Final Technical Report

Integrated Control of Leucaena Psyllid

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DFID PROJECT REFERENCE:	R6524
RNRRS PROGRAMME:	Forestry
RNRRS PROGRAMME PURPOSE:	The use of trees within farming systems, including community and farm woodlots, optimised.
RNRRS PRODUCTION SYSTEM:	Semi Arid System 1
COMMODITY BASE:	Tree fodder, fuel wood, poles.
BENEFICIARIES:	Resource poor farmers, pastoralists.
TARGET INSTITUTIONS:	ICRAF, national forestry and agriculture research organisations in Kenya, Tanzania and Malawi.

May 1999

Executive Summary

In 1992 the leucaena psyllid, *Heteropsylla cubana,* arrived on the East coast of Africa, having spread westwards form its origin in central America in just eight years. In Asia and the Pacific losses to the pest had been large, as the predominantly used *Leucaena leucocephala* is very susceptible to the insect.

In Africa *L. leucocephala* was also being promoted, though had not yet become as widespread as in Asia. Nevertheless the arrival of the psyllid was seen as a major threat, and investigations into its control were commenced. This project aimed to develop an integrated approach to control of the psyllid in Africa, focusing on pest resistant leucaenas and classical biological control.

Thirty six leucaena accessions largely from Oxford Forestry Institute collections were established in trials at Machakos (Kenya), Makoka (Malawi) and Tumbi, (Tanzania), 19 of which were grown at one site only. Growth, pest damage, pest populations and biological control agents were monitored in three replicates at each site.

L. macrophylla istmensis and *L. pallida* performed well at all sites. Other accessions growing well at one or more sites were an unknown hybrid (seed lot number 52/87), *L. magnifica, L. shannonii* and *L. trichandra.* Poor performers included *L. collinsii zacapana* and *L. esculenta.*

Visible damage by the psyllid was not necessarily correlated with poor growth. While *L. collinsii zacapana* showed the highest damage and poor growth, *L. esculenta* showed very little damage but poor growth. *L. pallida* showed moderate damage levels but still grew well. *L. collinsii collinsii, L. diversifolia* and *L. trichandra* all suffered little damage, confirming the pest resistance observed elsewhere.

Psyllid numbers were high in *L. collinsii zacapana* (Malawi), *L. pulverulenta, L. leucocephala* and *L. salvadorensis. L. diversifolia* supported moderate to high psyllid numbers, but suffered little damage indicating tolerance rather than antibiotic resistance. *L. trichandra, L. esculenta* and *L. collinsii collinsii* all had low psyllid populations, suggesting either they are unattractive for oviposition and/or poor survival of psyllid nymphs.

Tamarixia leucaenae (Hymenoptera: Eulophidae) was introduced and established in Malawi, and together with *Psyllaephagus yaseeni* (Hymenoptera: Encyrtidae) shown to be also established in Kenya and Tanzania. However, parasitism by both species was low at all sites. Thus there was no indication as to whether the parasitoids are more effective in some leucaenas than others, or whether different leucaena harvesting regimes affect their impact. There was no evidence that cutting has a major effect on psyllid numbers or damage over a 12 month period.

A socio-economic survey in Kenya indicated *Leucaena* is a popular tree, and that the psyllid is perceived to cause losses in various ways, particularly reducing fodder production and thus milk production. No effective control methods were known but farmers are in general keen to continue planting leucaena, particularly if the psyllid can be controlled.

Species already selected by target institutions for seed production or further trials include *L. collinsii zacapana* and *L. esculenta,* but the results of this work do not support further development. *L. esculenta* is highly resistant but grew poorly, while *L. collinsii zacapana* appears particularly sensitive to the psyllid, showing high levels of damage even with only moderate psyllid attack. *L. pallida* has also been identified for further work on-farm in Southern Africa, and this work supports that decision. The hybrid of unknown parentage (52/87) appears to have some potential, while *L. macrophylla istmensis* grows well despite having little resistance to the pest. In general the findings of this study support those from Asia and elsewhere.

Given highly productive leucaenas which are either tolerant or resistant to the psyllid, introduction of additional biological control agents (such as the two coccinellid predators used in Asia) is not recommended.

Acronyms

AFRENA	Agroforestry Research Networks for Africa
CI	Confidence Interval
FAO	Food and Agriculture Organisation, United Nations.
FRIM	Forestry Research Institute of Malawi
ICRAF	International Centre for Research in Agroforestry
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
OFI	Oxford Forestry Institute
RCD	Root Collar Diameter

1. Background

Leucaena leucocephala is the most widely planted multipurpose tree species in the tropics, covering some 2-5 million ha (Brewbaker & Sorensson, 1990), but a lack of genetic diversity within the species has resulted in problems of environmental adaptability, and susceptibility to attack from the defoliating psyllid, *Heteropsylla cubana*. The pest originates in Central America, but since 1983 has spread across the Pacific and Asia causing severe damage to *L. leucocephala*. In 1992 the psyllid arrived in mainland Africa, where within a short period it spread to Burundi, Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe.

Heavy damage particularly to young plants is observed in all infested areas, and surveys, for example by a women's afforestation project in Tanzania (Johansson, 1995), showed that the pest was seen as a major constraint to the productivity of semi-arid production systems, in some cases causing farmers to abandon the species. However, due to its many desirable qualities, the tree would continue to be widely used if the pest could be controlled.

A regional workshop held in Dar-es-Salaam in October 1994 (Ciesla and Nshubemuki, 1995) endorsed the use of two approaches for controlling the psyllid; biological control and the use of heritable host-plant resistance to the pest. These methods require little or no input from farmers, they are environmentally sustainable, and they are complementary. Both methods have been used individually with some success in Asia, but little quantitative information has been reported on the impact of biological control, and there is no work on the integration of host plant resistance and biological control.

Range-wide collections by Oxford Forestry Institute (OFI) had made available a greater range of leucaena germplasm, testing of which had commenced in Africa. At the same time, as part of emergency assistance provided by the Food and Agriculture Organisation (FAO) to the governments of Kenya and Tanzania, two specific biological control agents were being introduced to Kenya and Tanzania by early 1996. This study therefore aimed to combine entomological studies with the *Leucaena* species trials to develop an integrated approach to controlling the insect.

2. Project Purpose

The project purpose (indicative output 1.2 of semi arid system 1) was "Multi-purpose tree species with improved performance identified and their use in agroforestry promoted". The project aimed to develop an integrated approach to control of the leucaena psyllid in East and Southern Africa, focusing particularly on the use of pest resistant leucaena species and classical biological control. New knowledge was being sought on the performance of newly collected accessions of leucaena and their resistance/tolerance to the psyllid, and on the performance and impact of classical biological control agents.

3. Research Activities

3.1 On-station trials monitoring growth and production

Trials of leucaena species were established by ICRAF using seeds from OFI. Details are shown in Tables 1 and 3. The choice of accessions to plant at each site was made before this project started.

Table 1. Trial establishment details

Country	Site	Established	Accessions	Replicates	Layout
Kenya	Machakos	June 96	21	4 (3 sampled)	Plots, 6 x 6 tress
Malawi	Makoka	Dec. 95	19	3	Plots, 5x5 trees
Tanzania	Tumbi	Feb. 96	18 (16 sampled)	3	Lines, 10 trees, 2m spacing, 4m between lines

Survival, growth and biomass production was recorded as shown in Table 2. In addition, at each monthly field monitoring, (see section 3.2 for further details of sampling procedures), the number of shoots on each of the sample plants was recorded. This indicates the availability of resource for the psyllids, as they prefer ovipositing and feeding on young shoots. At the same time, the damage to ten (five at Machakos) individual shoots was recorded as healthy (score 1), slightly damaged (score 2) or heavily damaged (score 3). Shoots were selected from the uppermost downwards. Overall tree damage was also scored, using the widely adopted scale of Wheeler (1988) (Table 4).

Table 2. Growth recording in the species trials. (RCD=Root collar diameter).

Site	Date	Measurement
Machakos	December 1996 November 1997 April 1998 April 1999	Survival Survival, height, RCD Survival, height, RCD Survival, height, RCD
Makoka	June 1996 June 1997 June 1998 June 1999	Survival, height, RCD Woody and non-woody biomass (felled). Woody and non-woody biomass (felled) Woody and non-woody biomass (planned)
Tumbi	February 1997 February 1998 April 1999	Survival, height, RCD Survival, height, RCD Survival, height, RCD.

Table 3. Leucaena accessions planted at the three trial sites.

Species	Seed	Malawi	Tanzania	Kenya
L. collinsii collinsii	51/88	■		
L. collinsii collinsii	45/85	■		
L. collinsii collinsii	52/88	■	■	■
L. collinsii zacapana	57/88	■		
L. collinsii zacapana	18/94	■		
L. collinsii zacapana	56/88	■	■	■
L. diversifolia	82/92			■
L. diversifolia	45/87	■		
L. diversifolia	83/92			■
L. esculenta	47/87	■	■	■
L. esculenta	48/87	■		
L. hybrid	52/87	■	■	■
L. hybrid (Lilongwe)	52/87	■		
L. hybrid KX2	2/95		■	■
L. hybrid KX3	3/95			■
L. involucrata	87/92		■	■
L. lanceolata lanceolata	43/85		■	■
L. lempirana	6/91		■	■
L. leucocephala			■	
L. leucocephala glabrata	32/88			■
L. leucocephala glabrata	34/92		■	
L. macrophylla istmensis	39/89	■		
L. macrophylla istmensis	47/85	■	■	■
L. macrophylla macrophylla	55/88	■		
L. magnifica	19/84		■	■
L. pallida	79/92	■	■	■
L. pallida	137/94	■	■	■
L. pulverulenta	83/87		■	■
L. salvadorensis	34/88	■		
L. salvadorensis	36/88	■		■
L. salvadorensis	17/86	■		
L. shannonii	53/87	■		
L. trichandra (=revoluta)	?		■	
L. trichandra	4/91		■	■
L. trichandra	53/88		■	■
L. trichodes	61/88			■

Table 4. Scale for assessing tree damage (from Wheeler, 1988)

Damage score	Definition
1	No damage
2	Slight curling of leaves
3	Tips and leaves curling
4	Tips and leaves curling, covered with sap
5	Loss of up to 25% of young leaves
6	Loss of 26-50% of young leaves
7	Loss of 51-75% of young leaves
8	Loss of 76-100% of young leaves, blackening of lower leaves
9	Total leaf loss, blackened stem

3.2 Monitoring psyllid and natural enemy populations

Psyllid and natural enemy populations were monitored using destructive sampling conducted once every four weeks. As establishment and initial growth was poor at Tumbi, and at Machakos the trial was not planted until after project began, the start of destructive sampling to assess psyllid numbers was delayed at those sites (Table 5). Earlier trials comparing field monitoring of psyllid populations with laboratory counts from destructive samples showed that field monitoring is not practical for estimating actual numbers. Thus destructive sampling was necessary in which plant material was removed to the laboratory. At each sample occasion five (three at Tumbi) trees were sampled from each plot in each replicate.

Sample trees in each plot were initially selected at random, but thereafter the same trees were sampled, unless the tree died, in which case a replacement was selected at random. The sample from one tree comprised a randomly selected shoot, plus the next three leaves. The shoot was defined as the growing point including the first unfurled (but not fully expanded) leaf. The sample unit was removed to the laboratory in a tube of alcohol or polythene bag, where a binocular microscope was used to count the number of small (instars 1 and 2), medium (instars 3 and 4) and large (instar 5) psyllid nymphs.

Table 5. Details of sampling

Site	Trees sampled per plot/line	Start of field monitoring	Start of destructive sampling
Machakos	5	26.11.96	14.5.97
Makoka	5	27.6.96	2.7.96
Tumbi	3	6.4.97	4..4.97

In the same samples used to score psyllid populations, the number of unemerged parasitoid mummies on each sample unit was scored. Scoring parasitism by dissection proved impractical, but the mummies of *T. leucaenae* and *P. yaseeni* can be distinguished from each other so were scored separately. Percentage parasitism is defined as the percentage of the total number of nymphs entering the vulnerable stage that are attacked by the parasitoid. As parasitism is only detected when mummies form some time after attack occurs, it is therefore necessary to estimate both the density of mummies and the density of psyllids in the stage that psyllids surviving the vulnerable stage have reached by the time mummies form. In this study the survivors of parasitism are taken to be the large nymphs, so an index of parasitism is calculated as 100 x No. Mummies/(No. Mummies + Large nymphs).

As the trial at Tumbi established slowly, delaying commencement of sampling, a previously planted trial of *Leucaena leucocephala* accessions was monitored from June 1996 to June 1997 using similar methods. This was the trial in which the two species of biological control agent had been released in February 1996 under earlier work funded by FAO. The methods and results are described in a paper submitted to International Journal of Pest Management (Appendix 1).

3.3 Establishment and monitoring of cutting regime trials

Three *Leucaena* accessions were chosen for planting in a trial to make preliminary observations on the effect of cutting regimes on the biological control agents. The accessions chosen were *L. shannonii* (accession 19/84, moderately susceptible to the psyllid), *L. leucocephala* (accession 283/063/95, highly susceptible) and a hybrid of unknown parentage (accession 52/87, originally collected as *L. pallida* (Hughes, 1998), moderately resistant). Seeds were planted in November 1996, and the trial planted out in April 1997.

The trial had three blocks, each block with three plots of each accession. Plots were of 25 trees in a square with 1.5m spacing. The objective was to test tree-cutting regimes. The trial established poorly, and beating up was undertaken 3-4 months after planting out. Subsequently growth of the hybrid was adequate, but the other two accessions continued to grow poorly, in the case of *L. leucocephala* in part due to browsing by wild animals (despite placing a guard). Thus the experiment continued with only the hybrid.

In view of this, an existing hedgerow trial of *L. leucocephala* was used to start independent studies. Three lengths of hedgerow 21m in length with 4m between rows, were divided into three 7m sections each, one for each treatment in each replicate.

In both trials three cutting treatments were defined, based on the length of regrowth. All treatments were initially pruned, after which regrowth was measured until the cutting criterion for the treatment was reached. At that time the treatment was harvested, and the weight of woody and non-woody bimass determined. The cutting criteria are shown in Table 6

Table 6. Cutting criteria

Experiment	Regime	Criterion
L.leucocephala	1	Mean shoot length of longest 5 shoots>40cm on >50% stumps in all plots
	2	Mean shoot length of longest 5 shoots>60cm on >50% stumps in all plots
	3	Mean shoot length of longest 5 shoots>80cm on >50% stumps in all plots
L.hybrid	1	Mean shoot length of longest 5 shoots>40cm on >50% trees in all plots
	2	Mean shoot length of longest 5 shoots>60cm on >50% trees in all plots
	3	Mean shoot length of longest 5 shoots>80cm on >50% trees in all plots

Psyllid and biocontrol agent populations were monitored using the same methods as in the main trial. For the hedgerow experiment a randomly selected 50cm length of hedgerow was used instead of a tree, and three such units were selected from each hedgerow plot.

3.4 Import and release of biological control agents in Malawi

A permit for the import and release of biocontrol agents in Malawi was granted on 15 July 1997. This was later than anticipated as there was lengthy discussion concerning the desirability of releasing the agents before any national survey had been undertaken to assess the extent of infestation. In view of this, and because *T. leucaenae* was causing higher rates of parasitism in Kenya in the original *L. leucocephala* release plot, this species was selected for introduction to Malawi, and *P. yaseeni* was not introduced as originally planned.

Insects released in Malawi were sent from CAB International Africa Regional Centre in Nairobi, (formerly International Institute of Biological Control), which necessitated maintaining cultures of *T. leucaenae* for longer than planned. The cultures originated from insects sent from Trinidad. Two shipments were despatched by air, and 269 individuals were released at Makoka on 31 July 1997, and 446 on 15 August 1997. As the trial plot had recently been harvested, the insects were released in a stand of leucaena about 1km from the trial plot. The insects were released into muslin cages placed over colonies of psyllids, and after a few days the cages were removed. All the insects released were assumed to be female as *T. leucaenae* is thelytokous (Patil *et al.,* 1993). Mummies were subsequently observed at the release site, and on trees and hedges up to several hundred metres away, but in the trial plot none were recorded during sampling on 13 November 1997. On 18 November 1997 about 200 mummies were therefore collected from the release site and placed in the trial plots, and the procedure was repeated 10 days later, to ensure the parasitoids were present in the trial.

3.5 Socio-economic survey in Kenya

A socio-economic survey was undertaken in Kenya in three districts, Kilifi (coast region), Embu (central highlands), and Vihiga (western Kenya) to assess farmers' attitudes to the pest and the crop. A total of 134 households were interviewed. Details of the methodology, and the questionnaire used, are given in the survey report at Appendix 3

4. Outputs

4.1 On-station trials monitoring growth and production

Rainfall at the three sites is shown in Figures 1, 2 and 3.

Figures 4 and 5 show the maximum height and stem diameter for the trees in the trial at Machakos, for the final measurement in 1999, ranked in descending order. Analysis of variance showed there are significant differences between the accessions ($F=3.81$, $p<0.001$) in height. In the Figures 70% confidence interval bars are attached to the means to allow immediate comparisons; means whose confidence intervals do not overlap are significantly different at $p=0.05$. Interestingly there was no significant difference between accessions for root collar diameter of the broadest stem ($F=1.18$, $p=0.325$).

Tables 7 and 8 show the results for the biomass measurements at Makoka, Malawi. Analysis of these data by ICRAF awaits the completion of the experiment in June 1999, and mean values only have been provided.

Figures 6 and 7 show the growth results for the 1999 measurements at Tumbi, Tanzania. Tree height was significantly different ($F=3.39$, $p=0.002$) between accessions, and root collar diameter (a log transformation was used reduce overdispersion) was also significantly different between accessions ($F=2.20$, $p=0.033$), though the evidence is not strong.

Table 9 gives the growth ranks for all three sites for the data presented. *L. pallida* and *L. macrophylla istmensis* were the most consistent performers across sites. *L. pallida* (79/92) grew much less well than *L. pallida* (137/94) in Tanzania.

