THE PEST STATUS AND CHEMICAL CONTROL OF WHITEGRUBS AND CUTWORMS IN FORESTRY IN THE NATAL MIDLANDS

by

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ABSTRACT

The limited availability of land to forestry and the ensuing emphasis on intensive silviculture, developed a renewed interest in soil pests in the establishment of plantations. Ten field trials were planted over three seasons to determine the mortality factors influencing the establishment of commercial eucalypt and black wattle plantations in the Natal Midlands, and simultaneously, to investigate the chemical control of the soil pest component. A complex of indigenous soil pests contribute to an average 22,9% failure of *Acacia mearnsii* and *Eucalyptus grandis* seedlings from reaching full establishment. This pest complex, which includes termites, whitegrubs, cutworms, tipulid larvae, wireworms, millipedes and nematodes, was responsible for an average 12,3% of the failure of the plantings to establish.

In the absence of termites, in shallow humic soils, whitegrubs followed by cutworms were the most frequent and economically important pests. Eucalypts are more susceptible than wattle seedlings to whitegrub damage when planted in marginal sites. Seedlings in the summer rainfall region were most susceptible to whitegrub damage from December to April; and to cutworm damage during the first two months after planting. An average of 398 hectares was annually damaged by whitegrubs and cutworms. The total annual loss in planting costs and the additional costs of blanking over the three year study period were 1,22 and 2,65 million rands respectively.

Existing non-chemical control applicable to woodlot forestry is reported. Chemical control as one of the options in the management of whitegrubs and cutworms was evaluated. The controlled release formulations of carbosulfan 10% and chlorpyrifos 10% at 1,0 g active ingredient/tree (a.i./tree), gamma BHC 0,6% dust at 0,06 g a.i./tree and the synthetic pyrethroid deltamethrin 5% SC at 0,025 g a.i./tree were persistent and effective in controlling whitegrubs, even when applied early in the planting season. Deltamethrin 5% SC at 0,025 g a.i./tree was also successful in controlling cutworms.

Keywords: whitegrub, cutworms, wattle, eucalypts, chemical control, Natal Midlands

PREFACE

This study represents the original work of the author and has not been submitted in any form to another university. Where the author used the work of others it has been duly acknowledged in the text.

Note that interim progress reports on the chemical control trials were presented in the 1991 to 1993 Annual Research Reports of the Institute for Commercial Forestry Research. However, the results presented in this thesis are based on complete and revised data sets.

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CHAPTER 1: INTRODUCTION

During the last three years the area planted to exotic forestry tree species has expanded by 0,45% per annum (p.a.) in South Africa. The total area under plantations has increased by 11 676 hectares (ha) from the 1990/91 season (1 295 531 ha) to the 1992/93 season (1 307 207) (Department of Water Affairs and Forestry 1992, 1993, 1994). This increase over the last three years has been due to new plantings of pines (*Pinus* spp.) expanding at 1,7% p.a. The area under eucalypts (*Eucalyptus* spp.), black wattle (*Acacia mearnsii* De Wild) and other hardwoods (poplars and blackwood) has declined by 0,7%, 1,6% and 2,4% respectively. The expansion of pine plantations was largely into previous agricultural land in the eastern Cape. In contrast, the area under plantations in the Natal Midlands has declined by 0,85% p.a. over the same period, mainly because of the existing drought.

Burley *et al.* (1989) identified an intensifying shortage of wood in South Africa and expected demand to increase at the rate of 3,1% per annum for the next 20 years. This would and has resulted in an intense competition with agriculture and water production for land and has increased the pressure on a limited land resource. In some areas forestry successfully competes with crops such as sugarcane for prime sites. The increased forest production will therefore have to come from improved genetic material and cultural techniques and afforestation of marginal sites. There has also been a corresponding emphasis on intensive silviculture of existing plantations (Schönau, 1990). This has resulted in renewed interest in plantation establishment, in particular the impact and control of soil pests that affect the establishment and growth of trees.

In the last three years, some commercial forestry enterprises in the Natal Midlands, have recorded a failure of between 16,6% and 31% of wattle and between 15,7% and 42,3% of eucalypt seedlings to establish (Rusk *et al.*, 1992, 1993, 1994). The causes of this mortality are vaguely known and the impact of soil pests such as whitegrubs and cutworms are poorly understood. Information on their pest status, biology and control measures in forestry is lacking and limited information is available in the literature on similar pests affecting agricultural crops.

Ohmart (1990) maintains that the lack of ecological knowledge of many forestry pests can be overcome by studying problems as they arise in particular geographic areas and establishing insect population densities, levels of damage caused and the resulting growth loss. Cost/benefit analyses and the determination of economic injury levels would then place control procedures on a sound economic and ecological footing. Although research into control of insect pests should ideally be to develop more effective preventative controls, there will always be a need for curative procedures. Therefore research into the efficacy and evaluation of new insecticides on target insect populations was also needed. This study therefore attempted to provide some of this information on whitegrubs and cutworms and identify areas where more research is needed.

CHAPTER 2: REVIEW OF LITERATURE

The subfamilies Melolonthinae, Rutelinae, Cetoniinae and Dynastinae of the family Scarabaeidae (Order: Coleoptera) contain many phytophagous members of economic importance and are commonly known as chafer beetles, cockchafers, June beetles, Christmas beetles, monkey beetles, fruit beetles and rhinoceros beetles (Prins, 1984). Adults and/or larvae of these phytophagous members are pests of various cultivated plants in South Africa (Annecke and Moran, 1982). Rutelinae and Melolonthinae larvae are commonly known as whitegrubs. During the expansion of forestry into ex-croplands, some pests of previous agricultural crops now attack forestry transplants.

In the Natal Midlands, where black wattle has been grown on land that was previously under sugarcane or vice versa (which is often the case) or where black wattle and sugarcane were grown in juxtaposition, the larvae of *Hypopholis sommeri* Burmeister and *Schizonycha affinis* Boheman (known pests of wattle) have been associated with economic losses (Carnegie, 1974, 1988). The life-cycles, phenology and bionomics of various species of whitegrubs which attack sugarcane in South Africa and Swaziland have been considered by Carnegie (1974) and Sweeney (1967) respectively. Both the adult and larvae of *Heteronychus licas* Klug (Scarabaeidae, Dynastinae) damage cane in Swaziland (Sweeney, 1967).

Larvae of *Lepidiota (Eulepida) mashona* Arrow (Melolonthinae) were recorded as pests of field crops and pastures in southern Zimbabwe, and they have also been found feeding on the roots of wattle trees up to 3,66m high and they destroy plantations over wide areas. The adults are leaf feeders and cause considerable damage to the foliage of indigenous trees and wattle (Sherry, 1971).

In a check list of forest insects in South Africa, 31 species of scarabaeids have been found to be phytophagous on *Acacia mearnsii*. Among these, *Hypopholis sommeri* is also recorded on three *Eucalyptus* spp. and *Pinus patula* Schlechtendal and Chamisso (Swain and Prinsloo, 1986). However, all species are collectively grouped as adult leaf and flower/bud feeders and immature root feeders. Hepburn (1966) and Sherry (1971) recorded species in the genera *Hypopholis*, *Monochelus* and *Schizonycha* (Melolonthinae) and *Adoretus* and *Anomala*

(Rutelinae), amongst others, as damaging to wattle transplants and trees in the southern African region. Sherry (1971) regards *Hypopholis sommeri* as the most important wattle insect pest after wattle bagworm (*Chaliopsis junodi* Heylaerts) and wattle mirid (*Lygidolon laevigatum* Reuter).

Our knowledge of the biology and morphology of whitegrubs in South African is limited, except for the valuable study of Prins (1965) on three wattle chafers (*Monochelus calcaratus* Burmeister, *Hypopholis sommeri, Adoretus ictericus* Burmeister), the morphological study of eight South African Lamellicorn larvae by Oberholzer (1959) and the studies of whitegrubs attacking turf (Omer-Cooper *et al.*, 1942, 1948). Numerous economically important whitegrub larvae in South Africa are undescribed and also require studies on their biology and taxonomy. In contrast, the taxonomy and morphology of American scarabaeid larvae were extensively studied (Boving, 1942; Hayes,1929; Ritcher, 1943, 1945a, 1945b, 1945c, 1947, 1966; Gordon and Cartwright, 1988). The biology of the Japanese Beetle is comprehensively presented by Fleming (1972). Veeresh (1980) studied the taxonomy of Melolonthinae larvae in India.

Scarabaeoid larvae are cosmopolitan and have been recorded to attack and damage forestry seedlings in nurseries and plantations throughout the world (Baksha and Islam, 1990; Bandara, 1990; Natawiria, 1990). In addition Sutherland and Glover (1991) provides a comprehensive account of whitegrubs and cutworms in forest nurseries and their control in various countries (Australia, Canada, Northeast China, Haiti, India, Italy, Japan, New Zealand, Norway, Philippines, United States of America and Western Europe).

Unlike in South Africa, almost all the instances of economically important chafer damage in Australia, are caused by various species of the adult stage defoliating native and plantation eucalypt trees (Abbott, 1993; Bashford, 1993; Neumann, 1993; Phillips, 1993; Stone, 1993; Wylie and Peters, 1993).

Chemical control measures against whitegrubs in the past, in particular in sugarcane, consisted of applying persistent soil insecticides such as dieldrin (Sweeney, 1967; Carnegie, 1974). Cackett (1990) subsequently reported a build-up of resistance by *H. licas* to dieldrin.

Carbosulfan, isazophos and ethoprofos successfully controlled whitegrubs in sugarcane in South Africa (Carnegie, 1988). Extensive testing of the controlled release granule insecticide, chlorpyrifos, against whitegrubs in Australian sugarcane showed very successful results (DeGroot and Valvasori, 1989; Bull, 1986a, 1986b; Bull and Allsopp, 1988; Hitchcock *et al.*, 1984, 1989). Previous research on the chemical control of whitegrubs in forestry showed that gamma BHC dust was effective (Sherry and Schönau, 1966; Schönau, 1968; Schönau *et al.*, 1980). However, this was on line-sown wattle and not seedlings; nor was it tested on eucalypts or pines.

Two species of cutworms have been associated with damage to wattle seedlings, *viz. Agrotis segetum* Schiffermüller and *Agrotis longidentifera* Hampson (Sherry, 1971; Swain and Prinsloo, 1986). Cutworms are especially common in lands which were previously under agricultural crops (Sherry, 1971). All cutworm are polyphagous and feed on the young seedlings and roots of many crops, including vegetables, cereals, cotton, tobacco and root crops (Annecke and Moran, 1982, who also discuss the life cycle and biology of other species that attack cultivated plants). Although a range of insecticides are registered for use against cutworms affecting many crops (Department of Agriculture, 1993), research on the control of cutworms appears to be limited to maize (Blair, 1973; Drinkwater, 1980; Drinkwater and Van Rensburg, 1992).

CHAPTER 3: GENERAL MATERIALS AND METHODS

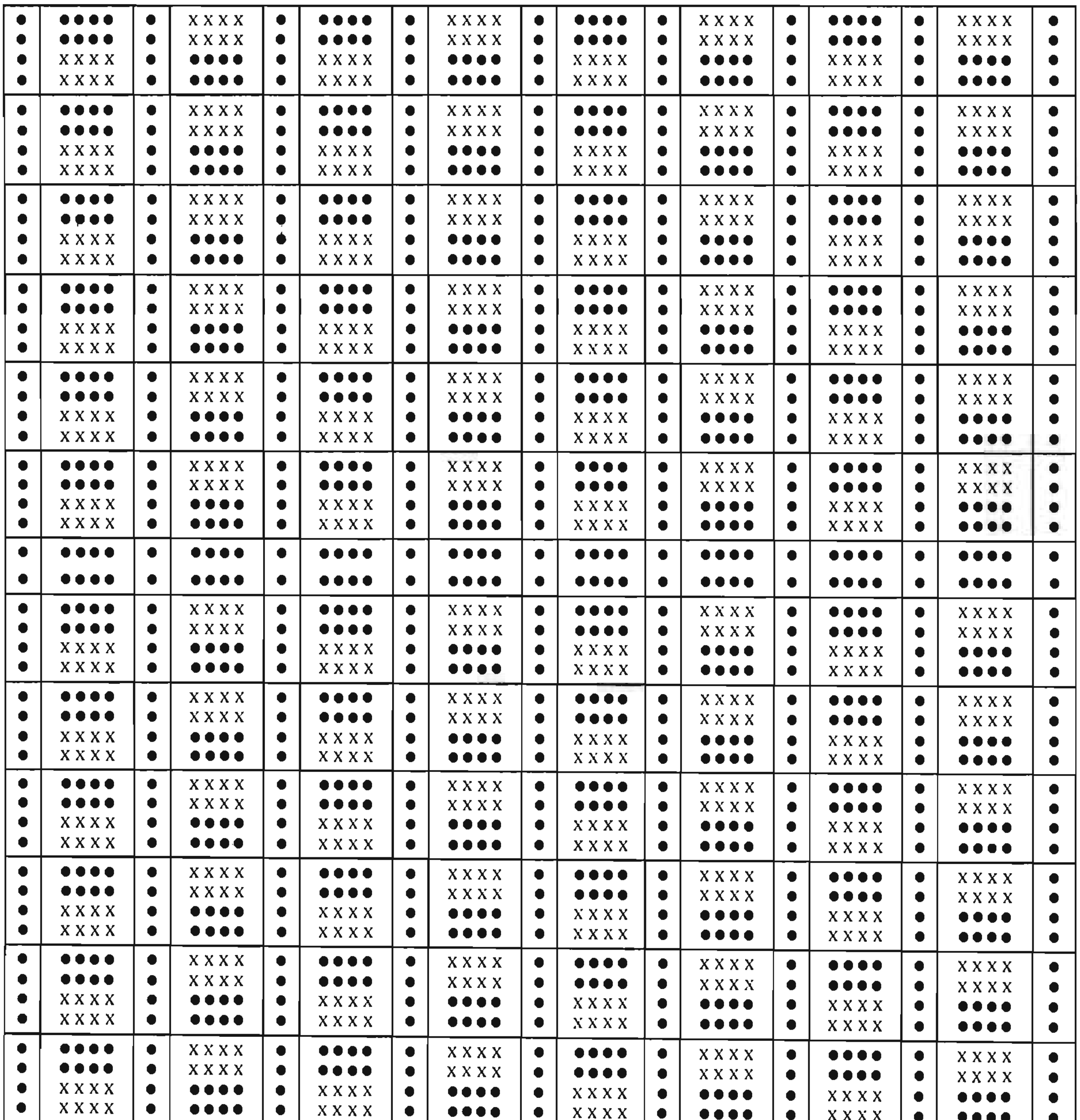
Ten trials were planted over three seasons to determine the mortality factors (especially soil pests) influencing the establishment of commercial eucalypt and wattle plantations and simultaneously to investigate the chemical control of these soil pests.

Six trials were planted during the 1990/1991 season (WG1 to WG6) and two each during the 1991/1992 (WG7 and WG8) and 1992/1993 seasons (WG9 and WG10) (***Plate 1***). Trials of the first season covered a wide range of land preparation practices. All trials were planted in various sites in the major timber producing areas of the Natal Midlands. Each commercial forestry company has its own silvicultural management policy which was followed in the maintenance of trials in the different company holdings. This gave one a wider representation of the general situation.

Each trial consisted of half *Eucalyptus grandis* (eucalypt) and half *Acacia mearnsii* (black wattle) seedlings (***Figure 1***). The trial design remained the same, although the number of replicates and treatments varied in the different trials. Trees were in split plots of treated and untreated (control) trees because the untreated trees were grouped to form reservoirs. The incorporation of these control trees into each plot was done so that the control mortality could be used as a covariate in the analysis to partition the variance due to aggregation of the various insects. The distribution of untreated trees throughout the trial meant a better, more representative measure of the various mortality factors than would have been the case if the controls had been gathered into discrete plots as is usual. Studies on the spatial patterns and sequential sampling plans for melolonthine larvae showed that the larvae were slightly aggregated (Allsopp and Bull, 1989; Allsopp and Chandler, 1990).

During the first year of growth, trials were assessed at monthly intervals after planting. Stressed, dead or dying trees were dug out and the roots and surrounding soil were examined to determine the cause of death. With time it became easier to recognise the damage caused by the various soil pests and these mortality factors were further confirmed in most instances by the presence of the pest, especially whitegrubs. The destructive sampling of trees was necessary to distinguish with certainty the various kinds of mortality, but this precluded any measurements of growth. A disadvantage of this technique is that it tended to add stressed trees, which may have lived, to the counts of dead trees.

A fixed volume of soil, one spadeful, or approximately 0,012 m^3, was examined when searching for soil pests. All collected specimens were preserved in Peterson's K.A.A. (paraffin-glacial acetic acid-ethanol) mixture (Peterson, 1955). These specimens are to be used in a later taxonomic and bionomic study. Modifications and deviations from these materials and methods are discussed separately in each chapter.



X = treated trees; ● = untreated trees

Figure 1: Trial design illustrating the split plot (of treated and untreated trees) and the distribution of untreated trees.

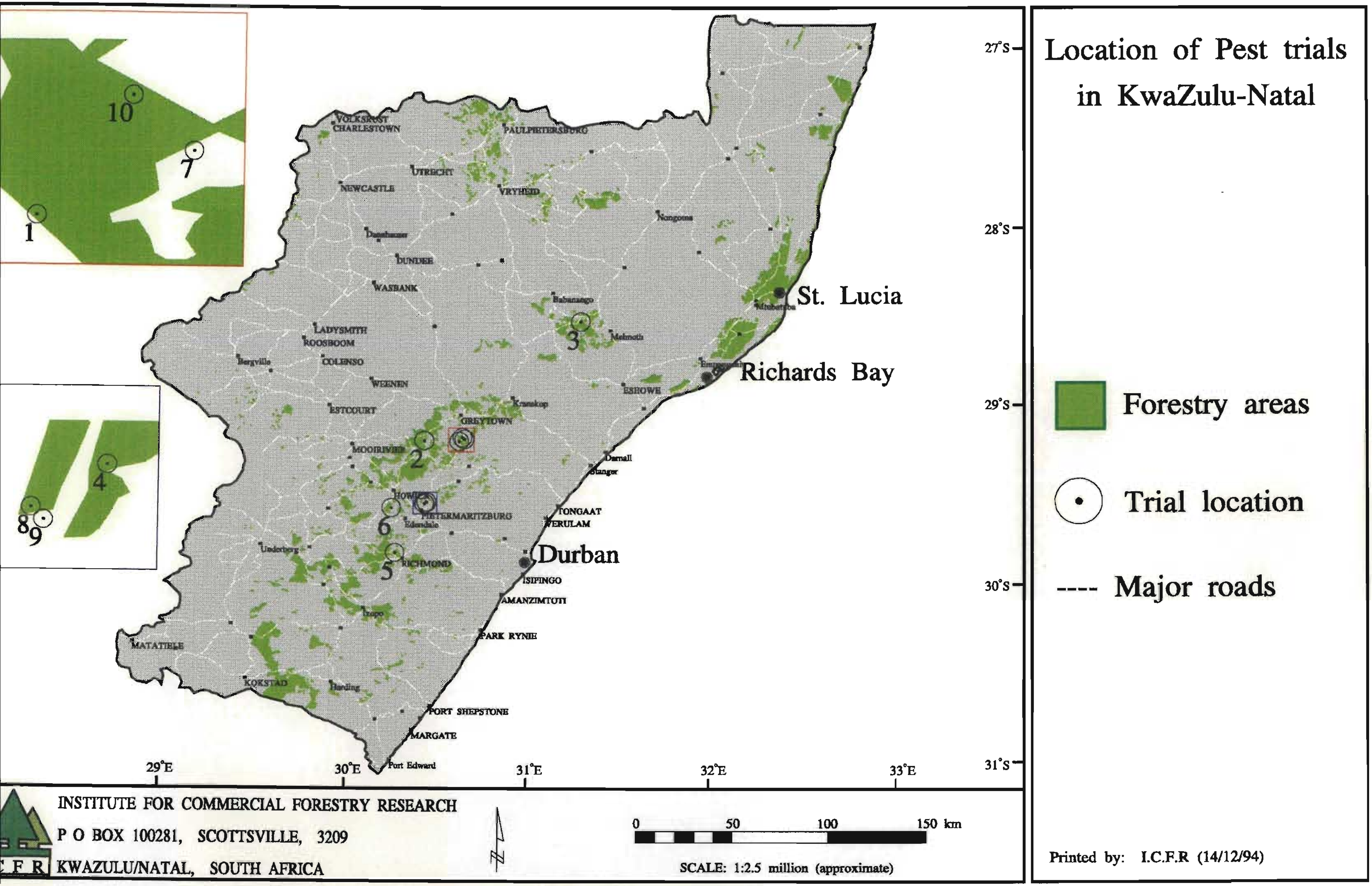


Plate 1: Location of trial sites in the Natal Midlands

CHAPTER 4: ESTABLISHMENT OF THE PEST STATUS OF WHITEGRUBS AND CUTWORMS

4.1 INTRODUCTION

Shallow soils having a high organic carbon and humus content, for example ex-wattle, ex-sugarcane, ex-croplands and grassland, house a complex of indigenous soil and above-ground pests that affect the establishment of pine, wattle and eucalypt seedlings. These pests account for about 12,33% of the total failure of wattle and eucalypt seedlings to reach full establishment and a mean blanking rate of about 22,9% (***Table 1***). Commercial forestry companies normally budget for between 10% and 20% blanking costs. This 12,33% (about 54% of the total failure of establishment) represents a mean estimate from the results of ten trials that were planted over three seasons, with a range from 1,13% to 34,68%. There appears to be no difference in susceptibility between wattle (mean estimate of 12,74%) and eucalypt (mean estimate of 11,92%) seedlings to the soil pests of establishment (***Table 1***).

4.2 METHOD

Only the untreated (control) trees in each trial were analysed to evaluate the pest status of whitegrubs and cutworms. A total of 7 140 and 7 152 untreated wattle and eucalypt trees respectively were evaluated over the three year study period.

All seedling mortality factors over a period of one year from the date of planting were tabulated and expressed as a percentage of the total deaths and as a percentage of the seedlings that failed to establish, for each of the ten trials. Percentages were calculated on untransformed data. Only the pest status of the soil insect pests are evaluated because most of the other seedling mortality factors can be overcome with a more careful application of existing silvicultural and nursery practices. The percentage of seedlings that failed to establish because of damage by soil pests is equivalent to the percentage infestation.

TABLE 1: Percentage infestation by members of the soil pest complex in Trials WG1 to WG10.

TRIALS	WG1		WG2		WG3		WG4		WG5		WG6		WG7		WG8		WG9		WG10		MEAN	
SPECIES	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
Whitegrubs Mean	8.34		0.85		4.27		27.75		1.17		1.41		3.27		11.97		16.77		3.60		7.94	
Whitegrubs	4.74	11.91	0.34	1.36	3.48	5.06	33.23	22.26	0.94	1.40	1.72	1.09	1.61	4.93	12.10	11.84	20.48	13.06	4.61	2.58	8.33	7.55
Cutworms Mean	1.85		1.75		exclude *		1.86		0.63		3.75		3.08		2.45		3.31		3.85		2.5	
Cutworms	2.85	0.84	0.79	2.71	9.59	16.44	1.13	2.58	0.47	0.78	3.59	3.90	4.52	1.64	1.61	3.29	4.35	2.26	5.59	2.10	2.77	2.23
Millipedes	-	0.11	-	0.11	0.32	0.74	0.32	1.94	-	-	-	-	-	-	-	-	-	-	-	-	0.59	
Nematodes	-	-	-	-	-	0.74	-	-	-	-	-	-	-	-	-	-	-	-	-	11.61	6.16	
Grasshoppers/ Crickets	-	-	-	-	-	-	-	-	0.62	0.16	-	-	-	-	0.16	-	-	-	-	-	0.31	
% soil pest infestation Mean	10.23		2.66		18.19		30.73		2.19		5.15		6.35		14.5		20.08		13.25		12.33	
% soil pest infestation	7.59	12.86	1.13	4.18	13.39	22.98	34.68	26.78	2.03	2.34	5.31	4.99	6.13	6.57	13.87	15.13	24.83	15.32	10.2	16.29	11.92	12.74
% failure to establish Mean	26.61		9.56		26.94		39.44		12.02		33.47		10.19		19.49		28.15		23.15		22.9	
% failure to establish	16.65	36.57	4.98	14.14	20.46	33.42	37.90	40.98	9.68	14.35	16.38	50.55	9.03	11.34	16.44	22.53	30.64	25.65	25.82	20.48	18.80	27.00

E = eucalypts
W = black wattle
* = explained in text
- = nothing found

4.3 RESULTS AND DISCUSSION

Trial WG1 was planted on a site that was previously under wattle. The slash (harvesting residue) was windrowed and burnt and the planting holes were manually pitted. In trial WG1, planted in late October 1990, a total of 16,65% eucalypt and 36,57% of wattle seedlings failed to establish. Whitegrubs were the most important soil pests and were responsible for 28,48% (4,74% infestation) and 32,56% (11,91% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively (***Table 2***). Cutworms were responsible for 17,09% (2,85% infestation) and 2,31% (0,84% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Millipedes were responsible for a negligible 0,29% (0,11% infestation) of the total wattle mortality. The unusually high number of nursery related deaths was because of a local forestry industry problem with seedling growing medium.

TABLE 2: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG1**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	28,48	4,74	32,56	11,91
CUTWORM	17,09	2,85	2,31	0,84
UNKNOWN	6,33	1,05	3,75	1,37
MILLIPEDE	0,00	0,00	0,29	0,11
NURSERY	23,42	3,90	49,28	18,02
HERBICIDE	5,06	0,84	0,86	0,32
GUMMOSIS	0,00	0,00	0,58	0,21
PLANTING	12,03	2,00	6,05	2,21
WEEDING	6,96	1,16	2,59	0,95
BROWSING	0,63	0,11	1,73	0,63
TOTAL	100%	16,65%	100%	36,57%

Trial WG2 was planted on a site that was previously under wattle. The slash was windrowed and burnt, ripped into rows with a single tine to a depth of 50 cm and seedlings were planted in the ripline. In trial WG2, planted in early December 1990, a total of 4,98% eucalypt and 14,14% wattle seedlings failed to establish. Cutworms were the most important soil pests and were responsible for 15,91% (0,79% infestation) and 19,2% (2,71% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively (***Table 3***). Whitegrubs were responsible for 6,82% (0,34% infestation) and 9,6% (1,36% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Millipedes were responsible for a low 0,8% (0,11% infestation) of the total wattle mortality. The higher status of cutworms was partly due to the poor weed management during the Christmas shutdown and largely because the ripping of the topsoil brought numerous whitegrubs to the surface and exposed them to their natural enemies (*Hagedashia hagedash* Latham were observed feeding on whitegrubs during planting). The organic matter of the topsoil was buried during inversion of the subsoil. This resulted in a food shortage for whitegrubs in the new topsoil (previously subsoil), which also became structured into clods when it dried.

TABLE 3: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG2**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	6,82	0,34	9,60	1,36
CUTWORM	15,91	0,79	19,20	2,71
UNKNOWN	20,45	1,02	7,20	1,02
MILLIPEDE	0,00	0,00	0,80	0,11
DROUGHT	6,82	0,34	20,80	2,94
HERBICIDE	27,27	1,36	12,00	1,70
PATHOGEN	0,00	0,00	0,80	0,11
PLANTING	11,36	0,57	17,60	2,49
WEEDING	11,37	0,56	11,20	1,59
BROWSING	0,00	0,00	0,80	0,11
TOTAL	100%	4,98	100%	14,14

Trial WG3 was planted on a site that was previously under wattle. The slash was windrowed and burnt and the planting holes manually pitted. In trial WG3, planted in mid December 1990, a total of 20,46% eucalypt and 33,42% wattle seedlings failed to establish (***Table 4***). This trial was planted just before the Christmas shutdown and the weed management before the first survey was very poor. The dense weed growth made it difficult to distinguish between cutworm damage (unless the insect was actually present) and grey duiker browsing (*Sylvicapra grimmia grimmia* Linnaeus) (spoor not visible because of the weeds). Cutworm and duiker damage combined were responsible for the unusually high 46,91% and 49,21% of the total mortality observed in eucalypt and wattle seedlings respectively. If most of the damage was caused by cutworms, then a chemical trial (to screen various insecticides against cutworms) that was planted within trial WG3, should have produced significant results (Chapter 6). This was not the case and one can deduce that most of the above damage was caused by duiker browsing. Hence these data were excluded from the results in *Table 1*.

TABLE 4: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG3**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	17,01	3,48	15,14	5,06
CUTWORM/ BROWSING	46,91	9,59	49,21	16,44
UNKNOWN	2,06	0,42	7,25	2,42
MILLIPEDE	1,55	0,32	2,21	0,74
NURSERY	22,16	4,53	14,19	4,74
NEMATODE	0,00	0,00	2,21	0,74
GUMMOSIS	2,58	0,53	0,32	0,11
PATHOGEN	0,00	0,00	2,84	0,95
PLANTING	7,22	1,48	3,47	1,16
WEEDING	0,00	0,00	0,95	0,32
HERBICIDE	0,51	0,11	2,21	0,74
TOTAL	100%	20,46	100%	33,42

Trial WG4 was planted on a site that was previously under wattle. The larger slash was used to make a duiker-proof fence around the trial, while the debris was windrowed and burnt. The planting holes were manually pitted. In trial WG4, planted in mid January 1991, a total of 37,9% eucalypt and 40,98% wattle seedlings failed to establish (***Table 5***). Whitegrubs were the most important soil pests and were responsible for 87,66% (33,23% infestation) and 54,33% (22,26% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Cutworms were responsible for 2,97% (1,13% infestation) and 6,3% (2,58% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Millipedes were responsible for 0,85% (0,32% infestation) and 4,72% (1,94% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively.

TABLE 5: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG4**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	87,66	33,23	54,33	22,26
CUTWORM	2,97	1,13	6,30	2,58
UNKNOWN	1,70	0,64	9,45	3,87
MILLIPEDE	0,85	0,32	4,72	1,94
PATHOGEN	2,13	0,81	17,72	7,26
PLANTING	2,13	0,81	1,97	0,81
WEEDING	2,56	0,96	0,79	0,32
BROWSING	0,00	0,00	4,72	1,94
TOTAL	100%	37,90%	100%	40,98%

Trial WG5 was planted on a site that was previously under wattle and then left to weeds and grasses for many years. The weeds were mowed but not disced and the site was manually pitted for planting. In trial WG5, planted in mid February 1991, a total 9,68% eucalypt and 14,35% wattle seedlings failed to establish (***Table 6***). Most of this damage was caused by frost and a nursery pathogen. Despite the low incidence of soil pests, whitegrubs were the most important and were responsible for 9,68% (0,94% infestation) and 9,78% (1,4% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Cutworms were responsible for 4,84% (0,47% infestation) and 5,43% (0,78% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Grasshoppers and crickets alternated with cutworms in importance and were responsible for 6,45% (0,62% infestation) and 1,09% (0,16% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively.

