in different water stressed seedlings could probably be explained by the changes in the shoot chemistry caused by drought stress (Larsson and Tenow, 1984). Increased amount of soluble carbohydrates (Mattson and Haack, 1987) amino acids (White, 1974) and decreased amount of defensive chemicals (Rhodes, 1985), increased the susceptibility of the host plant to attack especially for phloem feeders (Larsson, 1989).

Results in this study are in agreement with several studies on the population dynamics of leucaena psyllid were psyllid populations fluctuated overtime with the population peaking in the drier period of the year (Krishnamurthy *et al.*, 1989; Mangoendihardjo *et al.*, 1989; Mella *et al.*, 1989; Villacarlos *et al.*, 1989; Madoffe and Massawe, 1994; Napompeth, 1994). For

example, Villacarlos *et al.* (1989) observed that leucaena trees planted near water sources such as rice paddies were not defoliated, unlike trees planted along highways far from water source. Although this was not the case in the current study, it is possible that in the field, sites or localities play an interactive role with the presence of psyllid in promoting leaf fall.

The declining psyllid population towards the termination of the experiment could be associated with major leaf fall. Leaf fall can have constellation of effects on organisms other than the host tree (Day and McLean, 1991). There is a reduction in the habitat available (Parry, 1969) and some direct mortality when psyllid are lost with the falling leaves (Feath *et al.*, 1981), although it is likely that adult psyllid may be sensitive to falling leaves and move before leaf fall.

Contrary to results in this study and some other stress experiments, Larsson and Bjorkman (1993) found insignificant differences in the build-up of aphid densities between drought stressed and unstressed trees. Also Bray and Woodroffe (1988) found that on the sites with favourable moisture regimes leucaena grew continuously throughout the summer but they were very severely damaged than on the other sites where moisture was not favourable for leucaena to grow continuously. The reason lies in the apparent discrete generation of the psyllid. Eggs laid in the young just-expanding leaflets and moisture stressed plants (with no expanding leaves)

do not provide suitable sites for egg laying. It appears therefore that there is certain level of water stress which is favourable for the psyllid population to develop.

Although the damage level was increasing very fast in the seedlings that received water only once a week, the number of psyllid nymphs on this treatment level were decreasing and was increasing very fast in the seedlings receiving water every day compared to other water treatment levels. The reason for this antagonistic increase was probably due to lack of enough oviposition sites (Wagner and Frantz, 1990) and enough food material on the stressed seedlings and higher damage of the seedlings shoots. Increased population on the non-stressed seedlings make them more likely to lose more weight than in other treatment levels, thus it is obvious that even plants that get enough water can be defoliated heavily if exposed to heavy psyllid infestation. For instance, Burdeous (1986) showed that 4-months leucaena seedlings cannot tolerate the feeding of 100 adults allowed to infest the plants for 21 days. There was 40% defoliation of plants after this period. One hundred nymphs can cause defoliation of 36% during the same exposure. It implies that population of about 100 psyllid nymphs on this experiment was too big for the seedlings to withstand the damage although they were well watered.

5.2 Shading experiment

5.2.1 Effect of *Leucaena* psyllid attack on *leucaena*

Soon after commencement of the experiment seedlings in both infested and non-infested plots responded by increasing height of the shoots. In spite of this response, height and diameter growth of the infested plots was less vigorous especially after the fifth week of infestation. At the end of the experiment almost all seedlings in the infested plots were dwarfed, thin and dry weight biomass production was significantly reduced indicating that, *leucaena* psyllid attack is likely to be the main cause of this growth decline for the infested seedlings. However, infestation seems to have had minimal effect on the root growth. Carter and Nichols (1985) demonstrate that shoot infestation can seriously affect the overall height growth of a tree rather than root growth.

Similar to the results from this study Madoffe and Austarå (1990) found that pine woolly aphid cause reduction of height and diameter growth to about 12.2 and 14.1% respectively on *Pinus patula* seedlings. Further, they found about 20% reduction of shoot and stem dry weight biomass production. Contrary to the insignificant root growth due to psyllid infestation in this study, they observed a reduction of about 27.8% in root dry weight biomass production. It is possible that the differences in the duration of the experimental period contributed into this dissimilar results (six weeks as compared to fifteen weeks in the current study).