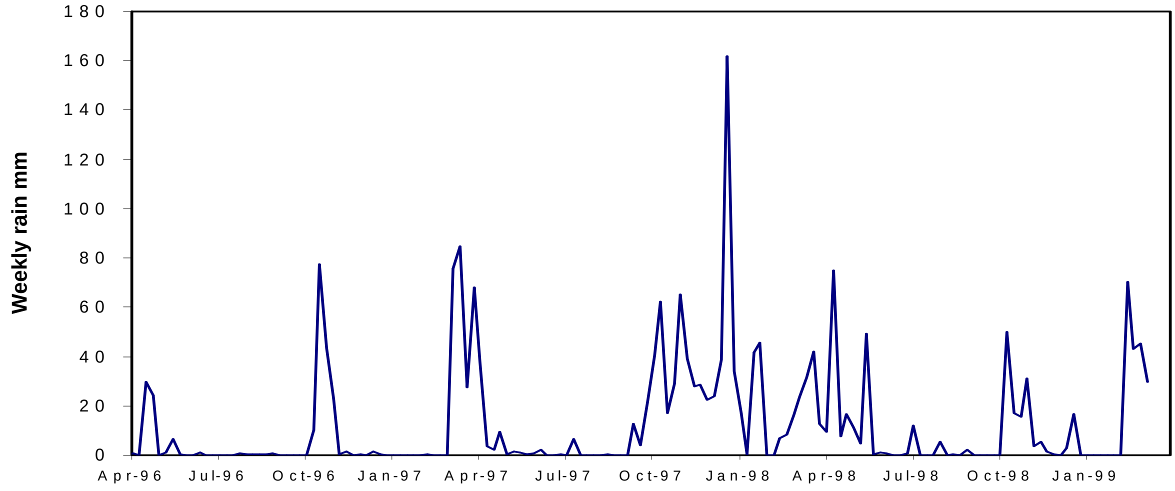


Figure 1. Rainfall at Machakos, Kenya

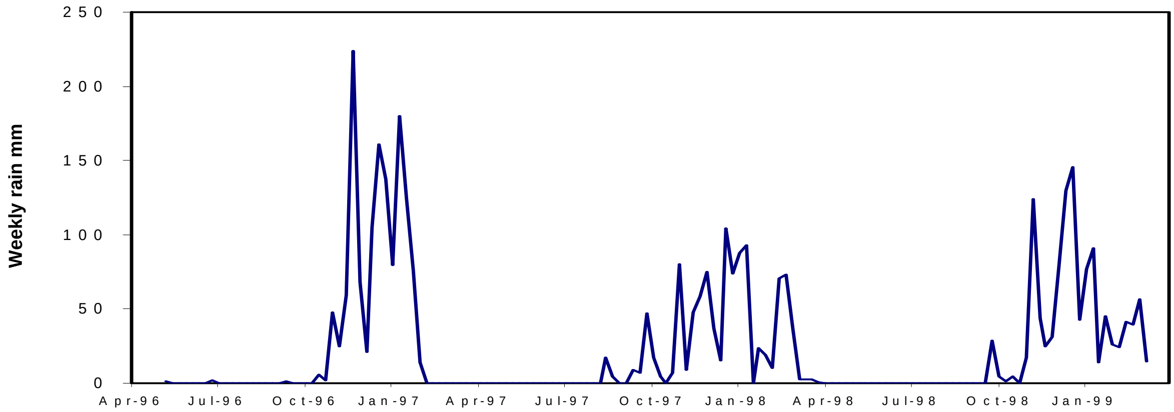
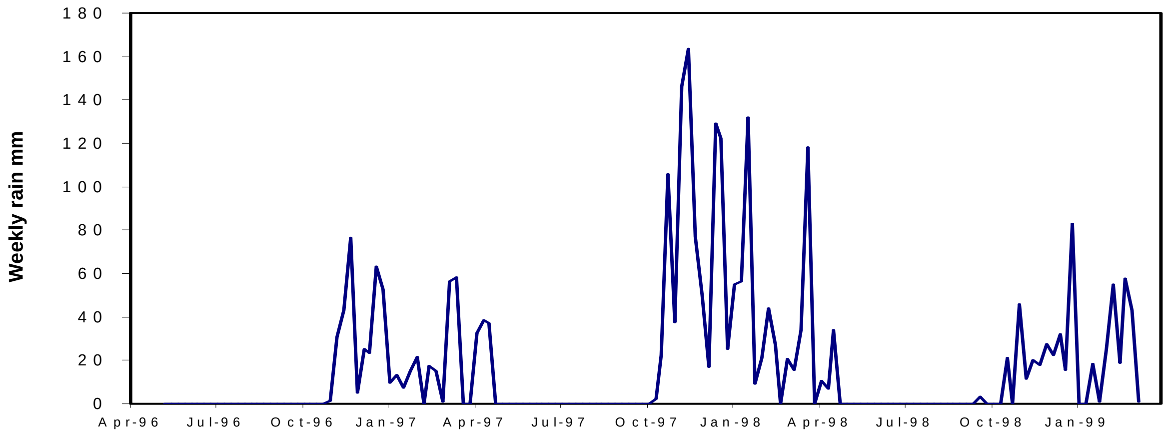


Figure 2. Rainfall at Makoka, Malawi



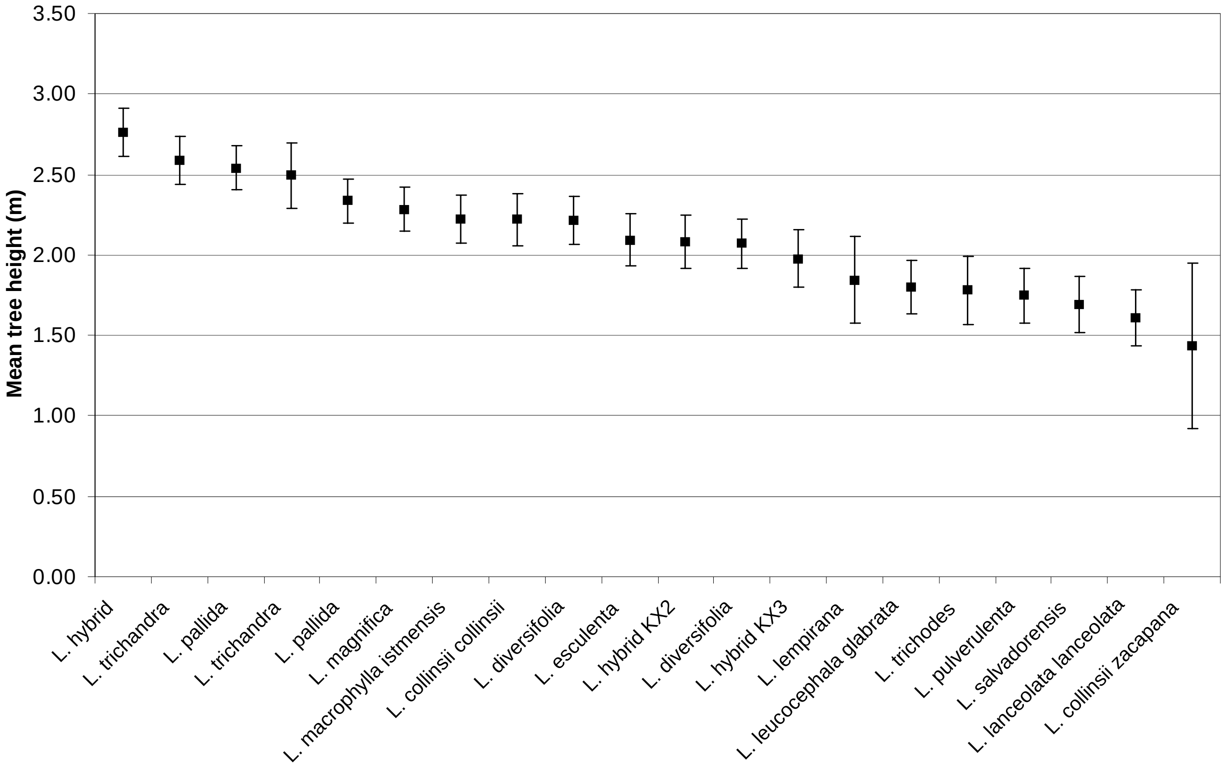


Figure 4. Ranked mean tree heights ± 70% C.I., Machakos, 1999

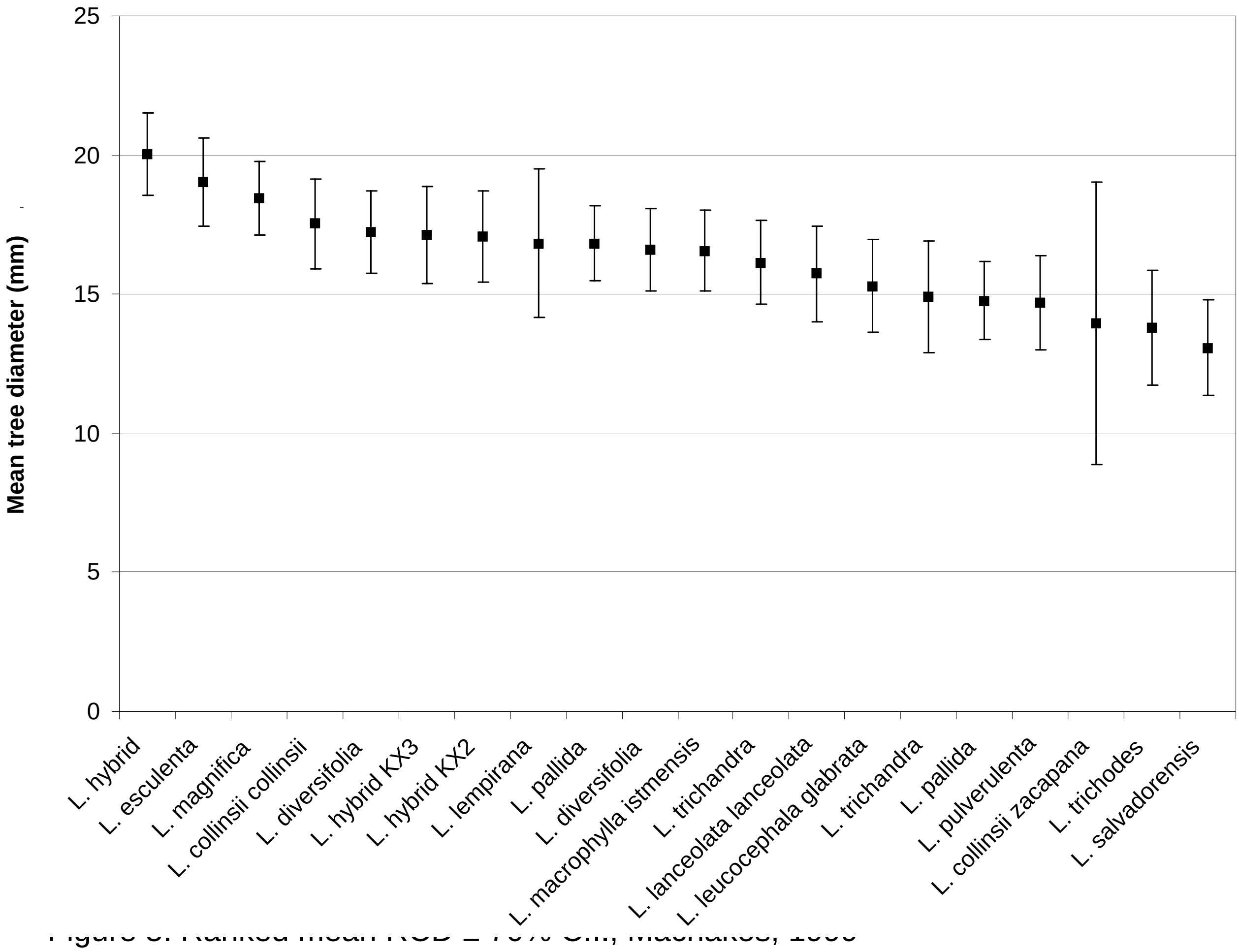


Figure 5. Ranked mean RCD ± 70% C.I., Machakos, 1999

Table 7. Biomass and growth data from Makoka, Malawi, June 1997 cutting.

OFI	Leucaena	Biomass (ton/ha)							
Seed	**Species**	**Foliage**	**Rank**	**Wood**	**Rank**	**Height (m)**	**Rank**	**RCD (cm)**	**Rank**
51/88	L. collinsii collinsii	0.98	15	2.69	13	2.71	12	3.49	16
57/88	L. collinsii zacapana	1.05	13	2.36	16	2.58	14	3.60	13
52/87	L. hybrid (Lilongwe)	1.47	11			3.63	2	5.07	2
39/89	L. macrophylla istmensis	2.52	3	7.10	3	2.77	9	4.03	8
45/85	L. collinsii collinsii	2.2	7	4.32	8	2.9	8	4.32	4
47/87	L. esculenta	0.98	16	1.42	19	1.57	19	3.60	14
34/88	L. salvadorensis	1.47	12	3.26	11	3.31	4	4.30	5
55/88	L. macrophylla macrophylla	1.71	8	2.45	14			4.22	7
18/94	L. collinsii zacapana	0.73	19	2.45	15	3.04	6	3.34	18
36/88	L. salvadorensis	2.45	4	7.26	2	2.57	15	3.30	20
56/88	L. collinsii zacapana	0.81	18	2.20	18	2.73	10	3.33	19
17/86	L. salvadorensis	1.63	9	4.48	6	3.4	3	4.27	6
45/87	L. diversifolia	1.54	10	4.08	9	2.53	16	3.68	12
137/94	L. pallida	2.45	5	4.97	4	2.51	17	3.76	10
48/87	L. esculenta	1.05	14	2.35	17	1.82	18	4.66	3
52/88	L. collinsii collinsii	0.65	20	2.81	12	2.63	13	3.72	11
53/87	L. shannonii	3.92	2	4.41	7	3.87	1	5.91	1
79/92	L. pallida	2.28	6	4.59	5	2.96	7	3.97	9
47/85	L. macrophylla istmensis	4.08	1	8.26	1	3.16	5	3.51	15
52/87	L. hybrid (?)	0.98	17	3.43	10	2.72	11	3.39	17

Table 8. Biomass and growth data from Makoka, Malawi, June 1998 cutting.

OFI	Leucaena	Biomass (ton/ha)							
Seed	Species	Foliage	Rank	Wood	Rank	Height (m)	Rank	RCD (cm)	Rank
51/88	L. collinsii collinsii	1.54	14	7.96	10	3.45	8=	5.44	12
57/88	L. collinsii zacapana	1.3	16	3.62	18	2.8	17	2.87	20
52/87	L. hybrid (Lilongwe)	1.2	17	6.23	15	2.69	18	7.82	1
39/89	L. macrophylla istmensis	7.37	2	21.32	2	4.82	1	6.10	5
45/85	L. collinsii collinsii	1.66	12	10.20	8	3.42	10=	6.04	6
47/87	L. esculenta	1.41	15	1.62	20	1.47	20	5.55	11
34/88	L. salvadorensis	1.81	11	7.1	13	3.29	12	5.84	9
55/88	L. macrophylla macrophylla	1.98	10	6.8	14	4.19	4	4.34	18
18/94	L. collinsii zacapana	1.14	18	5.22	16	3.56	7	5.86	8
36/88	L. salvadorensis	2.46	9	7.85	11	3.59	6	4.70	16
56/88	L. collinsii zacapana	0.74	20	2.51	19	2.95	15	6.12	4
17/86	L. salvadorensis	3.55	6	15.56	5	4.22	3	6.74	2
45/87	L. diversifolia	2.54	8	11.80	7	3.42	10=	6.04	7
137/94	L. pallida	8.39	1	16.95	4	3.86	5	5.82	10
48/87	L. esculenta	0.98	19	4.04	17	1.82	19	4.90	15
52/88	L. collinsii collinsii	1.65	13	7.23	12	3.1	13	5.38	13
53/87	L. shannonii	4.11	5	13.59	6	2.92	16	4.15	19
79/92	L. pallida	3.13	7	9.37	9	3.45	8=	5.21	14
47/85	L. macrophylla istmensis	7.15	3	19.72	3	4.6	2	6.58	3
52/87	L. hybrid (?)	6.95	4	26.29	1	2.99	14	4.50	17