TABLE 6: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG5**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	9,68	0,94	9,78	1,40
CUTWORM	4,84	0,47	5,43	0,78
UNKNOWN	3,23	0,31	2,17	0,31
ORTHOPTERA	6,45	0,62	1,09	0,16
FROST	20,97	2,03	23,92	3,43
HERBICIDE	6,45	0,62	0,00	0,00
PATHOGEN	25,81	2,50	18,48	2,65
PLANTING	4,84	0,47	7,61	1,09
WEEDING	8,06	0,78	14,13	2,03
BROWSING	8,06	0,78	16,30	2,34
DROUGHT	1,61	0,16	1,09	0,16
TOTAL	100%	9,68%	100%	14,35%

Trial WG6 was planted on a site that was previously under wattle. After harvesting this site was left to weeds for about a year. The weeds were sprayed with herbicide prior to planting. Planting holes were manually pitted. In trial WG6, planted in mid March 1991, a total 16,38% eucalypt and 50,55% wattle seedlings failed to establish (***Table*** 7). Most of this damage was caused by a nursery pathogen and cattle browsing. Cutworms were the most important soil pests and were responsible for 21,9% (3,59% infestation) and 7,72% (3,9% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Whitegrubs were responsible for 10,48% (1,72% infestation) and 2,16% (1,09% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. It appears that the change in pest status of cutworms is related to the poor weed management prior to planting.

TABLE 7: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG6**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	10,48	1,72	2,16	1,09
CUTWORM	21,90	3,59	7,72	3,90
UNKNOWN	1,91	0,31	0,31	0,16
NURSERY	0,00	0,00	1,54	0,78
PATHOGEN	21,90	3,59	56,17	28,39
PLANTING	1,91	0,31	0,31	0,16
BROWSING	41,90	6,86	31,79	16,07
TOTAL	100%	16,38%	100%	50,55%

Trial WG7 was planted on a site that was previously under wattle. The slash was arranged into brushpiles and burnt during the spring of 1991. The site was planted to wattle in October 1991 but this was removed in December 1991 to make space for this trial. The planting holes were manually pitted. In trial WG7, planted in early December 1991, a total of 9,03% eucalypt and 11,34% wattle seedlings failed to establish (***Table 8***). The status of whitegrubs and cutworms alternated in importance in the two tree species. Whitegrubs were responsible for 17,86% (1,61% infestation) and 43,48% (4,93% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Cutworms were responsible for 50% (4,52% infestation) and 14,49% (1,64% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively.

TABLE 8: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG7**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	17,86	1,61	43,48	4,93
CUTWORM	50,00	4,52	14,49	1,64
UNKNOWN	8,93	0,81	26,09	2,96
PATHOGEN	14,28	1,29	15,94	1,81
PLANTING	3,57	0,32	0,00	0,00
WEEDING	3,57	0,32	0,00	0,00
DROUGHT	1,79	0,16	0,00	0,00
TOTAL	100%	9,03%	100%	11,34%

Trial WG8 was planted on a site that was previously under wattle. The larger slash was used to make a duiker-proof fence around the trial, while the debris was windrowed and burnt. The planting holes were manually pitted. In trial WG8, planted in mid January 1992, a total of 16,44% eucalypt and 22,53% wattle seedlings failed to establish (***Table 9***). Whitegrubs were the most important soil pests and were responsible for 73,54% (12,10% infestation) and 52,55% (11,84% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Cutworms were responsible for 9,8% (1,61% infestation) and 14,6% (3,29% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Grasshoppers were responsible for a negligible 0,98% (0,16% infestation) of the total eucalypt mortality.

TABLE 9: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG8**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	73,54	12,10	52,55	11,84
CUTWORM	9,80	1,61	14,60	3,29
UNKNOWN	9,80	1,61	8,76	1,97
ORTHOPTERA	0,98	0,16	0,00	0,00
PATHOGEN	1,96	0,32	21,17	4,77
PLANTING	0,98	0,16	1,46	0,33
WEEDING	0,98	0,16	0,00	0,00
DROUGHT	1,96	0,32	1,46	0,33
TOTAL	100%	16,44%	100%	22,53%

Trial WG9 was planted on a site that was previously under wattle. However, in recent years the site was used for a trial on root studies, where the saplings were destructively sampled. The remaining debris was windrowed and burnt. The weeds were manually line cleaned and the planting holes were manually pitted. An electric fence around the trial prevented duiker damage. In trial WG9, planted in late October 1992, a total of 30,64% eucalypt and 25,65% wattle seedlings failed to establish (***Table 10***). Whitegrubs were the most important soil pests and were responsible for 66,84% (20,48% infestation) and 50,94% (13,06% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Cutworms were responsible for 14,21% (4,35% infestation) and 8,81% (2,26% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively.

TABLE 10: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG9**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	66,84	20,48	50,94	13,06
CUTWORM	14,21	4,35	8,81	2,26
UNKNOWN	5,26	1,61	7,55	1,94
PATHOGEN	6,32	1,94	22,01	5,65
PLANTING	2,63	0,81	3,77	0,97
WEEDING	4,74	1,45	6,92	1,77
TOTAL	100%	30,64%	100%	25,65%

Trial WG10 was planted on a site that was previously under wattle. The slash was arranged into brushpiles and burnt and the planting holes were manually pitted. In trial WG10, planted in late October 1992, a total of 25,82% eucalypt and 20,48% wattle seedlings failed to establish (***Table 11***). Silvicultural factors and the drought were responsible for most of the eucalypt seedling mortality, while an unexpected nematode infestation accounted for most of the wattle seedling mortality. The low incidence and status of whitegrubs and cutworms alternated in importance in the two tree species. Whitegrubs were responsible for 17,83% (4,61% infestation) and 12,60% (2,58% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively. Cutworms were responsible for 21,66% (5,59% infestation) and 10,24% (2,10% infestation) of the total mortality observed in eucalypt and wattle seedlings respectively.

TABLE 11: Mortality factors in untreated trees expressed as a percentage of total mortality and seedlings that failed to establish in **Trial WG10**.

MORTALITY FACTORS	EUCALYPTS		WATTLE	
	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH	% OF TOTAL MORTALITY	% FAILURE TO ESTABLISH
WHITEGRUB	17,83	4,61	12,60	2,58
CUTWORM	21,66	5,59	10,24	2,10
SILVICULTURE *	54,14	13,98	5,51	1,13
NEMATODE	0,00	0,00	56,69	11,61
PATHOGEN	6,37	1,64	14,96	3,06
TOTAL	100%	25,82%	100%	20,48%

* silviculture includes planting, weeding and herbicide application

The infestation levels of each pest were tabulated for each trial and then averaged for all ten trials over the three year study period. The averaged infestation level was used as an index to rank these pests and evaluate their pest status. The order from most important pest status to least important was whitegrubs (7,94% infestation), nematodes (6,16% infestation), cutworms (2,5% infestation), millipedes (0,59% infestation) and grasshoppers/crickets (0,31% infestation) (***Table 1***). However, nematode (2 out of 10 cases), millipede (6 out of 20 cases) and grasshopper/cricket (3 out of 20 cases) infestations were very sporadic (***Table 1***). Only whitegrub and cutworm infestations occurred at regular intervals (in all twenty cases). Therefore the two most frequent and important soil pests are whitegrubs and cutworms.

4.4 THE EFFECT OF WHITEGRUB FEEDING ON ESTABLISHED SAPLINGS

This analysis was attempted in the final year of study to investigate if feeding by whitegrubs, after establishment of seedlings, affected the performance of saplings. In these trials (WG9 and WG10) only dead and very stressed trees were destructively sampled to determine the causes of mortality. Stressed but established trees were not dug; instead the heights of all surviving trees were measured six months after planting. The tree height used in the analysis of variance (ANOVA) (Genstat) was the mean height of treated and untreated trees per treatment plot. No transformation of the data was necessary because height is a continuous variate.

In trial WG9, when the heights of eucalypts were assessed (***Figure 2***), only trees treated with deltamethrin SC at 0,05 g a.i./tree were significantly taller than the control. Similarly in trial WG10 (***Figure 3***, different format to Figure 2 because there were significant differences between the controls of the various treatments), trees treated with deltamethrin SC at 0,05 g and 0,025 g a.i./tree were significantly taller than the control. One would expect that because gamma BHC and carbosulfan CRG were successful in preventing whitegrub damage to the roots of seedlings during establishment (Govender, 1993), that trees so treated would be taller than the control. A possible explanation is that gamma BHC dust and carbosulfan controlled release granule (CRG) formulations provide the seedling with localised protection around the root plug, while deltamethrin SC is applied as a drench and therefore disperses to the outer region of the lateral roots where protection is needed. As the seedling establishes, only the lateral roots have young, tender, fine roots that whitegrub larvae can feed upon.

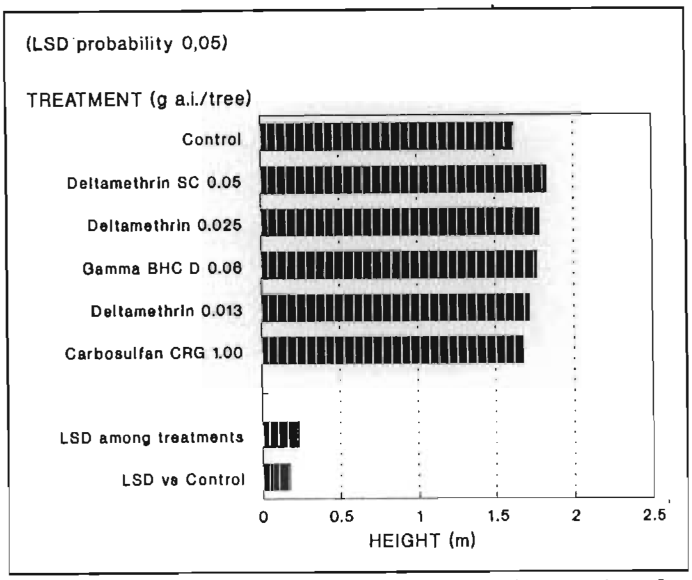


Figure 2: Average height of eucalypts at six months after planting in Trial WG9.

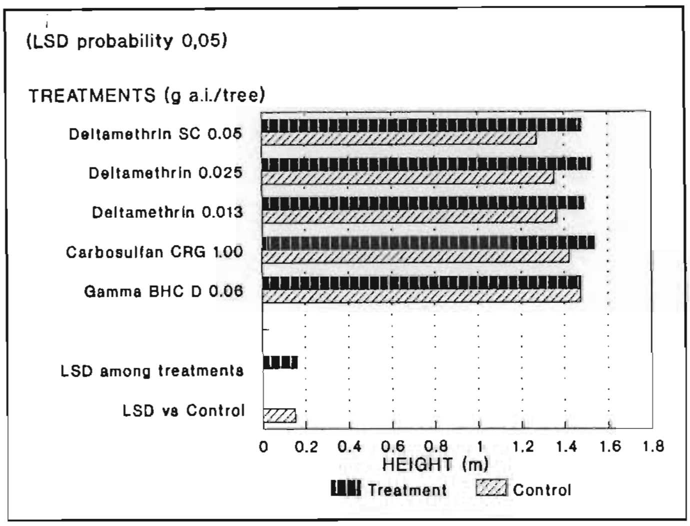


Figure 3: Average height of eucalypts at six months after planting in Trial WG10.

In trial WG9 and WG10, where the heights of wattle were assessed, (*Figure 4*) and (*Figure 5*), none of the trees in treated plots were significantly taller than the control trees. However, in trial WG10 where a high incidence of nematode damage was observed, trees treated with carbosulfan CRG were the tallest, although this result was not statistically significant. In trial WG9, there was a high incidence of whitegrub damage and it is surprising that the heights of treated trees were no better than the control. Both trials were planted in sites that were better suited to the growth of wattle than eucalypts. Wattle trees are more tolerant to damage by whitegrubs and grow more uniformly than eucalypts which are not suited to these shallow sites (M Herbert, personal communication). Eucalypts that are planted in shallow, marginal sites will therefore be afforded greater protection from whitegrub damage if they are treated with a deltamethrin SC drench as opposed to gamma BHC dust and carbosulfan CRG. These preliminary findings need to be more thoroughly researched.

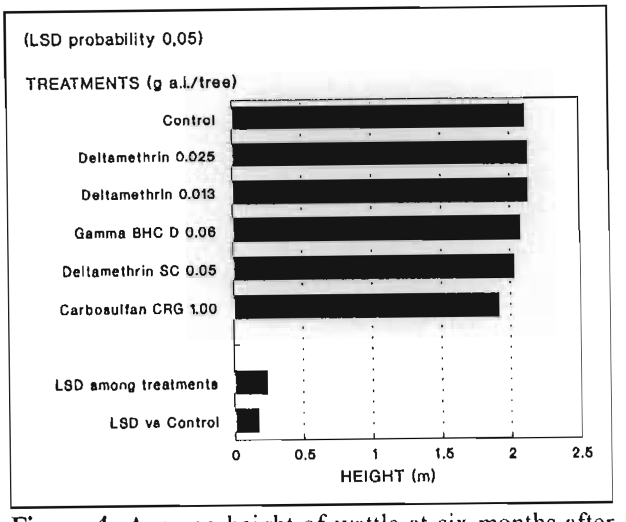


Figure 4: Average height of wattle at six months after planting in Trial WG9.

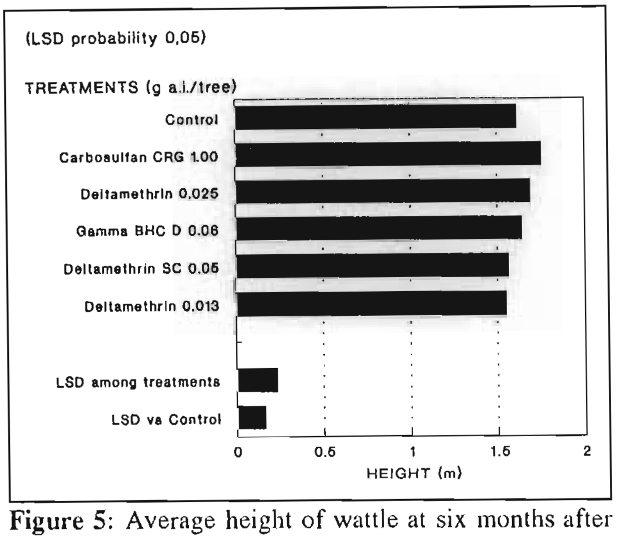


Figure 5: Average height of wattle at six months after planting in Trial WG10.

These results further demonstrate the importance of whitegrubs. Whitegrub feeding on established saplings (that were chemically protected or escaped attack at planting), significantly affects the height of 'off-site' (shallow and marginal soil) plantings of eucalypts. Older wattle stands on poor sites were seriously debilitated by continual root damage over long periods by *Eulepida mashona* Arrow (Scarabaeidae, Melolonthinae) in Zimbabwe (Sherry, 1971). The frequency and choice of chemical control of whitegrubs in established saplings needs to be further evaluated to ascertain whether this practice would be economically beneficial to the yield at harvesting age.

CHAPTER 5: SEEDLING MORTALITY FACTORS

5.1 MINOR COMPONENTS OF THE SOIL PEST COMPLEX

Members of the soil pest complex (excluding whitegrubs and cutworms which are discussed separately), which affect the establishment of eucalypt and wattle seedlings include termites, tipulids, millipedes, eelworms, wireworms, crickets and grasshoppers.

5.1.1 TERMITES (Isoptera: Termitidae)

Termites eat the roots, root collar and bark of living plantation trees. The majority of the damage is caused by the fungus-growing termites *viz. Macrotermes natalensis* Haviland, *M. falciger* Gerstäcker and *M. mossambicus* Hagen. Termites, unlike whitegrubs and cutworm, appear to be associated with deep, well-drained soils in warmer (north of 30^0S latitude, below about 1300 m altitude) and drier areas (less than about 900 mm mean annual rainfall) (Atkinson *et al.*, 1991). These soils generally have a high clay but low organic carbon or humic content. An exception is the coastal area of Natal where the rainfall can be much higher and where serious termite damage by *Odontotermes* extends further south (Atkinson, 1991). Eucalypt and wattle trees are susceptible up to two years old, but most of the mortality occurs in the first six to nine months, tending to cease after canopy formation. Termites attack seedlings throughout the year during the first six to nine months after planting (Govender and Atkinson, 1993).

5.1.2 TIPULIDS (Diptera: Tipulidae)

Tipulid or cranefly larvae (leather-jackets) are seldom encountered as soil pests, but when present they girdle the stem above and below the soil line and may consume some of the upper roots. Girdling affects water transport to the shoots. No species are as yet recorded as pests in the South African literature and this pest was found sporadically in only one trial. However, *Nephrotoma* spp. has been found in association with wattle in South Africa (Hepburn, 1966). *Nephrotoma sodalis* Loew strips the bark from the roots of *Pinus strobus* Linnaeus seedlings and is recorded as a pest in North America and Canada (Browne, 1968). *Tipula paludosa* Meigen is an introduced pest that attacks white spruce seedlings in the coastal areas of British Columbia (Sutherland and Van Eerden, 1980).

5.1.3 MILLIPEDES (Diplopoda: Juliformia)

Millipedes have been reported to cause damage but this is not easily distinguishable from that by whitegrubs. The roots of seedlings may be damaged or destroyed, either mechanically by burrowing or by feeding. Where damage has already begun by other pests, millipedes may be present in sufficient numbers to aggravate the injury (personal observation). Atkinson (1994) reports that millipedes emerge from brush lines or brush piles in summer and move along the rows of seedlings, chewing the stems at or above soil level. The stems may be severed, or broken at the calloused wound or the seedling may be ringbarked (similar to cutworm damage).

There are examples in the literature of both types of damage. In England, two species of millipedes *Brachydesmus superus* Latzel and *Blaniulus guttulatus* Bosch are reported to stunt and even kill sugar-beet seedlings in spring by their aggregated feeding on young roots (Baker, 1974). In Western Nigeria, *Odontopyge* Brandt species is sometimes a pest in nursery beds of *Gmelina arborea* Roxburgh and *Tectona grandis* Linnaeus in the high forest zone; it destroys young seedlings by eating through the stems (Browne, 1968). In South Africa, amongst the worm-like millipedes, *Gymnostreptus pyrrocephalus* is widely distributed in localized areas and is reported to show little discrimination in its choice of food (Lawrence, 1984). However, Lawrence (1984) states that millipedes should not be regarded as pests of primary importance and that in general they prefer already damaged and decaying plant tissue as food; when millipedes are found attacking vegetation this can often be construed as a symptom rather than a cause of damage previously effected by accident or by some more serious pest. Several different unidentified stadia (different larval stages of the millipede) or species of juliform millipedes have been collected from the surrounding soil of stressed seedlings.

5.1.4 EELWORMS (Nematoda)

Plant parasitic nematodes or eelworms damage the roots of seedlings and cause stunted growth. *Meloidogyne* spp., commonly referred to as the root knot nematode, is often abundant in soils and roots of *Acacia mearnsii*. Damage results in the formation of small nodules, galls or knots. *Paratrichodorus* spp. is another debilitating ectoparasitic nematode that accumulates at and feeds on the growing tips of roots, resulting in root necrosis and terminal thickening of the roots. Other genera include *Pratylenchus*, *Helicotylenchus* and *Xiphinema* (V W Spaull, personal communication). Although nematode damage has been recorded in wattle (Govender, 1993) and pines (Marais and Buckley, 1993), there is no evidence or record of nematodes attacking eucalypts in South Africa (Atkinson *et al.*, 1991; Govender and Atkinson, 1992b; Govender, 1993).

5.1.5 WIREWORMS (Coleoptera: Tenebrionidae)

Tenebrionidae or false wireworm were occasionally found in the vicinity of stressed or dead seedlings. In those instances where whitegrub larvae were absent, and false wireworms were present, there still appeared signs of root feeding. It was therefore assumed that the false wireworms were responsible for this damage. *Somaticus varicollis varicollis* Koch and *Gonocephalum simplex* Fabricius are recorded as pests of maize in Natal (Drinkwater, 1989); while *Somaticus angulatus* Fahraeus is regarded as one of the most economically important pests of maize and groundnuts in South Africa (Drinkwater and Giliomee, 1991; Van Eeden *et al.*, 1991; 1994a; 1994b). Ex-agricultural land is often afforested during the expansion of forestry and the above species of wireworms may be responsible for damage to the roots of seedlings.

5.1.6 CRICKETS AND GRASSHOPPERS (Orthoptera)

The elegant grasshopper, *Zonocerus elegans* Thunberg (Pyrgomorphidae), has been observed to occasionally feed on the growing tips and other tender tissue of young seedlings. Damage is characterised by a rough, diagonal cut of severed stems. Grasshopper damage to forestry seedlings has also been recorded by Hepburn (1966) and Browne (1968).

Crickets, especially *Gryllus bimaculatus* Degeer (Gryllidae), strip the bark off the stem at ground level and feed on the underlying tissue mainly at night. This results in a dried frayed bark and ringbarked stem. This damage is sporadic and usually occurs after an area has been aerially treated with herbicide prior to planting and during a dry season. *Brachytrypes membranaceus* Drury (Gryllidae) was identified damaging wattle plantations (Hepburn, 1966). Recently the same species was reported damaging eucalypt seedlings in the coastal plantations of Zululand (personal observation).

PLATE 2: Whitegrub larva and a damaged *Acacia mearnsii* seedling.

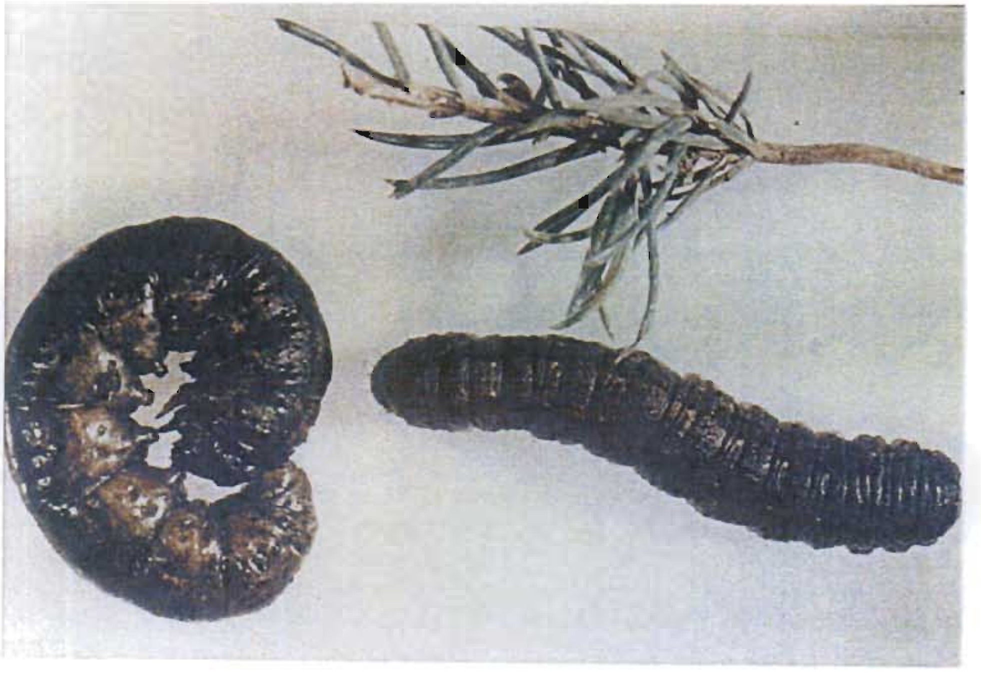


PLATE 3: Typical cutworm in a curled and extended position.

5.2 WHITEGRUB DAMAGE

5.2.1 DESCRIPTION OF THE INSECT

Whitegrubs are the immature stages of various kinds of cockchafer beetles (Order: Coleoptera, Family: Scarabaeidae, Subfamilies: Melolonthinae and Rutelinae). They have C-shaped (scarabaeiform), milky-white, stout bodies with three pairs of prominent legs (increasing in size from front to back) and darker (reddish-brown), sclerotized heads and mouth parts. The hind part of the abdomen is dark, smooth, shiny and distended, the body contents showing through the skin (***Plate 2***). Whitegrubs vary in size, and range from 2,6 mm to 36,0 mm in length (Borthwick, 1990b).

5.2.2 DESCRIPTION OF DAMAGE

Whitegrubs live in the soil and eat the fine roots of young trees. This causes a reduction in growth, and frequently the death of newly emerged wattle seedlings and young wattle, pine and eucalypt transplants. As a result, affected seedlings or transplants can easily be pulled from the tree rows. The foliage of damaged seedlings initially appears stressed and then turns brown and dries out. In severe cases the root plug of transplants is completely devoured and the tap root is ring barked up to ground level. Above the site of damage the stem tissue appears calloused. Trees older than one year are affected less since they have developed sufficient lateral roots to withstand whitegrub attack better. High populations of whitegrubs in the soil can cause the failure of re-establishment of plantations as well as loss in growth of young trees with consequent reduction in bark and timber yields. The adult cockchafer beetles feed on wattle, pine and sometimes eucalypt foliage during the summer months. They can on occasion cause severe defoliation to all age-classes of plantation trees.

5.2.3 INCIDENCE OF DAMAGE

For each of the ten trials, all seedling damage caused by whitegrubs was tabulated for each monthly survey and expressed as a percentage of the total whitegrub damage, over a one year period.

Trials WG1, WG9 and WG10 were all planted very early in the growing season, that is, October. In trial WG1 (***Figure 6***) and trial WG 9 (***Figure 7***), whitegrub damage began soon after planting and peaked in February. In trial WG10 (***Figure 8***), the highest incidence of whitegrub damage was in April. Trial WG10 was planted in a dry area, during a severe drought, where all transplants were constantly stressed. Transplants were only dug when they died as opposed to appearing stressed, to prevent one from unnecessarily digging up drought-stressed transplants. Therefore the deaths recorded in April, represent earlier incidences of whitegrub damage, that is, during February and March.

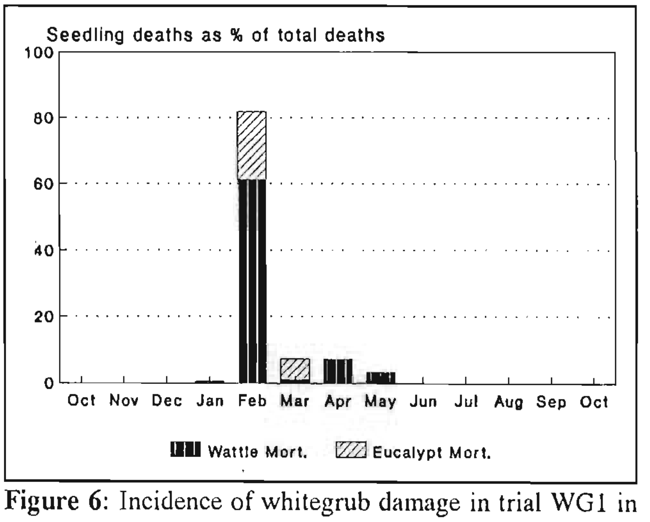


Figure 6: Incidence of whitegrub damage in trial WG1 in relation to the month of planting (October 1990).

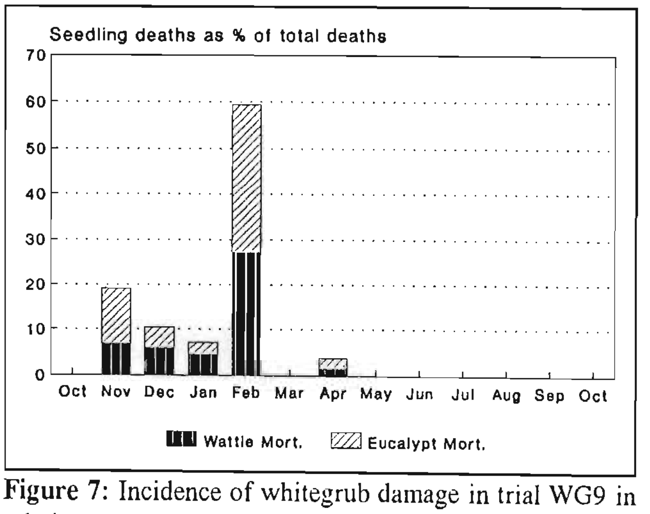


Figure 7: Incidence of whitegrub damage in trial WG9 in relation to the month of planting (October 1992).

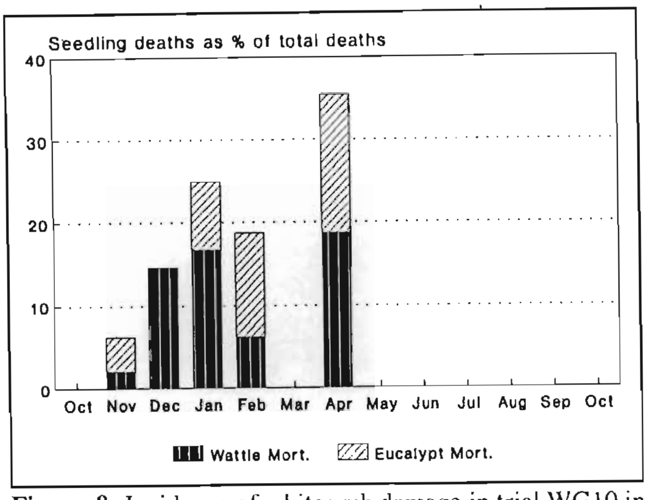


Figure 8: Incidence of whitegrub damage in trial WG10 in relation to the month of planting (October 1992).

In trial WG2 (***Figure 9***), which was planted in November, the incidence of whitegrub damage also began soon after planting and peaked in February.

Trials WG3 and WG7 were planted in December. In trials WG3 (***Figure 10***) and WG7 (***Figure 11***), the highest incidences of whitegrub damage was in March and January respectively.

Trials WG4 and WG8 were planted in January. The highest incidence of whitegrub damage in trial WG4 was in March (***Figure 12***), and in trial WG8 was in February (***Figure 13***).

Trial WG5 was planted in mid February and the highest incidences of whitegrub damage was in February and March (***Figure 14***).

Trial WG6 was planted towards the end of the planting season in March. The highest incidence of whitegrub damage was in April (***Figure 15***).

Overall, whitegrub damage begins soon after planting, follows a bell shaped curve, peaking in February and tails off sharply towards June. Carnegie (1974) observed a similar incidence of larval numbers in the soils of both wattle and sugarcane over a three year period. Transplants in the summer rainfall region were most susceptible to whitegrub damage from December to April. Chemical control measures that are applied on a preventative basis in early season plantings must therefore be persistent or regularly renewed to control whitegrubs.

This generalization refers to a pooled species composition fròm the different trials because in all trials several different species were found to be causing damage at the same time. However, some species have a one year life cycle and other species have a two year life cycle (Prins, 1965). Many of the most destructive species of whitegrubs in North America normally complete their life cycle in one year (Tashiro, 1990). One would therefore expect that different species and species with different life cycles may have different economic importance. Different species may also be related to different soil types. These subjects form part of another study and will be reported on at a later time. From a cursory examination of the whitegrubs that were collected during this study, it appears that *Hypopholis sommeri* was the most numerous and destructive. *H. sommeri* is reported to have a two year life cycle (Prins, 1965).

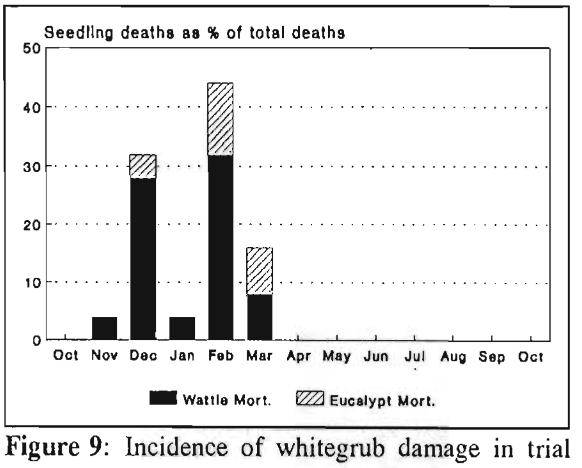


Figure 9: Incidence of whitegrub damage in trial WG2 in relation to the month of planting (December 1990).