In this study growth decline was more pronounced in the 10% shaded seedlings and least in the intermediate (25%) shaded seedlings. It appears that, like other insect species, leucaena psyllid respond to shade by changing distribution according to their preferences for light or shade (Day and MacLean, 1991). Light intensity is an important factor for growth (Spur and Barnes, 1964), it also determine the quality of the food of the plant material (Basset, 1992) hence the distribution of insects (Day and MacLean, 1991). High impact observed in the 10% shaded seedlings was probably caused by more psyllid population on this treatment level which resulted into high defoliation of the seedlings. According to Kulman (1971) defoliation of tree result in a loss of stored food and a change in production regulators which will affect the process of photosynthesis and hence growth decline of the host plant. Alternatively, different levels of shading exposed the seedlings into different growth conditions leading to different food qualities (Dubt and Shurer, 1994).

The reason for more damage in the heavily shaded seedlings than in the moderately shaded seedlings may be explained by the findings reported by Dubt and Shurer (1994) that, under deep shade, concentration of phenolics decreases in shade tolerant species like in *C. florida*. They further demonstrated that, concentration of phenolics is inversely related to insect herbivory thus indicating high insect numbers in the deep shaded seedlings.

This study has demonstrated that, planting of leucaena trees under shade tree could reduce the psyllid infestation levels. However, because this experiment was performed in a screen enclosure it is possible that the level of shade provided was a bit higher than the intended percentage. For example Egar and Jones (1977) found reduction of 70 per cent of the outside sunlight in the glass house. Pathak *et al.* (1983) reported good height and total dry matter production under *L. leucocephala* seedlings shaded at 45% light condition in the field than in other light treatments. Basing on this observation integration which could provide shade of about 25% in the field could result into high height and diameter growth as well as high biomass production with minimum psyllid effect.

5.2.2 Intensity of leucaena psyllid attack

The psyllid nymphs population were relatively high in the 10% shaded seedlings, which resulted into heavy damage of the shoots and defoliation of almost 100% of the young leaves. In the other shading treatments, population was also high enough to cause severe damage. In spite of leaves provide an improved substrate for psyllid development (Fisher, 1987) one which promises to promote population growth. In this experiment population increased slowly from the first week of infestation to the fifth week. This was probably due to late adaptation of the psyllid to the newly introduced environment. The shade and the enclosure could also increase the inside temperature (although this parameter was not monitored) and

consequently decelerated adaptation rates. The declined population towards the end of the experiment was most likely caused by high defoliation of the seedlings which lead to lack of enough food material.

The observation in this study where psyllid population increase rate is affected by shading (light intensity), agrees with the observation reported on the leucaena psyllid dynamics by several authors. Mangoendihardjo *et al.* (1989) observed positive correlation between physical factors of solar light intensity and psyllid population size. In another observation, Diravian and Viaktamath (1992) found that, the psyllid predator *C. coeruleus* respond positively towards several factors, such as its prey hours of sunshine and wind speed which means that even psyllid population respond positively towards hours of sunshine.

Working on the other insect species, Jakucs and Viragh (1975) observed that, caterpillar damage was more severe for light adapted plants than for shade-adapted leaves and shoots. Barbosa and Greenblatt (1987) demonstrated that, *H. cunea* larvae preferred sun-exposed leaves to shaded leaves. Contrary to these observations Agarwala and Bhattacharya (1993) found that, *P. kesiya* were more affected by *C. atrotibialis* when are in shade by large trees than other trees.

The reason for high population and damage in the mild and heavy shaded

seedlings is probably related to type of food quality. Basset (1992) reported that local illumination regime for host young leaf production and its indirect effects on the spatial distribution of arboreal arthropods is an important factor in the determination of food quality especially to phloem feeding insects. This suggest that, insects may prefer sites with more light intensity due to quality of food available. On the other hand, Kuenen *et al.* (1994) showed that *Korscheltellus gracilis* initiated wing fanning when light intensity is reduced, factor which evoked males shortly thereafter. This Indicate that, reduction of light intensity for some insects encourage mating hence high reproduction rate. Thus, the exact reason for this increase and decrease is still unknown, remaining an area for further investigation.

5.3 Relationship between nymph count to damage level and shoot health

Both damage level and shoot health indicated strong relationship to nymph counts. But the relationship was stronger between nymph count and shoot health than with damage level. It seems that about 81-88% of the psyllid population could be estimated by using shoot health while, about 50-60% could be explained by level of damage. Several methods for rating psyllid population size have been developed (Bray and Woodroffe, 1988), but they have been found insufficiently detailed for accurate population monitoring (Bray *et al.*, 1989). Findings from this study indicate that, apart from sub-sampling or counting methods developed by Stechman *et al.* (1987), shoot health may also be used to estimate the size of the psyllid population.