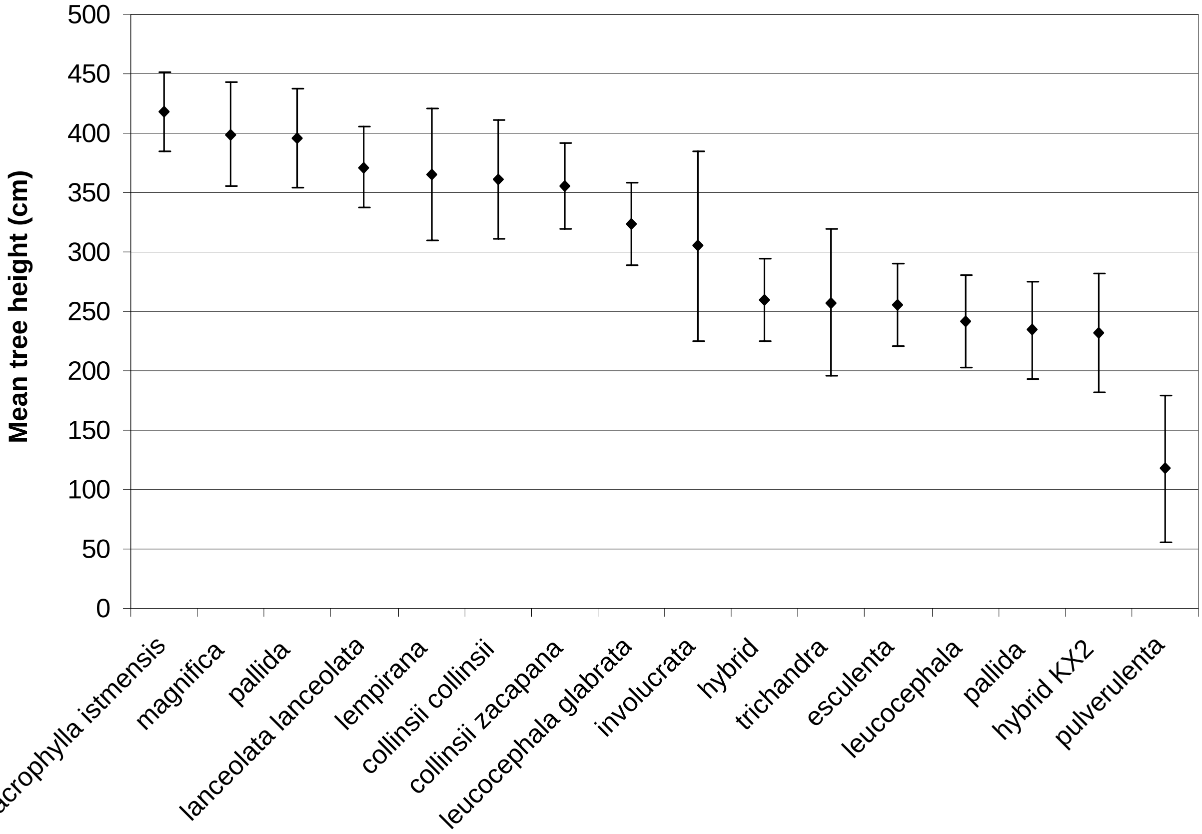
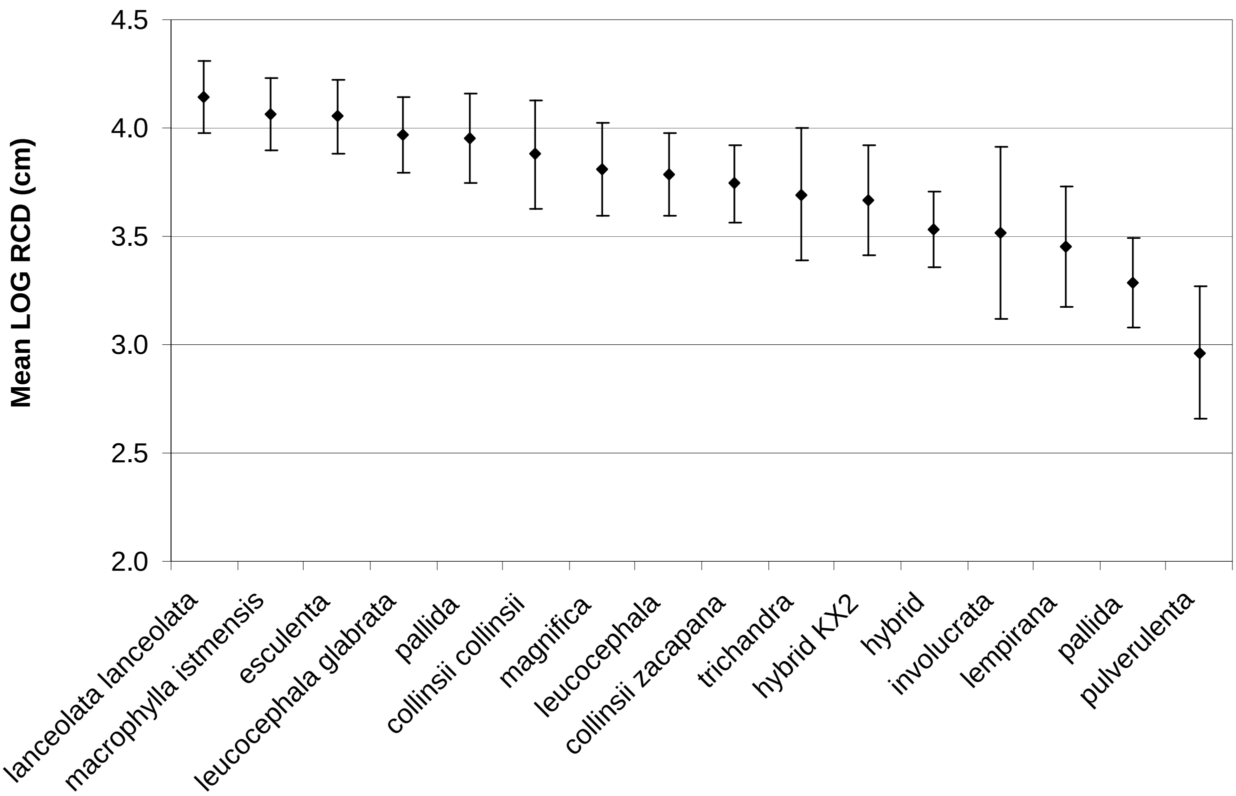


Figure 6. Ranked mean tree heights, Tumbi, Tanzania, 1999, ± 70% confidence interval.



confidence interval.

Table 9. Combined growth/yield ranks for the three sites. Rank 1 is the highest yield/growth at the site for a given parameter.

		Malawi 1997				Malawi 1998				Tanzania		Kenya	
Species	Seed	Foliage	Wood	Ht	RCD	Foliage	Wood	Ht	RCD	Ht	RCD	Ht	RCD
L. collinsii collinsii	45/85	7	8	8	4	12	8	10=	6				
L. collinsii collinsii	51/88	15	13	12	16	14	10	8=	12				
L. collinsii collinsii	52/88	20	12	13	11	13	12	13	13	6	6	7=	4
L. collinsii zacapana	18/94	19	15	6	18	18	16	7	8				
L. collinsii zacapana	56/88	18	18	10	19	20	19	15	4	7	9	20	18
L. collinsii zacapana	57/88	13	16	14	13	16	18	17	20				
L. diversifolia	45/87	10	9	16	12	8	7	10=	7				
L. diversifolia	82/92											12	10
L. diversifolia	83/92											9	5
L. esculenta	47/87	16	19	19	14	15	20	20	11	12	3	10	2
L. esculenta	48/87	14	17	18	3	19	17	19	15				
L. hybrid	52/87	17	10	11	17	4	1	14	17	10	12	1	1
L. hybrid (Lilongwe)	52/87	11		2	2	17	15	18	1				
L. hybrid KX2	2/95									15	11	11	7
L. hybrid KX3	3/95											13	6
L. involucrata	87/92									9	13		
L. lanceolata lanceolata	43/85									4	1	19	13
L. lempirana	6/91									5	14	14	8
L. leucocephala										13	8		
L. leucocephala glabrata	32/88											15	14
L. leucocephala glabrata	34/92									8	4		
L. macrophylla istmensis	39/89	3	3	9	8	2	2	1	5				
L. macrophylla istmensis	47/85	1	1	5	15	3	3	2	3	1	2	7=	11
L. macrophylla macrophylla	55/88	8	14		7	10	14	4	18				
L. magnifica	19/84									2	7	6	3
L. pallida	137/94	5	4	17	10	1	4	5	10	3	5	3	9
L. pallida	79/92	6	5	7	9	7	9	8=	14	14	15	5	16
L. pulverulenta	83/87									16	16	17	17
L. salvadorensis	17/86	9	6	3	6	6	5	3	2				
L. salvadorensis	34/88	12	11	4	5	11	13	12	9				
L. salvadorensis	36/88	4	2	15	20	9	11	6	16			18	20
L. shannonii	53/87	2	7	1	1	5	6	16	19				
L. trichandra	4/91											4	15
L. trichandra	53/88											2	12
L. trichandra (=revoluta)	?									11	10		
L. trichodes	61/88											16	19

The unknown hybrid (52/87) showed mixed performance, but appears to regrow well after harvest; the 1998 yield in Malawi was much better than the 1997 yield which was poor. *L. magnifica* performed well in Kenya and Tanzania.

Figures 8, 9 and 10 show the numbers of shoots per tree, the tree damage score and proportion of healthy shoots, over all accessions. To analyse differences between accessions, comparisons were made at peaks in damage.

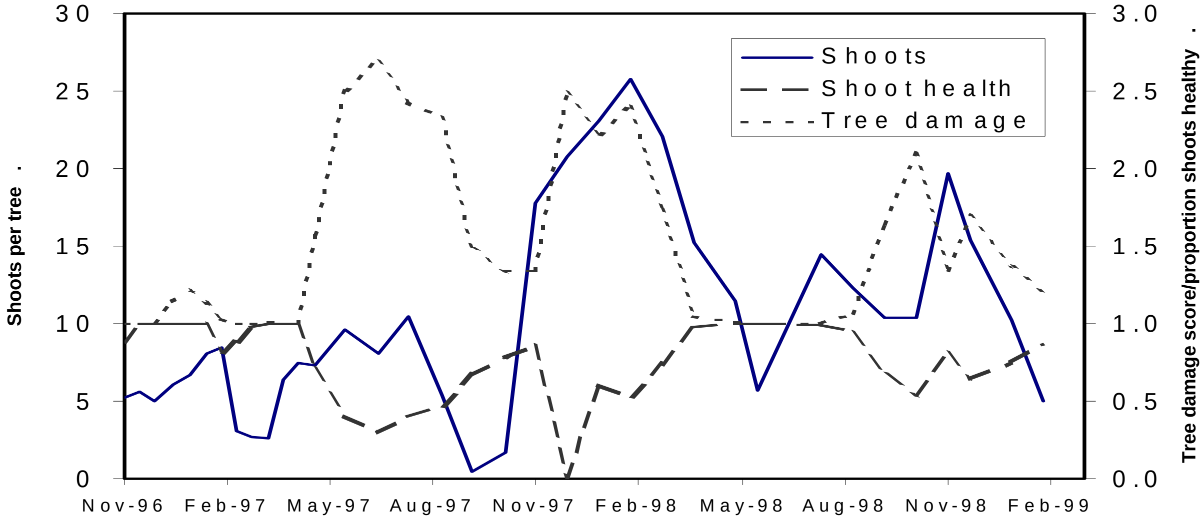
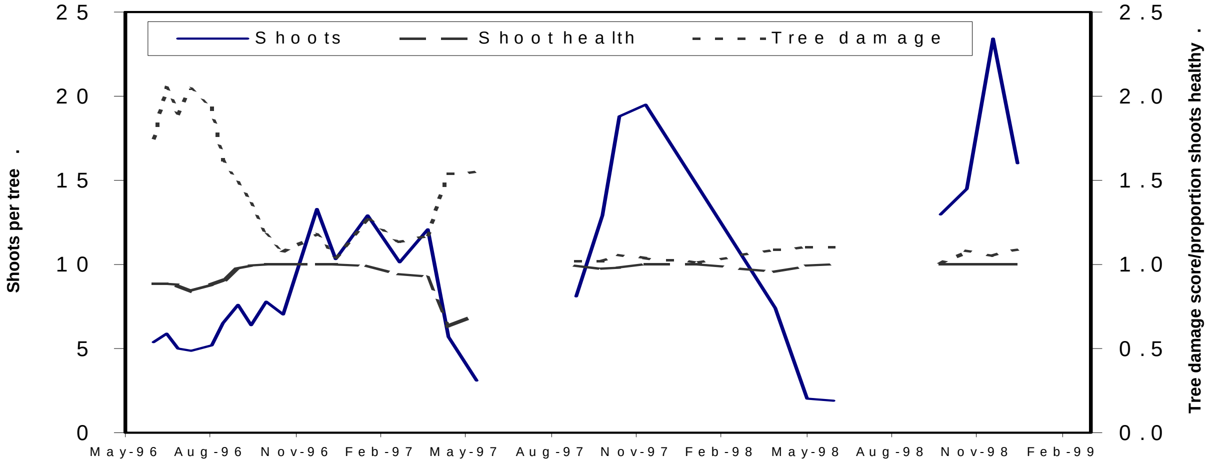


Figure 8. Mean shoot number, tree damage and shoot health, Machakos, Kenya



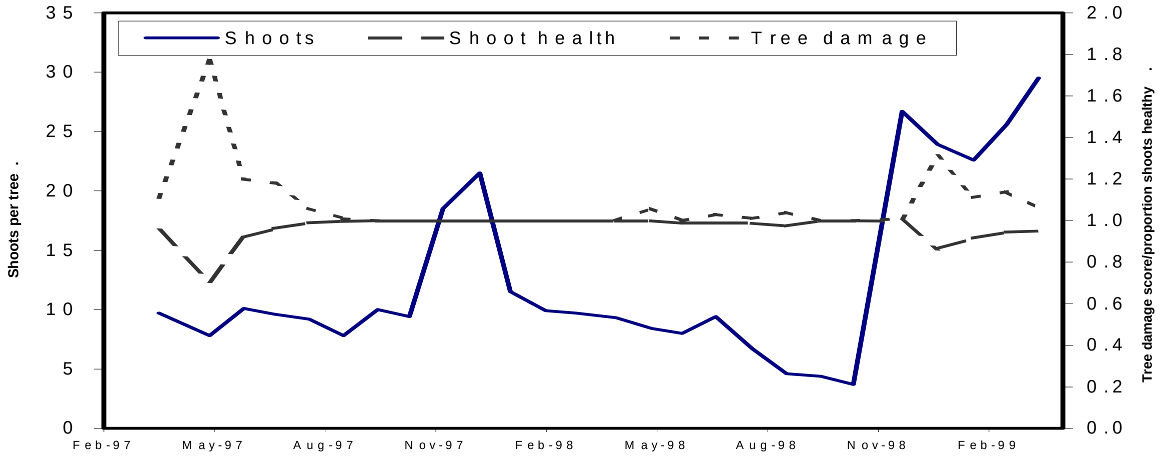


Figure 10. Mean shoot number, tree damage and shoot health, Tumbi, Tanzania

Figures 11 to 18 show the ranked tree damage and shoot health data for selected peaks, in Kenya (Figures 11-14), Malawi (Figures 15-16) and Tanzania (Figures 17-18). In all cases there was a significant difference between accessions; in Kenya $p<0.001$ in all cases, in Malawi $p=0.033$ and 0.022 for tree damage and shoot health respectively, and in Tanzania $p<0.001$ and $p=0.023$ for tree damage and shoot health respectively.

In Table 10 the ranks for tree and shoot damage are combined for the three sites to allow comparison. To aid comparison, shoot damage rank is presented rather than shoot health as used in the analyses.

The most consistent result is the high level of damage to *L. collinsii zacapana* (56/88). In contrast *L. collinsii collinsii* (52/88) showed very little damage, as did *L. esculenta*. As would be expected *L. leucocephala* generally showed a high level of damage. *L. macrophylla istmensis* showed moderate to high damage, despite which it yielded well. *L. pallida* had low levels of damage in Kenya and Tanzania, but moderate in Malawi.

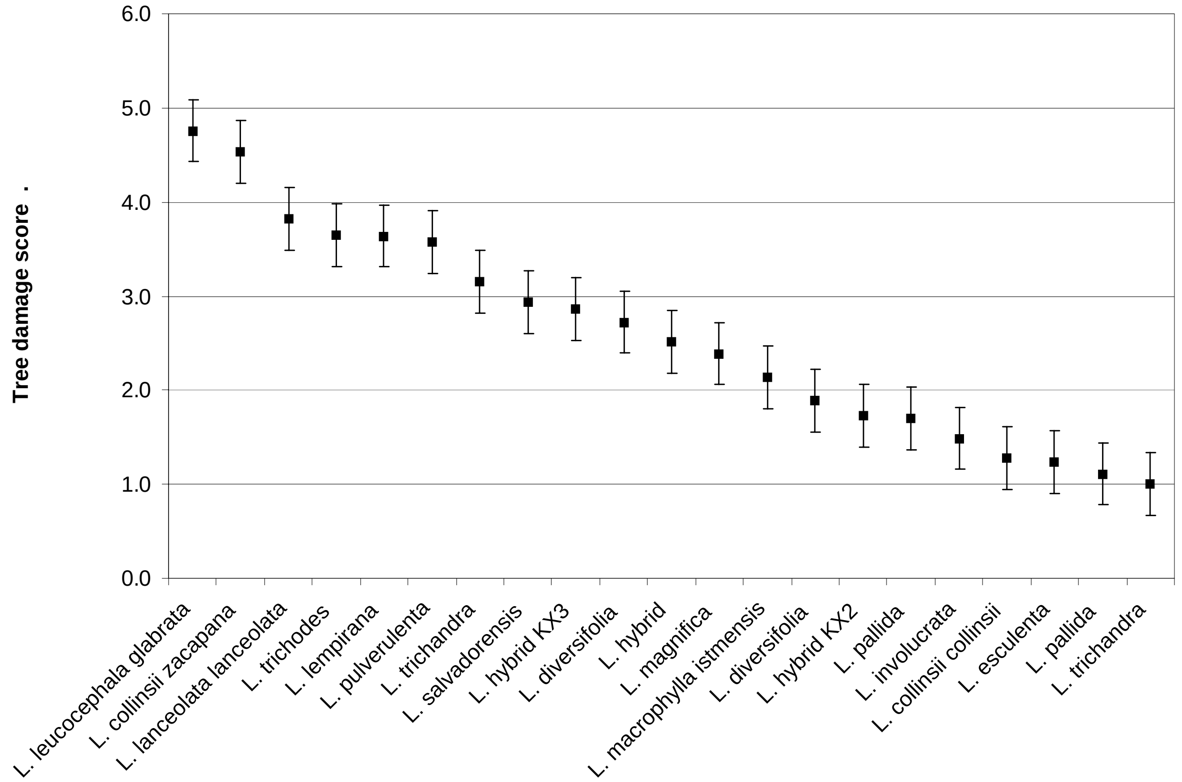
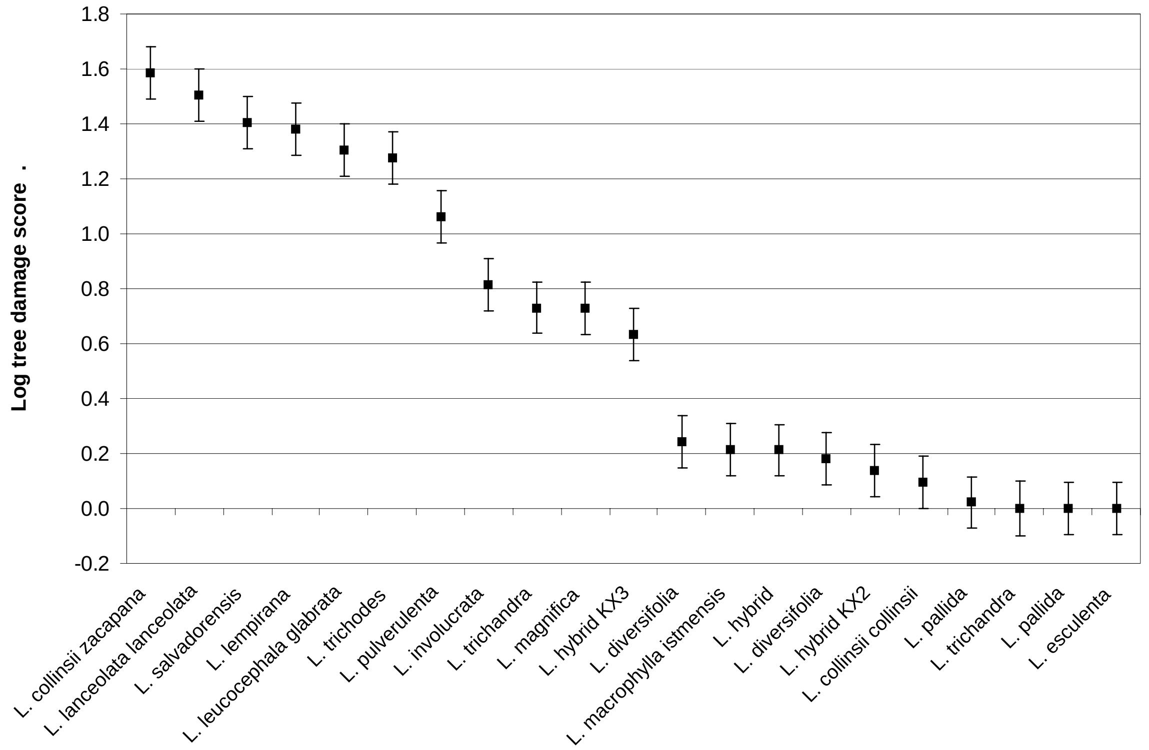


Figure 11. Ranked mean tree damage±70% C.I., June-August 1997, Machakos



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Machakos.