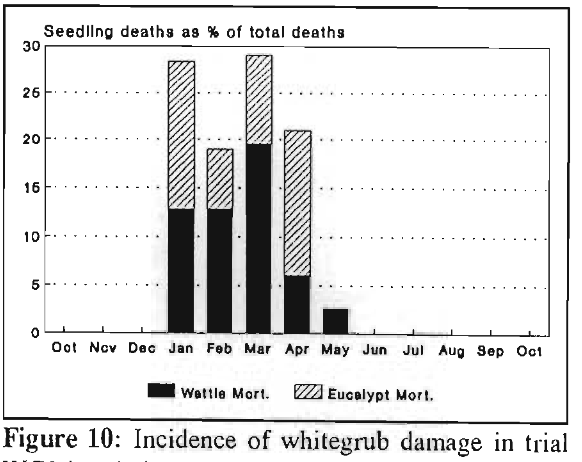


Figure 10: Incidence of whitegrub damage in trial WG3 in relation to the month of planting (December 1990).

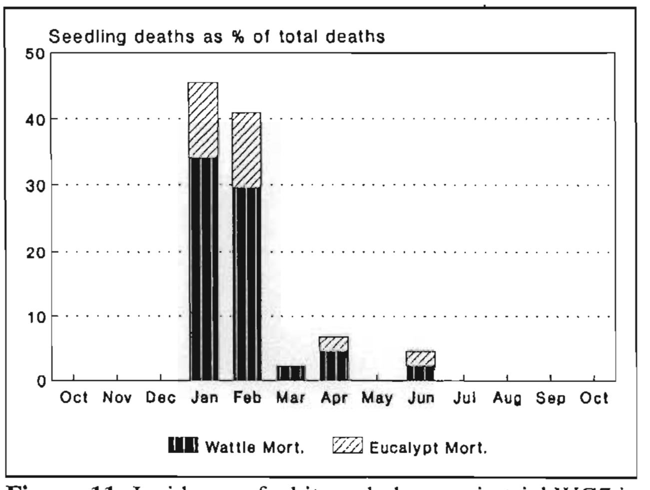


Figure 11: Incidence of whitegrub damage in trial WG7 in relation to the month of planting (December 1991).

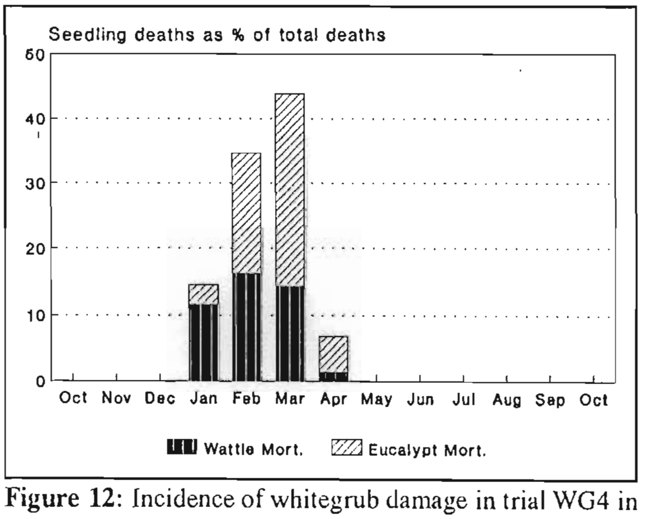


Figure 12: Incidence of whitegrub damage in trial WG4 in relation to the month of planting (January 1991).

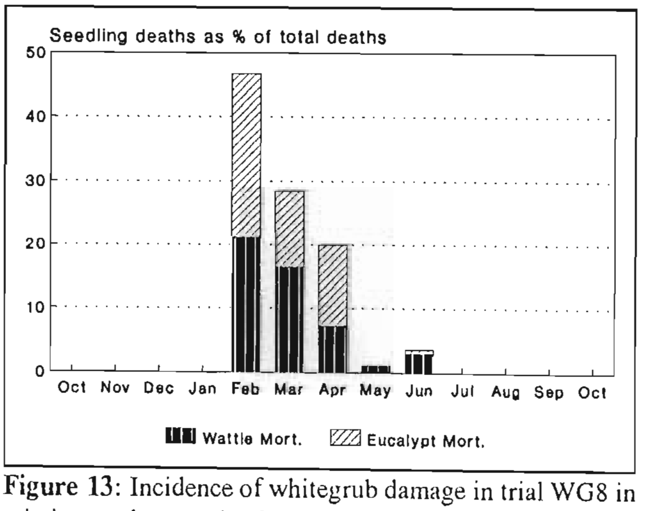


Figure 13: Incidence of whitegrub damage in trial WG8 in relation to the month of planting (January 1992).

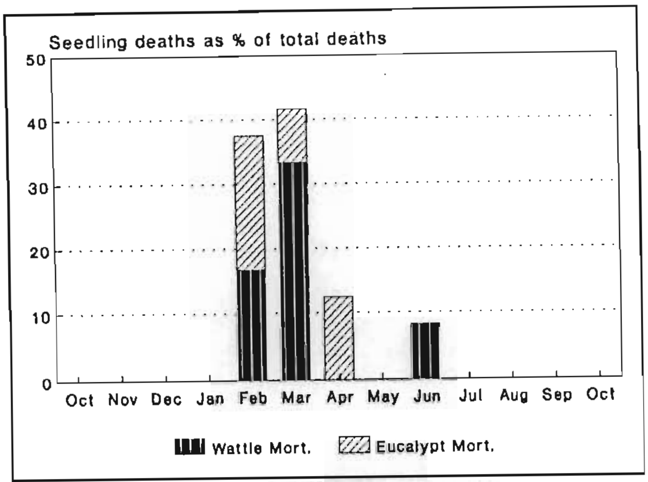


Figure 14: Incidence of whitegrub damage in trial WG5 in relation to the month of planting (February 1991).

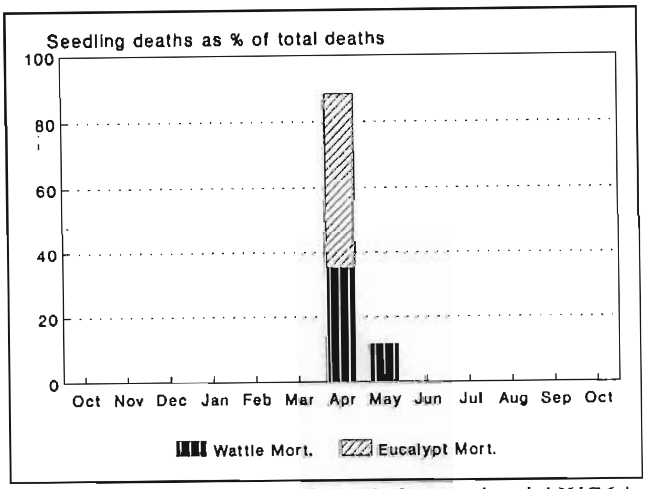


Figure 15: Incidence of whitegrub damage in trial WG6 in relation to the month of planting (March 1991).

5.3 CUTWORM DAMAGE

5.3.1 DESCRIPTION OF THE INSECT

Cutworms are the caterpillars of a number of species of moths (Order: Lepidoptera, Family: Noctuidae). *Agrotis segetum* and *Agrotis longidentifera* have been observed to damage forestry seedlings (Sherry, 1971). Cutworms are a dull, greyish or brown colour, and have a hairless, smooth, waxy skin (***Plate 3***). They curl up into a tight ring when removed from the soil. They reach a length of about 30 mm when fully grown (Borthwick, 1990a). Cutworms are characterised by the presence of paired leg-like protrusions (prolegs) along the abdomen, in addition to the three pairs of thoracic legs.

5.3.2 DESCRIPTION OF DAMAGE

Cutworms cut off the tender stems (before stems become woody) of young transplants at ground level, leaving a stump. The growing tips and foliage are dragged below ground and fed upon. Cutworms are active at night and during the day they can be found hiding in the soil to a depth of five to ten centimetres in the vicinity of the damaged plants. Older transplants are also attacked by cutworms; the stem is not severed but notched. Actively growing transplants react by producing callous tissue around the constricted area of the wound. This creates a weak spot in the stem and later the stems of these damaged saplings break in the wind. These damaged stems sometimes take on an 'elbowed' appearance. This damage is often noticed four or five months later, by which time one cannot 'blank' or replant seedlings because the planting season may be over and blanking would result in a stand of trees of uneven growth.

Several adjacent transplants may be attacked by a single cutworm. Hence all recorded instances of cutworm damage could not be confirmed by the presence of the pest. The diagnosis was further compounded by the fact that cutworm damage is similar to browsing by duiker. The presence or absence of a duiker spoor around the seedling often assisted one in making a more accurate diagnosis.

5.3.3 INCIDENCE OF DAMAGE

In trials WG3 (***Figure 16***), WG4 (***Figure 17***), WG5 (***Figure 18***), WG6 (***Figure 19***), WG7 (***Figure 20***), WG8 (***Figure 21***), WG9 (***Figure 22***), and WG10 (***Figure 23***), irrespective of the month of planting, cutworm damage began immediately after planting and peaked in the first or second month thereafter. The reduced incidence of later damage represented old damage where the stem was not severed when initially attacked.

Trials WG1 (***Figure 24***) and WG2 (***Figure 25***) showed that cutworm damage also began immediately after planting but increased to peak in the fourth month after planting. These two trials were the first to be planted and the initial monthly surveys were a learning exercise, where variations in cutworm damage could not be easily diagnosed.

Overall, cutworm damage begins soon after planting and the seedlings are most susceptible during the first one to two months after planting, before the stem becomes woody.

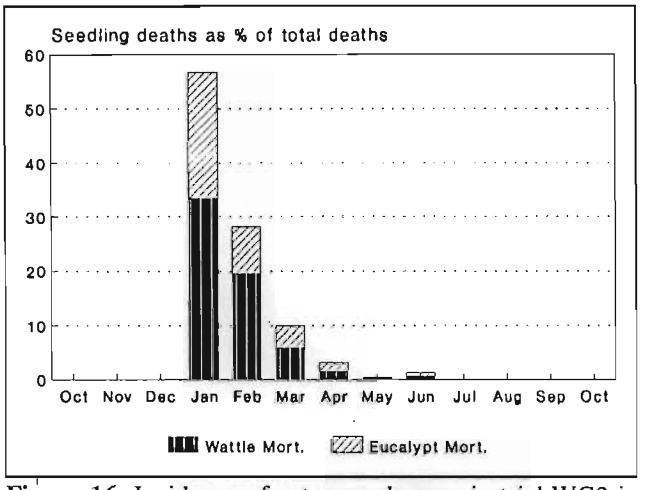


Figure 16: Incidence of cutworm damage in trial WG3 in relation to the month of planting (December 1990).

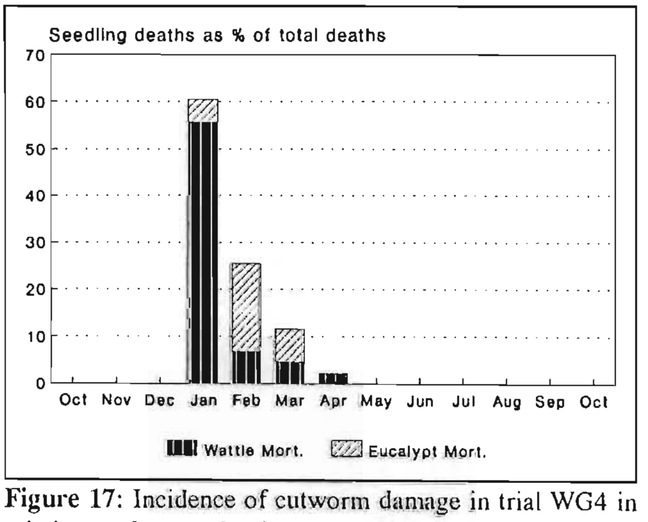


Figure 17: Incidence of cutworm damage in trial WG4 in relation to the month of planting (January 1991).

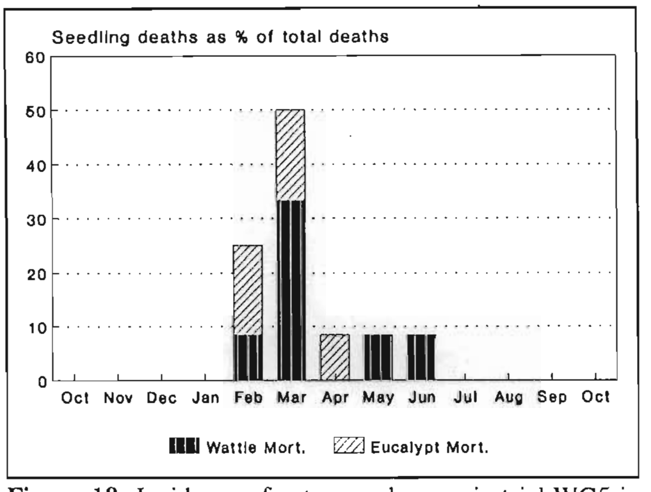


Figure 18: Incidence of cutworm damage in trial WG5 in relation to the month of planting (February 1991).

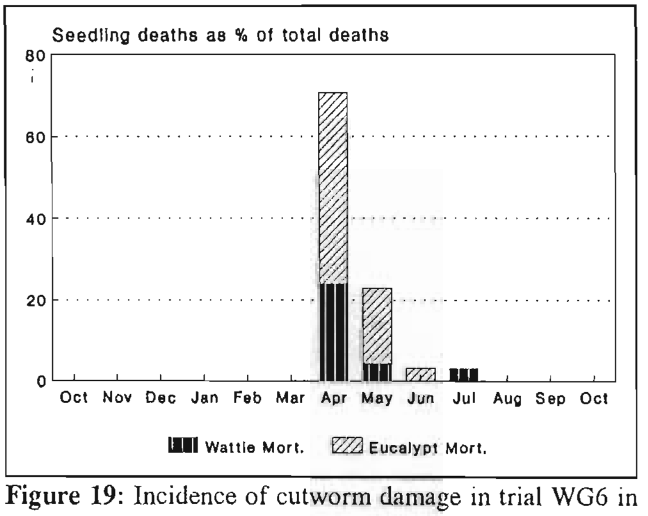


Figure 19: Incidence of cutworm damage in trial WG6 in relation to the month of planting (March 1991).

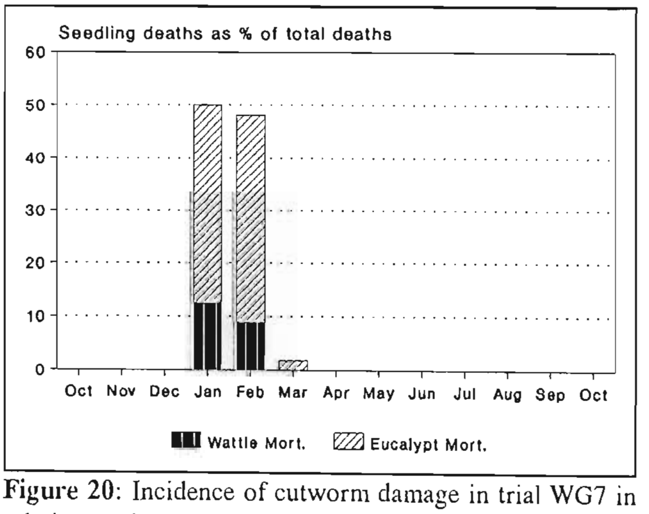


Figure 20: Incidence of cutworm damage in trial WG7 in relation to the month of planting (December 1991).

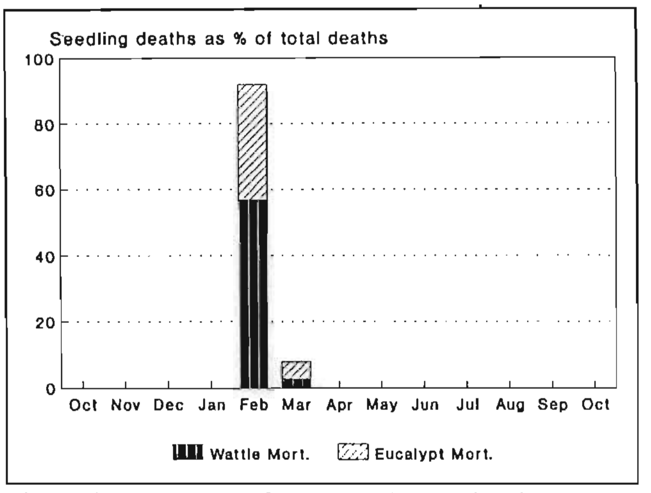


Figure 21: Incidence of cutworm damage in trial WG8 in relation to the month of planting (January 1992).

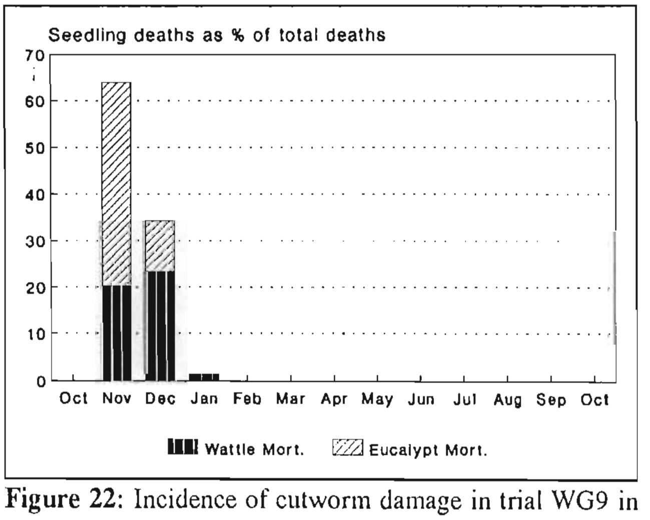


Figure 22: Incidence of cutworm damage in trial WG9 in relation to the month of planting (October 1992).

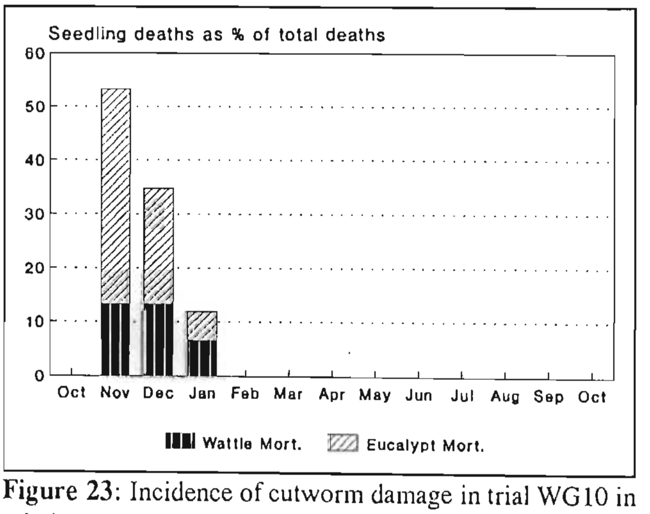


Figure 23: Incidence of cutworm damage in trial WG10 in relation to the month of planting (October 1992).

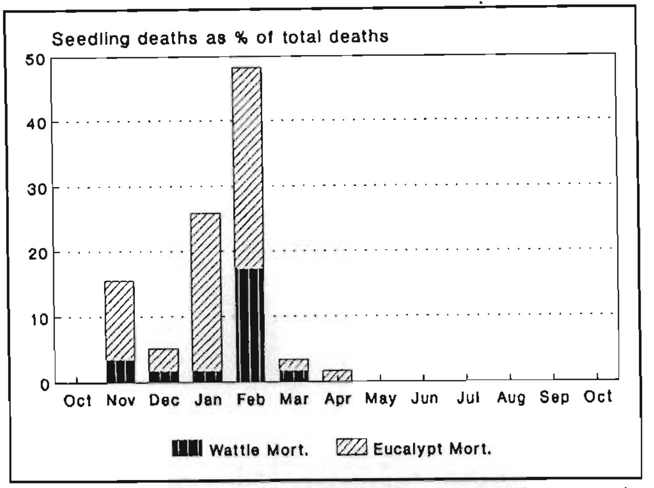


Figure 24: Incidence of cutworm damage in trial WG1 in relation to the month of planting (October 1990).

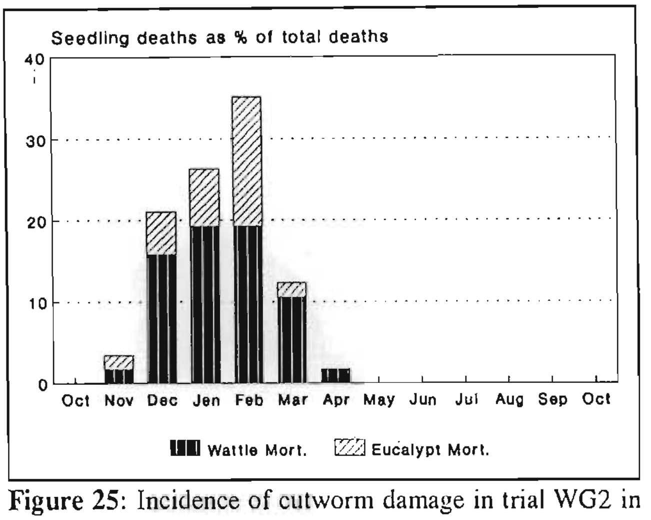


Figure 25: Incidence of cutworm damage in trial WG2 in relation to the month of planting (December 1990).

5.4 SILVICULTURAL AND OTHER FACTORS

Silviculture is the growing of trees and silvicultural factors refer to all management practices that ensure the rapid growth and establishment of seedlings. Seedlings were often damaged or killed by careless weed management (for example, hoe damage during manual line or ring weeding) or mowed while weeding the interrow or sprayed with herbicides. Some mortalities were related to planting practices, for example, J-root, shallow pit planting, or planting too close to the stump line, or planting in the leaf litter as opposed to the mineral soil. Other mortalities were nursery related, for example, poor growing medium and resultant weak seedlings or seedlings infested with nursery related pathogens or too young or too old seedlings.

Numerous nursery pathogens attack commercial tree species (Nichol, 1993), but the pathogen causing the most damage in this study was identified as *Cylindrocladium scoparium* Morgan (N S Nichol, personal communication).

Browsing by grey duiker, scrub hare (*Lepus* spp.) and cattle (*Bos* spp.) was another mortality factor which caused the failure of seedlings to reach full establishment. Duiker and hare often selectively browsed the growing shoots of young seedlings and in those instances where this damage was not severe, seedlings were able to coppice and recover. Severe duiker damage soon after planting is very similar to cutworm damage. Cattle feeding was more destructive on recently planted seedlings because seedlings were uprooted during feeding.

The last category in the mortality factors was termed 'unknown' because none of the pests or their associated damage symptoms could be found. This could have been caused by natural seedling death, transplant shock or excessive transpiration during planting under drought conditions.

5.5 INFLUENCE OF THE ABIOTIC ENVIRONMENT ON THE INCIDENCE OF WHITEGRUB ATTACK

It has generally been observed that whitegrub larvae occur in soils with a high humus content as opposed to termites that prefer soils with a high clay and low humus content. A multiple linear regression analysis (Genstat) showed that the percentage whitegrub infestation had a strongly positive linear relation to the percentage organic carbon in the topsoil ($r = 0{,}871$, d.f. $= 19$, $t = 5{,}52$, $p < 0{,}01$, $n = 20$) (***Figure 26***). The percentage organic carbon of the topsoil in each trial was determined by the wet-oxidation technique using the Walkley-Black Method (Walkley, 1947). The percentage whitegrub infestation is the same as that determined in section 4.3. The percentage whitegrub infestation was not related to the percentage clay in the top soil ($t = 0{,}98$, d.f. $= 19$, $p < 0{,}05$, $n = 20$). A linear regression gave a better fit to the regression than an exponential regression ($r = 0{,}847$). The best fitting curve therefore improves the prediction of whitegrubs infestations if the percentage organic carbon of the topsoil is known. There was also no differential effect between wattle and eucalypts, that is, both species were equally susceptible to whitegrub damage ($t = 0{,}38$, d.f. $= 19$, $p < 0{,}01$, $n = 20$).

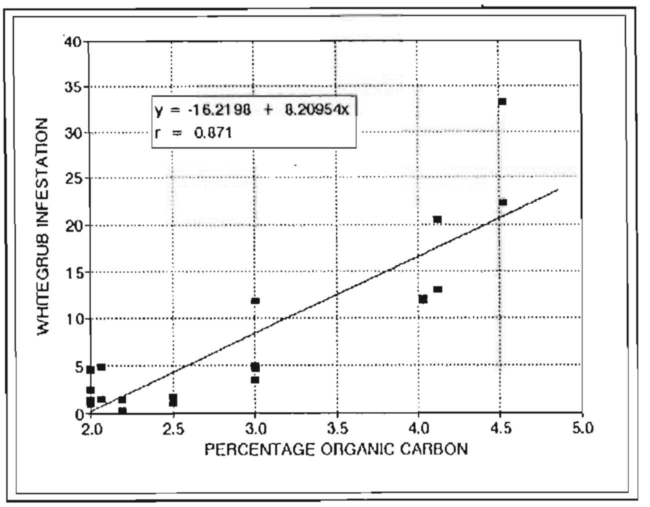


Figure 26: Relationship between whitegrub infestation and percentage organic carbon in trials WG1 to WG10.

Soils that have an organic carbon content greater than 1,8% are referred to as humic, for example, Inanda, Kranskop and Magwa, while soils with an organic carbon content less than 1,8% are referred to as orthic, for example, Hutton, Griffin and Clovelly (C Smith, personal communication). One can therefore generalise that soils with a humic phase are more likely to develop whitegrub infestations than soils with an orthic phase.

This general guideline can serve as a useful tool when deciding to treat seedlings preventatively with insecticides at planting. Most forestry soils are presently classified and the percentage organic carbon is being captured on a Geographical Information System (R Kunz, personal communication). High risk areas can therefore be identified and more ecologically sound recommendations on the control of whitegrubs can then be made.

Whitegrubs are sensitive to the moisture of the soil and move up or down in the soil as moisture conditions change, in an attempt to remain in a habitat with optimum moisture (Speers and Schmiege, 1961; Fleming, 1972). Stone and Bueno (1987) revealed that both larval mortality and vertical migration were significantly affected by larval density; and that larval migration was higher in sandy soils. Insecticidal treatments would therefore be more effective under moist soil conditions and in sandy soils, where whitegrubs are closer to the surface and deep penetration of the treatment is not required.

CHAPTER 6: CONTROL MEASURES

6.1 NON-CHEMICAL CONTROL

Burley *et al.* (1989) estimated that besides the existing woodlots in South Africa and neighbouring homelands, there is, for example, an additional need for 147 300 ha of woodlots to supply the fuelwood and pole requirements of the rural people of the Transkei. There is the potential for smallholders or limited-resource agriculture to supply the sawmilling, mining timber or pulp industries in South Africa with raw material from woodlots as small as one hectare. There is, therefore, a need for cheap alternative control measures to chemical control.

6.1.1 WHITEGRUBS

6.1.1.1 BIOLOGICAL CONTROL

During their life in the soil, whitegrubs are attacked by a number of natural enemies which, although they kill a large number of grubs, and may achieve reductions of their numbers in localised areas, do not make any meaningful reduction of the total population in the soil of plantations (Borthwick, 1990b). The predacious and parasitic insects which destroy whitegrubs in the soil include the larvae of robber flies (Asilidae), horse flies (Tabanidae), tachinid flies (Tachinidae), click beetles (Elateridae), tiphiid wasps (Tiphiidae), assassin bugs (Reduviidae), the larvae and adults of ground beetles (Carabidae) and earwigs (Dermaptera) (Prins, 1965). Vertebrate enemies of whitegrubs and adult chafers include pigs, shrews, moles, rats, toads, birds and monkeys (Prins, 1965; Veeresh, 1977). Carnegie (1974) identified the heron *Bubulcus ibis* Linnaeus and the hadeda *Hagedashia hagedash* preying on whitegrubs.

Parasitic nematodes have been used to control *Trochalus* spp. attacking hops in the Cape Province but with limited success (D Brits, personal communication). However, the entomogenous nematodes, *Steinernema feltiae* Filipjev and *Heterorhabditis heliothidis* Kahn, Brooks and Hirschmann provided over 60% control of *Popillia japonica* Newman larvae infesting turf grass in New York, which was equivalent to the control achieved with chlorpyrifos, trichlorofon and isofenphos (Villani and Wright, 1988). Similar effectiveness of the above nematodes was also observed by Kard *et al.* (1988) in North Carolina and Shetlar *et al.* (1988) in Ohio.

Bacteria (*Bacillus popillia* Dutky, *B. lentimorbus* Dutky: Hanula and Andreadis, 1988) , viruses, protozoa (*Adelina* spp.: Longworth, 1976), (*Actinocephalus* spp., *Ovavesicula popilliae* Andreadis and Hanula, *Adelina* spp.: Hanula and Andreadis, 1988), fungi and rickettsia (*Rickettsiella popilliae* Dutky and Gooden: Hanula and Andreadis, 1988) are also known to attack whitegrubs in various parts of the world. Viruses are very specific, kill the pest rapidly, are easy to produce, can be stored for years without losing infectivity and can be used to full advantage in forest ecosystems (Longworth, 1976).

The green muscardine fungus, *Metarrhizium anisopleae* Metch has been recorded to control grubs of *Holotrichia nilgiria* Arrow in India (Prakasan, 1987; Veeresh, 1977). *M. anisopleae* also controls *Oryctes rhinoceros* Linnaeus in coconut (Pillai, 1987).

6.1.1.2 CULTURAL CONTROL

Strip cropping in agroecosystems can restrict the movement of adult whitegrubs (Bohlen and Barrett, 1990); this would amount to strip planting compartments of wattle or pine with compartments of eucalypts in forestry.

In Karnataka (India) the cleaning of infested fields to keep them free from plants and then heaping this plant refuse at intervals, helped to concentrate the whitegrubs into limited areas under these heaps. Grubs were then killed either chemically or mechanically (Veeresh,1977). One could expect that this practice would also help control cutworms which may seek refuge under the plant refuse during the daylight hours.

The soil is ploughed and disced to clear away any grass and weeds after harvestinng the previous crop and hence prevent oviposition in the soil by adults (Veeresh, 1977). This also exposes whitegrubs in the soil to predation by birds and monkeys (personal observation). A reservoir of diseases and parasites that affect whitegrubs are always left in the soil (Borthwick, 1990b). Trap crops may be planted and then destroyed before planting the main crop (Veeresh, 1977).

6.1.1.3 MECHANICAL CONTROL

The collection and killing of adults of *Holotrichia serrata* Fabricius in Bangalore (India), especially when the adult emergence was synchronous after the first rains appeared to be a satisfactory control measure. Light trapping of adults was ineffective (Veeresh, 1977).

6.1.2 CUTWORMS

6.1.2.1 BIOLOGICAL CONTROL

Cutworms are attacked by a number of predators, parasites and diseases. Although these reduce the population, they do not control cutworms sufficiently to prevent damage to seedlings (Borthwick, 1990a).