It is possible that less strong correlation found for damage level was attributed by the size of the rating scales. Damage level contains about 1-9 scales while shoot health contain only 0-5 scales thus, making more clear differences between each scale.

5.4 Life cycle determination

In this study the life cycle for the psyllid took between 16 and 19 days. Development of leucaena psyllid from egg stage to adult differ from country to country and place to place within the same country. For example, in Malaysia total nymphal period took 10-17 days while in Philippines developmental period was 11-16 days, in Indonesia was 14.92 (Rauf *et al.*, 1989) and 17.95 in Thailand (Napompeth and Maneerat, 1989). Differences in environmental conditions such as temperature and relative humidity have been pointed out as the factors causing this differences (Guan-soon *et al.*, 1989).

Therefore due to this wide variation of the life cycle duration found in several countries, it is difficult to confirm the real life cycle of leucaena psyllid throughout Tanzania. This could be done through trials, replicated in space and time.

CHAPTER SIX**6. CONCLUSION AND RECOMMENDATIONS****6.1 Conclusions**

On the basis of this study the following conclusions could be made:

- Both watering and shading affects leucaena psyllid caused impact, moderately stressed seedlings (watered after every other day) and lightly shaded seedlings (10% shade) being more affected. The psyllid attack reduced biomass production expressed in dry weight of whole plant by 18.6% and 15.9% for seedlings watered after every other day and shaded at 10 per cent respectively. This would imply that, in the field situation, marginal areas, pure leucaena stands and lightly shaded stands should be discouraged for the management of leucaena trees.

- Severe defoliation could lead to leucaena psyllid population crash consequently leading to seedling recovery. The rate of recovery, however, is not known as it was not monitored in the current study.

- There is a strong relationship ($r = 81-88\%$) between shoot health and psyllid population. This implies that shoot health could be used to project the relative psyllid population.

- The life cycle of leucaena psyllid in Tanzania is estimated between 16 to 19 days. This would mean that leucaena psyllid has overlapping generations (up to 20/year), which could partly contribute to its pest status.

6.2 Recommendations

- Farmers should be discouraged to grow leucaena under light shade and avoid arid and semi-arid areas. Irrigation where feasible, would be important management tool.

-The information obtained here could be used with other control strategies, such as biological control,cultural and genetical for an integrated Pest Management Programme (IPM).

- Further research is recommended to investigate on the optimal watering and shading interactions which disfavour the performance of leucaena psyllid.

REFERENCES

- Agarwala, B.K. and Bhattacharya, S. (1993) Niche specialization in pine aphid *Cinara atrotibialis* (Homoptera:Aphididae). *Journal of Biological Science*. 59:6,537-542.
- Barbosa, P. and Schultz, J.C. (1987) *Insect outbreak*. Academic press, New York. pp 578.
- Basset, Y. (1992) Influence of leave traits on spatial distribution of arboreal arthropods within an overstorey rain forest tree. *Abstract of Entomology* 23:6, AB-50.
- Beardsley, J.W. (1986) Psyllidae or jumping plant lice: Note on biology and control. *Leucaena Research Reports* 7, 2-5.
- Berryman, A.A. (1981) Site characteristics and population dynamics; A theoretical perspective. *In: Proc IUFRO World Congress*. Japan. pp 541 - 549.
- Bray, R.A.and Woodroffe, T.D. (1988) Resistance of some *Leucaena* species to leucaena psyllid. *Tropical Grasslands* 22: 1, 11- 26.
- Bray, R.A., Julien, M.H., and Room, P.M. (1989) *Leucaena psyllid* in Australia: The current situation. *In: Leucaena psyllid: problems and management. (Edited by Napompeth, B. and MacDicken, K.G.)*. Thailand. pp 8 - 11