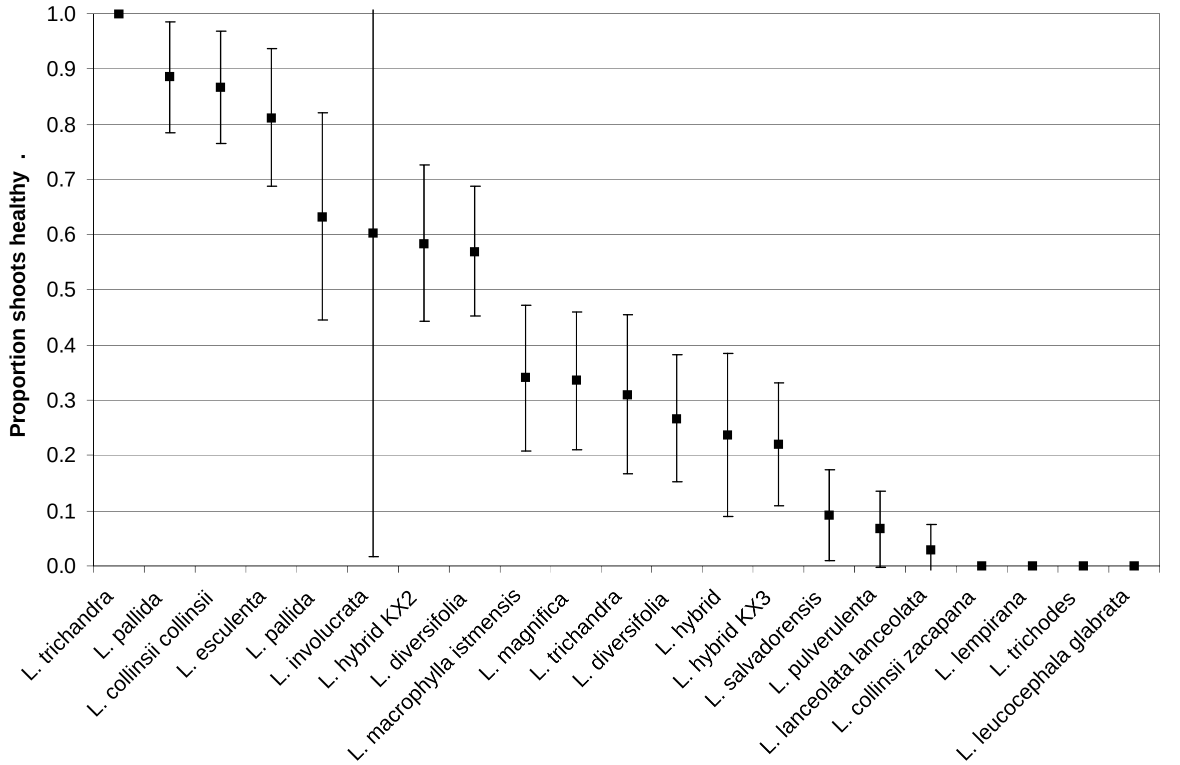
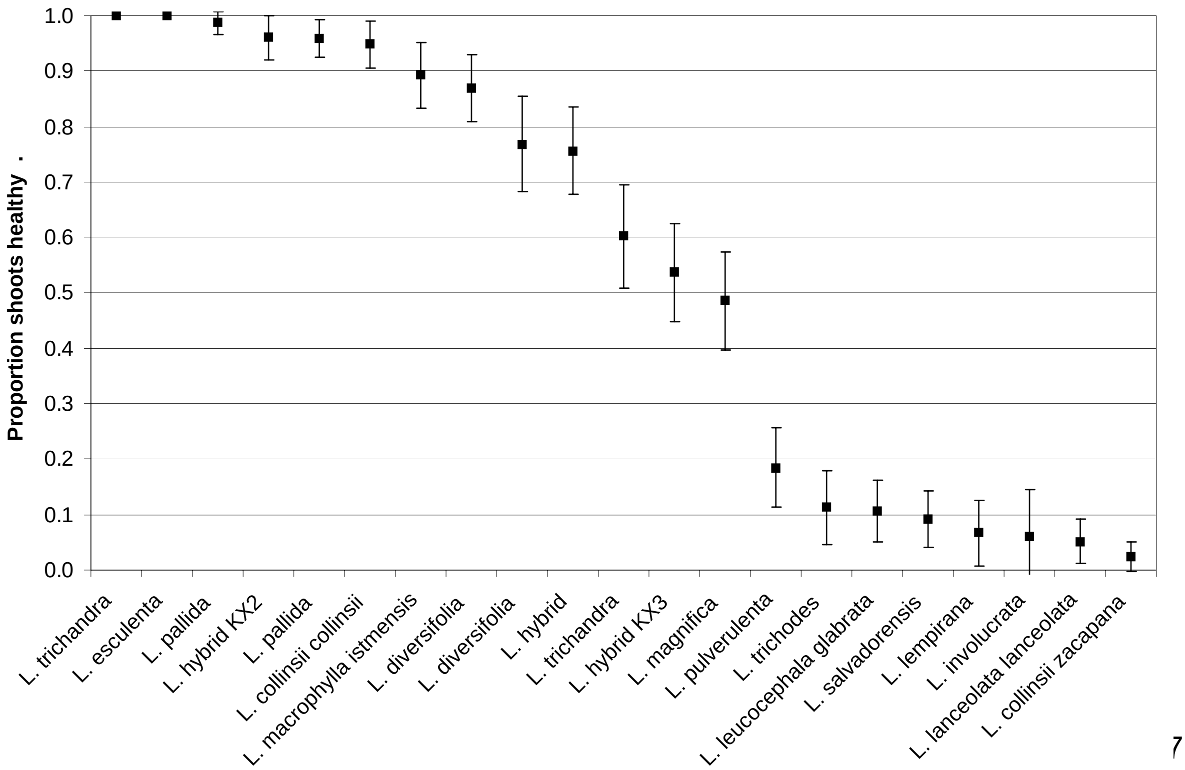


Figure 15: Ranked mean proportion healthy shoots ±95% CI, June August 1997, Machakos.



F 7-
February 1998, Machakos.

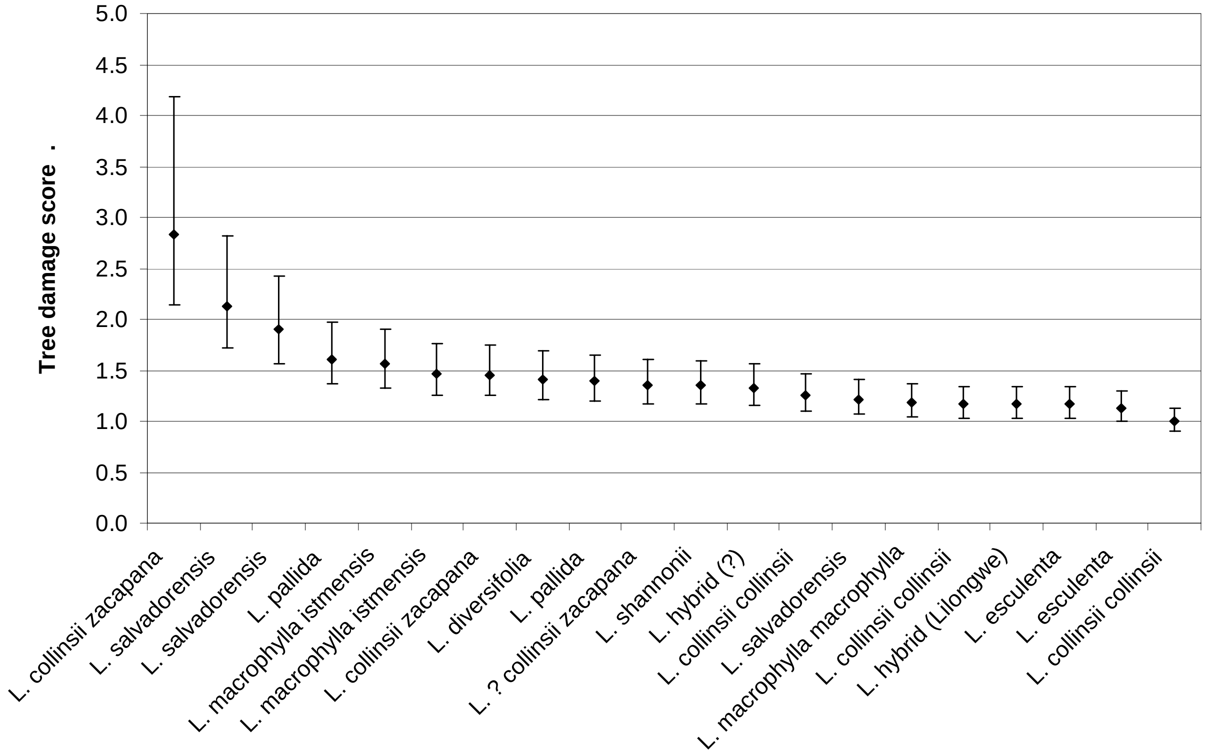


Figure 15. Ranked mean tree damage±70% C.I. (back transformed from reciprocal), May-June 1997, Makoka

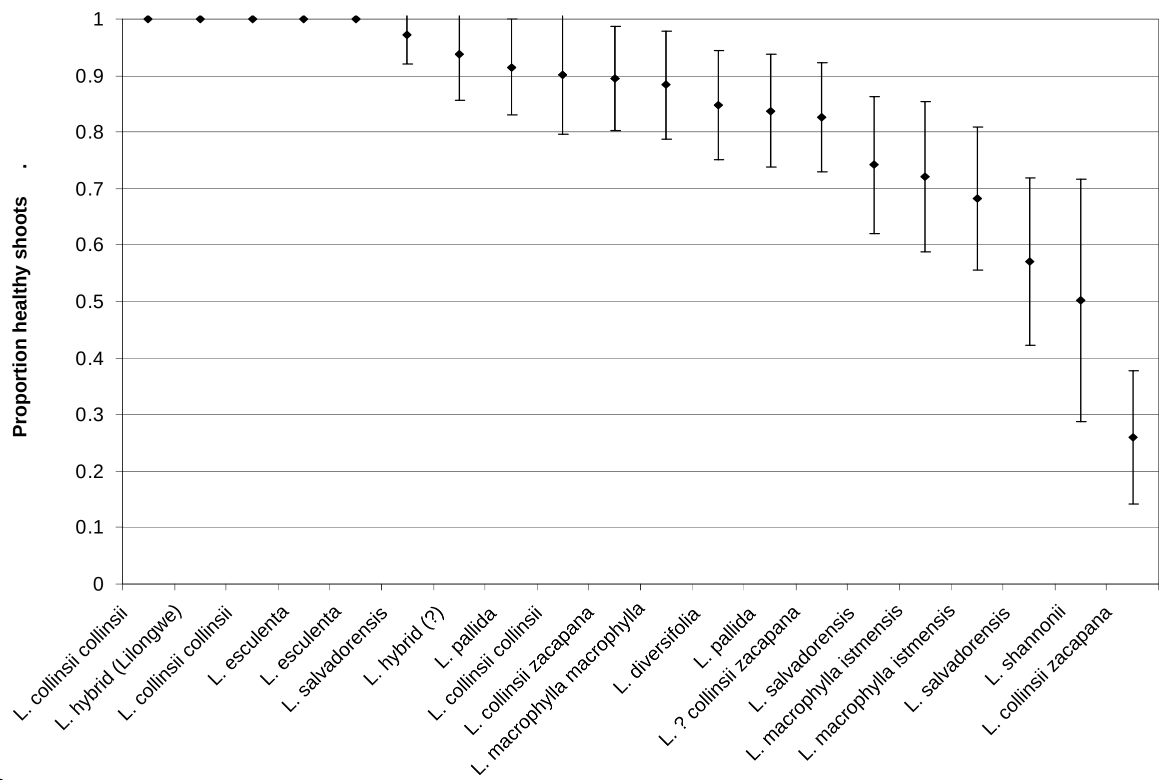


Figure 16. Ranked mean proportion healthy shoots ±70% C.I., May-June 1997, Makoka

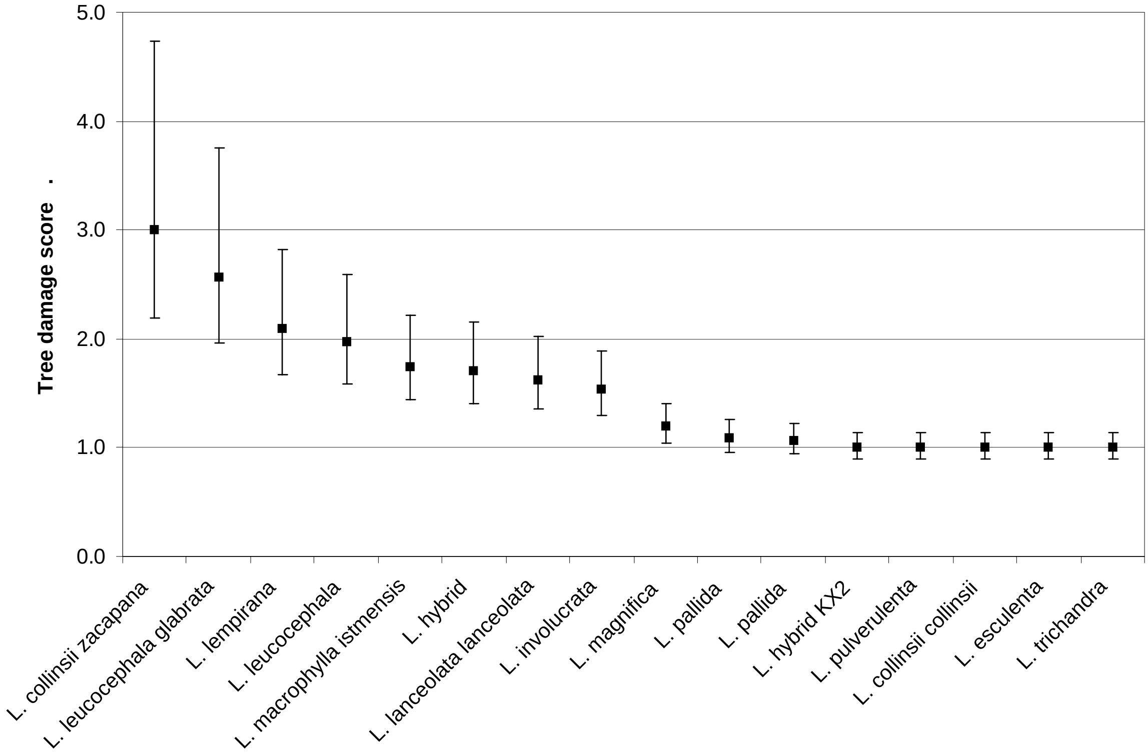
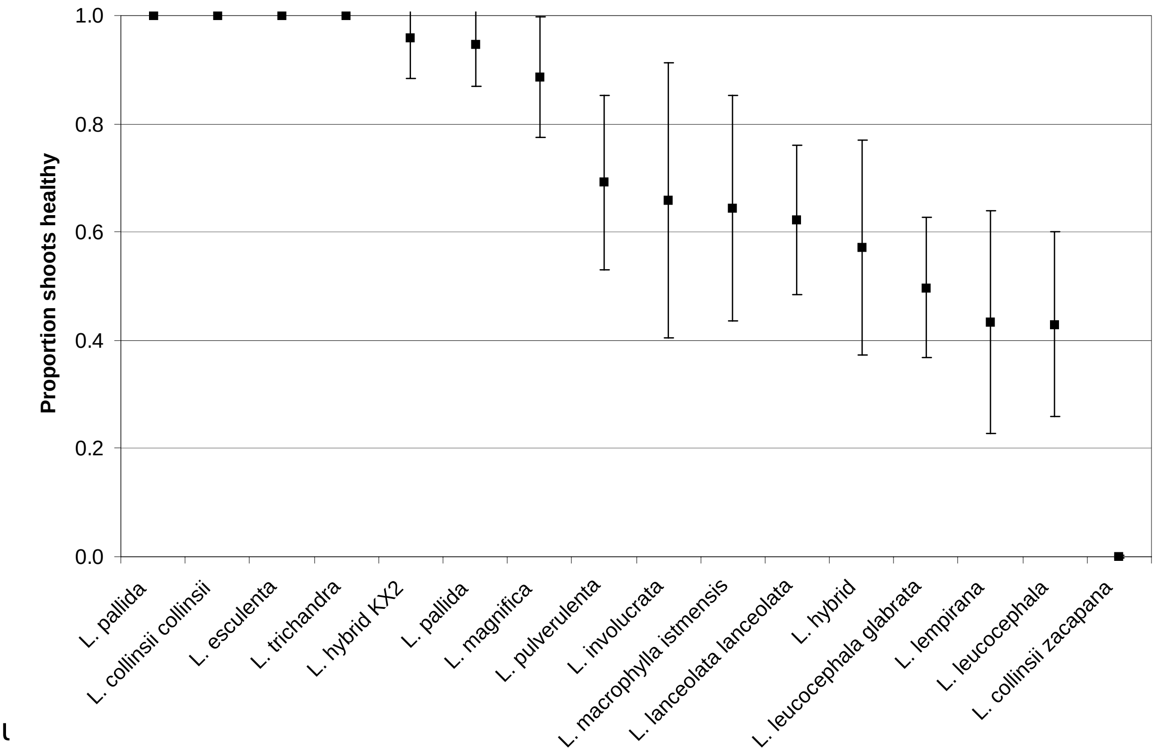


Figure 17. Ranked mean tree damage±70% C.I. (back transformed from reciprocal), May 1997, Tumbi



Figu

Table 10. Combined tree and shoot damage ranks for the three sites. Rank 1 denotes the highest damage (note for ranking shoot damage has been converted to proportion damaged rather than proportion healthy as in the analyses).