6.1.2.2 CULTURAL CONTROL

Total ploughing of newly afforested land to a minimum depth of 10 cm during autumn or winter, followed by disc-harrowing in spring will kill or starve most cutworms present in the soil, and the lack of weeds resulting from complete cultivation will ensure that females do not oviposit in these areas. The maintenance of weed-free plantations, especially at time of re-establishment, is important in reducing cutworm populations (Annecke and Moran, 1982; Borthwick, 1990a).

Cultural control of cutworms in Australia is achieved by allowing plantations to be heavily grazed up to the time of planting (Abbott, 1993).

6.1.2.3 MECHANICAL CONTROL

The literature gives no indication that mechanical control has been used.

6.2 INVESTIGATIONS INTO CHEMICAL CONTROL MEASURES FOR WHITEGRUBS AND CUTWORMS

The results are arranged separately for each year/season of the three-year study period. Each seasons' results are followed by a discussion. Conclusions are only drawn at the end of the third season.

6.2.1 1990/91 SEASON

6.2.1.1 INTRODUCTION

In South Africa, there are no chemicals registered for use in forestry against whitegrubs and cutworms. Schönau *et al.*(1980) showed that gamma BHC 0,6% Dust (D), applied at 10 kg/ha in the seed sowing furrow, gave significantly better survival of line sown wattle seed than untreated seed. This work did not distinguish between mortality caused by whitegrubs and that caused by cutworms. The above study was conducted on line sown wattle and not seedlings, hence its rate of application on seedlings is uncertain. The efficacy and rate of application of gamma BHC 0,6% D on pests of establishment of eucalypt seedlings also requires evaluation. Gamma BHC 0,6% D has historically been used under registration for insects affecting many crops. The introduction of different chemical groups and new formulations of insecticides, that are registered or have shown promise for the control of similar pests in other cultivated crops, identifies the need for further research in forestry.

6.2.1.2 MATERIALS AND METHODS

Six screening trials (WG1 to WG6) were planted in the first season, one per month from October 1990 to March 1991. Each trial consisted half of *Eucalyptus grandis* and half of *Acacia mearnsii* (***Figure 1***, as an example). Five insecticide formulations, generally at two rates each, were tested in the first season, *viz.*

Chlorpyrifos 10% controlled release granule (CRG)
Carbosulfan 10% controlled release granule (CRG)
Isazofos 10% controlled release granule (CRG)
Ethoprofos 20% emulsifiable concentrate (EC)
Alphamethrin 10% suspension concentrate (SC)
Deltamethrin 5% suspension concentrate (SC)
Gamma BHC 0,6% dust (D)
Cadusafos 10% granule (G)

Gamma BHC 0,6% D is a persistent organochlorine insecticide which has successfully controlled most soil pests in many cultivated crops (Department of Agriculture, 1993). Chlorpyrifos 10% CRG is an organophosphate insecticide and is registered for use against sugarcane whitegrubs in Australia (DeGroot and Valvasori, 1989). Carbosulfan 10% CRG is a carbamate insecticide and is registered for use against termites in forestry and has shown promise in the control of sugarcane whitegrubs in South Africa (Department of Agriculture, 1993; Carnegie, 1988). Isazophos 10% CRG and ethoprofos 20% EC are organophosphate insecticides, and both have shown promise for the control of sugarcane whitegrubs in South Africa (Carnegie, 1988). Ethoprofos 20% EC is also registered for the control of sugarcane whitegrubs in Australia (Allsopp and Chandler, 1990). Cadusafos 10% G is an organophosphate insecticide, is long lasting, works in all soil types and generally controls most soil pests (Thomson, 1992). Deltamethrin 5% SC and alphamethrin 10% SC are both synthetic pyrethroids, are a persistent soil formulation and are both registered for the control of cutworms affecting many crops (Department of Agriculture, 1993). Seedlings that are treated at planting early in the season, may require protection from whitegrub attack later in the season. The emphasis in the choice of insecticides was therefore on persistence or renewal from controlled release granular formulations. Cadusafos 10% G and ethoprofos 20% EC were the only non-persistent and non-renewable materials.

Liquids were applied in two litres of water as a drench around the stem at planting. Granules and dusts were applied around the root plug at planting, and the plants received two litres of water. Untreated trees (controls) also received two litres of water at planting. Trials were surveyed once a month for a period of one year to assess and determine the causes of mortality.

Twelve treatments were replicated six times for each species in a randomised block design for trials WG1, WG2 and WG3 (***Appendices 1, 2 and 3***). The dosage rates of the different treatments were determined according to its history of success in controlling soil pests in forestry and other tree crops here and elsewhere. The rate of application of treatments cited as being registered on other agricultural crops above, were calculated to be the equivalent of similar treatments on tree crops. Some dosage rates of treatments were halved and their efficacy tested, in an attempt to make these expensive treatments more cost effective. In trials WG4, WG5 and WG6, eight treatments were replicated six times for each species in a randomised block design (***Appendices 4, 5 and 6***). Because of time constraints in assessing field trials, only the higher dosage rates of treatments were tested. Lower rates of selected treatments were to be tested in further trials. Each treatment plot consisted of 16 trees (8 treated and 8 untreated trees) which was separated from the next plot in each replicate by a guard row of untreated trees (***Figure 1***). This design was adopted because of the patchy distribution of whitegrubs and cutworms within a trial site (see ***Chapter 3***).

6.2.1.3 RESULTS

Analysis of variance (ANOVA) (Genstat 5, Rothamsted Experimental Station) was used to test the difference between the various treatments and the grand mean for the controls. The least significant difference test (LSD) was used for making comparisons between the treatments and the grand mean for the controls and also between treatments. Mortality or survival (dead or alive) is a bionomial variate and it is therefore necessary to transform data. Although logits are theoretically the correct transformation, work with termite induced mortality had shown that the use of square root arcsin transformation was perfectly adequate and much simpler to apply and analyse (P R Atkinson, personal communication). For this purpose programs written in Genstat (numerical algorithms group) were used. Raw data were captured on the ICFR database. Allsopp and Bull (1989) showed that there were functional relationships between the variance and mean of untransformed population counts for all

Australian whitegrub species. This affects the analysis of such data and demonstrates the need for data transformation.

The analysis of variance of the overall or total mortality (all mortality factors) produced inconclusive results because of the variable influence of different mortality factors, except possibly to identify phytotoxic treatments. These phytotoxic effects produced symptoms that could not be diagnosed with certainty during the monthly field assessments. Therefore the phytotoxic effect was either identified as unknown or nursery related. After analysing the total mortality of both eucalypts and wattle in all six screening trials of the first season phytotoxic treatments were identified as being those treatments that showed a significantly greater mortality than the controls. Total mortality analysis of the second and third season trials did not show any phytotoxic treatments because these treatments were refinements of treatments selected after the first season (Govender and Atkinson, 1992a; Govender, 1993). Successful treatments appeared more consistently and became more meaningful when treatment effects were evaluated according to the mortality caused by the dominant soil pest. The analysis is presented separately for whitegrubs and cutworms and also the two tree species because the application for registration of successful insecticides requires that one specify the insecticide for each pest and the crop affected.

6.2.1.3.1 WHITEGRUB MORTALITY

Acacia mearnsii

Trial WG1 was planted in October 1990 in Seven Oaks (Natal). This screening trial tested persistence of the various treatments because it was planted early in the season. In trial WG1 (***Figure 27***), deltamethrin 5% SC at 0,05 and 0,1 g active ingredient per tree (a.i./tree), ethoprofos 20% EC at 0,2 g a.i./tree, alphamethrin 10% SC at 0,1 and 0,55 g a.i./tree, carbosulfan 10% CRG at 0,5 and 1,0 g a.i./tree, cadusafos 10% G at 1,2 and 0,6 g a.i./tree and chlorpyrifos 10% CRG at 1,0 g a.i./tree showed significantly less mortality than the control. The incidence of whitegrub damage was high (11,91% infestation), hence the effect of the treatments was better evaluated than trials with a lower infestation. The traditional treatment for whitegrub of gamma BHC 0,6% D, applied at 0,06 g a.i./tree showed no significant difference in mortality to the control. No treatments showed significantly more mortality than the control; and there were no significant differences between treatments. The percentage infestation refered to above and in the rest of this chapter has already been cited in chapter 4 from the relevant tables.

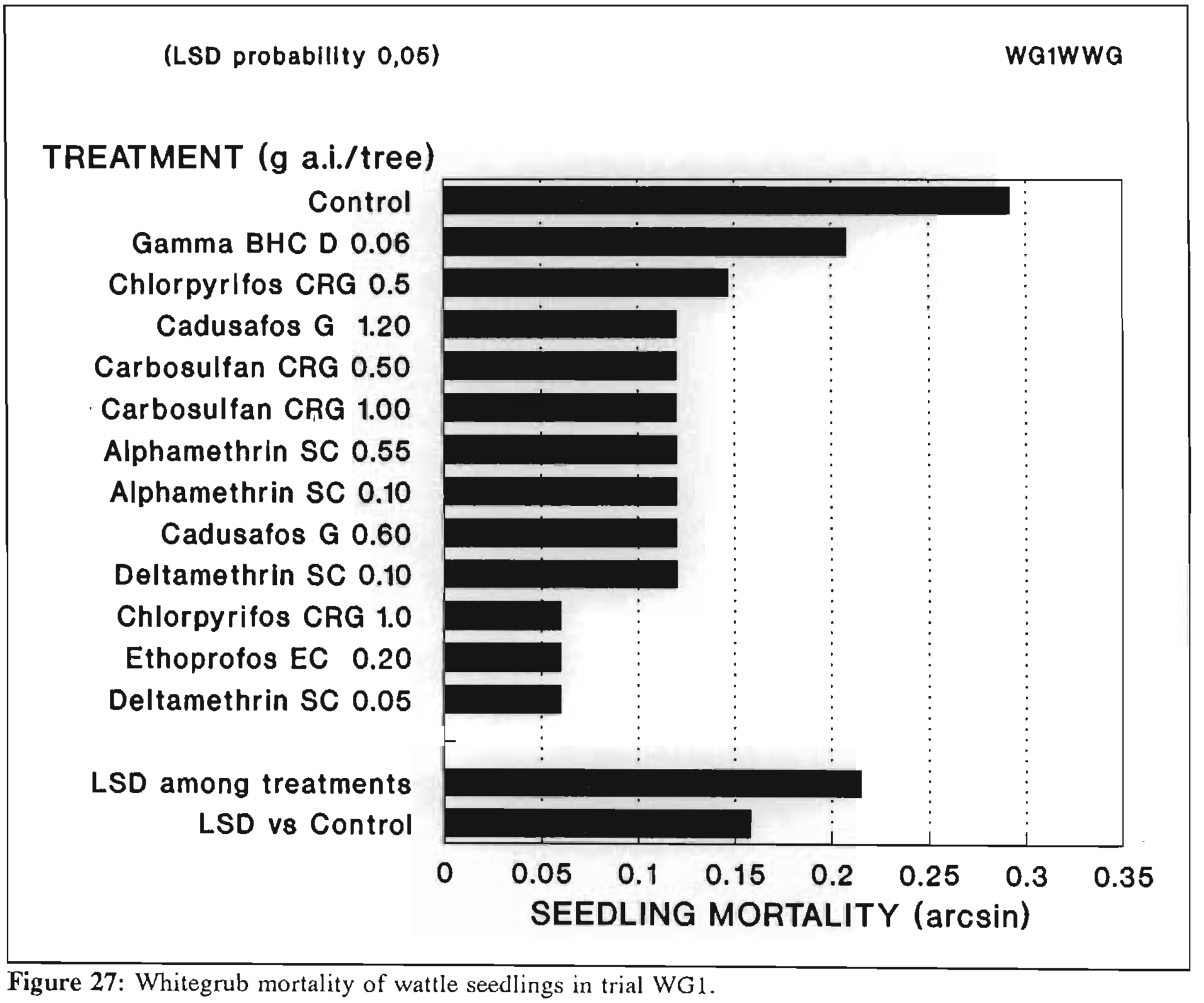


Figure 27: Whitegrub mortality of wattle seedlings in trial WG1.

Trial WG2 was planted in early December 1990 in Umvoti (Natal). No treatments showed significantly less mortality than the control because of the low incidence of whitegrub damage (1,36% infestation) (*Figure 28*). Alphamethrin 10% SC at 0,55 g a.i./tree showed significantly more mortality than the control. Deltamethrin 5% SC at 0,05 and 0,1 g a.i./tree, cadusafos 10% G at 1,2 g a.i./tree, chlorpyrifos 10% CRG at 0,5 and 1,0 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree showed significantly less mortality than alphamethrin 10% SC at 0,55 g a.i./tree.

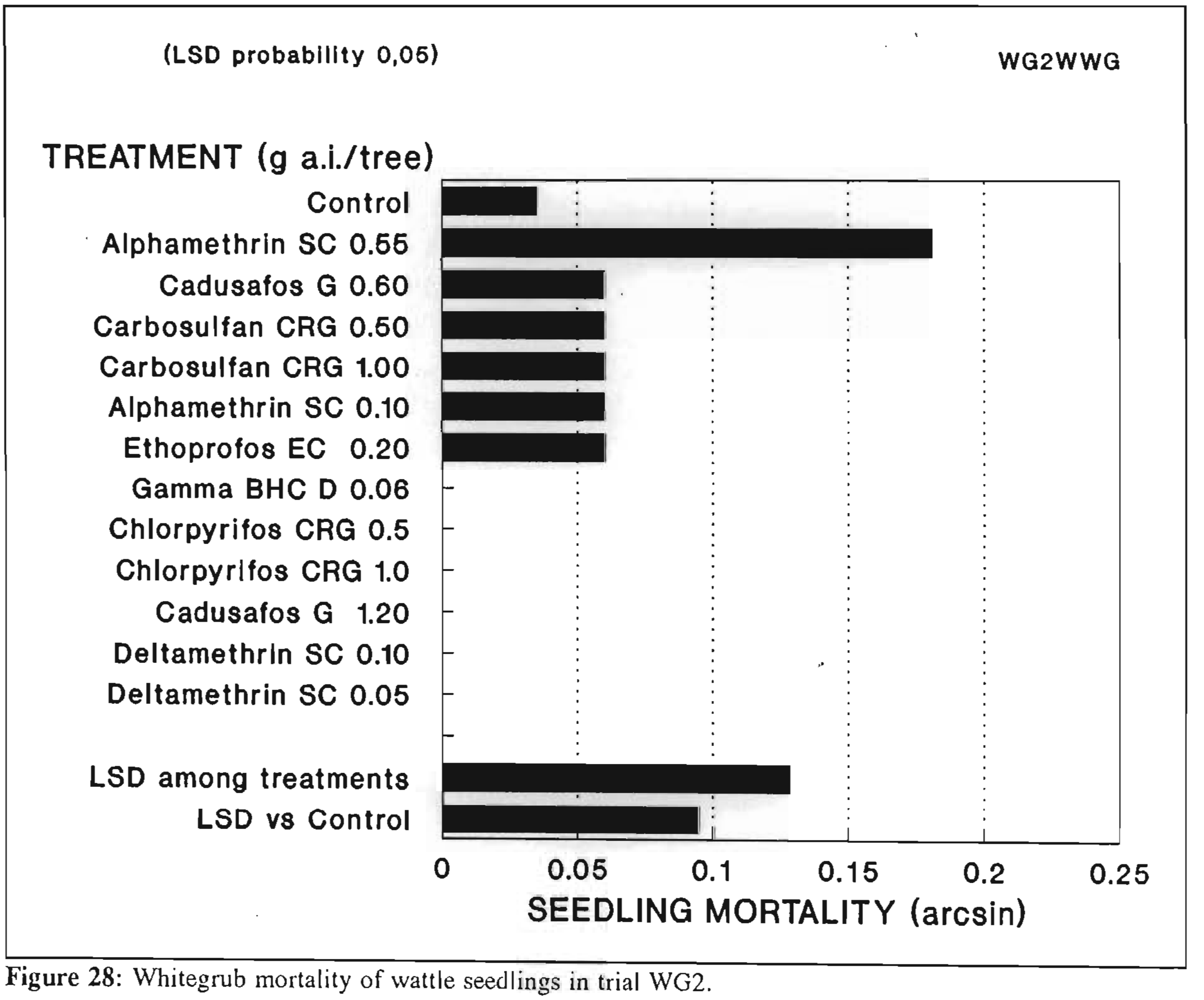


Figure 28: Whitegrub mortality of wattle seedlings in trial WG2.

Trial WG3 was planted in December 1990 in Melmoth (Zululand). There were significant differences between the controls of the various treatments. Each treatment effect was therefore evaluated against the mean treatment plot control resulting in a different figure format. Carbosulfan 10% CRG at 1,0 g a.i./tree, cadusafos 10% G at 1,2 g a.i./tree and chlorpyrifos 10% CRG at 0,5 g a.i./tree showed significantly less mortality than their control (***Figure 29***). No treatments showed significantly more mortality than their control. Carbosulfan 10% CRG at 1,0 g a.i./tree, isazofos 10% CRG at 1,0 g a.i./tree and chlorpyrifos 10% CRG at 1,0 and 0,5 g a.i./tree showed significantly less mortality than carbosulfan 10% CRG at 0,5 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree.

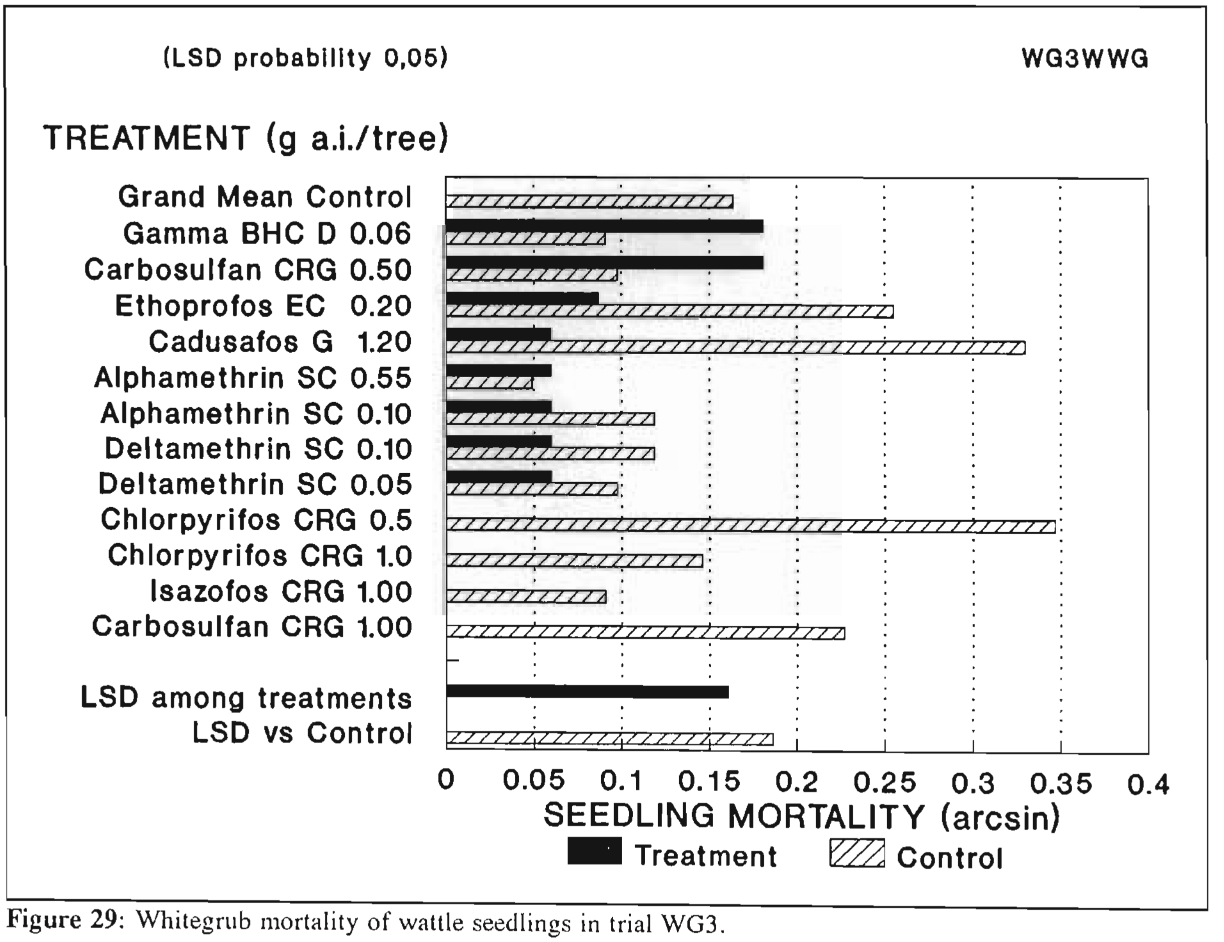


Figure 29: Whitegrub mortality of wattle seedlings in trial WG3.

Trial WG4 was planted in January 1991 in Pietermaritzburg (Natal). There was a high infestation of whitegrubs (22,26% infestation). All treatments, *viz*. deltamethrin 5% SC at 0,1 g a.i./tree, ethoprofos 20% EC at 1,0 g a.i./tree, alphamethrin 10% SC at 0,1 and 0,55 g a.i./tree, carbosulfan 10% CRG at 1,0 g a.i./tree, chlorpyrifos 10% CRG at 1,0 g a.i./tree, cadusafos 10% G at 1,2 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree showed significantly less mortality than the control (***Figure 30***). Ethoprofos 20% EC at 1,0 g a.i./tree and cadusafos 10% G at 12 g a.i./tree showed significantly less mortality than deltamethrin 5% SC at 0,1 g a.i./tree.

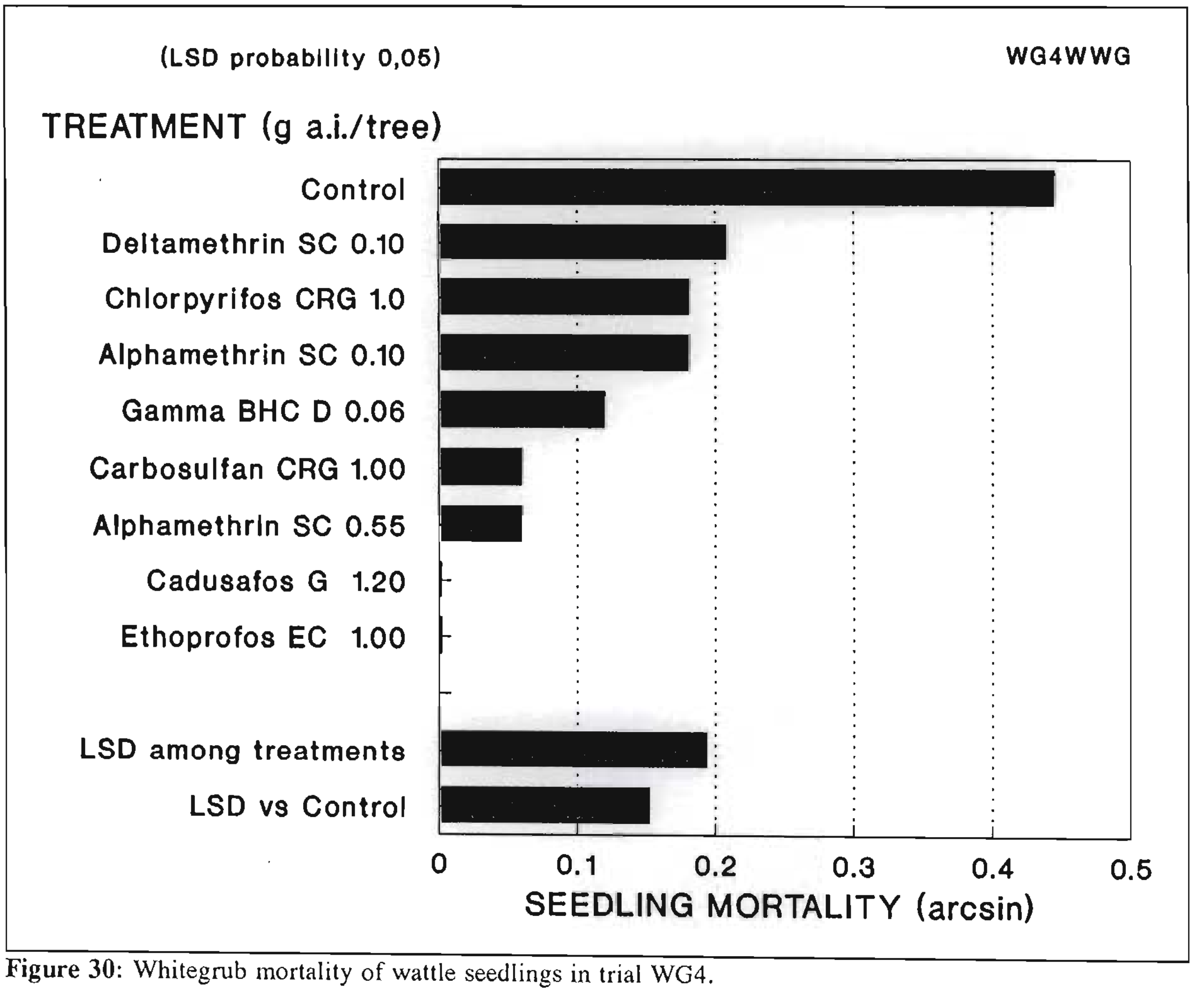


Figure 30: Whitegrub mortality of wattle seedlings in trial WG4.

Trial WG5 was planted in February 1991 in Richmond (Natal). No treatments showed significantly less mortality than the control because of the low incidence of whitegrub damage (1,4% infestation) (*Figure 31*). No treatments showed significantly more mortality than the control and there were no significant differences between treatments.

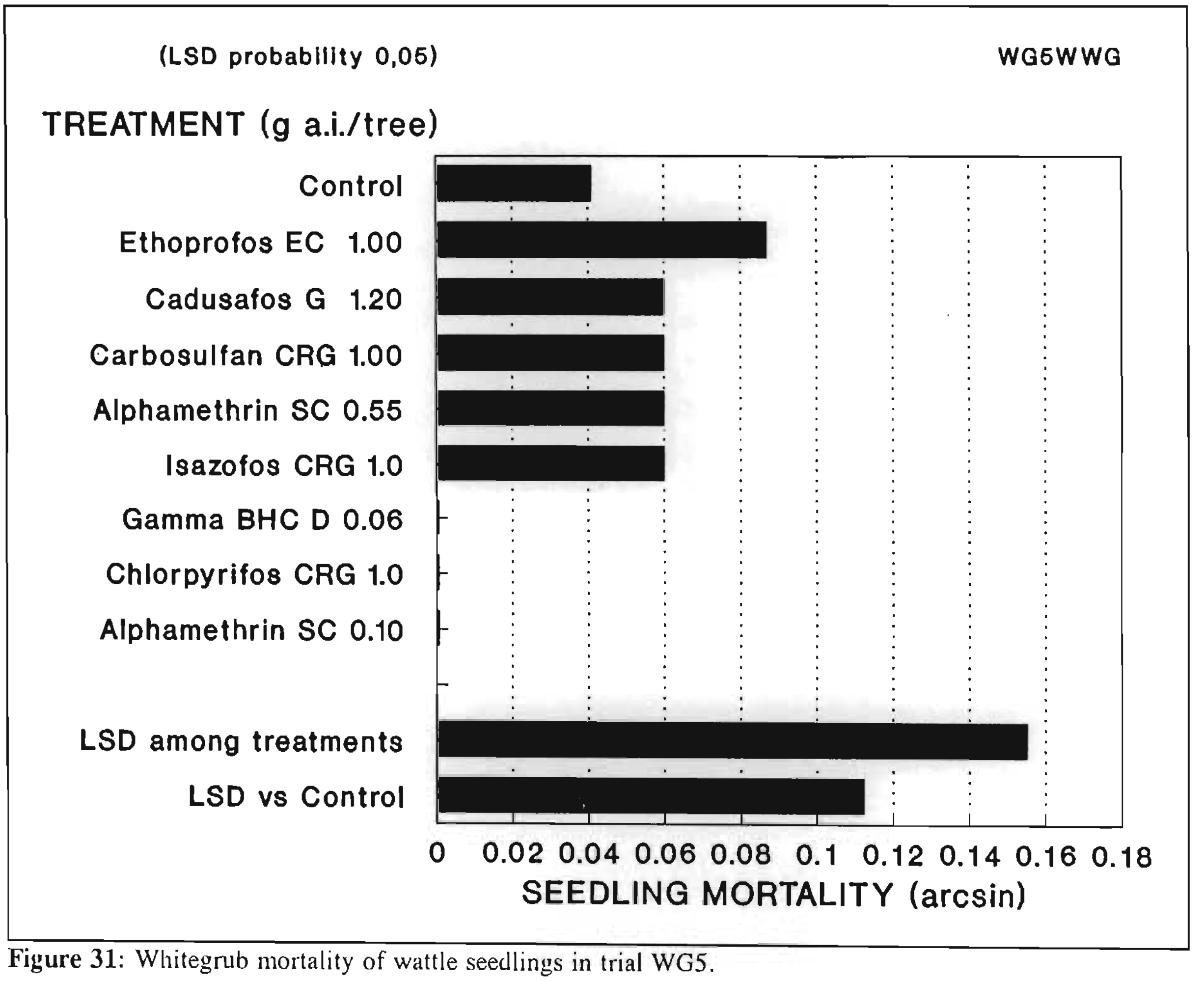


Figure 31: Whitegrub mortality of wattle seedlings in trial WG5.

Trial WG6 was planted in March 1991 in Hilton (Natal). No treatments showed significantly less mortality than the control because of the low incidence of whitegrub damage (1,09% infestation) (***Figure** 32*). Ethoprofos 20% EC at 1,0 g a.i./tree showed significantly more mortality than the control and all other treatments. Ethoprofos 20% EC at 1,0 g a.i./tree was probably phytotoxic to wattle trees.