- Bray, R.A and Woodroffe, T.D.(1991) Effect of leucaena psyllid on yield of *Leucaena leucocephala* Cv Cunningham in Southeast. Queensland. *Tropical Grassland* 25, 356-357
- Bray, R.A. (1992) The Leucaena psyllid. CAB International Nairobi, Kenya. pp 5
- Brewbaker, J.L.(1987) Species in the genus leucaena. *Leucaena Research Report*. 7:2, 6-20
- Brewbaker, J.L. and Sorensson, C.T. (1987) *Leucaena diversifolia* and its hybrids for highlands. *Leucaena Research Report* 9, 11-13
- Burdeous, A.T., (1986) Effect of population density of psyllid (*Heteropsylla cubana*) on defoliation of ipil-ipil (*Leucaena* sp). Epidemiology of plant diseases. VISCA, Baybay, Leyte Philippines. pp 13.
- Carter, C.I. and Nichols, J.F.A. (1985) Some resistance features of trees that influence the establishment and development of aphid colonies. *Z. Ang. Ent.* 99, 64-67.
- Ciesla, W.M. (1992) Worldwide introduction of forest pests. In: *Sub-regional Workshop on leucaena psyllid: a threat to agroforestry in Africa*. (Edited by Ciesla, M. and L. Nshubemuki) Dar es Salaam, Tanzania. 10 - 14 October 1994. pp 236.
- Chilima, C.Z , Meke, G.S., Staubi L.A., and Coote, C. (1994) The status of leucaena psyllid in Malawi. In: *Sub-regional Workshop on leucaena psyllid: a threat to agroforestry in Africa*. (Edited by Ciesla, M and L. Nshubemuki) Dar es Salaam, Tanzania 10 - 14 October. pp 236

- Craig, T.P., Wagner, M.R, McCullogh, and Frantz, D.P. (1987) Effect of experimentally plant moisture stress on the performance of Neodiprion sawflies. *Forest Ecology and Management*. 39, 247-261
- Day, K.R. and McLean, S.I. (1991) Influence of the green spruce aphid defoliation and radial stem growth of Sitka spruce. *Annal Applied Biology*. 119: 415-423
- Diravian, J. and Viraktamath, C.A. (1992) Population dynamics of the introduced ladybird beetles, *Cirunus coeruleus* Mulsant in relation to it psyllid prey (*Heteropsylla cubana* Crawford) in Bangalore. *Abstract of Entomology* 23: 10, AB-50.
- Dolling, W.R. (1991) *The Hemiptera*. Oxford University Press, New York, USA. PP 274.
- Dubt, J.F and Shurer, D.J. (1994) The influence of light and nutrients on foliar phenolic and insect herbivory. *Journal of Ecology* 75:1, 86-98
- Elder, R.J. and Mayer, D.G. (1990) An improved sampling method for *Heteropsylla cubana* Crawford (Hemiptera: psyllidae) on *Leucaena leucocephala*. *Journal of the Australian Entomology Society*. 29, 131- 137
- Egar, K. and Jones, R.J (1977) The effect of shading on seedling growth of leguminous shrub *Leucaena leucocephala*. *Australian Journal of Experimental Agricultural and Animal Husbandry* 17: 976-981

- Faeth, S.H. Connor, E.F. and Simberloff, D. (1981) Early leaf abscission a neglected source of mortality for folivores, *American Naturalist*. 117: 409-415.
- Fisher, M. (1987) The effect of previously infested spruce needles on the growth of green spruce aphid, *Elatobium abietinum* and effect of the aphid on amino acid balance of the host plant. *Annal Applied Biology*. 11, 33-41.
- Funasiki, G.Y., Lai, P.Y. and Nakahara, M. (1989) Status of natural enemies of *Heteropsylla cubana* (Crawford Homoptera: Psyllidae) in Hawaii. In: *Leucaena psyllid: problems and management (Edited by Napompeth B. and MacDicken, K.G.)* Funny Publishing Limited Partnership, Thailand. pp 153 - 159.
- Friend, D.J.C., Perry, M.H and Yamamoto, H.Y. (1988) Shade adaptation of photosynthesis and growth of seedlings of wild and giant cultivars of *Leucaena leucocephala*. *Leucaena Research*. 7:2, 128-131
- Guan-Soon. L., Chai-Lin, T. and Choi-Chee, W. (1989) Studies on leucaena psyllid in Malaysia. In: *Leucaena psyllid: problems and management. (Edited by Napompeth, B. and MacDicken, K.G.)*. Funny Publishing Limited Partnership, Thailand. pp 28 - 39.
- Hertel, G.D., Modoffe, S.S., Mbita, G.M., and Mbithi S. (1994) Assistance for management of *Leucaena psyllid*. TCP FAO/RAF/4451(A) Tanzania. pp 7.