		Kenya				Malawi		Tanzania	
		Tree	Tree	Shoot	Shoot	Tree	Shoot	Tree	Shoot
Species	Seed	Peak 1	Peak 2	Peak 1	Peak 2	Peak 1	Peak 1	Peak 1	Peak 1
L. collinsii collinsii	45/85					20	7		
L. collinsii collinsii	51/88					16=	16=		
L. collinsii collinsii	52/88	18	16=	19	16	13	16=	12=	12=
L. collinsii zacapana	18/94					10	12		
L. collinsii zacapana	56/88	2	1	1=	1	1	1	1	1
L. collinsii zacapana	57/88					7	11		
L. diversifolia	45/87					8	9		
L. diversifolia	82/92	10	12=	10	13				
L. diversifolia	83/92	14	12=	14	14				
L. esculenta	47/87	19	18=	18	20=	19	16=	12=	12=
L. esculenta	48/87					16=	16=		
L. hybrid	52/87	11	12=	9	12	12	14	5	4
L. hybrid (Lilongwe)	52/87					16=	16=		
L. hybrid KX2	2/95	15=	16=	15	17=			12=	11
L. hybrid KX3	3/95	8=	11	8	10				
L. involucrata	87/92	17	8	16	3			8	7
L. lanceolata lanceolata	43/85	3	2	5	2			5	5
L. lempirana	6/91	5=	3=	1=	4			3	2=
L. leucocephala								3	2=
L. leucocephala glabrata	32/88	1	5=	1=	6=				
L. leucocephala glabrata	34/92							2	3
L. macrophylla istmensis	39/89					5	4		
L. macrophylla istmensis	47/85	13	12=	12=	15	6	5	5	6
L. macrophylla macrophylla	55/88					15	10		
L. magnifica	19/84	12	9=	12=	9			9	9
L. pallida	137/94	15=	18=	17	17=	4	8	10	12=
L. pallida	79/92	20	18=	20	19	9	13	10	10
L. pulverulenta	83/87	5=	7	6	8			12=	8
L. salvadorensis	17/86					14	15		
L. salvadorensis	34/88					2	6		
L. salvadorensis	36/88	8=	3=	7	5	3	3		
L. shannonii	53/87					11	2		
L. trichandra	4/91	7	9=	11	11				
L. trichandra	53/88	21	18=	21	20=				
L. trichandra (=revoluta)	?							12=	12=
L. trichodes	61/88	4	5=	1=	6=				

4.2 Monitoring psyllid and natural enemy populations

Psyllid populations have been highest at Machakos, while at Tumbi the insects were at very low levels for over a year from July 1997 (Figures 19-21). However the mean values presented in these graphs hide large variation between accessions, and Figures 22-24 show data from a few accessions to demonstrate this range. In general the pattern of psyllid populations is the same for different accessions, but with the susceptible lines having higher peaks.

Peaks in damage follow peaks in psyllid numbers as would be expected, so as for damage, one way to analyse differences between accessions is to compare populations at the peaks. Overall damage over a period could also be expected to be related to the total psyllid load, which can be estimated by summing the monthly population estimates. In both these analyses a log transformation was used, apart from for the total count and first peak at Machakos, where transformation was found unnecessary.

Figures 25-28 show the results for the Machakos trial. Differences between accessions were highly significant ($p<0.001$) in all cases apart from the November 1997-January 1998 peak ($p<0.028$). In Malawi (Figures 29-32) the total count was significantly different ($p<0.001$), as were the peaks in April 1997 ($p<0.001$) and March 1998 ($p=0.003$). Differences between accessions at the peak in November 1997 were not significant ($p=0.059$), due to medium and large psyllid numbers being similar across accessions. Differences in Tanzania were highly significant ($p<0.001$) for the total count and at the singly peak in May 1997; thereafter there were very few psyllids recorded.

Table 11 combines the psyllid number ranks for all analyses at all sites, and as would be expected, psyllid numbers were generally highest where the greatest damage was observed (Table 10). However, in Tanzania and Kenya *L. collinsii zacapana* (56/88) had moderate to low numbers of psyllids, but still had the worst damage, suggesting particular sensitivity to psyllid attack. Conversely *L. diversifolia* (82/92) had high numbers of psyllids, but only moderate damage, indicating tolerance to attack.

Thus as has been found elsewhere, resistance to the psyllid comprises two effects; low psyllid populations and low damage. The results here suggest that while both are desirable, either may be sufficient to allow good growth to occur.

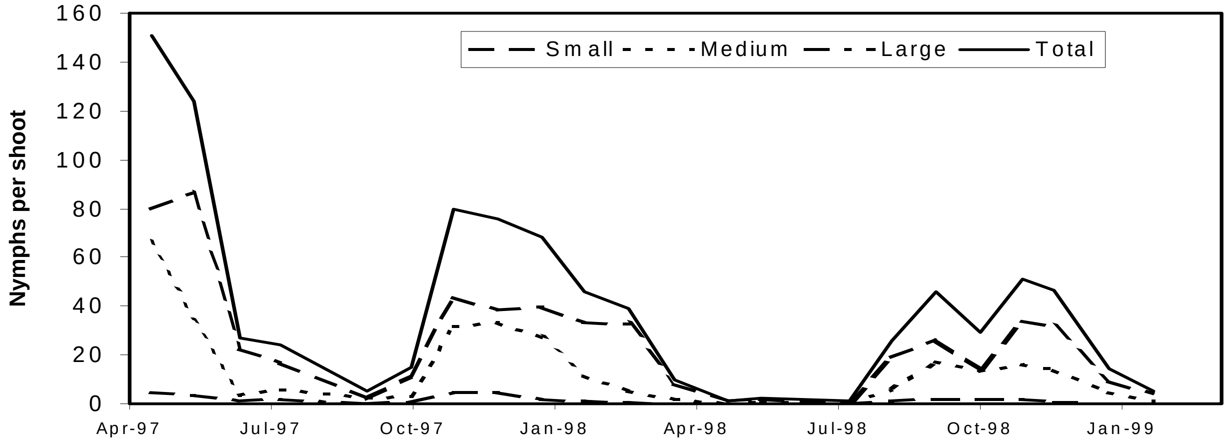


Figure 19. Psyllid numbers averaged over all accessions, Machakos, Kenya

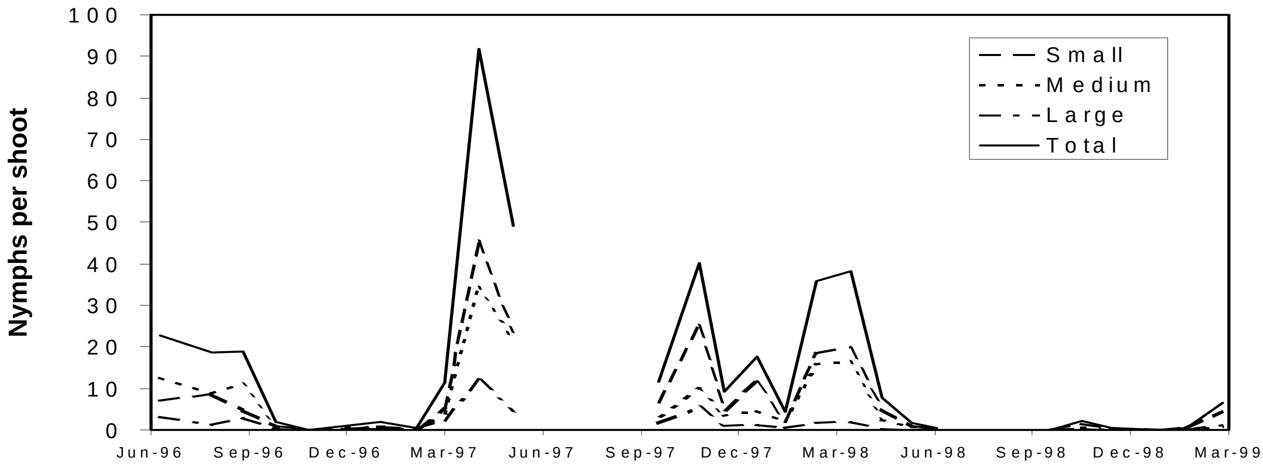


Figure 20. Psyllid numbers averaged over all accessions, Makoka, Malawi

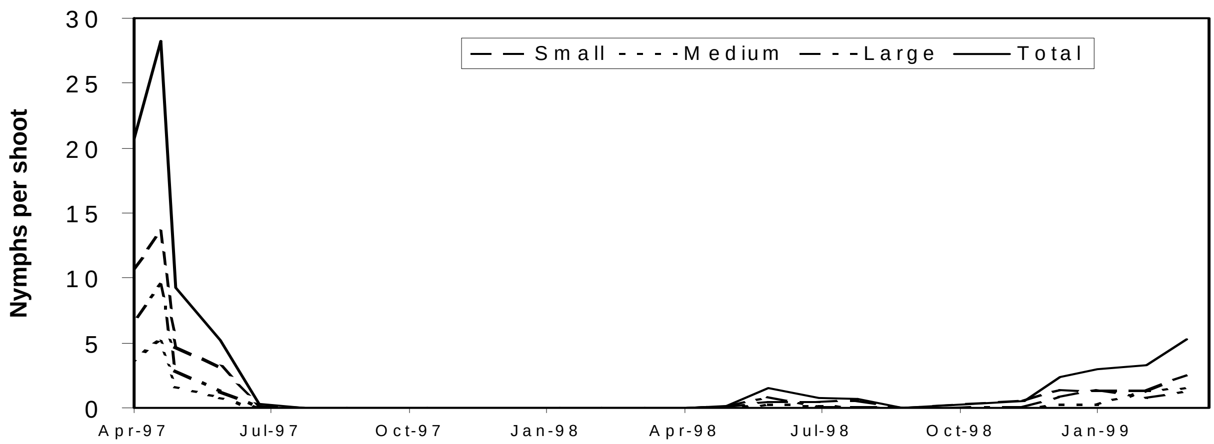


Figure 21. Psyllid numbers averaged over all accessions, Tumbi, Tanzania

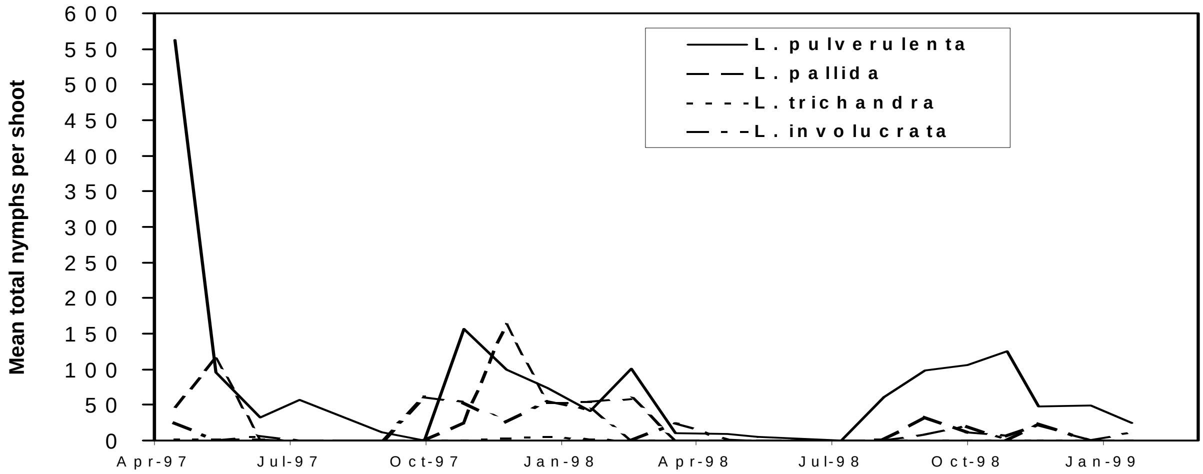


Figure 22. Psyllid populations on selected accessions covering the range of susceptibility, Machakos, Kenya

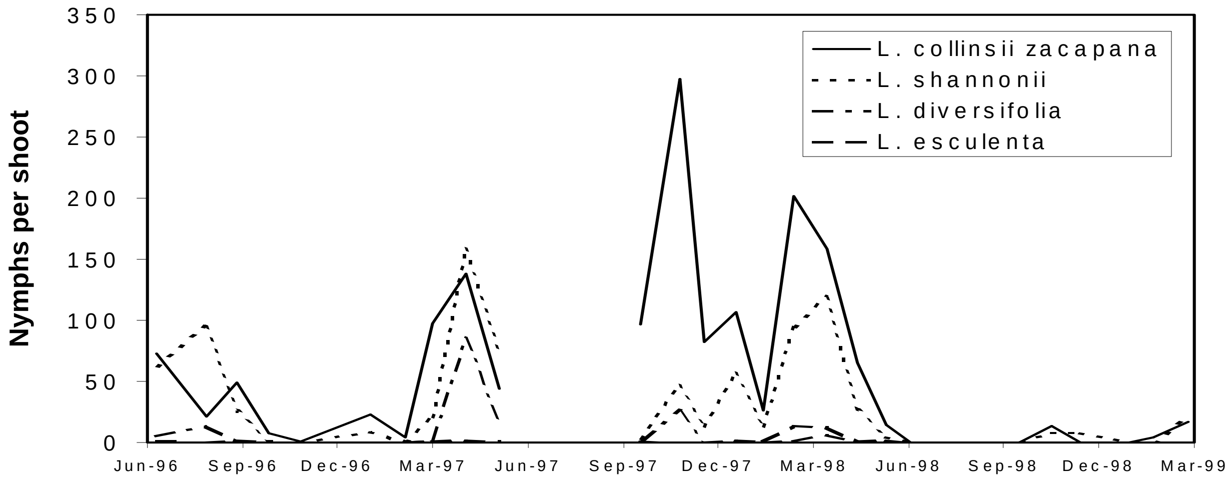


Figure 23. Psyllid populations on selected accessions covering the range of susceptibility, Makoka, Malawi

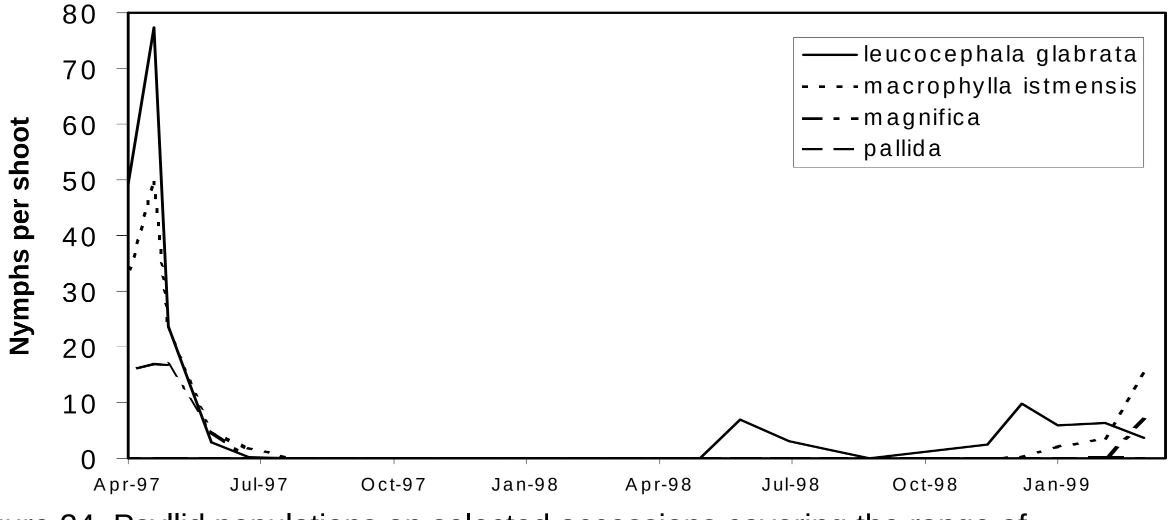


Figure 24. Psyllid populations on selected accessions covering the range of susceptibility, Tumbi, Tanzania

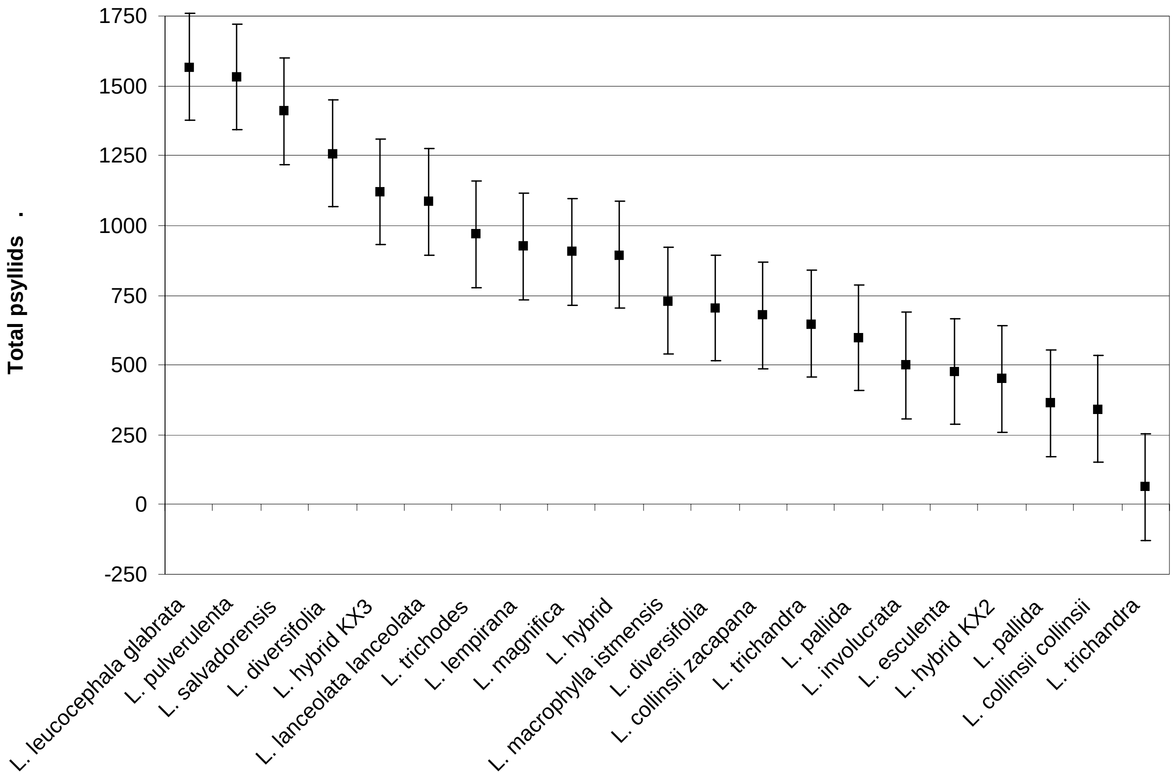


Figure 25. Ranked mean total psyllids ±70% C.I., May 1997-February 1999, Machakos