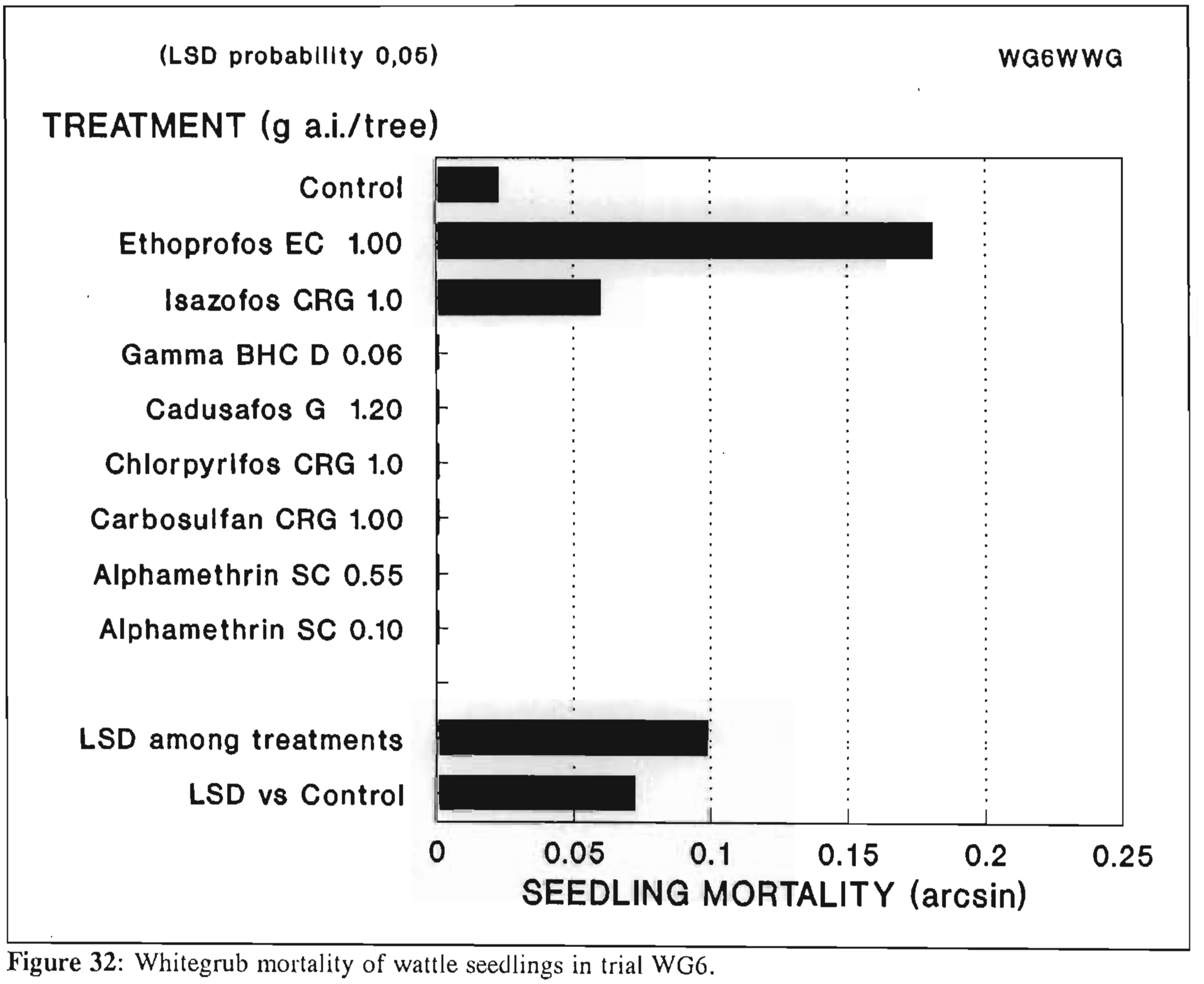


Figure 32: Whitegrub mortality of wattle seedlings in trial WG6.

Eucalyptus grandis

In trial WG1 where treatments were assessed for the control of whitegrubs in eucalypts (***Figure 33***), deltamethrin 5% SC at 0,05 g a.i./tree, alphamethrin 10% SC at 0,55 g a.i./tree, carbosulfan 10% CRG at 1,0 g a.i./tree, cadusafos 10% G at 0,6 g a.i./tree, chlorpyrifos 10% CRG at 0,5 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree showed significantly less mortality than the control and alphamethrin 10% SC at 0,1 g a.i./tree. No treatments showed significantly more mortality than the control. There was a lower whitegrub infestation (4,74%) in the eucalypt compared to the wattle section of trial WG1, hence the failure of those other treatments that were successful at controlling whitegrubs in the wattle section. An interesting observation is the success of chlorpyrifos 10% CRG at 0,5 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree in the eucalypt section compared to the wattle, illustrating the variability of treatment efficacy because of the patchy distribution of whitegrubs within a trial site.

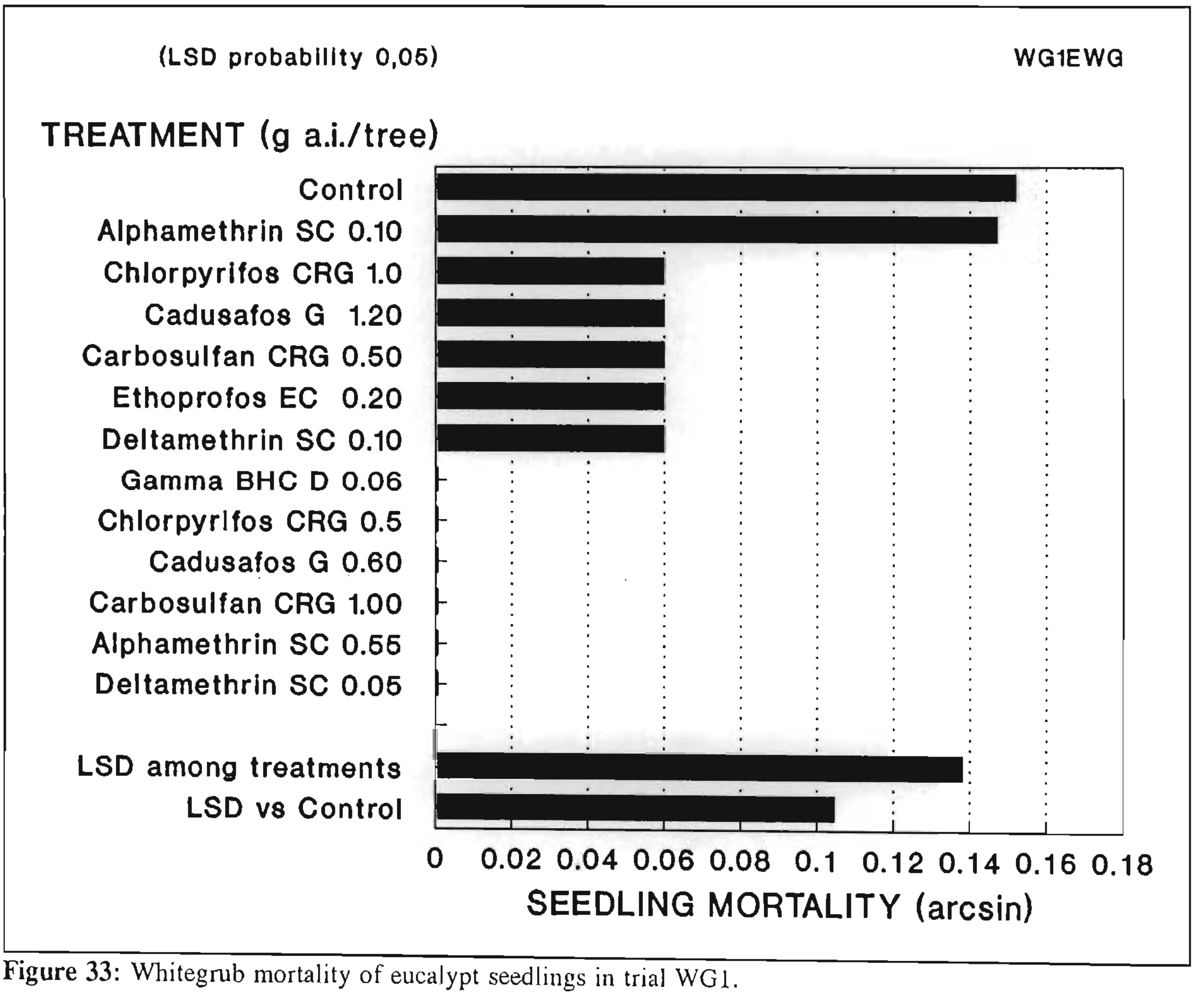


Figure 33: Whitegrub mortality of eucalypt seedlings in trial WG1.

In trial WG2 (***Figure 34***), no treatments showed significantly less mortality than the control because of the low incidence of whitegrub damage (0,34% infestation). However, gamma BHC 0,6% D at 0,06 g a.i./tree showed significantly more mortality than the control and all other treatments except carbosulfan 10% CRG at 1,0 g a.i./tree.

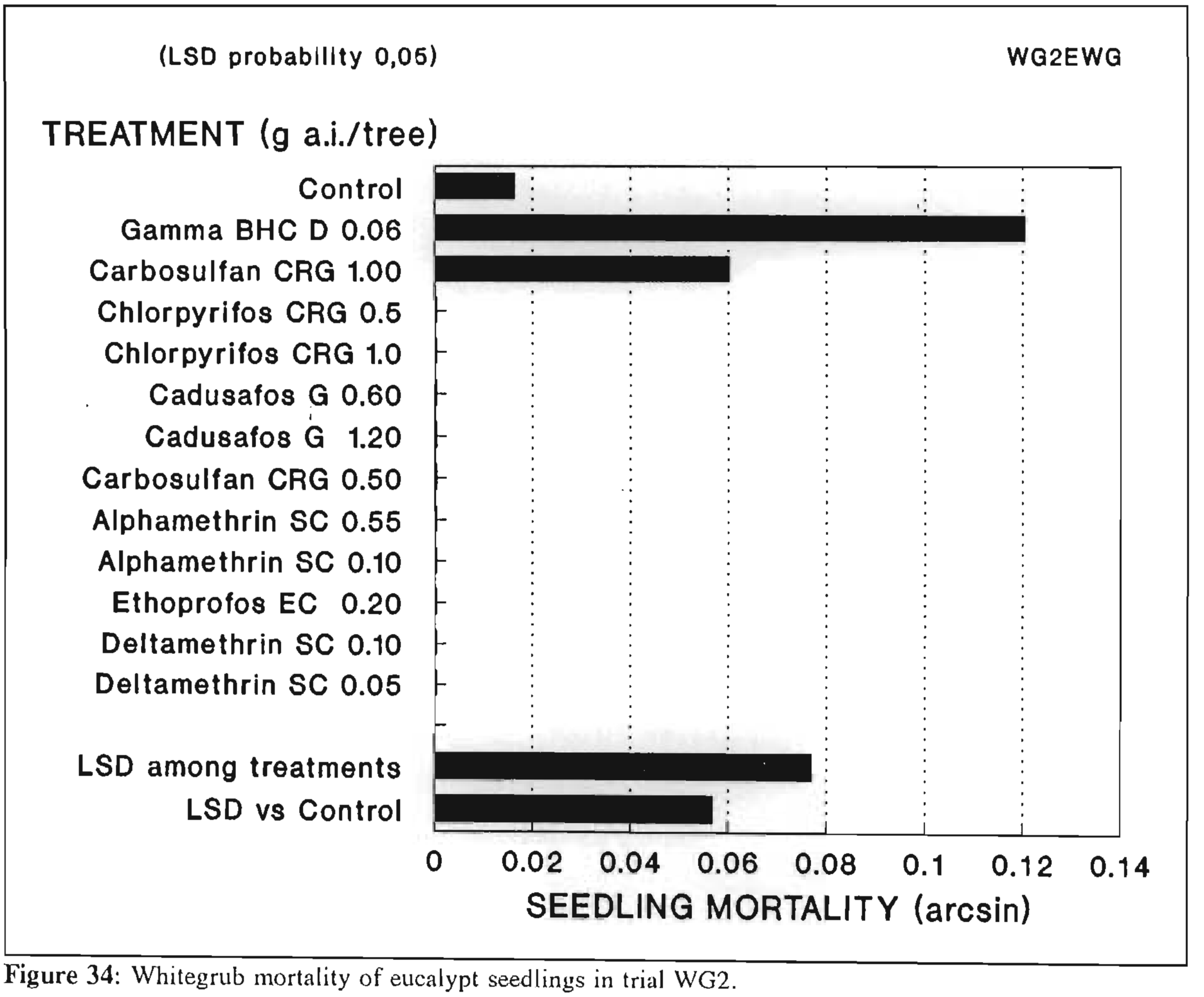


Figure 34: Whitegrub mortality of eucalypt seedlings in trial WG2.

In trial WG3 (***Figure 35***), no treatments showed significantly less mortality than the control because of the low incidence of whitegrub damage (3,48% infestation). No treatments showed significantly more mortality than the control. Alphamethrin 10% SC at 0,55 g a.i./tree, cadusafos 10% G at 1,2 g a.i./tree, isazofos 10% CRG at 1,0 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree showed significantly less mortality than alphamethrin 10% SC at 0,1 g a.i./tree and deltamethrin 5% SC at 0,1 g a.i./tree.

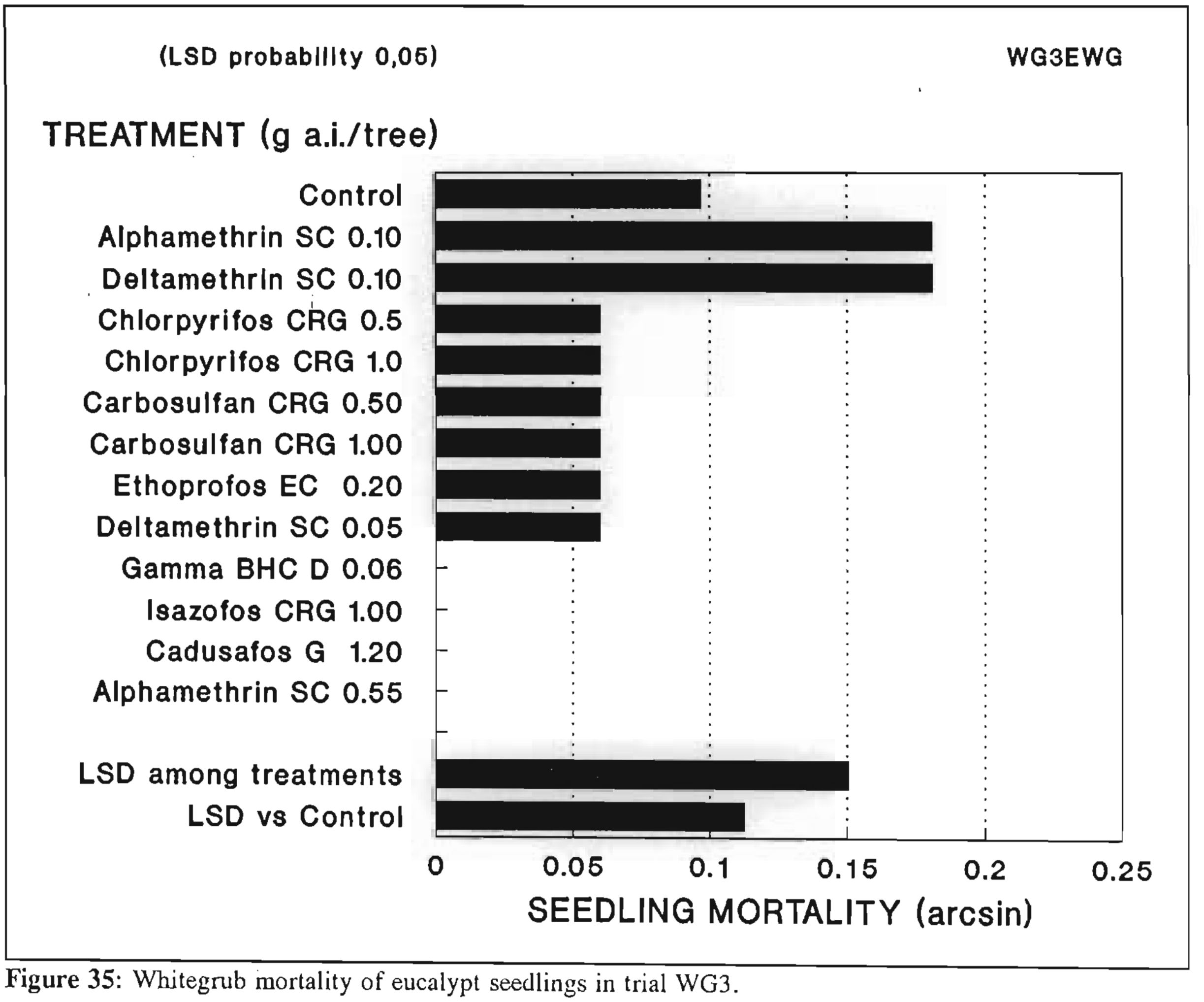


Figure 35: Whitegrub mortality of eucalypt seedlings in trial WG3.

The highest level of whitegrub infestation (33,23%) was recorded in the eucalypts of trial WG4. All treatments showed significantly less mortality than the control and there were no significant differences between treatments (*Figure 36*).

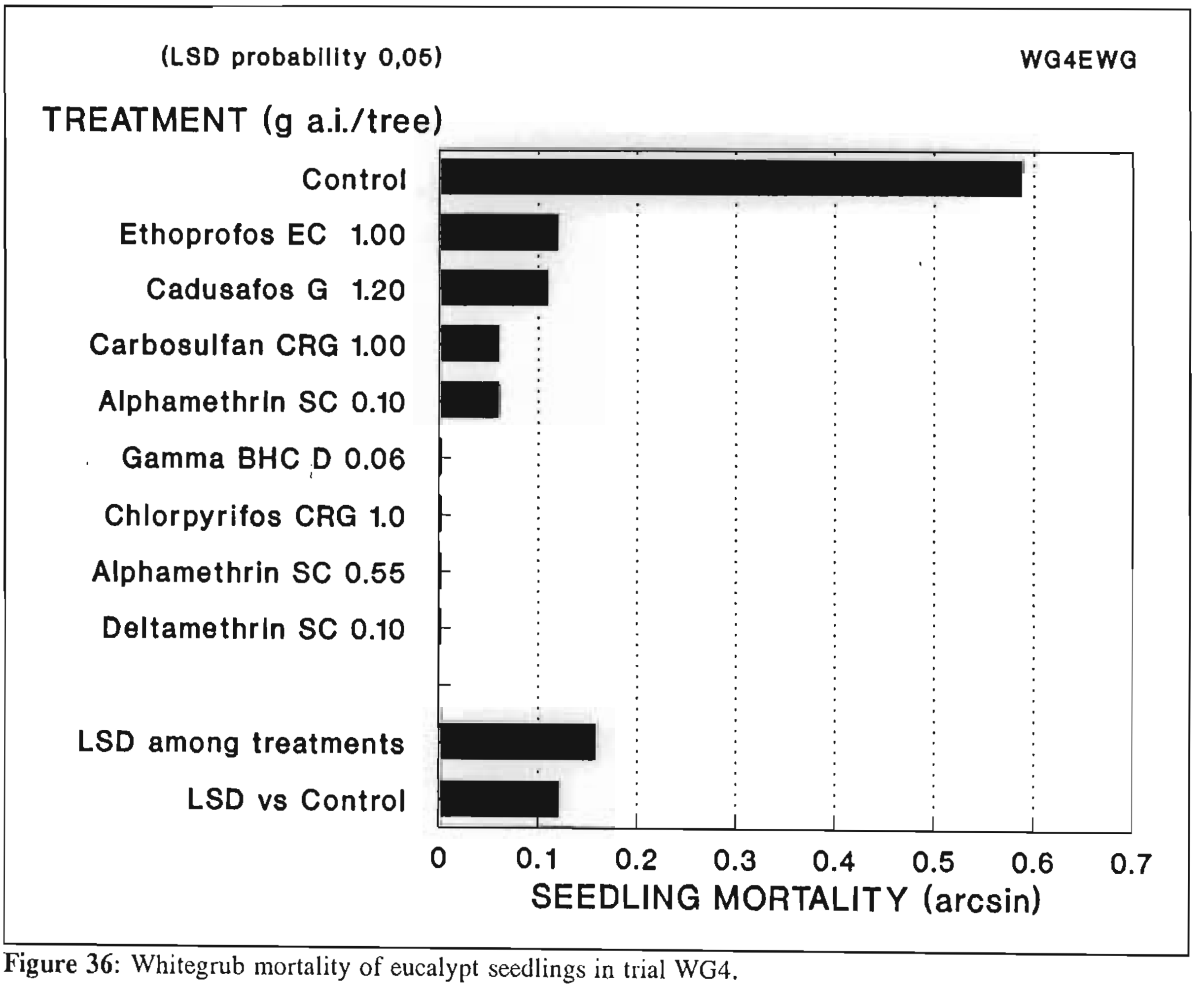


Figure 36: Whitegrub mortality of eucalypt seedlings in trial WG4.

In trial WG5 (*Figure 37*), no treatments showed significantly less or more mortality than the control because of the low incidence of whitegrub damage (0,94% infestation). However, there were significant differences between the controls of the various treatments and each treatment effect was therefore evaluated against the mean treatment plot control. There were no significant differences between treatments.

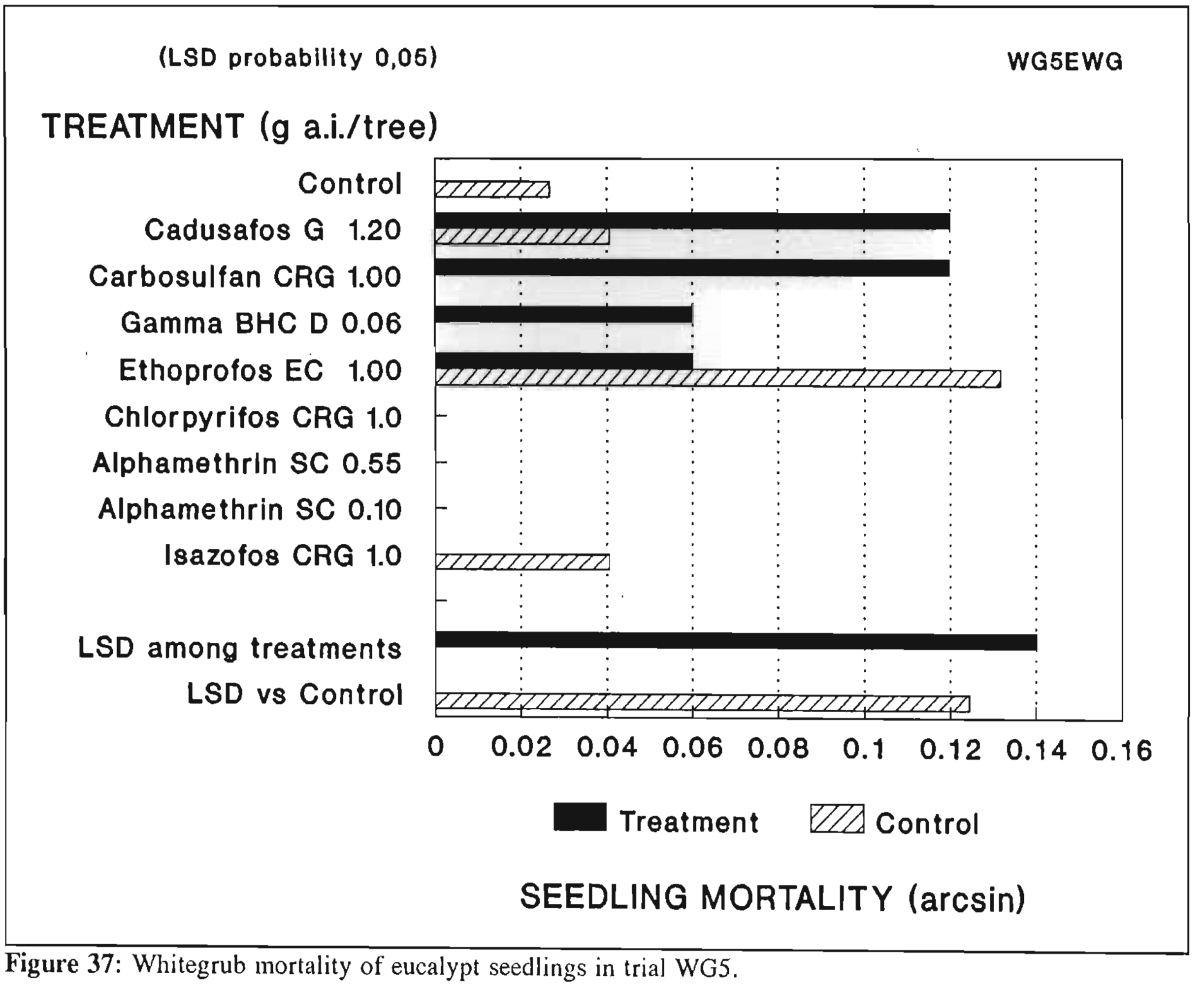


Figure 37: Whitegrub mortality of eucalypt seedlings in trial WG5.

In trial WG6 (*Figure 38*), no treatments showed significantly less or more mortality than the control because of the low incidence of whitegrub damage (1,72% infestation). There were no significant differences between treatments.

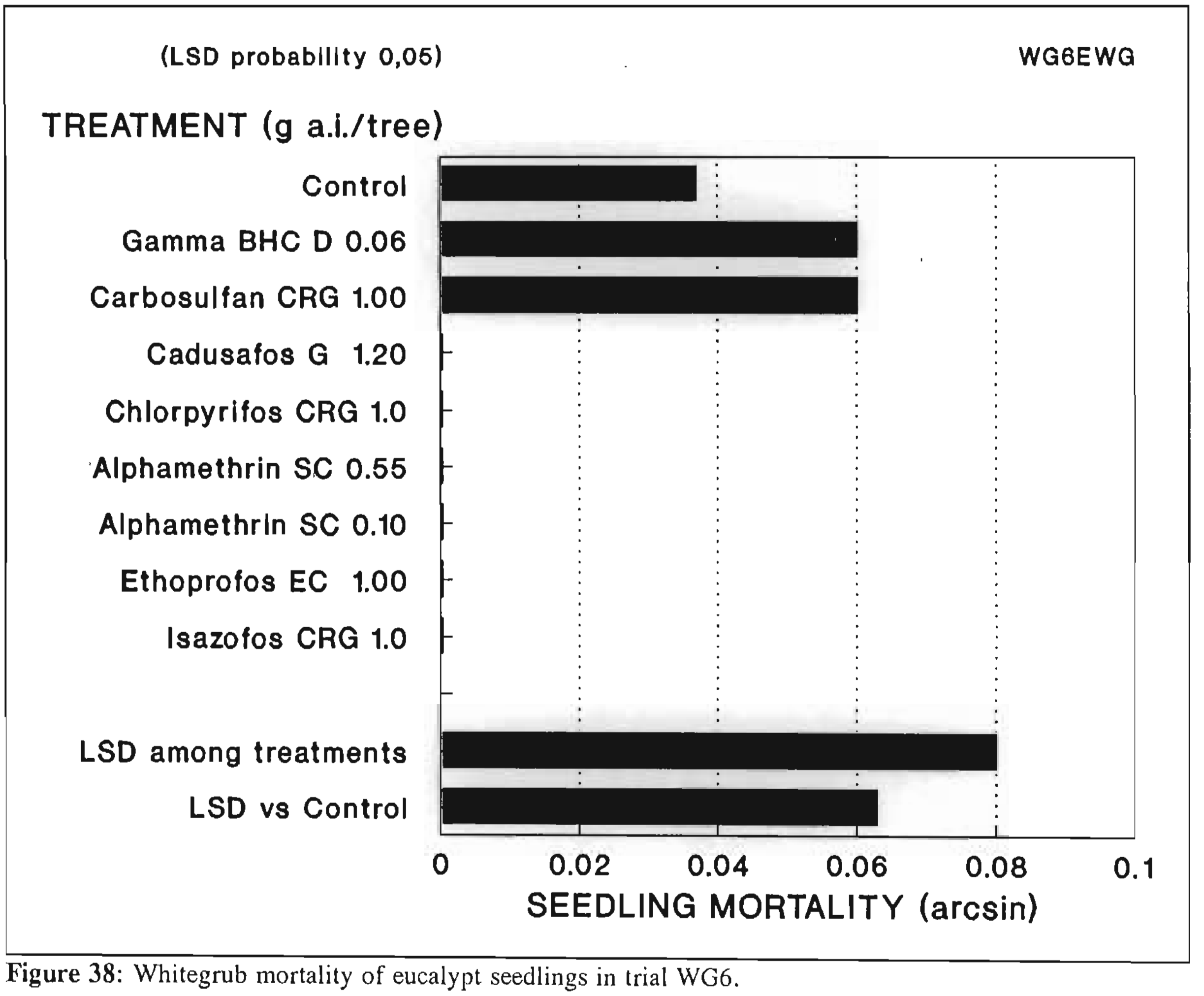


Figure 38: Whitegrub mortality of eucalypt seedlings in trial WG6.

6.2.1.3.2 CUTWORM MORTALITY

Acacia mearnsii

The incidence of cutworm damage on wattle was low in both trial WG1 (***Figure 39***) (0,84%) and trial WG2 (***Figure 40***) (2,71%). No treatments showed significantly less or more mortality than the control and there were no differences between the treatments.

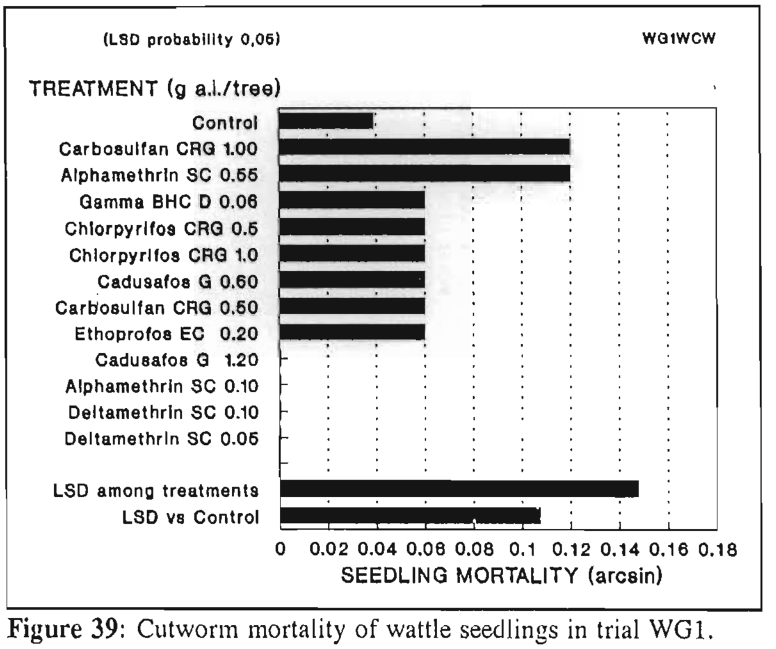


Figure 39: Cutworm mortality of wattle seedlings in trial WG1.

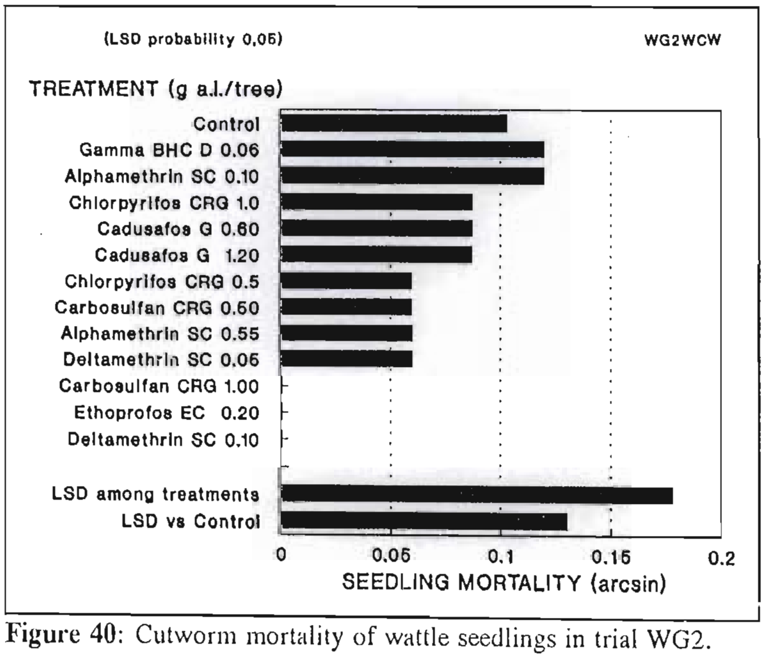


Figure 40: Cutworm mortality of wattle seedlings in trial WG2.