- Heynold, D. and Affonso, M. (1991) Economic review of psyllid damage in Southeast Asia and Australia. *Australian International Development Assistance Bureau (AIDAB) Report* Wallingford, Oxford, UK. pp 12.
- Hollis, D. (1992) *Leucaena* psyllid (*Heteropsylla cubana* Crawford) newly recorded on Mauritius and Reunion. *FAO plant protection Bulletin*. 40(1-2): 42-50.
- IIBC. (CAB International Institute of Biological Control) (1992) *Biological control Annual report*. Wallingford Oxford, U.K. pp 25-26
- Jackus, P. and Viragh, K. (1975) Change in the area and weight of light- and shade adapted leaves and shoots of *Quercus petraea* and *Quercus cerris* in Hungarian forest ecosystem. *Journal of Acta-Botanica-Scientiarum-Hungaricae*. 1:2, 25-36
- Johansson, A. (1994) Effect of *Leucaena* psyllid on women's enterprises. A case of Morogoro In: *Sub-Regional Workshop on leucaena psyllid: a threat to agroforestry in Africa*. (Edited by Ciesla, M. and L. Nshubemuki) 10-14 October 1994. Dar es salaam, Tanzania. pp 236
- Jones, R.J. and Aliyu, A.S. (1976) The effect of the weed grass *Eleusine indica*, herbicides and activated charcoal on the seedlings growth of *Leucaena leucocephala* cv. Peru. *Tropical Grasslands*, 10: 195.
- Kisaka, E.Z. (1994) Incidence of forest pest in Tanzania a special reference to the *leucaena* psyllid. In: *Sub-Regional Workshop on leucaena psyllid: a threat to agroforestry in Africa* (Edited by Ciesla, M. and L. Nshubemuki) 10-14 October, 1994. Dar es Salaam, Tanzania. pp 236

- Kuenen, L. P.S., Wagner, D.L., Wallner, W.E. and Carde, R.T. (1994) Female in *Korscheltellus gracilis* (Grote) Lepidoptera: Hapialidae. *Abstract of Entomology* 25: 6
- Kulman, H.M. (1971) Effects on insect defoliation on growth and mortality of trees. *Annual Review of Entomology* 16: 289-324.
- Krishnamurthy, M.K., Munegowda, M.K. and Rajagopal, D. (1998) Outbreak of psyllid *Heteropsylla cubana* on *Leucaena* and its outlook on Alley Cropping in India. In: *Leucaena psyllid: Problems and Management*. (Edited by B. Napompeth and K.G. MacDicken). Funny Publishing Limited Partnership, Thailand. pp 417-24
- Lapis, E.B. and Borden, J.H., (1992) Growth performance of two *leucaena* species exposed to natural infestation by *leucaena* psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae). *Journal of Sylvatrop* 2:1, 61-72.
- Larsson, S. and Tenow, O. (1984) Aerial distribution of *Neodprion sertifer* (Hym. Diprionidae) outbreak on scots pine as related to stand condition. *Holarctic Ecology* 7:2, 81-90
- Larsson, S. (1989) Stressful times for the plant stress insect performance hypothesis. *OIKOS* 56:2, 277-283
- Larsson, S. and Bjorkman, C. (1993) Performance of chewing and phloem-feeding insects on stressed trees. *Scandinavian Journal of Forest Research* 8: 550-559

- Lulandala, L.L.L. (1978) *The establishment technique of Leucaena leucocephala. Effect of different treatments of the germination and growth performance.* MSc Dissertation. University of Dar es Salaam, Tanzania. pp 153.
- Lulandala, L.L.L. (1985) *Intercropping Leucaena leucocephala with maize and beans.* Ph.D Thesis. Morogoro (Tanzania). Sokoine University of Agriculture. pp 254
- Lulandala, L.L.L. and Hall, J.B. (1991) *Leucaena leucocephala* potential role in rural development. *International Centre for Research in Agroforestry, Working paper No. 65:* Nairobi. pp.78
- Madoffe, S.S. and Massawe, A. (1994) Periodicity of *Leucaena* psyllid infestation of *Leucaena leucocephala* in Morogoro: preliminary observation In: *Sub-regional Workshop on leucaena psyllid: a threat to agroforestry in Africa (Edited by Ciesla, M. and L. Nshubemuki)* 10 - 14 October Dar es Salaam, Tanzania. pp 236
- Madoffe, S.S. and Austarå, Ø. (1990) Impact of pine woolly aphid, *Pineus pini* (Macquart) Hom., Adelgidae), on growth of *Pinus patula* seedlings in Tanzania. *Journal of Applied Entomology.* 110: 421-424
- Mangoendihardjo, S.F.X., Wagiman, J.A. Trisyono and Sujono, M. (1989) Seasonal abundance of *Leucaena* psyllid populations in Yogyakarta, Indonesia: In: *Leucaena psyllid: Problems and Management (Edited by Napompeth, B. and MacDicken, K.G).* Funny Publishing Limited Partnership Thailand. pp 112-114