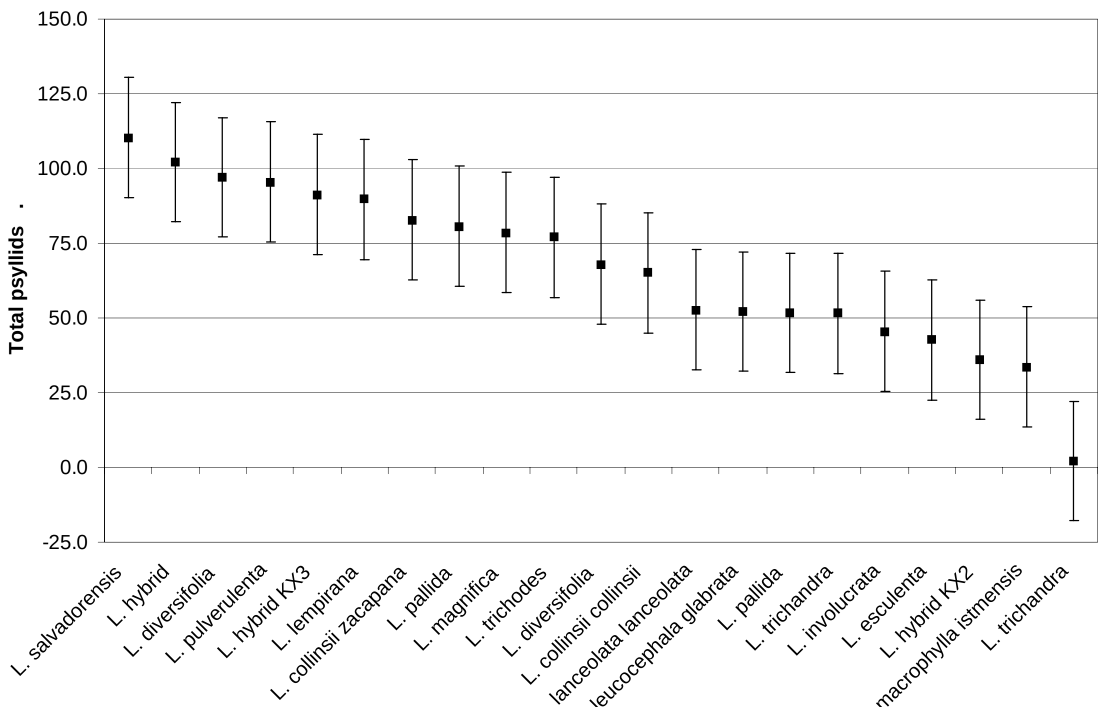


Figure 26. Ranked mean total psyllids ±70% C.I., November 1997-January 1998, Machakos

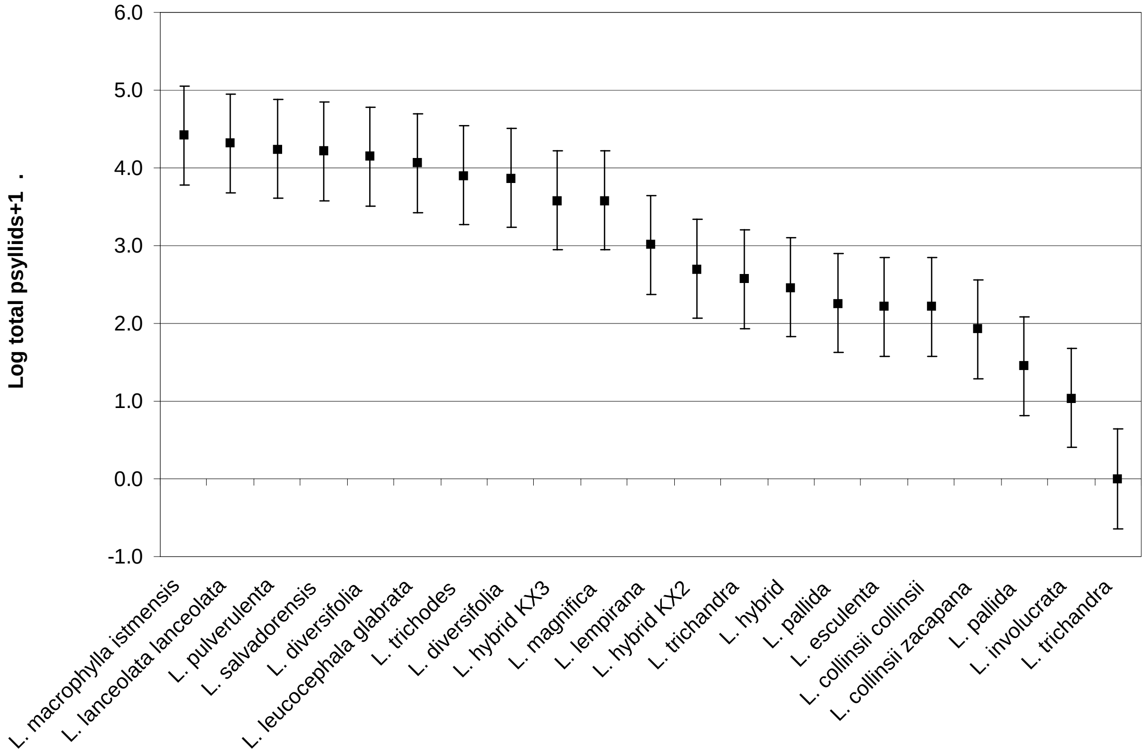
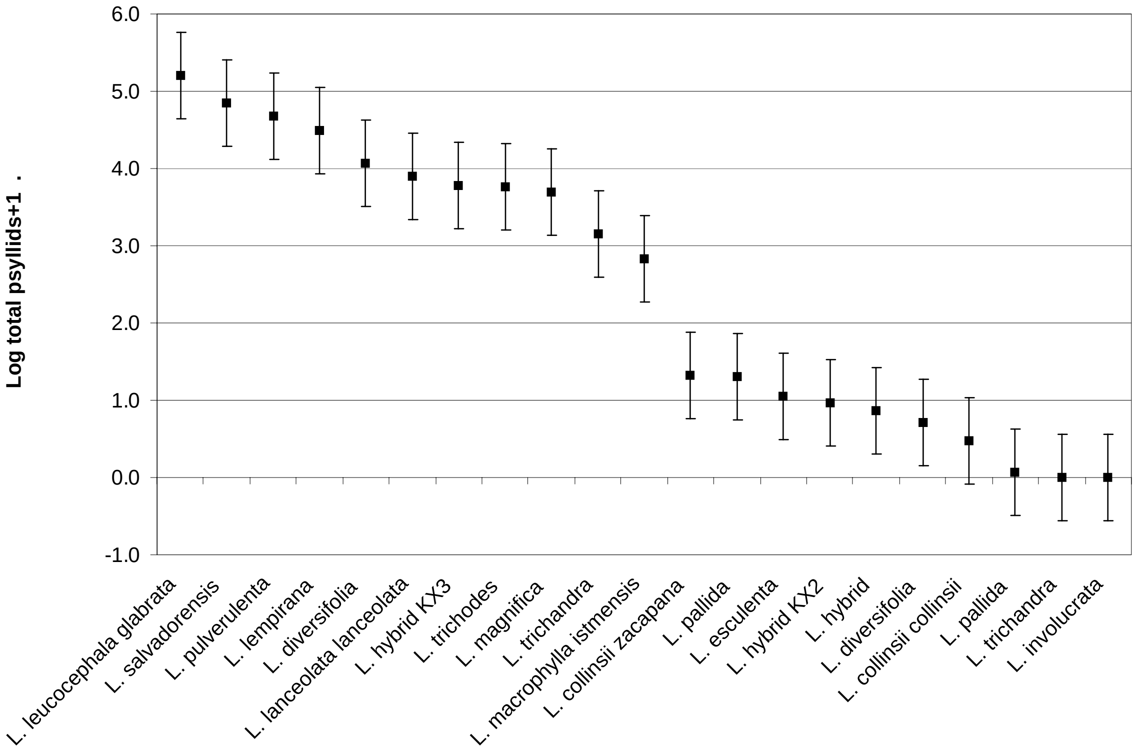


Figure 27. Ranked mean log total psyllids+1 ±70% C.I., September 1998, Machakos



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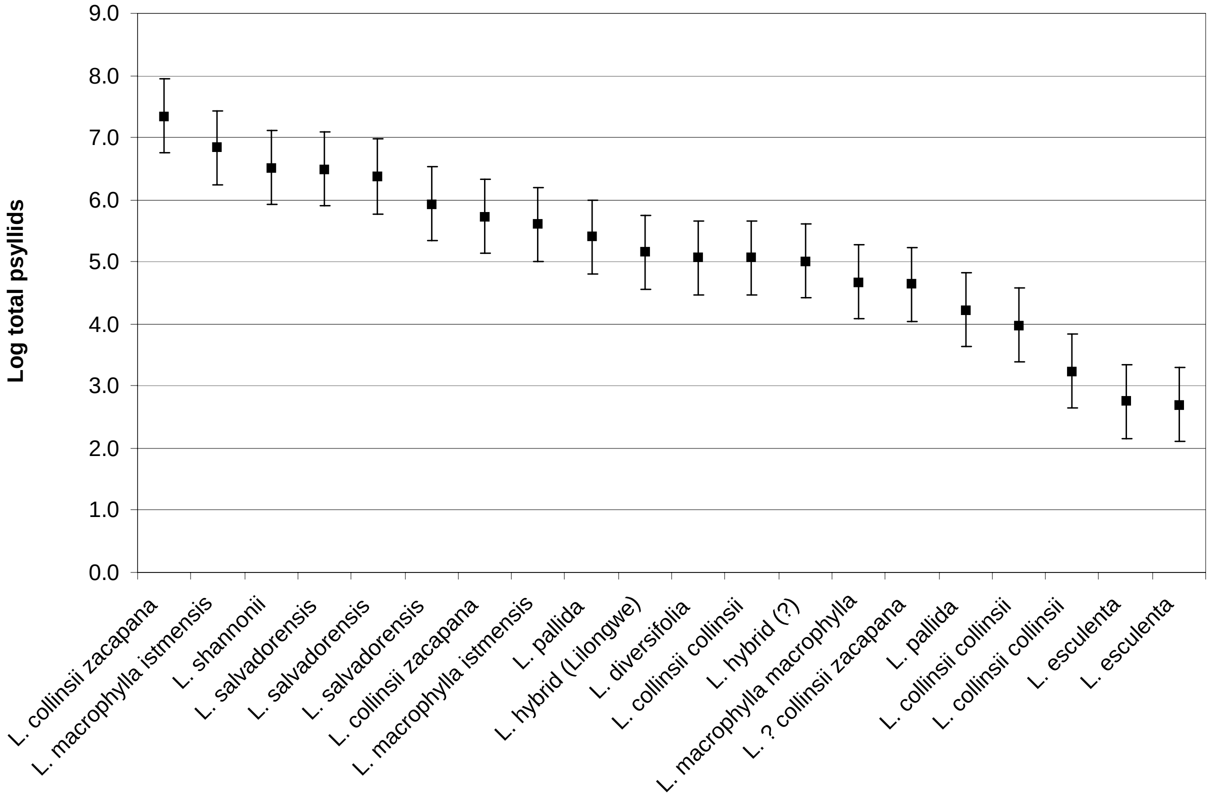


Figure 29. Ranked mean log total psyllids ±70% C.I., July 1996-March 1999, Makoka

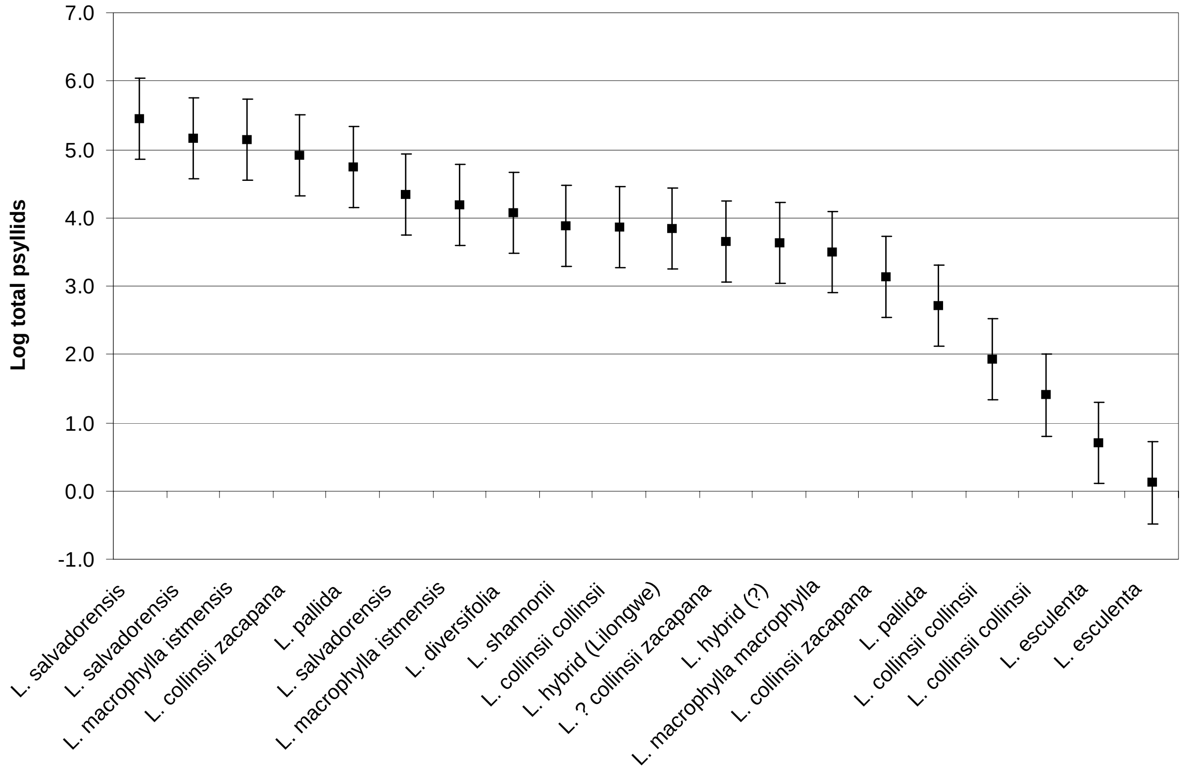


Figure 30. Ranked mean log total psyllids ±70% C.I., April 1997, Makoka

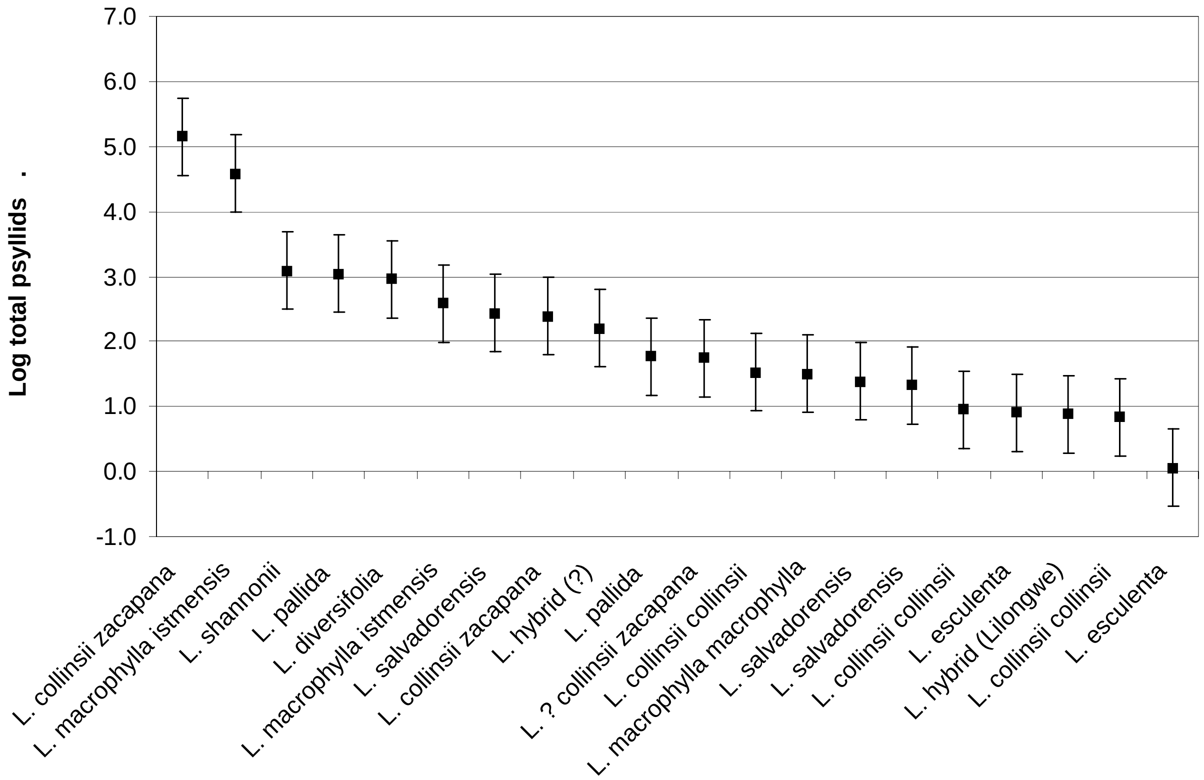
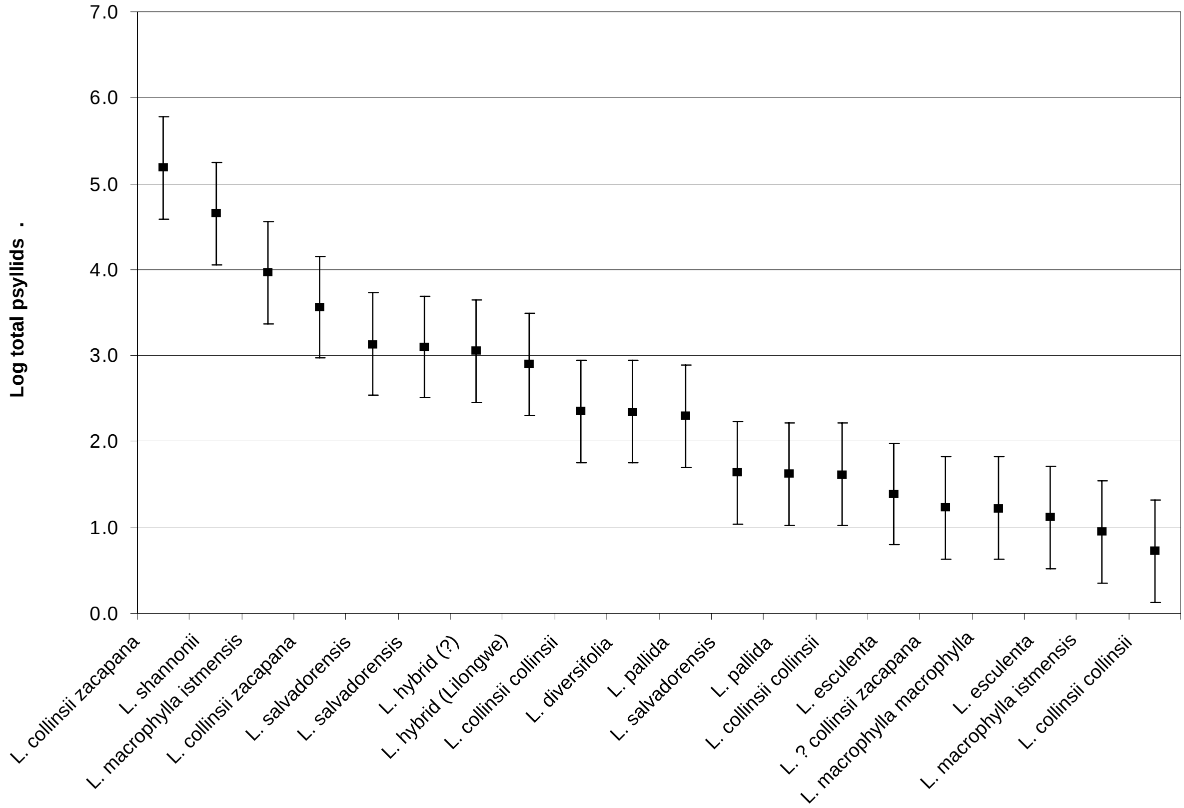