In trial WG3 (***Figure 41***), no treatments showed significantly less or more mortality than the control. An unusually high incidence of damage (16,44% infestation) was recorded as being caused by both cutworms and browsing combined. The lack of successful treatments indicates that most of the mortality was probably caused by browsing instead of cutworms. There were no differences between treatments.

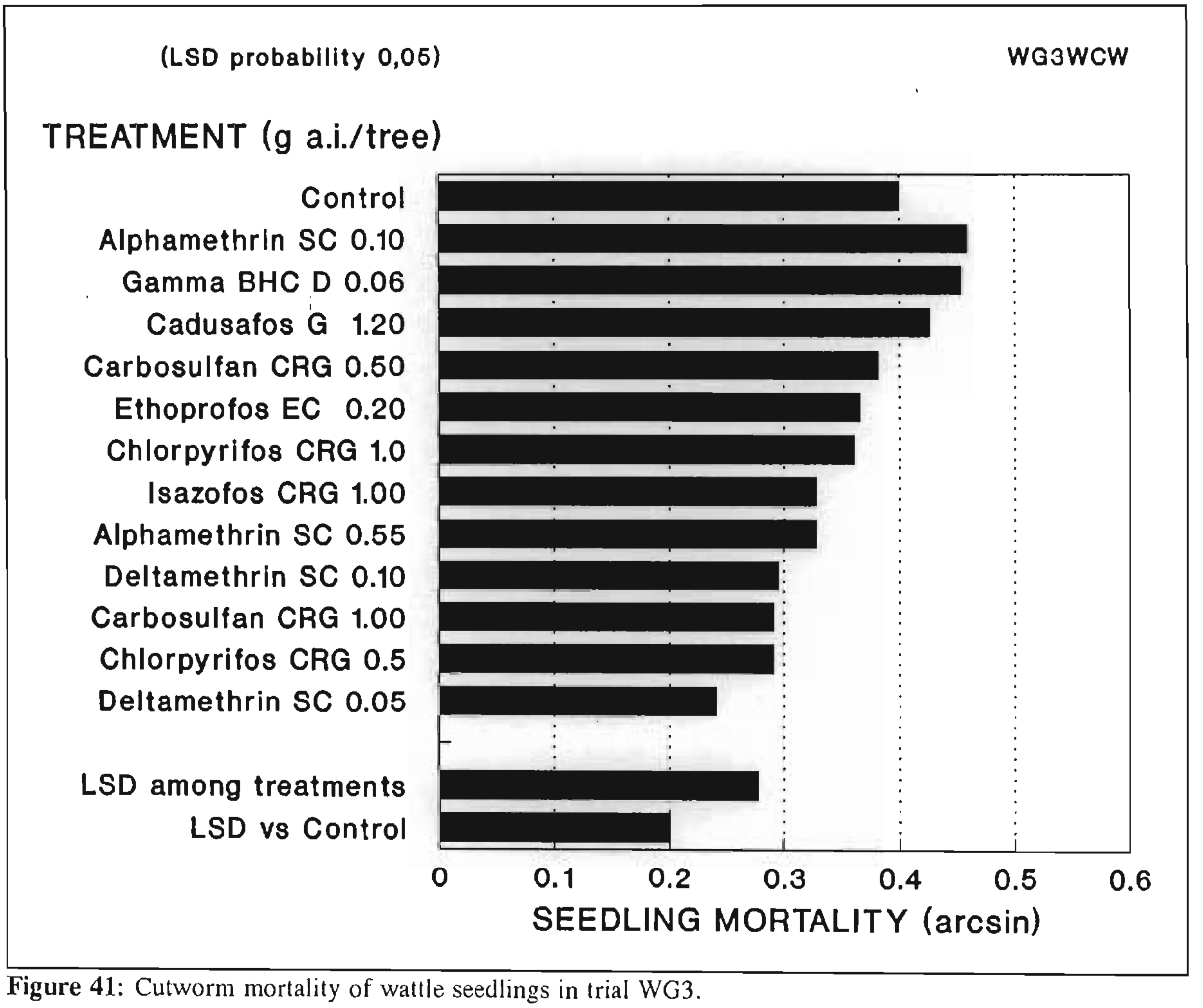


Figure 41: Cutworm mortality of wattle seedlings in trial WG3.

In trial WG4 (*Figure 42*), with a cutworm infestation of 2,58%, no treatments showed significantly less mortality than the control. Carbosulfan 10% CRG at 1,0 g a.i./tree showed significantly more mortality than the control. Cadusafos 10% G at 1,2 g a.i./tree and ethoprofos 20% EC at 1,0 g a.i./tree showed significantly less mortality than carbosulfan 10% CRG at 1,0 g a.i./tree.

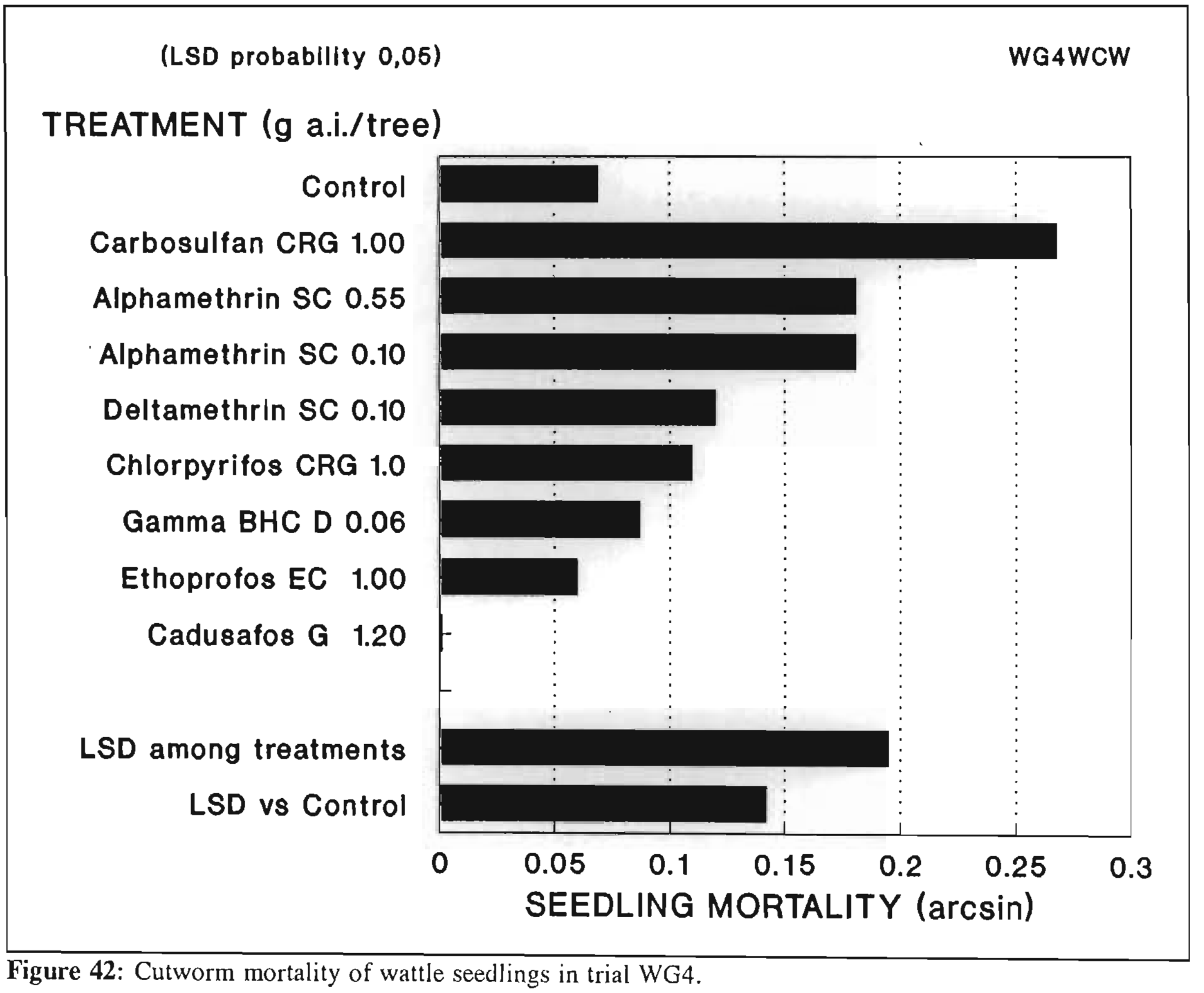


Figure 42: Cutworm mortality of wattle seedlings in trial WG4.

In trial WG5 (*Figure 43*), with a cutworm infestation of 0,78%, no treatments showed significantly less mortality than the control. Cadusafos 10% G at 1,2 g a.i./tree showed significantly more mortality than the control and all other treatments except carbosulfan 10% CRG at 1,0 g a.i./tree.

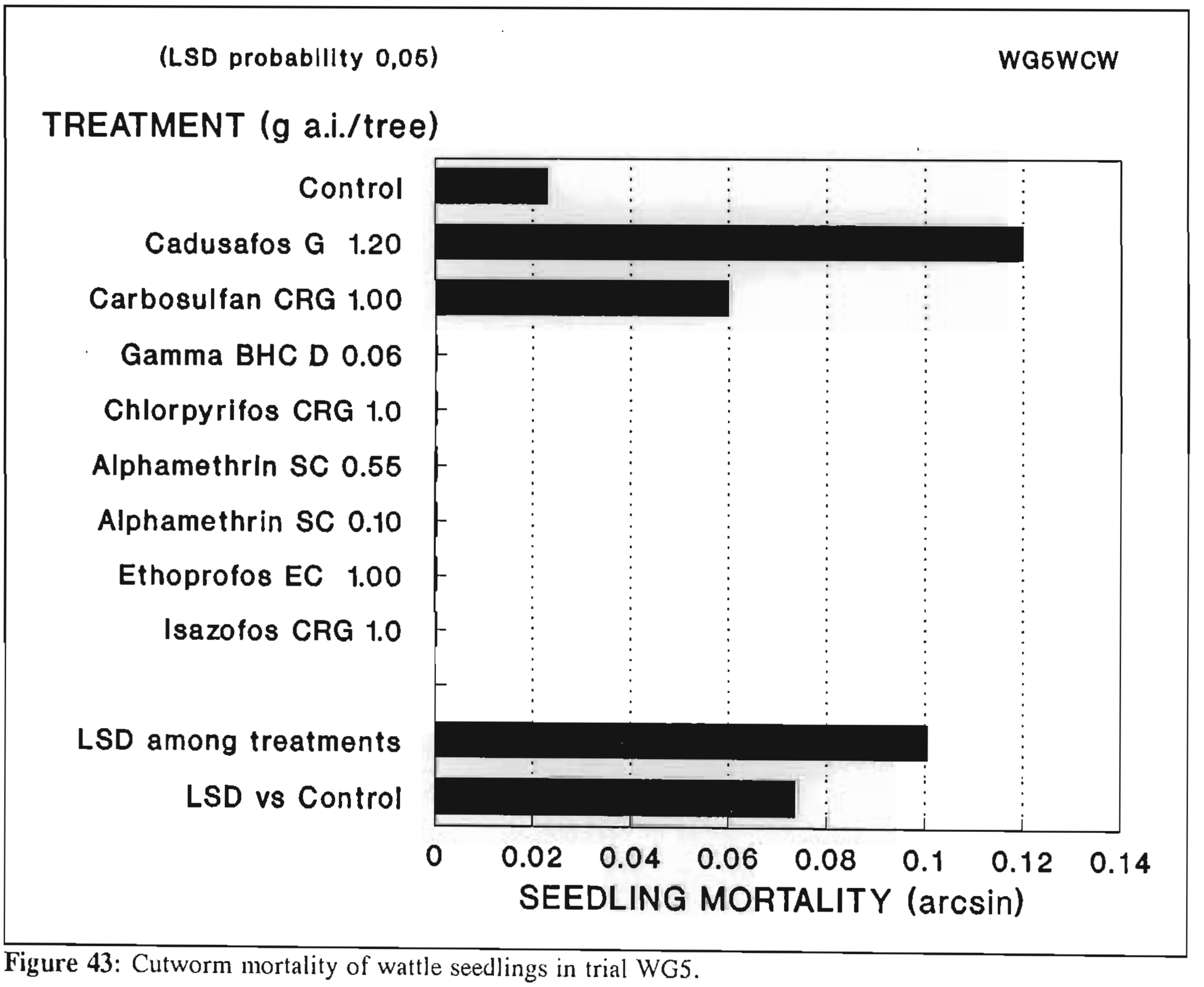


Figure 43: Cutworm mortality of wattle seedlings in trial WG5.

In trial WG6 (***Figure 44***), with a cutworm infestation of 3,9%, no treatments showed significantly less or more mortality than the control. There were no significant differences between treatments.

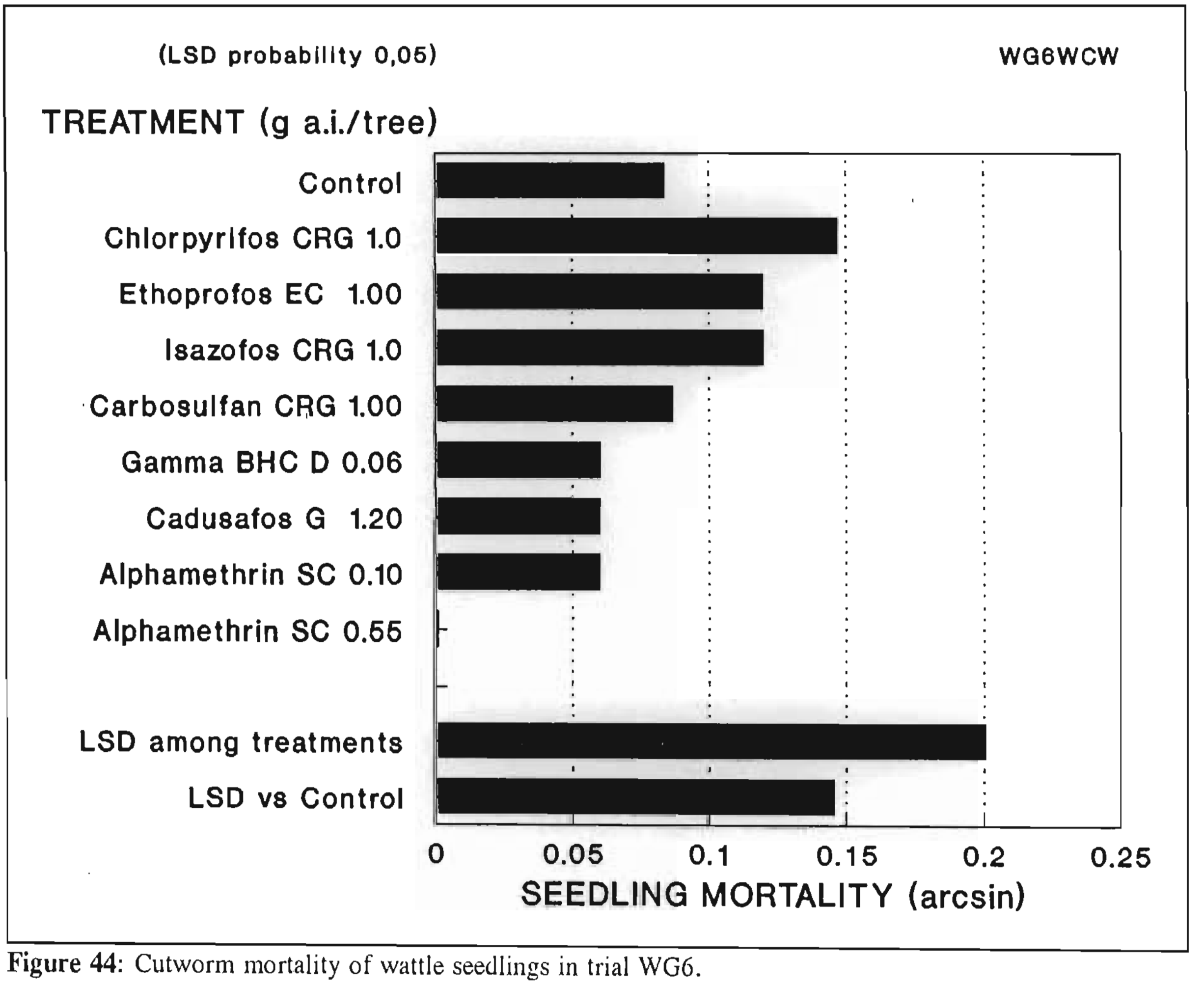


Figure 44: Cutworm mortality of wattle seedlings in trial WG6.

Eucalyptus grandis

In trial WG1 (***Figure 45***), with a cutworm infestation level of 2,85%, no treatments showed significantly less or more mortality than the control. However, chlorpyrifos 10% CRG at 1,0 g a.i./tree, carbosulfan 10% CRG at 1,0 g a.i./tree, alphamethrin 10% SC at 0,55 g a.i./tree and deltamethrin 5% SC at 0,1 g a.i./tree showed significantly less mortality than ethoprofos 20% EC at 0,2 g a.i./tree and alphamethrin 10% SC at 0,1 g a.i./tree.

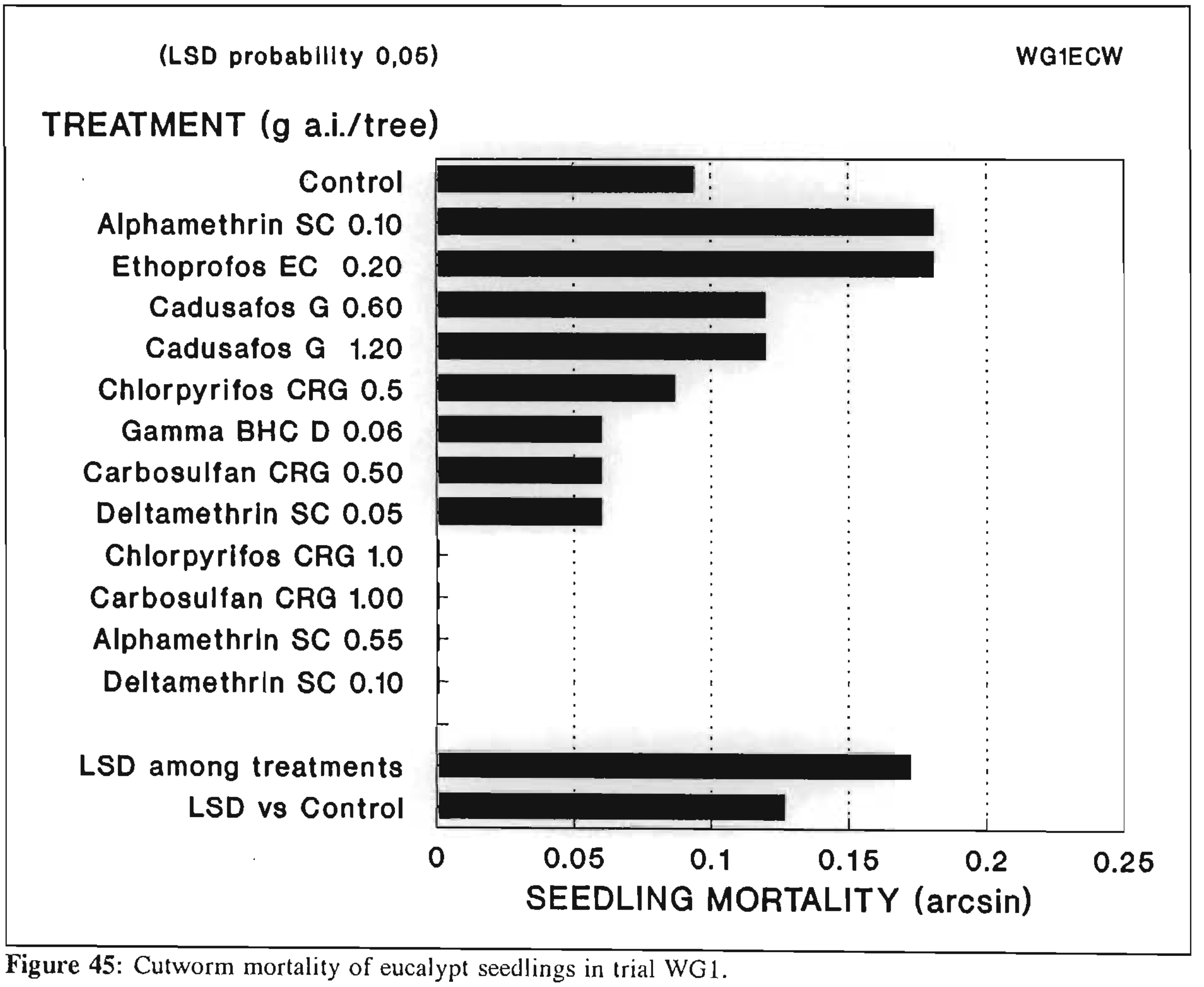


Figure 45: Cutworm mortality of eucalypt seedlings in trial WG1.

In trial WG2 (***Figure 46***), no treatments showed significantly less mortality than the control because of a low cutworm infestation of 0,79%. Cadusafos 10% G at 0,6 g a.i./tree showed significantly more mortality than the control. There were no significant differences between treatments.

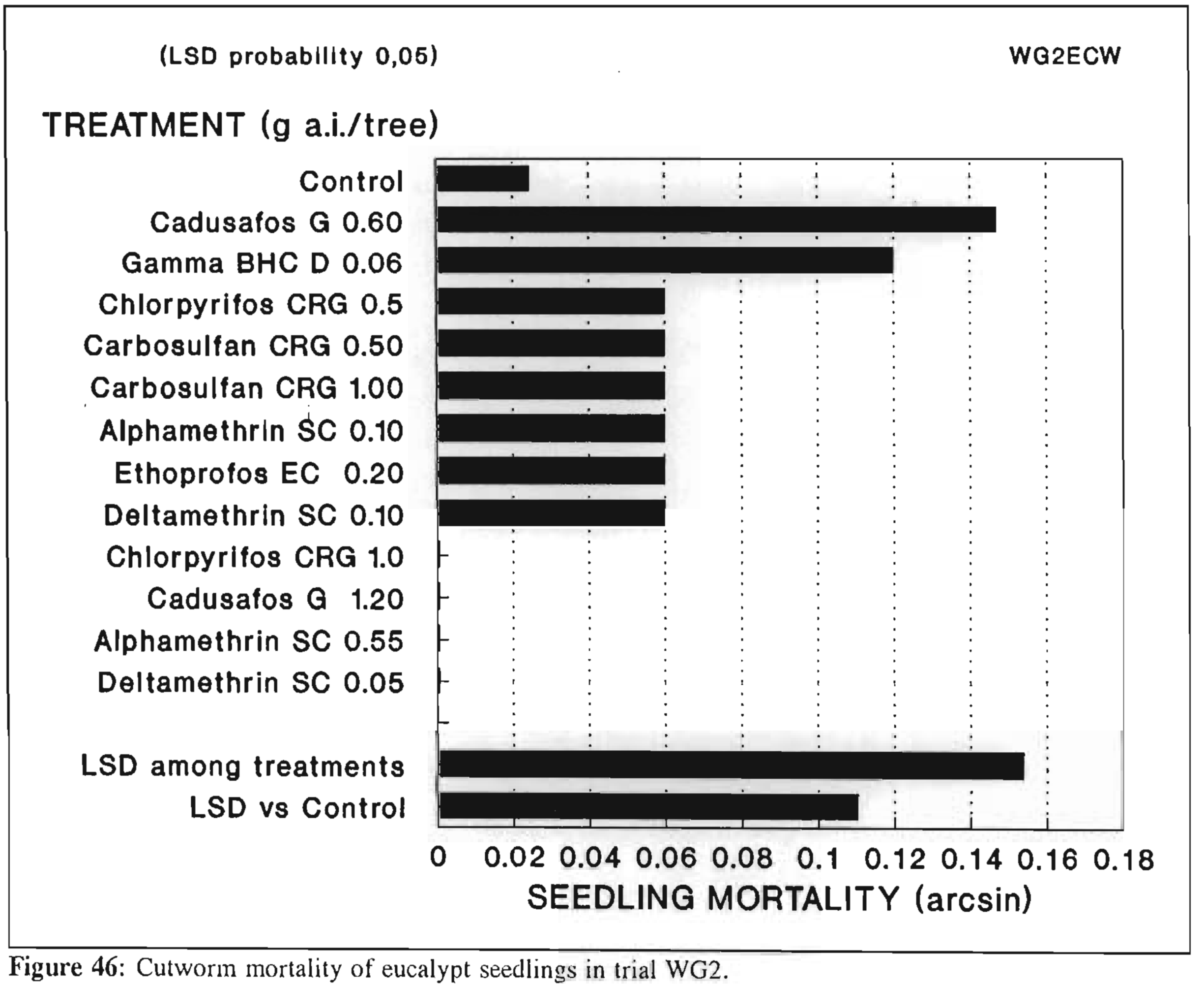


Figure 46: Cutworm mortality of eucalypt seedlings in trial WG2.

In trial WG3 (***Figure 47***), no treatments showed significantly less or more mortality than the control. An unusually high incidence of damage (9,59% infestation) was recorded as being caused by both cutworms and browsing combined. The lack of successful treatments indicates that most of the mortality was probably caused by browsing instead of cutworms. Deltamethrin 5% SC at 0,05 g a.i./tree showed significantly less mortality than cadusafos 10% G at 1,2 g a.i./tree, chlorpyrifos 10% CRG at 0,05 g a.i./tree, alphamethrin 10% SC at 0,1 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree.

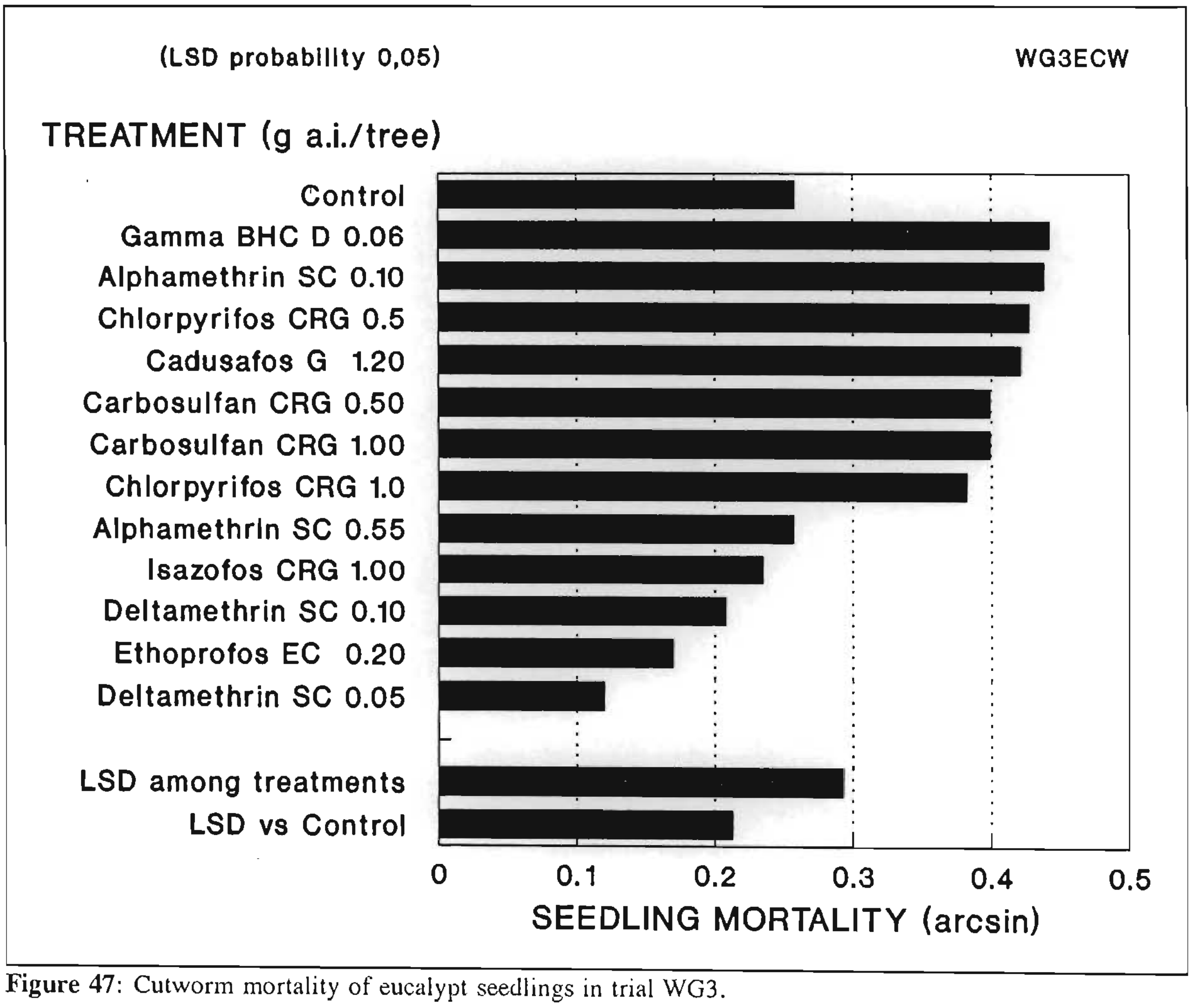


Figure 47: Cutworm mortality of eucalypt seedlings in trial WG3.

In trial WG4 (*Figure 48*), with a cutworm infestation of 1,13%, no treatments showed significantly less mortality than the control. Cadusafos 10% G at 1,2 g a.i./tree showed significantly more mortality than the control. Deltamethrin 5% SC at 0,1 g a.i./tree, alphamethrin 10% SC at 0,1 g a.i./tree and gamma BHC 0,6% D at 0,06 g a.i./tree showed significantly less mortality than cadusafos 10% G at 1,2 g a.i./tree.