Market Development Bureau (1988) Review of ruminant livestock industry.

MALD, Dar-es- Salaam. pp 132

Mattson, W. J. and Haack, R.A. (1987) The role of drought in outbreaks of plant-eating insects : Droughts physiological effects on plants can predict its influence on insect populations. *Bioscience* 37:2, 110-118.

Mella, P., Zaingo, M. and Janing, M. (1989) Resistance of leucaena and some other tree legumes to *Heteropsylla cubana* in West Timor, Indonesia. *In: Leucaena psyllid: Problems and Management (Edited by Napompeth, B. and MacDicken, K.G.)*. Funny publishing Limited Partnership Thailand. pp 56-61.

Muddiman, S.B., Hodkinson, I.D and Hollis, D. (1992) Legume feeding psyllid of the genus *Heteropsylla* (Homoptera: Psyllidae). *Bulletin of Entomological Research* 82: 73-117.

Napompeth, B. (1989) Leucaena psyllid problems in Asia and pacific *In: Leucaena psyllid: Problems and Management (Edited by Napompeth, B. and Macdicken, K.G.)*. Funny Publishing Limited Partnership, Thailand. pp 1-11

Napompeth, B. and Maneerat, T. (1989) Biological and partial ecology life tables of *Heteropsylla cubana* Crawford and its predator *Curinus coeruleus* Mulsant in Thailand: *In Leucaena psyllid: problem and management (Edited by Napompeth, B. and MacDicken, K.G.)*. Funny publishing Limited Partnership, Thailand. pp 130-138

- Napompeth, B. (1994) *Leucaena psyllid in the Asia pacific Regions implication for its management in Africa*. Papa, Bangkok. pp 27.
- NAS, (1984) *Leucaena promising forage and tree crop for the tropics*. USA, NFTA, PP.50
- Nitrogen Fixing Trees Highlight (NFTH), (1988) *Leucaena psyllid A review of the problem and its solutions. Leucaena Research Report 3-5*
- Oka, I. N. and Bahagiawati, A. H. (1988) Operative program towards integrated control of leucaena psyllid a new insect pest of leucaena tree in Indonesia, Indonesia Agricultural Research and Development.
- Oka, I.N. (1989) Progress and future activities of the leucaena psyllis research program in Indonesia. *In: Leucaena psyllid: Problem and Management (Edited by B. Napompeth and MacDicken, K.G.)*. Funny publishing limited partnership, Thailand. 25-27
- Otsyina, K. and Dzowela, B. (1994) Importance of Leucaena in Africa In: *Sub-Regional Workshop of Leucaena psyllid: a threat to agroforestry in Africa (Edited by Ciesla and L. Nshubemuki)* 10 - 14 October 1994, Dar es Salaam, Tanzania. pp 236
- Palmer, B., Bray, R.A., Ibrahim, T.M., Fulloon, M.G. (1989) The effect of leucaena psyllid on the yield of *Leucaena leucocephala* CV. cunningham at four sites in the tropics. *Tropical Grasslands*. 23: 105-107
- Pan, F.J. (1987) Psyllid resistance of leucaena species in Taiwan. *Leucaena Research Reports* 7:2, 35-38