Figure 31. Ranked mean log total psyllids ±70% C.I., November 1997, Makoka



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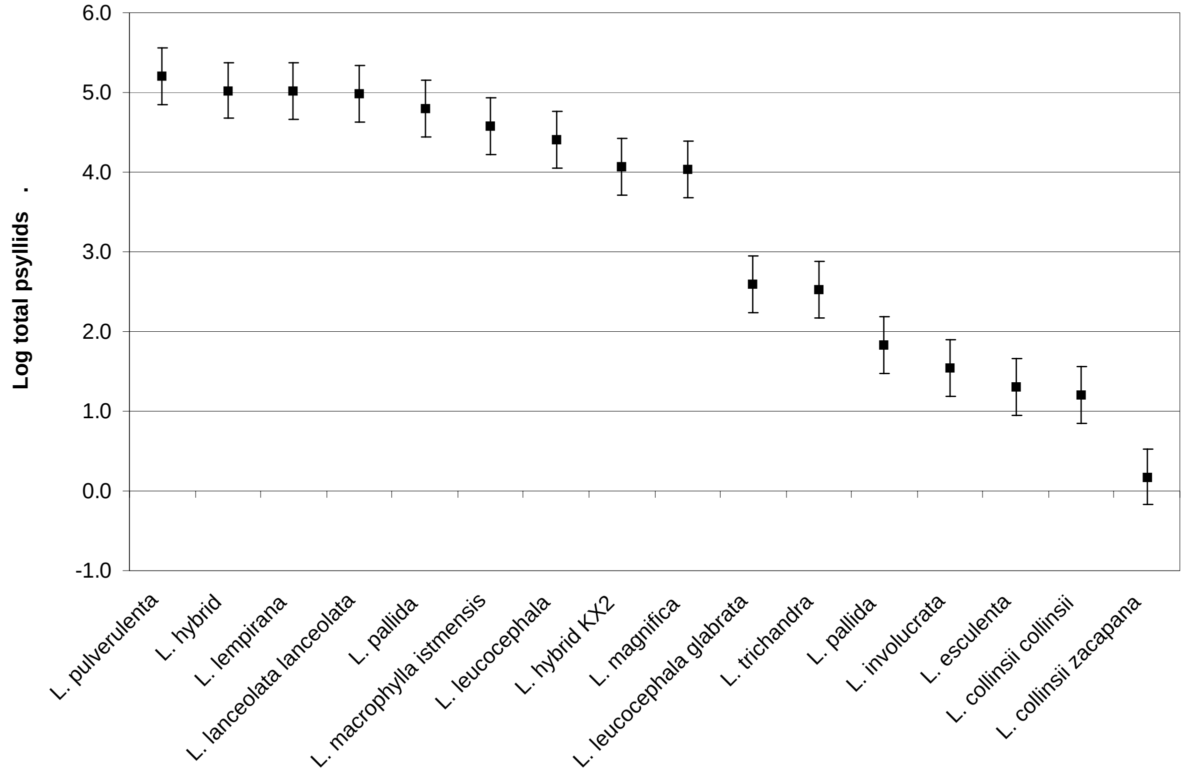

Figure 33. Ranked mean log total psyllids ±70% C.I., April 1997-March 1999, Tumbi

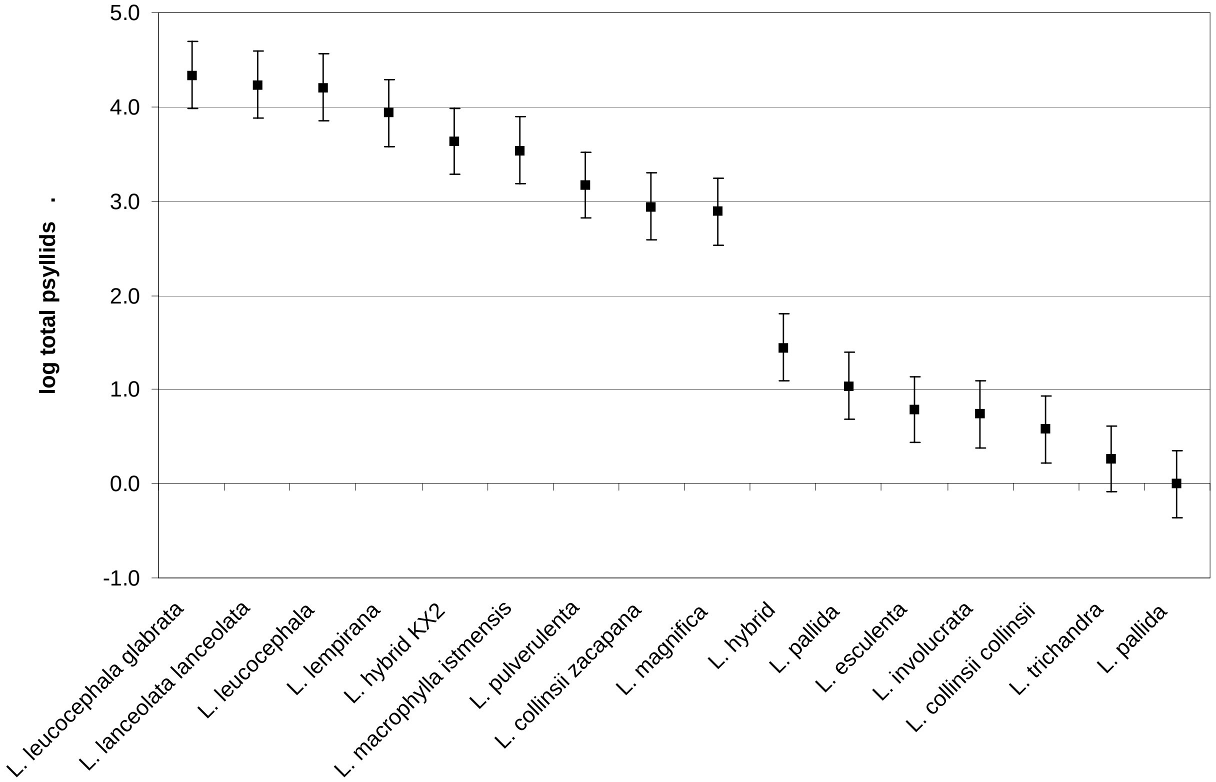

Table 11. Psyllid number ranks for the three sites. Rank 1 denotes the highest psyllid number.

		Kenya				Malawi				Tanzania	
Species	Seed	Total	Peak 1	Peak 2	Peak 3	Total	Peak 1	Peak 2	Peak 3	Total	Peak 1
L. collinsii collinsii	45/85					18	18	19	20		
L. collinsii collinsii	51/88					17	17	16	12=		
L. collinsii collinsii	52/88	20	12	16=	18	11=	9=	12=	9	15	14
L. collinsii zacapana	18/94					15	12=	11	16=		
L. collinsii zacapana	56/88	13	7	18	12=	1	4	1	1	16	8
L. collinsii zacapana	57/88					7	15	7=	4		
L. diversifolia	45/87					11=	8	4=	10=		
L. diversifolia	82/92	4	3	3=	5						
L. diversifolia	83/92	12	11	7=	17						
L. esculenta	47/87	17	18	16=	14=	19	20	17=	18	14	12
L. esculenta	48/87					20	19	20	15		
L. hybrid	52/87	10	2	14	16	13	12=	9	5=	2	10
L. hybrid (Lilongwe)	52/87					10	11	17=	8		
L. hybrid KX2	2/95	18	19	12	14=					8	5
L. hybrid KX3	3/95	5	5	9=	7=						
L. involucrata	87/92	16	17	20	20=					13	13
L. lanceolata lanceolata	43/85	6	13	2	6					4	2
L. lempirana	6/91	8	6	11	4					3	4
L. leucocephala										7	3
L. leucocephala glabrata	32/88	1	14	6	1						
L. leucocephala glabrata	34/92									10	1
L. macrophylla istmensis	39/89					2	2=	2	3		
L. macrophylla istmensis	47/85	11	20	1	11	8	7	6	19	6	6
L. macrophylla macrophylla	55/88					14	14	12=	16=		
L. magnifica	19/84	9	9	9=	9					9	9
L. pallida	137/94	15	8	15	12=	9	5	4=	10=	5	16
L. pallida	79/92	19	15	19	19	16	16	10	12=	12	11
L. pulverulenta	83/87	2	4	3=	3					1	7
L. salvadorensis	17/86					6	6	15	12=		
L. salvadorensis	34/88					5	1	14	5=		
L. salvadorensis	36/88	3	1	3=	2	3=	2=	7=	5=		
L. shannonii	53/87					3=	9=	3	2		
L. trichandra	4/91	14	16	13	10						
L. trichandra	53/88	21	21	21	20=						
L. trichandra (=revoluta)	?									11	15
L. trichodes	61/88	7	10	7=	7=						

Results of the *L. leucocephala* trial at Tumbi monitored to determine establishment of the parasitoids are in a paper submitted for publication (Appendix 1). Parasitoid populations have been low at all sites, resulting in low levels of parasitism (Figures 35-37). Highest parasitism generally occurred after the peak psyllid numbers, when populations were already falling. This suggests that the parasitoid populations do not respond rapidly enough to increases in psyllid numbers to effect control. Numbers of parasitoid mummies recovered were too low to analyse differences between accessions, even at Machakos where psyllid and parasitoid populations were highest.

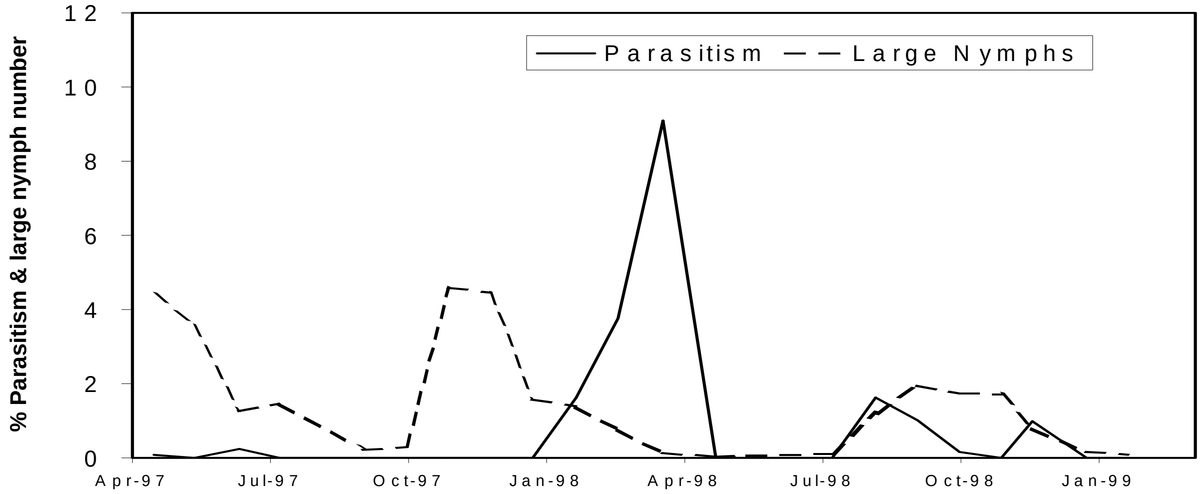

Figure 35. Large nymph population and index of parasitism, Machakos, Kenya

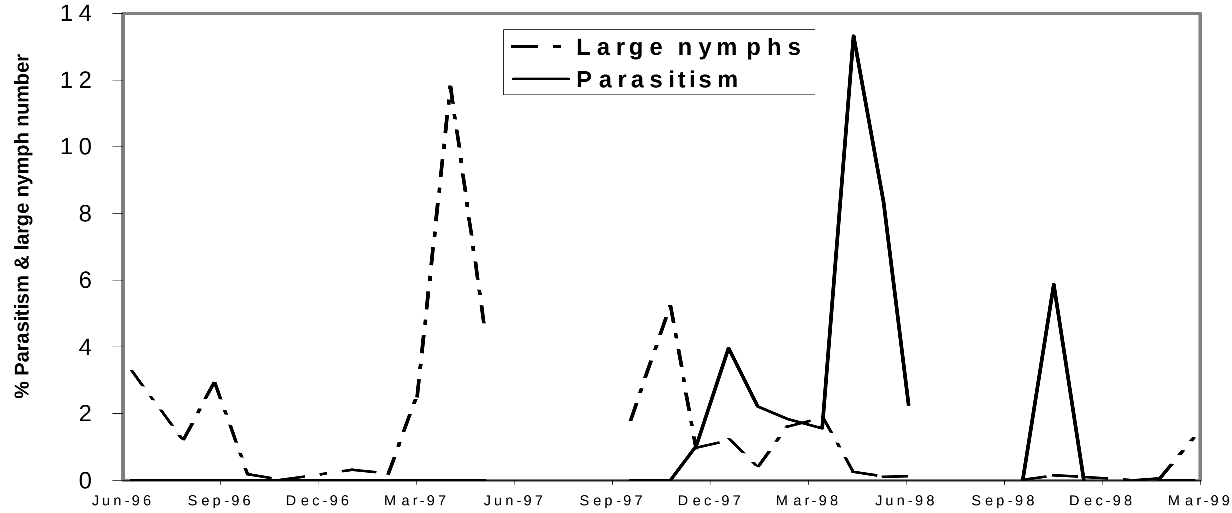

Figure 36. Large nymph population and index of parasitism, Makoka, Malawi

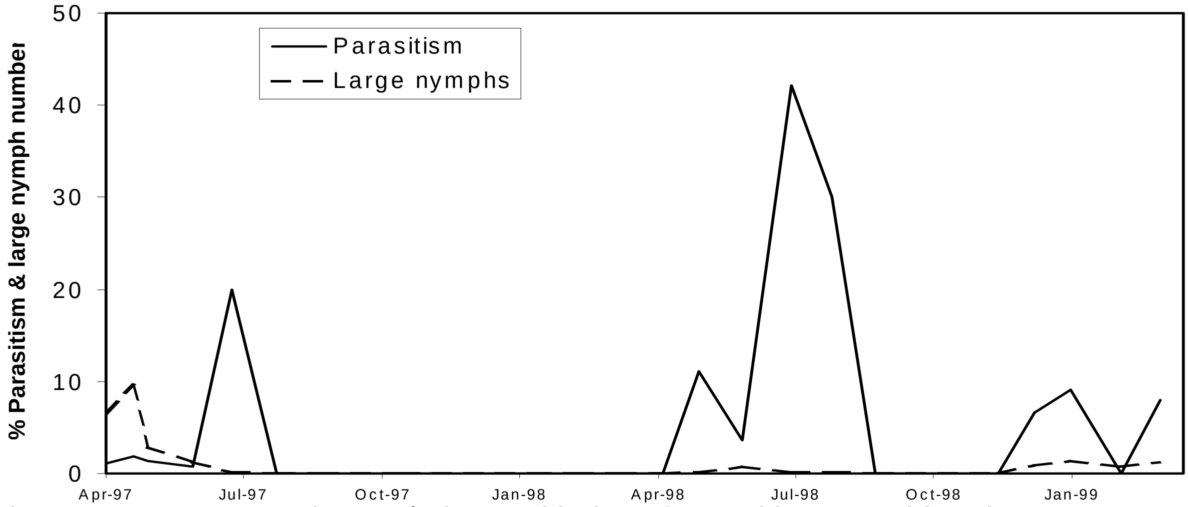

Figure 37. Large nymph population and index of parasitism, Tumbi, Tabora

4.3 Cutting regime trials

As shown in the previous section, parasitoid populations were low, so assessing the effect of different cutting regimes on parasitism became impossible. However, over the period in which monitoring was undertaken (reduced by the poor establishment of the trial) there were no marked differences in tree damage or shoot health under the different cutting regimes(Figures 38-40). Analysis of differences between regimes in the total psyllid load over the experiments (regime 1 was cut three times, regime 2 twice and regime 3 once) gave a variance ratio of 1.78 (p=0.279) in the *L. leucocephala* hedge experiment, and 0.35 (p=0.727) in the hybrid trees. However, even after log transforming the data, the variances were unequal. Thus it is tentatively concluded that cutting regimes do not affect the overall psyllid load, and cutting is not likely to be an effective method of control.