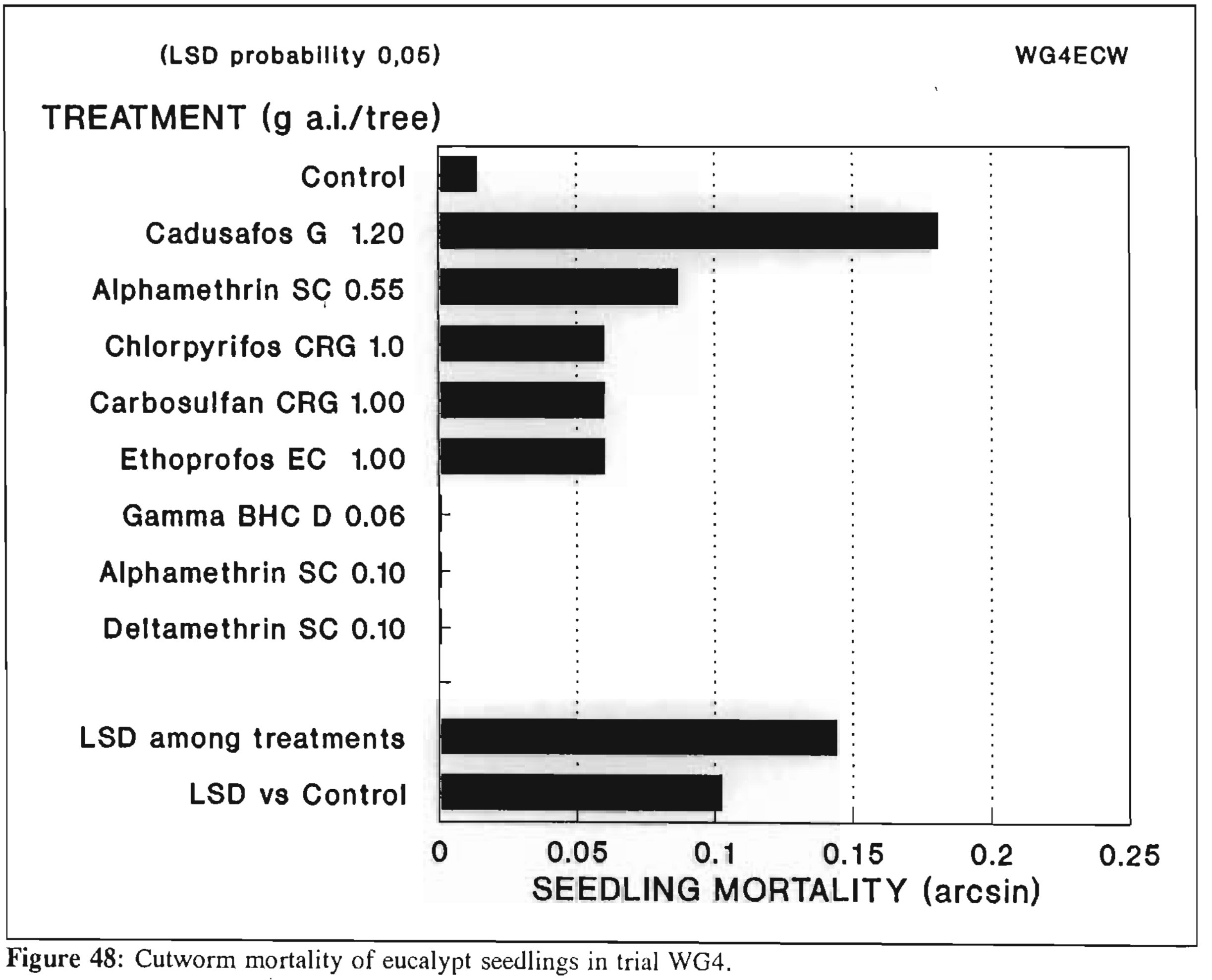


Figure 48: Cutworm mortality of eucalypt seedlings in trial WG4.

In trial WG5 (*Figure 49*), with a low cutworm infestation of 0,47%, no treatments showed significantly less or more mortality than the control. There were no significant differences between treatments.

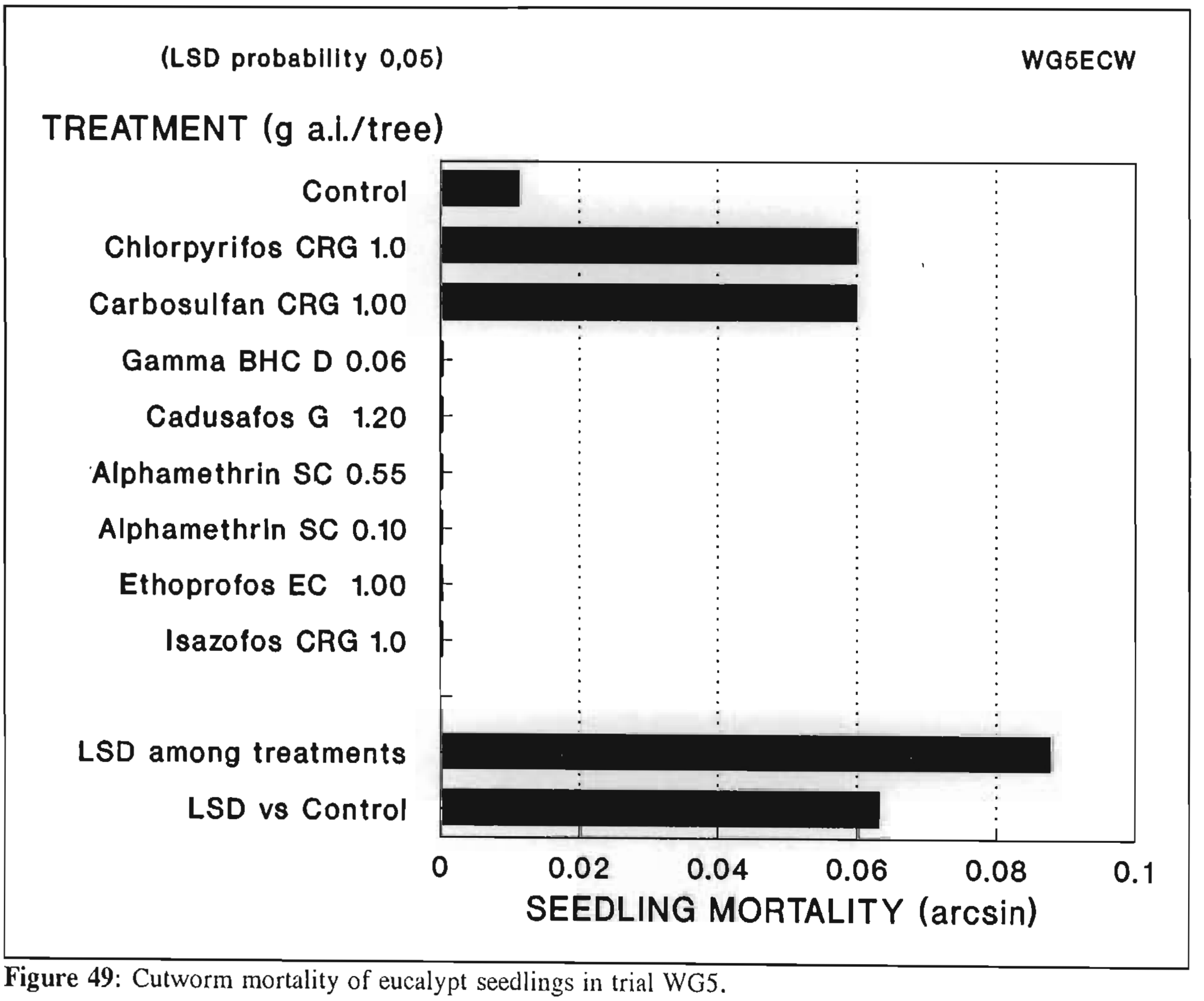


Figure 49: Cutworm mortality of eucalypt seedlings in trial WG5.

In trial WG6 (*Figure 50*), with a cutworm infestation of 3,59%, no treatments showed significantly less or more mortality than the control. There were no significant differences between treatments.

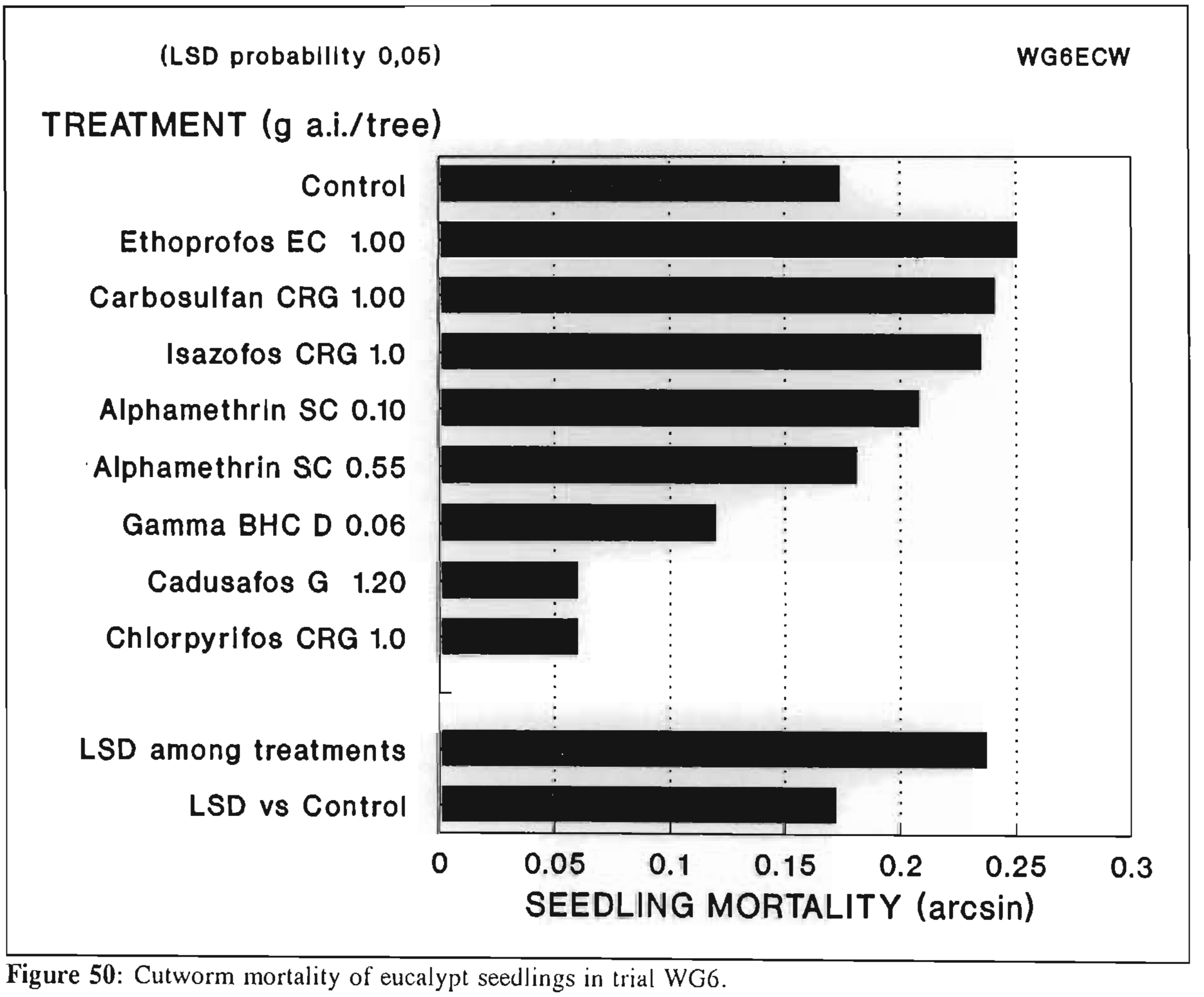


Figure 50: Cutworm mortality of eucalypt seedlings in trial WG6.

6.2.1.3.3 TOTAL MORTALITY

The successful insecticidal treatments for whitegrubs and cutworms have been identified above. These results differed markedly from those obtained when analysing treatment effects for total mortality because of the numerous mortality factors involved. Therefore in this section only those treatments that showed significantly more mortality than the control and were possibly phytotoxic, are discussed.

Acacia mearnsii

In trial WG1 (***Figure 51***), no treatments showed significantly less or more mortality than the control. There were no significant differences between treatments.

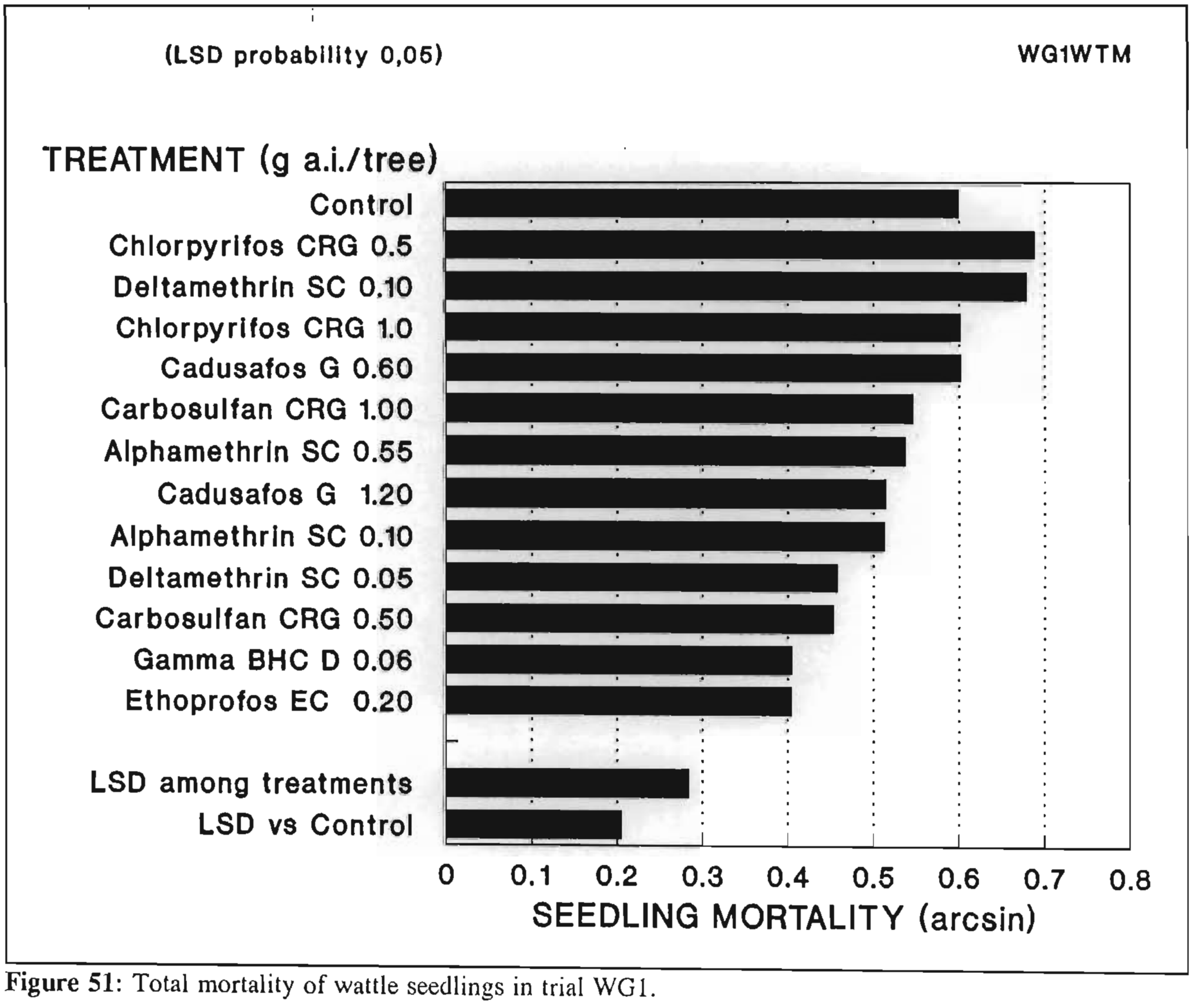


Figure 51: Total mortality of wattle seedlings in trial WG1.

In trial WG2 (*Figure 52*), no treatments showed significantly less or more mortality than the control. There were significant differences between treatments.

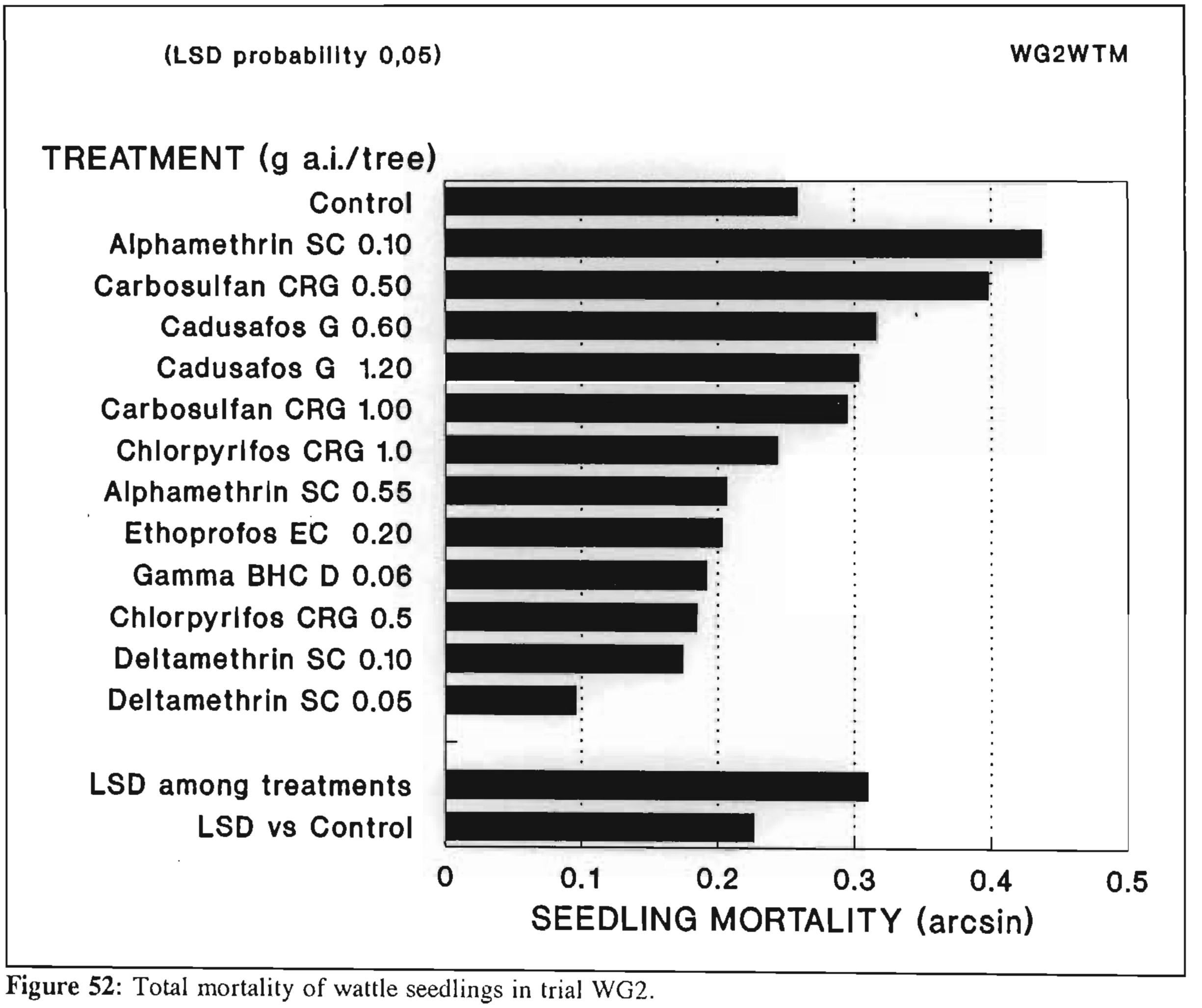


Figure 52: Total mortality of wattle seedlings in trial WG2.

In trial WG3 (***Figure 53***), alphamethrin 10% SC at 0,1 g a.i./tree showed significantly more mortality than the control and all other treatments. There were also other significant differences between treatments.

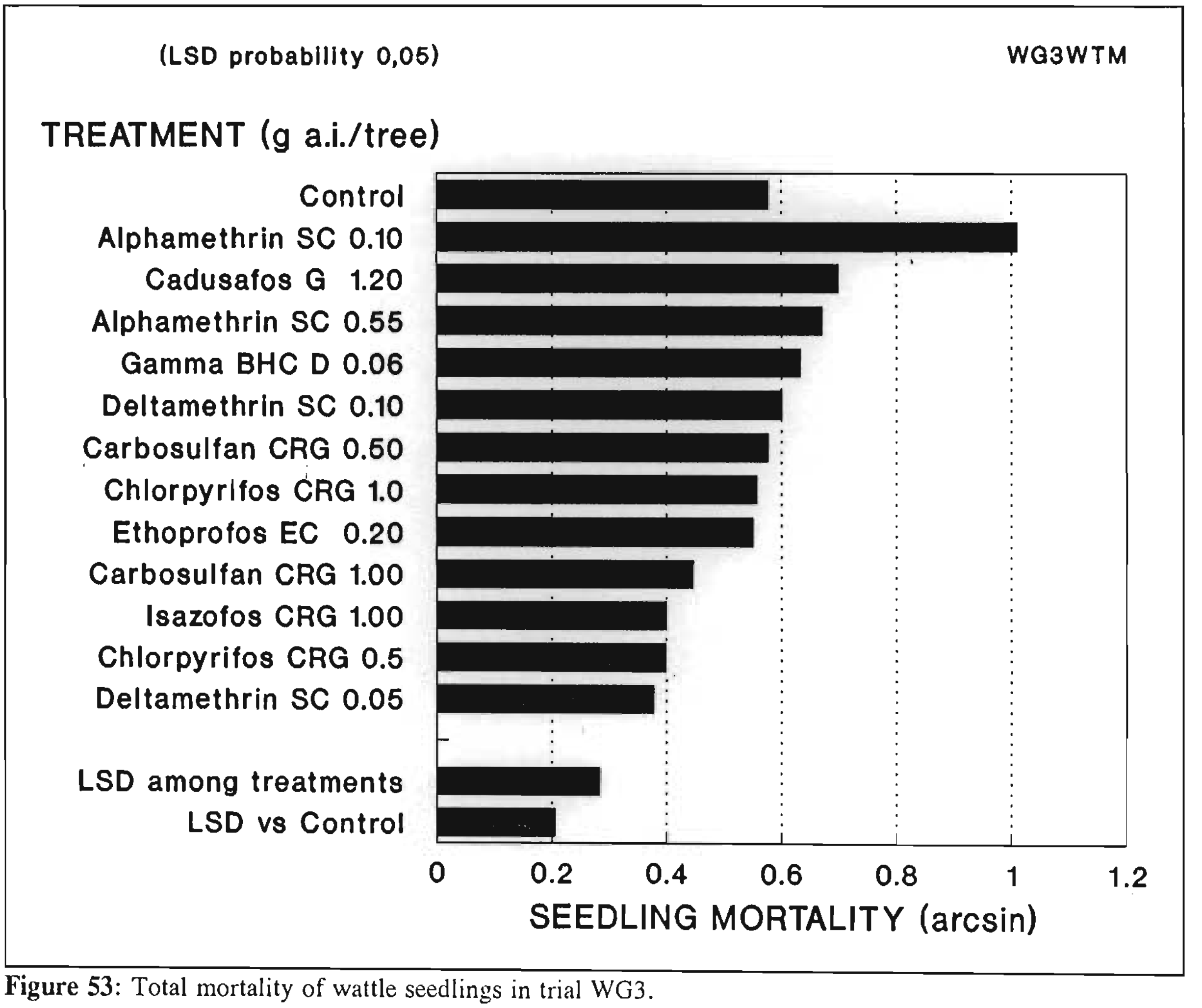


Figure 53: Total mortality of wattle seedlings in trial WG3.

In trial WG4 (***Figure 54***), no treatments showed significantly more mortality than the control. However, ethoprofos 20% EC at 1,0 g a.i./tree (applied in error at five times the previous rate of 0,2 g a.i./tree in trials WG1, WG2 and WG3), showed significantly more mortality than the best treatment chlorpyrifos 10% CRG at 1,0 g a.i./tree (this chlorpyrifos treatment also showed significantly less mortality than the control).

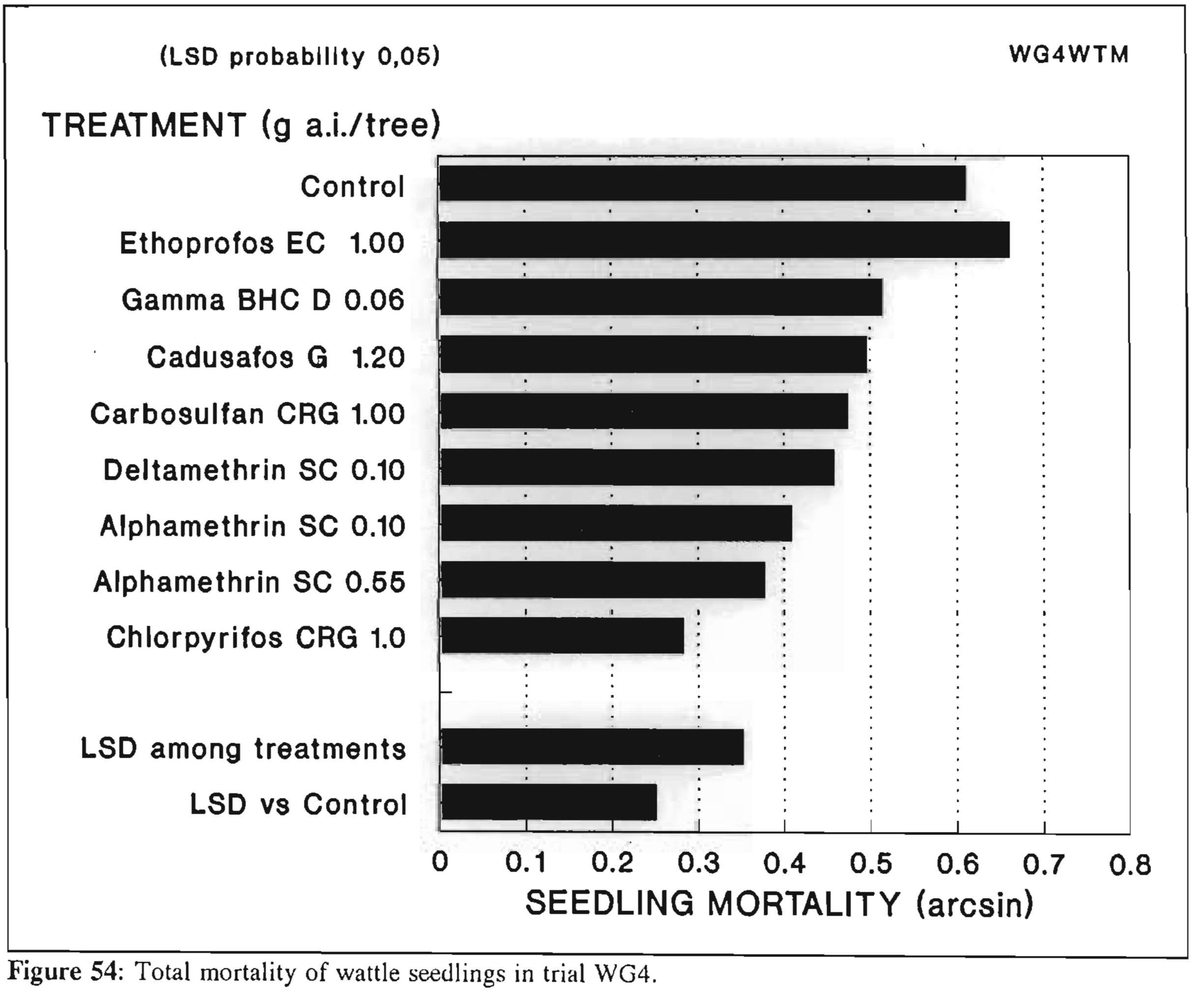


Figure 54: Total mortality of wattle seedlings in trial WG4.

In trial WG5 (***Figure 55***), ethoprofos 20% EC at 1,0 g a.i./tree and cadusafos 10% G at 1,2 g a.i./tree showed significantly more mortality than the control. All other treatments also showed significantly less mortality than ethoprofos 20% EC at 1,0 g a.i./tree.

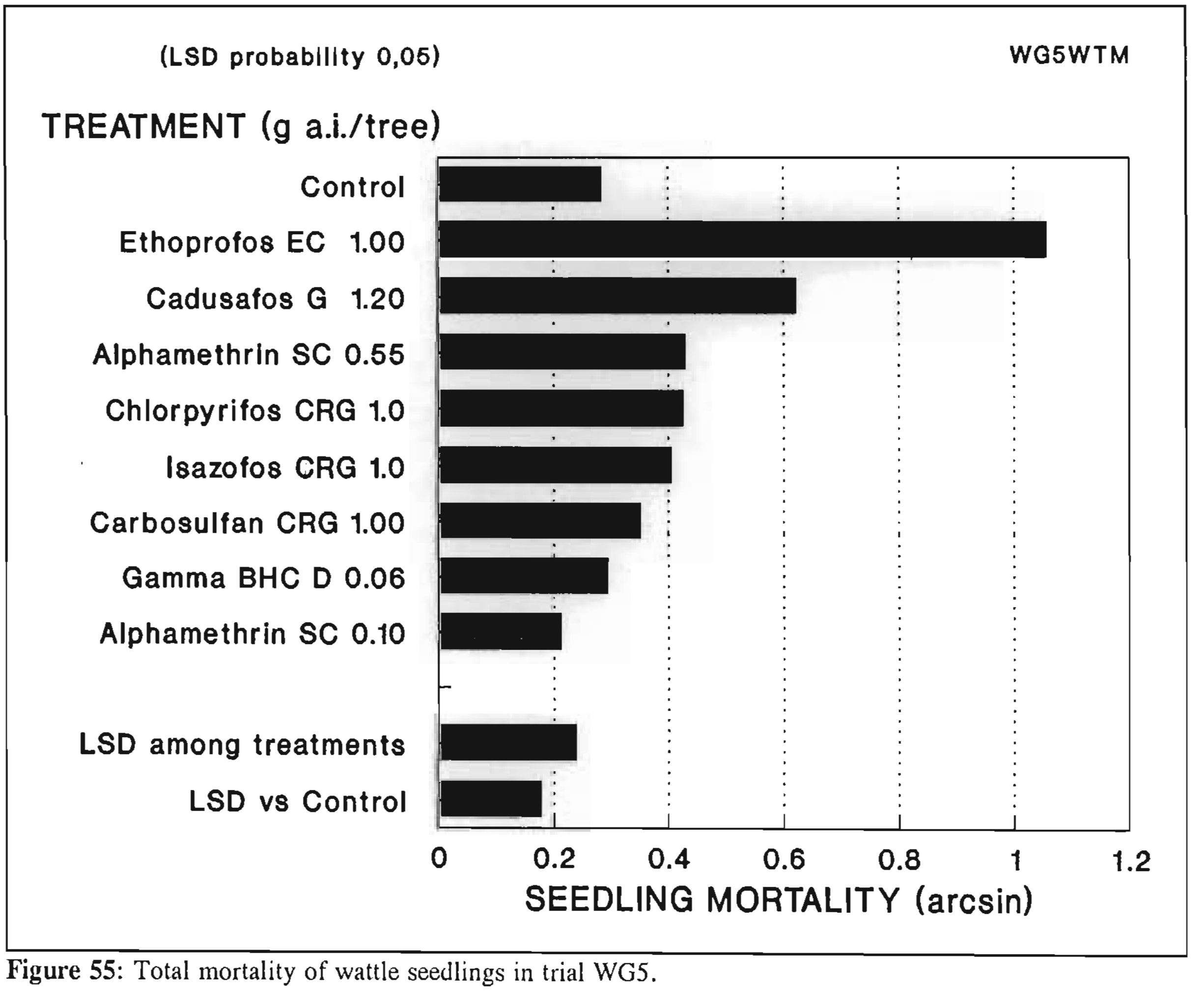


Figure 55: Total mortality of wattle seedlings in trial WG5.

In trial WG6 (***Figure 56***), ethoprofos 20% EC at 1,0 g a.i./tree showed significantly more mortality than the control and all other treatments except gamma BHC 0,6% D at 0,06 g a.i./tree.