- Parry, W.H. (1969) A study of relationship between defoliation of Sitka spruce and population levels of *Elatobium abietinum* (Walker). *Forestry*. 42: 69-82
- Pathak, P.S., Rai, M.P. and Roy, R.D., (1983) Seedlings growth of *Leucaena leucocephala* (LAM.) de Wit 1 Effect of shading. *Indian Journal of Forestry*. 6:1, 28-31.
- Rauf, A., Hidayat, P., Maryana, N. and Winasa, I.W. 1989) Biology and demography of *Heteropsylla cubana* Crawford (Homoptera: Psyllidae) In: *Leucaena psyllid: Problems and Management*. Edited by (B. Napompeth and MacDicken, K.G.) Funny Publishing Limited Partnership, Thailand. pp 114- 118.
- Reynold, L. and Bimbuzi, S. (1992) *Leucaena* psyllid arrives in Kenya. *Journal of Agroforestry Today*. pp 4-5
- Rhodes, D.F., (1985) Offensive defensive interaction between herbivores and plant. Their relevance in herbivore population and ecological theory. *Am Nat* 125: 205-238
- Rhodes, D.F. (1993) Herbivore population dynamics and plant_chemistry: *In variable plants and insect herbivores in natural and managed systems (edited by Denno, R.F. and McCLure, M.S.)* PP 155-220 Academic Press New York.
- Southwood, T.R.F. (1987) *Ecological methods with particular reference to the study of insect populations*. Chapman and Hall. pp 524

- Speight, M.R. and Wainhouse, D. (1986) *Ecology and management of forest insects*. Oxford university press. U.S.A. pp 370
- Spur, S.H. and Barnes, B.V. (1964). *Forestry ecology*. John Wiley and Sons Inc. U.S.A pp 386
- Stechman, D.H., Lataimauni, H. and Foliaki, S. (1987) Studies on *Heteropsylla cubana* Crawford in Tonga. *Leucaena Research Reports*. 7:2, 50-58.
- Subyanto, A.S. and Wagiman (1989) Field observation of resistant leucaena species in Bondowoso East Java. *In: Leucaena psyllid problems and Management. (Edited by B. Napompeth and K.G. MacDicken)* Funny Publishing Limited Partnership, Thailand. pp 71-72.
- Tanzania Forest Division. (1983) *Trees for village forestry*. Ministry of Natural Resources and Tourism, Dar es salaam, Tanzania. pp 126.
- Tisdale, R.A. and Wagner M.R. (1991) Host stress influences viposition preference and performance of a pine sawfly. *Ecological Entomology*. 16:371-376.
- USAID. (1991) Environmental assessment of the classical biological control of leucaena psyllid in Indonesia, Laos, Malaysia, Nepal, Philippines and Thailand. *USAID Report*. Washington DC.
- Vanden Belt, J. and Napompeth, B. (1992) Leucaena psyllid comes to Africa. *Journal of Agroforestry today* 4:4, 11-12

- Veeresh, G.K.(1989) The status of leucaena psyllid *Heteropsylla cubana* Crawford, in India In: *Leucaena psyllid: Problems and Management. (Edited by B. Napompeth and MacDicken K.G.)*. Funny Publishing Limited Partnership Thailand. pp 12-13
- Villacarlos, L.T. Robin, R.P. and Panglinawan, R.V. (1989) Factor affecting leucaena psyllid population in Leyte philippines In: *Leucaena psyllid: Problems and Management (Edited by Napompeth, B. and MacDicken K.G.)*. Funny Publishing Limited Partnership Thailand. pp 122-130.
- Waage, J. (1989) Exploration for biological control agents of Leucaena psyllid in tropical America In: *Leucaena psyllid: Problems and Management (Edited by Napompeth and MacDicken, K.G.)*. Funny Publishing Limited Partnership, Thailand. pp 144 - 152.
- Wagner, M.R. and Frantz, D.P. (1990) Influence of induced water stress in Ponderosa pine on pine sawflies. *Oecologia* 83: 452- 457
- Wallner, R. (1987) *Ecology and management of forest insects*. Oxford University Press, New York. U.S.A. pp 17.
- Wheeler, R.A. (1988) Leucaena psyllid trial at Wamanalo, Hawaii, *Leucaena Research Reports* 9: 25-29.
- White, T.C.R. (1974) A hypothesis to explain outbreak of looper caterpillars, with special reference to population of *Scalidosema suavis* in a plantation of *Pinus radiata* in New Zealand *Oecologia* 22: 119-134

- White, T.C.R. (1976) Weather, food and plagues of locusts. *Oecologia (Berlin)*. 63: 90-105
- Young, A. (1987) The potential of agroforestry for soil conservation: 2 Maintenance of fertility. Working paper 43 Nairobi ICRAF. pp 135