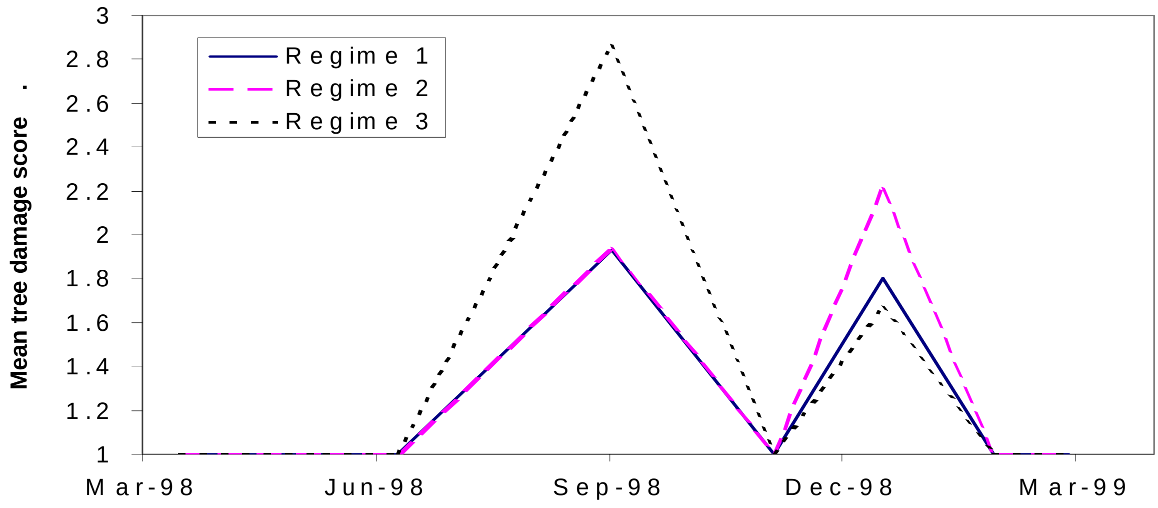

Figure 38. Tree damage scores in the L. hybrid cutting trial.

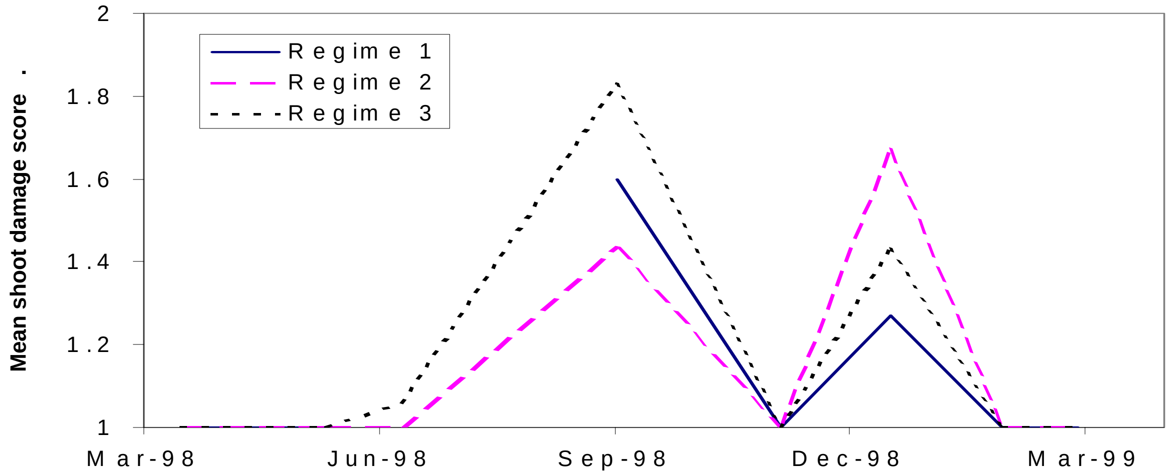

Figure 39. Shoot damage scores in the L. hybrid cutting trial.

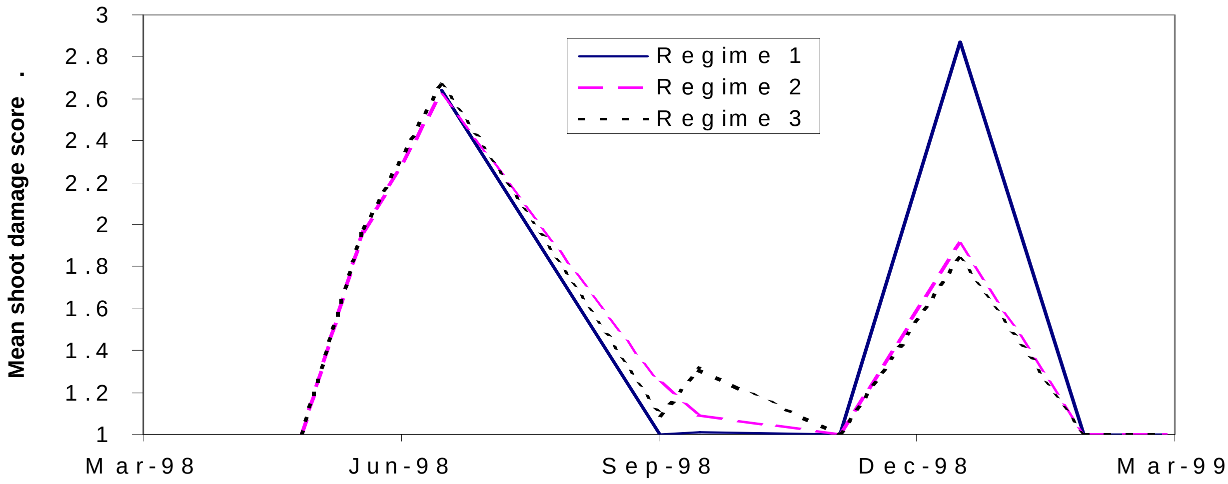

Figure 40. Shoot damage scores in the *L. leucocephala* cutting trial.

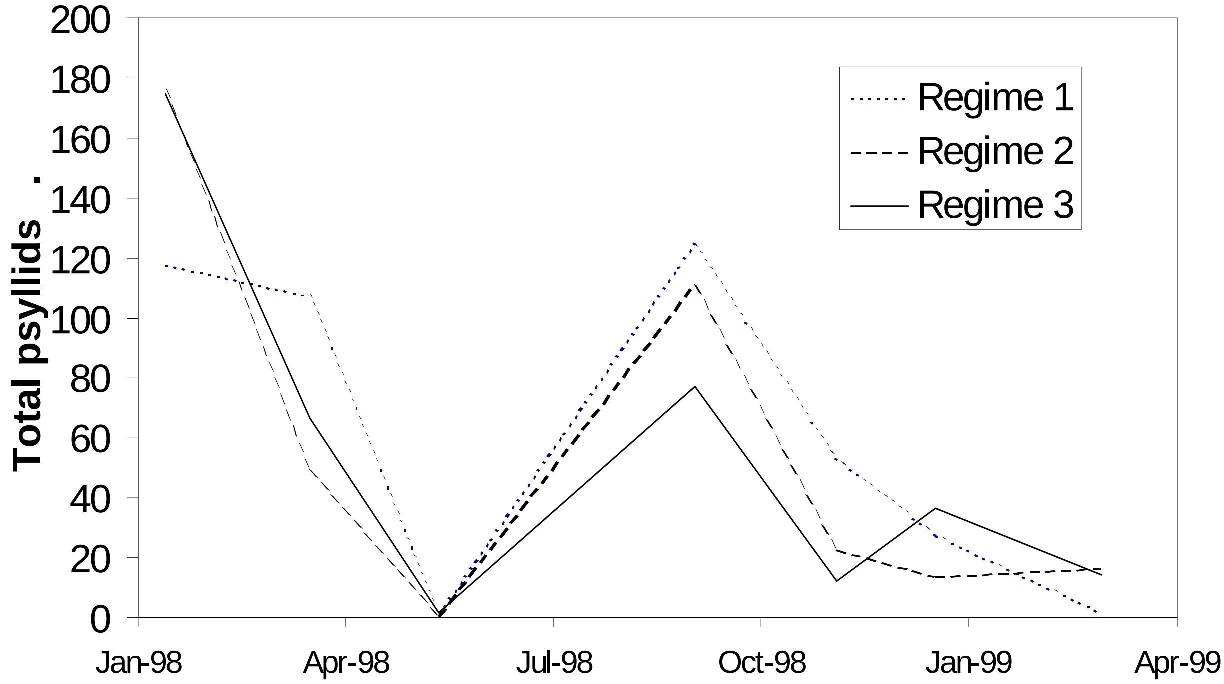

Figure 41. Psyllid population in the L. hybrid cutting trial

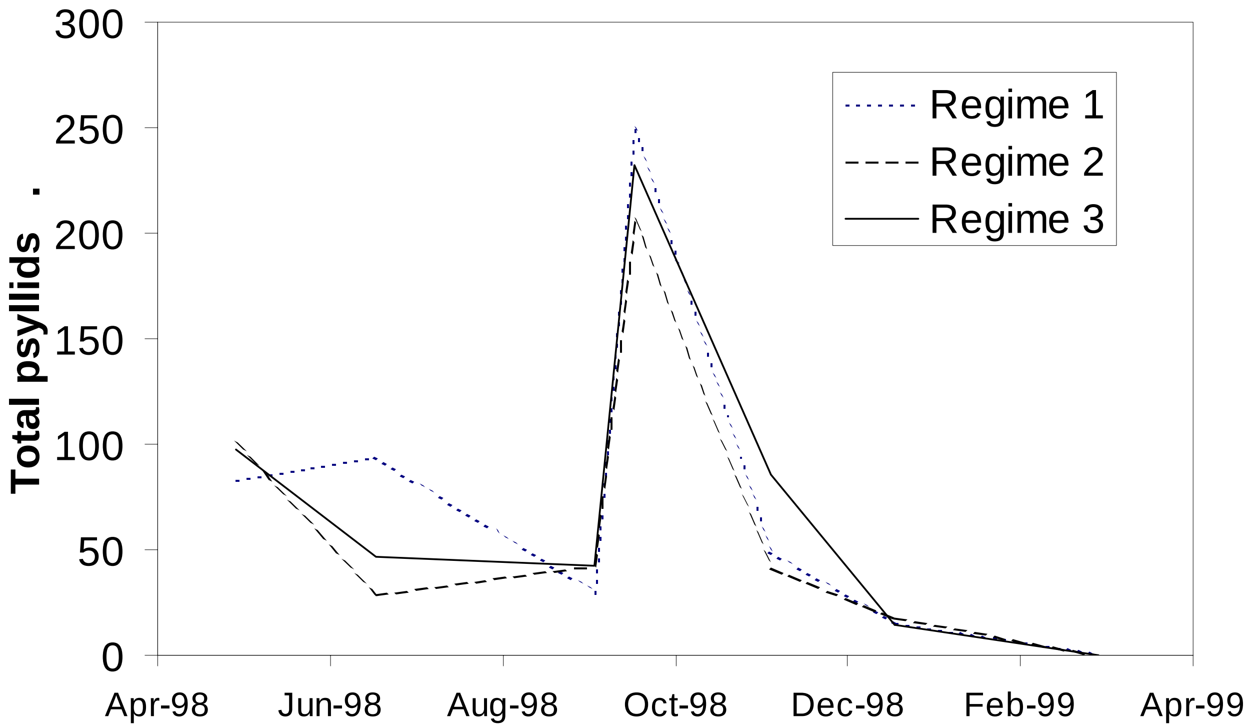

Figure 42. Psyllid population in the *L. leucocephala* cutting trial

4.4 Import and release of biological control agents in Malawi

T.leucaenae was successfully established in Malawi. Results are described in a paper submitted for publication given in Appendix 2 .

4.5 Socio-economic survey in Kenya

Results of the socio-economic survey are in the report in Appendix 3.

5. Contribution of Outputs

5.1 Contribution to DFID's Developmental Goals

Leucaena is a popular tree amongst small-scale farmers in Africa. In the socio-economic survey conducted in Kenya during this project, average land holding was about 2ha, with agriculture by far the major source of income. *Leucaena* was one of the most popular tree species, planted mainly for fodder, but also for fuelwood, soil conservation and building. The species is thus an important tree amongst poor farmers.

Losses by the leucaena psyllid are variable, but less than 20% of farmers in the survey reported no losses. In Tanzania a survey in Morogoro district in 1994 also found *Leucaena* to be important to small scale farmers, the psyllid causing loss of fodder, firewood and poles translating to a loss of $US 90 per household for two year old trees, and more for older trees (Johansson, 1995). As in Kenya, the women in the Tanzania study still showed interest in planting leucaena, more so if the pest could be controlled. However, no satisfactory control was available in Africa at the start of this project.

In addressing the problem of the leucaena psyllid, the project has therefore been seeking to maintain and improve the livelihoods of poor farmers. The approaches investigated, biological control and pest resistant leucaenas, are environmentally benign, and as they require no repeated interventions by the grower, should be sustainable.

The project has gone some way to delivering a solution to the problem. Biological control agents have been established in Malawi, and those in Kenya and Tanzania shown to be able to persist. However, mortality by the agents has been low, particularly in the new leucaenas being tested. Biological control therefore has not in this case provided adequate suppression of the pest population.

Amongst the leucaenas tested, there are species and hybrids that grow well and are resistant to, or tolerant of, psyllid attack. These materials, provided they meet fodder quality requirements, can deliver increased productivity to farmers.

5.2 Promotion pathways to target institutions and beneficiaries

Seminars attended by representatives from target institutions have been held in Malawi and Tanzania (see Appendix 4 for attendees). Most of the target institutions were involved in the project, so are aware of the results, while those not directly involved collaborate with one or more of the project partners. Copies of this report and publications will be circulated to key personnel in the target institutions. The Southern AFRENA regional planning meeting was attended in July 1998, and the project manager has been invited to the 1999 meeting to be held in Mangochi, Malawi, to present and discuss the results.

Some representatives of the project beneficiaries (extensionists and farmers) were present at the project seminars (Appendix 4), but the primary promotion pathway to beneficiaries will be through interactions between the target institutions and beneficiary representatives, such as NGOs, farmer groups etc. These interactions take the form of field day/farmer visits to the research stations where the work was conducted, on-farm trials, and extension literature.

The leucaena psyllid manual produced by this project (Appendix 5) will be circulated to district extension offices in the three countries, and the Southern Africa AFRENA includes a vigorous dissemination component, producing a newsletter (Living with Trees) and leaflets aimed at improving farmer uptake of research results.

5.3 Follow up action/research

Four areas of follow up action/research are indicated.

1. On farm trials of productive/tolerant leucaena species. The most productive accessions also showing at least moderate tolerance to the psyllid should be included in on-farm trials. *L. pallida* and *L.diversifolia* are already in on-farm tests in Tanzania, with *L.pallida* yielding up to 10t/ha. Other accessions that could be tested are the hybrid 52/87, and where the leucaena is also grown for wood production, *L.macrophylla istmensis*, which yielded well in these trials despite moderate to high numbers of psyllids.

2. Planting seed orchards. A constraint to adoption of improved or superior trees can be availability of seeds, but if these are planted once trials have been completed, there can be a period in which demand greatly exceeds supply. One strategy to avoid this is to “best guess” the outcome of trials and plant seed orchards early. The following species have been planted in orchards in Kenya by ICRAF; *L.trichandra* (53/88), *L.diversifolia* (45/87), *L.esculenta* (47/87) and a hybrid (52/87) originally collected as *L.pallida.* The hybrid gave mixed results in this work, showing good growth at some sites, though poor early growth. *L.trichandra* (53/88) survival at Tumbi was very poor, but it showed very high resistance in Kenya. *L.diversifolia* (45/87) was only planted at Makoka where it grew moderately well with moderate resistance. *L.esculenta* (47/87) was highly resistant at all sites but grew poorly. To these could be added *L.pallida* (137/94) which generally out-performed 79/92, and perhaps *L.macrophylla istmensis,* susceptible but productive at all sites.

L. pallida (137/94) has been established at Tumbi, along with *L.esculenta* (47/87) and *L.collinsii zacapana* (56/88), neither of which performed well in these trials. *L. collinsii zacapana* (56/88) appears to be particularly sensitive to the psyllid, consistently being the most damaged accession in all analyses, so its continued development is not supported by these results. *L.collinsii collinsii* appears preferable to *L.collinsii zacapana* from this work.

In Zimbabwe 75 trees have been established on each of 10 farms of *L.diversifolia* and *L.pallida.*

3. Fodder quality studies. *L. leucocephala* is a superior fodder species, so a suitable replacement species must at least approach its quality if it is to be acceptable to farmers. Relatively little work has been completed examining the quality of most of the accessions in the trials reported here, and the interactions between the various factors that contribute to fodder quality are not well understood. Thus where leucaena is being grown particularly for feeding to livestock, it will be to ascertain the quality of the psyllid tolerant accessions. Studies on *L. pallida, L. diversifolia* and *L. esculenta* are being set up in Tanzania and Zimbabwe in 1999.

4 Redistribution of biological control agents. The two species of biological control have not performed well in the trials, suggesting their long-term impact will be minor. However, there are indications that they are more effective in *L. leucocephala,* and as much of the leucaena already on farms is this species, redistribution of the agents to areas where they are not present could be beneficial. This could be achieved at low cost if post release monitoring was confined to checking for establishment. *T. leucaenae* has been released and established in Eastern Zambia, but no releases have been made in other countries of East, Central and Southern Africa. There is no immediate plan or provision for this work to be undertaken.

Two other biological control agents have been used against the psyllid in Asia, with some success reported. However, they are both coccinellid predators which are known to attack a range of prey apart from *H.cubana* Given the opportunity to minimise pest damage through the use of other *Leucaena* species, the introduction of these species in Africa is not recommended.

In addition to these areas, a complete analysis of the growth data collected by ICRAF in these trials will be required, including data from the final harvest at Makoka planned for June.