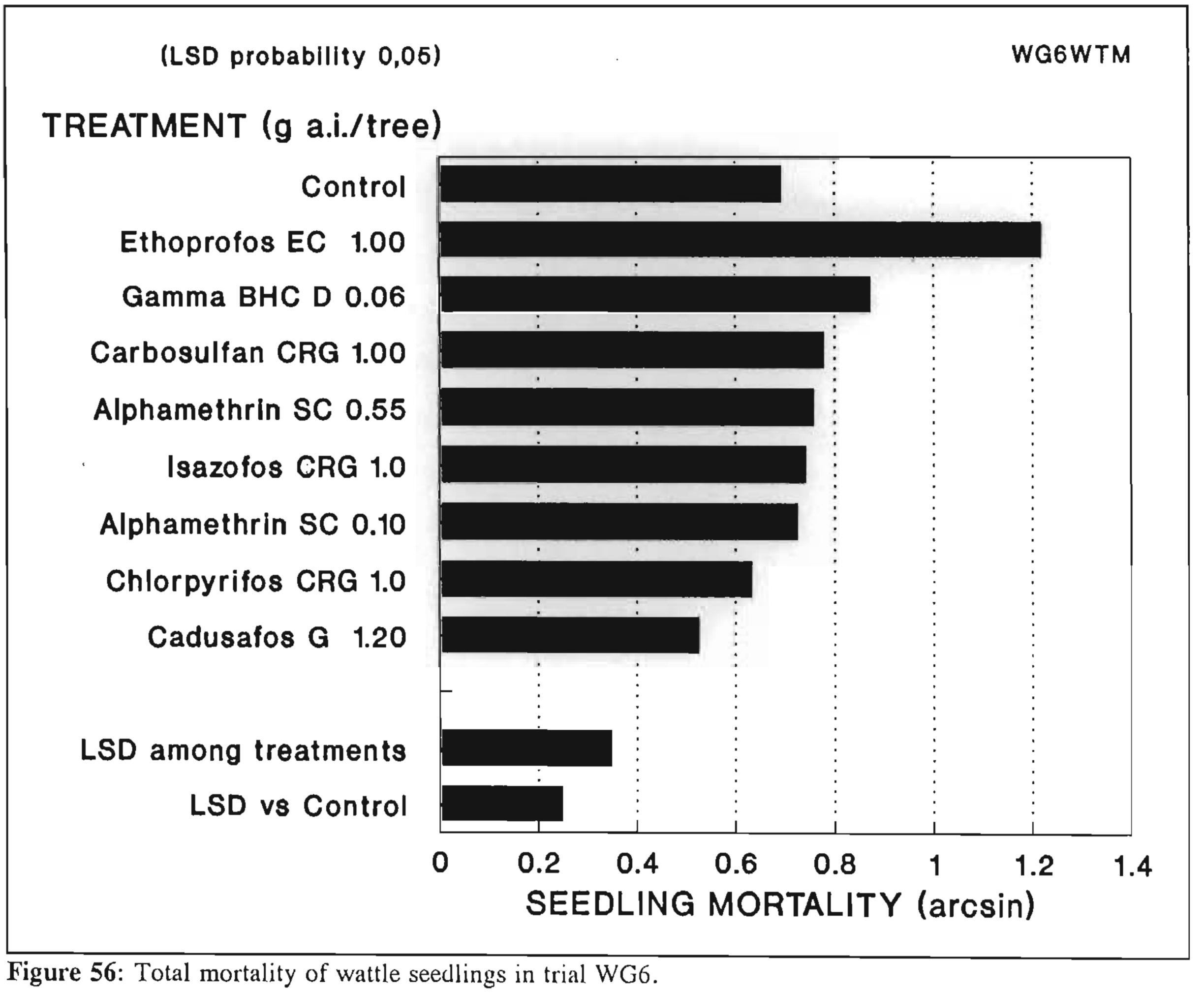


Figure 56: Total mortality of wattle seedlings in trial WG6.

Eucalyptus grandis

In trial WG1 (*Figure 57*), cadusafos 10% G at 1,2 g a.i./tree showed significantly more mortality than the control. Some treatments showed significantly less mortality than the control and there were significant differences between treatments.

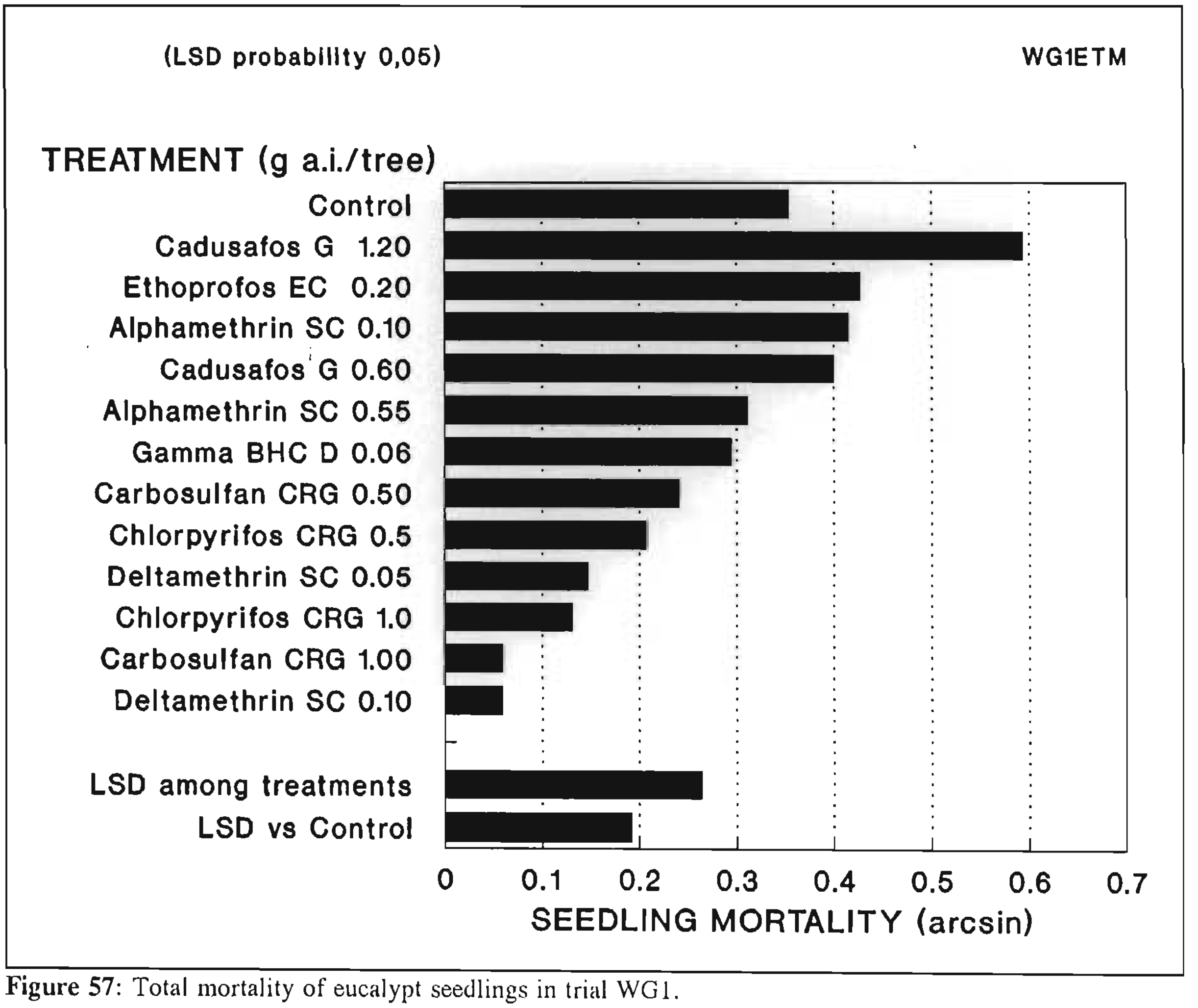


Figure 57: Total mortality of eucalypt seedlings in trial WG1.

In trial WG2 (*Figure 58*), no treatments showed significantly less or more mortality than the control. There were significant differences between treatments.

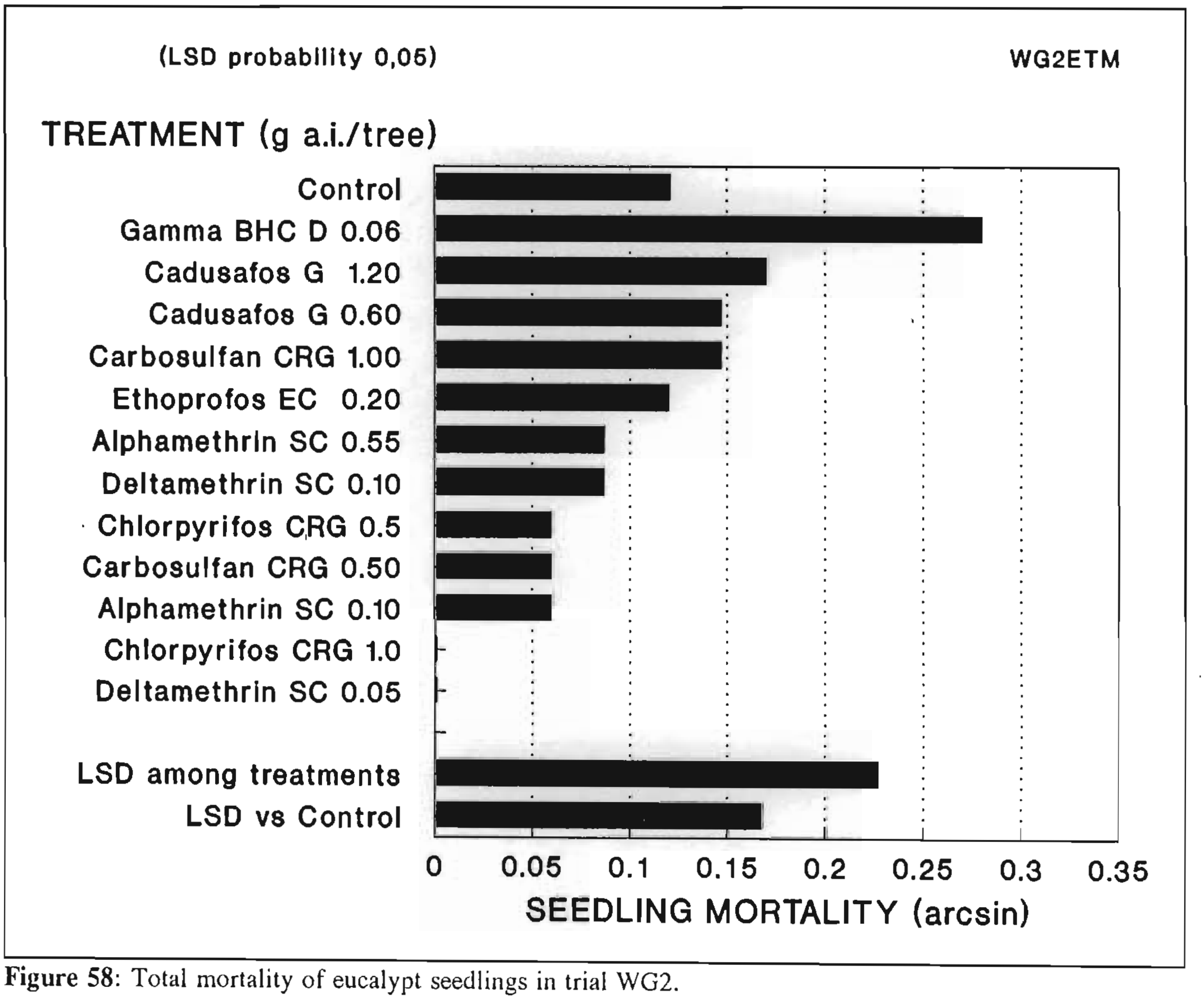


Figure 58: Total mortality of eucalypt seedlings in trial WG2.

In trial WG3 (*Figure 59*), cadusafos 10% G at 1,2 g a.i./tree showed significantly more mortality than the control and all other treatments. There were also other significant differences between treatments.

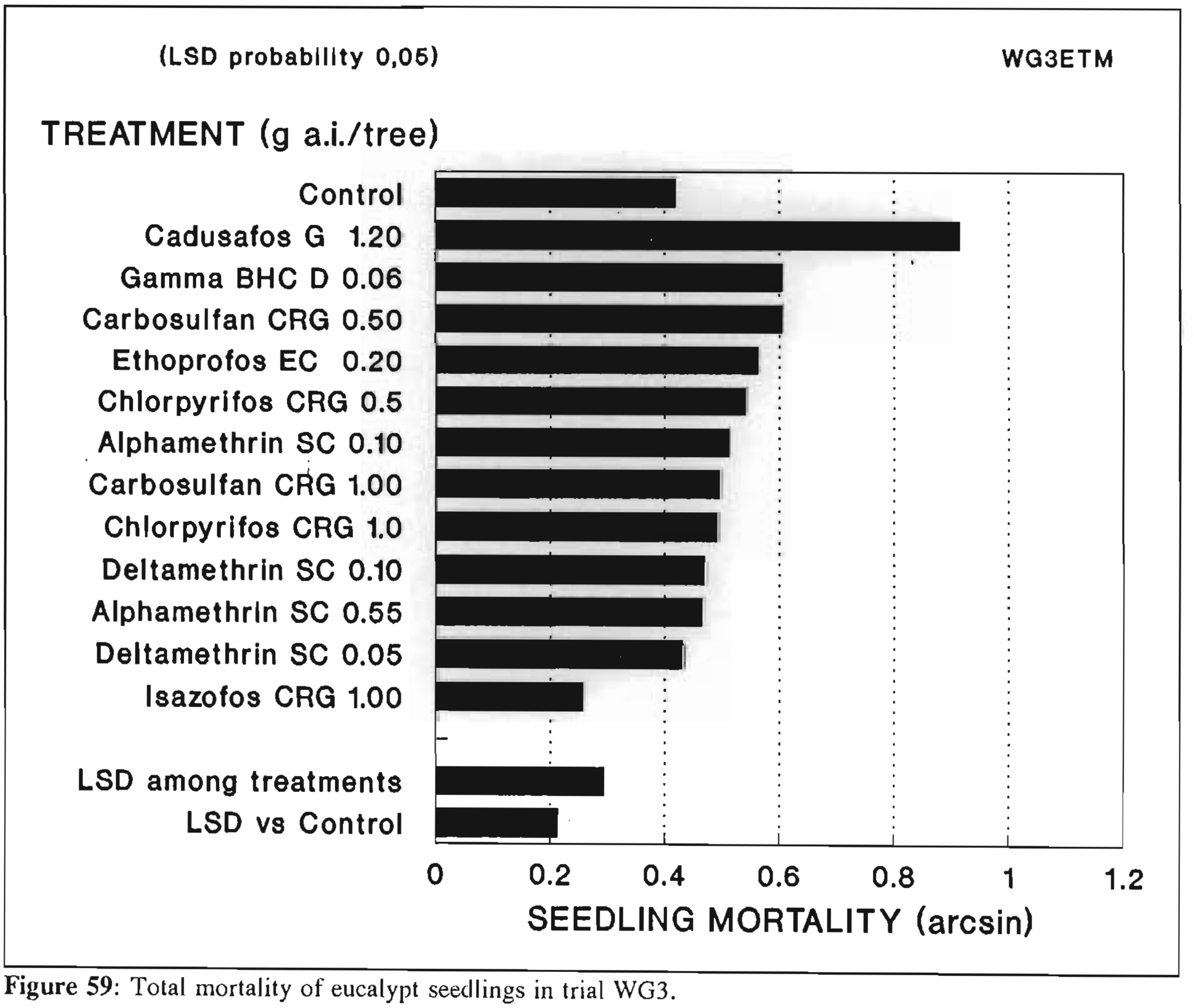


Figure 59: Total mortality of eucalypt seedlings in trial WG3.

In trial WG4 (***Figure 60***), no treatments showed significantly more mortality than the control. However, ethoprofos 20% EC at 1,0 g a.i./tree and cadusafos 10% G at 1,2 g a.i./tree showed significantly more mortality than all other treatments.

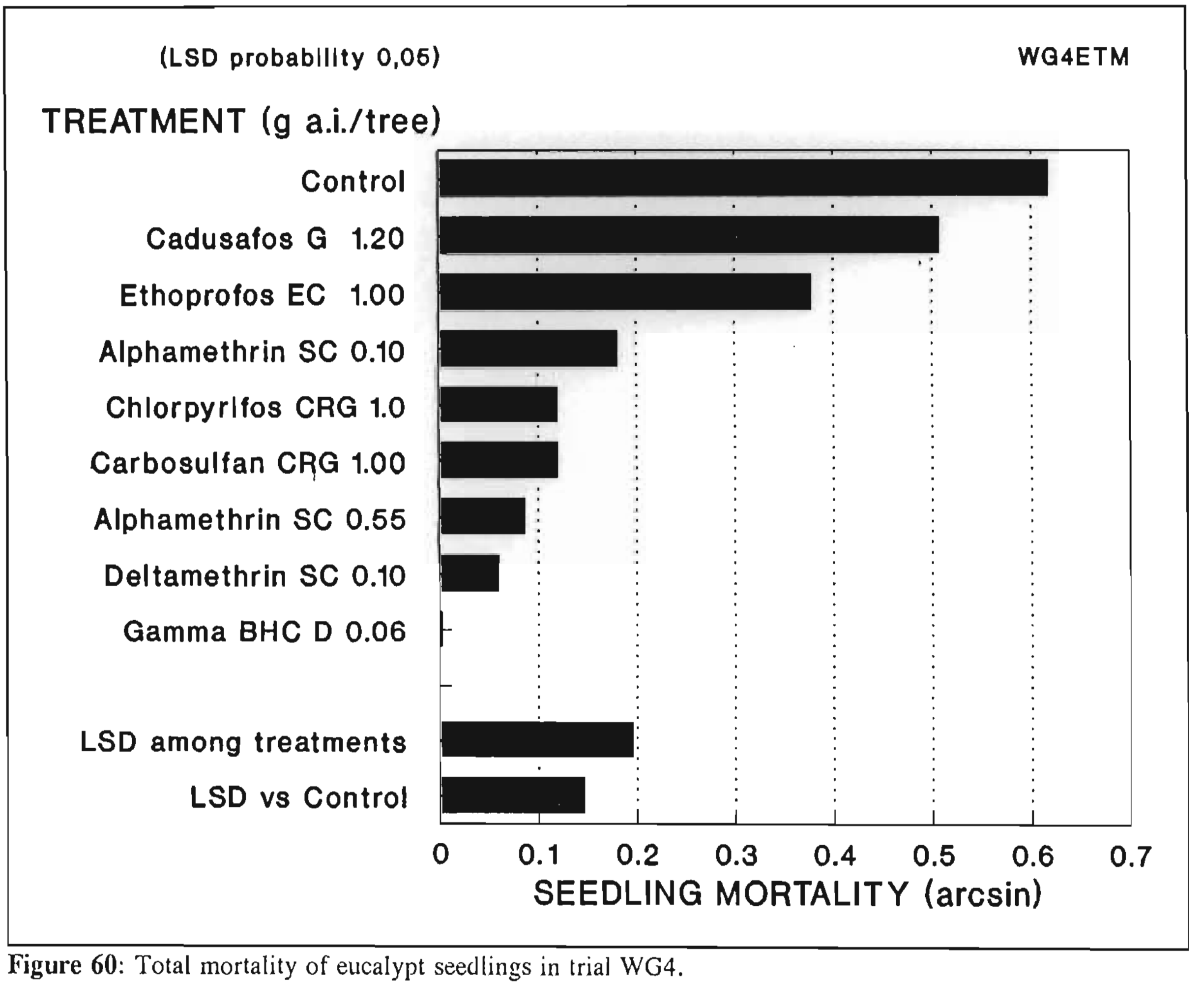


Figure 60: Total mortality of eucalypt seedlings in trial WG4.

In trial WG5 (***Figure 61***), isazofos 10% CRG at 1,0 g a.i./tree, ethoprofos 20% EC at 1,0 g a.i./tree and cadusafos 10% G at 1,2 g a.i./tree showed significantly more mortality than the control. There were also significant differences between treatments.

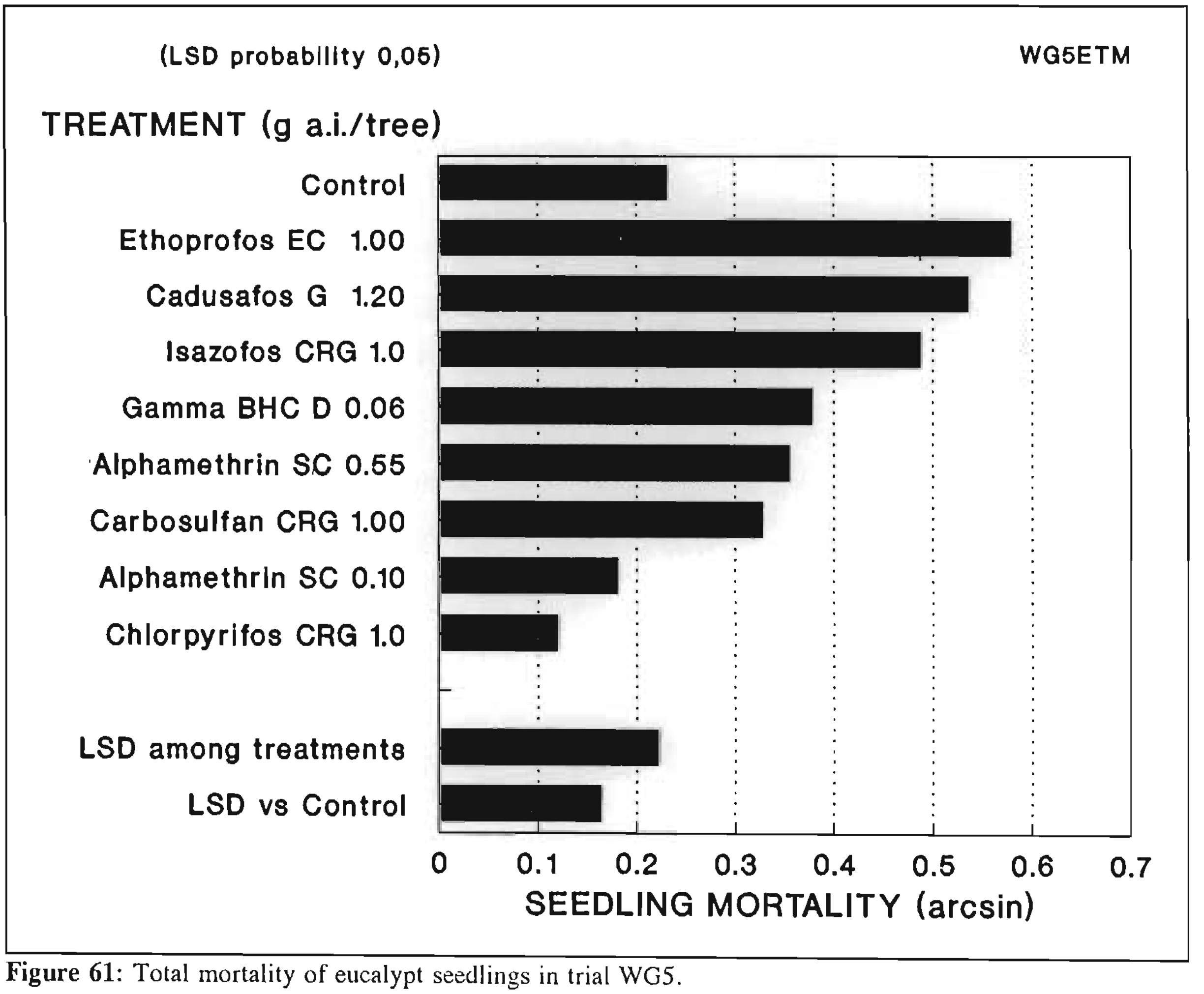


Figure 61: Total mortality of eucalypt seedlings in trial WG5.

In trial WG6 (*Figure 62*), ethoprofos 20% EC at 1,0 g a.i./tree showed significantly more mortality than the control and all other treatments.

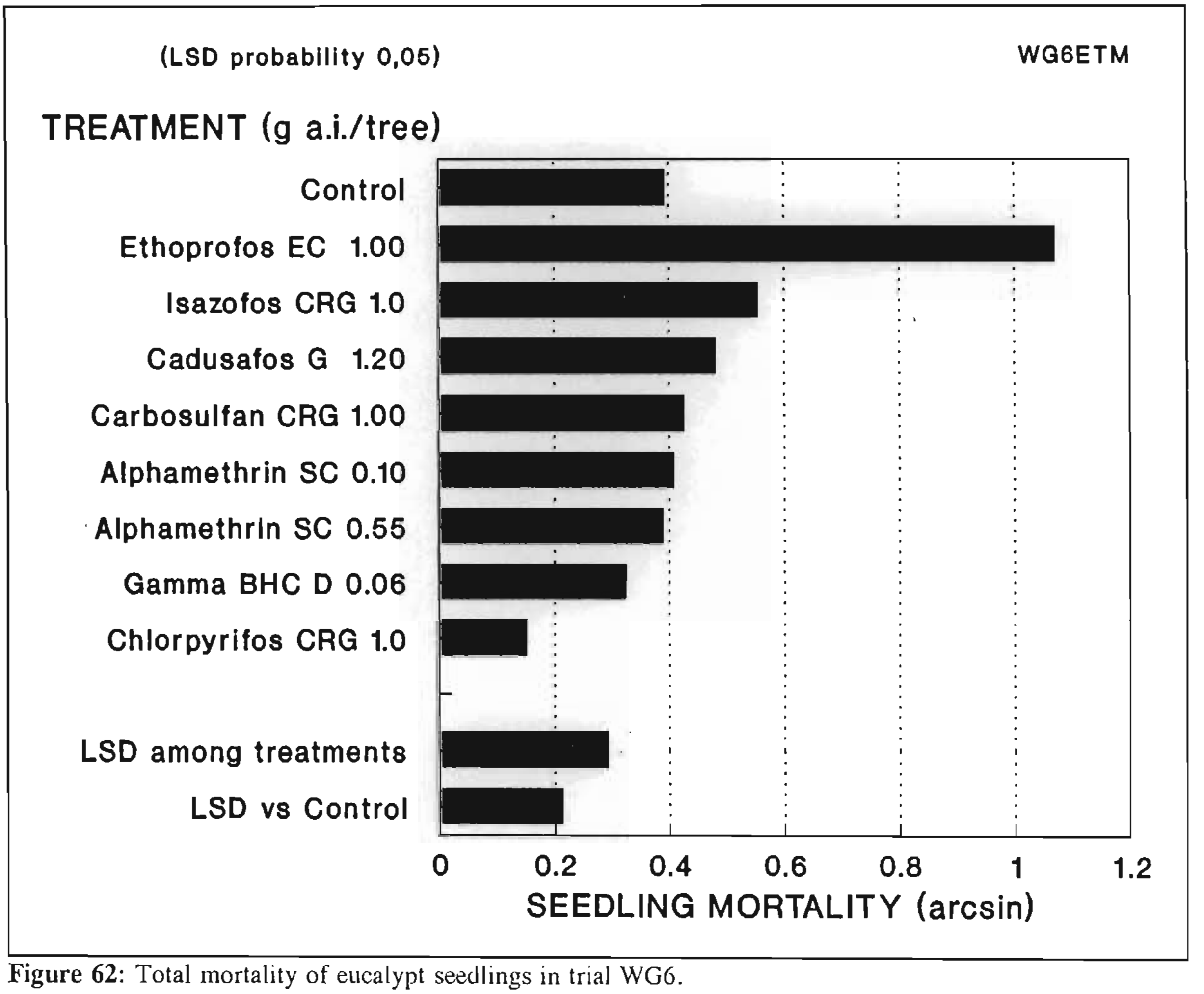


Figure 62: Total mortality of eucalypt seedlings in trial WG6.

6.2.1.3.4 DISCUSSION

The controlled release granule formulations of carbosulfan and chlorpyrifos successfully controlled whitegrubs in both wattle and eucalypt seedlings. Carbosulfan at the higher rate of application (1,0 g a.i./tree) was consistently effective against whitegrub infestations that were higher than 4,76%. Carbosulfan 10% CRG at 1,0 g a.i./tree is already registered for use against termites in forestry (Department of Agriculture, 1993). Chlorpyrifos was effective at both rates of application. Isazofos showed promise for the control of whitegrubs in those few trials (because of limited insecticide availability) where it was used. Cadusafos granules at the higher rate of application (1,2 g a.i./tree) were very effective against whitegrubs but were phytotoxic to both wattle and eucalypt seedlings; eucalypts appeared to be more sensitive than wattle.

Gamma BHC 0,6% D effectively controlled whitegrubs but was inconsistent in its efficacy.

Ethoprofos 20% EC effectively controlled whitegrubs, especially at the higher rate (1,0 g a.i./tree) of application. However, ethoprofos 20% EC at this high rate was extremely phytotoxic to both wattle and eucalypts.

The synthetic pyrethroid alphamethrin 10% SC effectively controlled whitegrubs but at the unrealistically high rate of 0,55 g a.i./tree (introduced at this rate as a standard for comparison for registered cutworm control). This high rate was also not cost effective. The lower rate of application was only effective when the levels of whitegrub infestation were high.

The synthetic pyrethroid deltamethrin 5% SC at 0,05 and 0,1 g a.i./tree was moderately effective at controlling whitegrubs; even at low infestation levels.

No treatments for the control of cutworms showed significantly less mortality than the control in all six trials because of the low infestation levels. The synthetic pyrethroids often showed significantly less mortality than the controlled release granule formulations and gamma BHC 0,6% D at controlling cutworms. Deltamethrin and alphamethrin are already registered for use against cutworms affecting many crops (Department of Agriculture, 1993). Deltamethrin, because of its lower rate of application and efficacy against whitegrubs, therefore shows promise as a combined treatment against whitegrubs and cutworms at planting. To be cost effective, lower application rates needed to be tested. The persistence of deltamethrin applied early in the planting season and the protection it provides the seedling from whitegrub attack later in the season also needed to be tested.

6.2.2 1991/92 SEASON

6.2.2.1 INTRODUCTION

Trials of the second season tested the efficacy of lower rates of application of deltamethrin, selected from the first season because of the possibility that it could be used as a combined treatment for both whitegrubs and cutworms at planting. Their effect was compared to gamma BHC D which was routinely being used in the forestry industry.

6.2.2.2 MATERIALS AND METHODS

Two trials, WG7 (**Appendix 7**) and WG8 (**Appendix 8**), were planted in December 1991 and January 1992 respectively. Each trial consisted half of *Eucalyptus grandis* and half of *Acacia mearnsii*. There were five treatments *viz*. gamma BHC 0,6% dust (D) applied at 0,06 g a.i./tree, deltamethrin 5% SC applied at 0,05 g, 0,025 g, 0,013 g and 0,005 g a.i./tree. These treatments were replicated ten times for each species. Trials were surveyed once a month to assess and determine the causes of mortality. Each treatment plot consisted of 16 trees (8 treated and 8 untreated trees), and was separated from the next plot in each replicate by a guard row of untreated trees.

Liquids were applied at planting in two litres of water as a drench around the stem. Gamma BHC dust was applied around the root plug at planting, and received two litres of water. Untreated trees (controls) also received two litres of water at planting.

6.2.2.3 RESULTS

6.2.2.3.1 WHITEGRUB MORTALITY

Acacia mearnsii

In both trials WG7 (infestation of 4,93%) and WG8 (infestation of 11,84%) (***Figures 63 and 64***), all treatments showed significantly less mortality than the control. There were no significant differences between treatments. Trial WG7 and to a lesser extent trial WG8, showed a rate response to the deltamethrin 5% SC treatments.

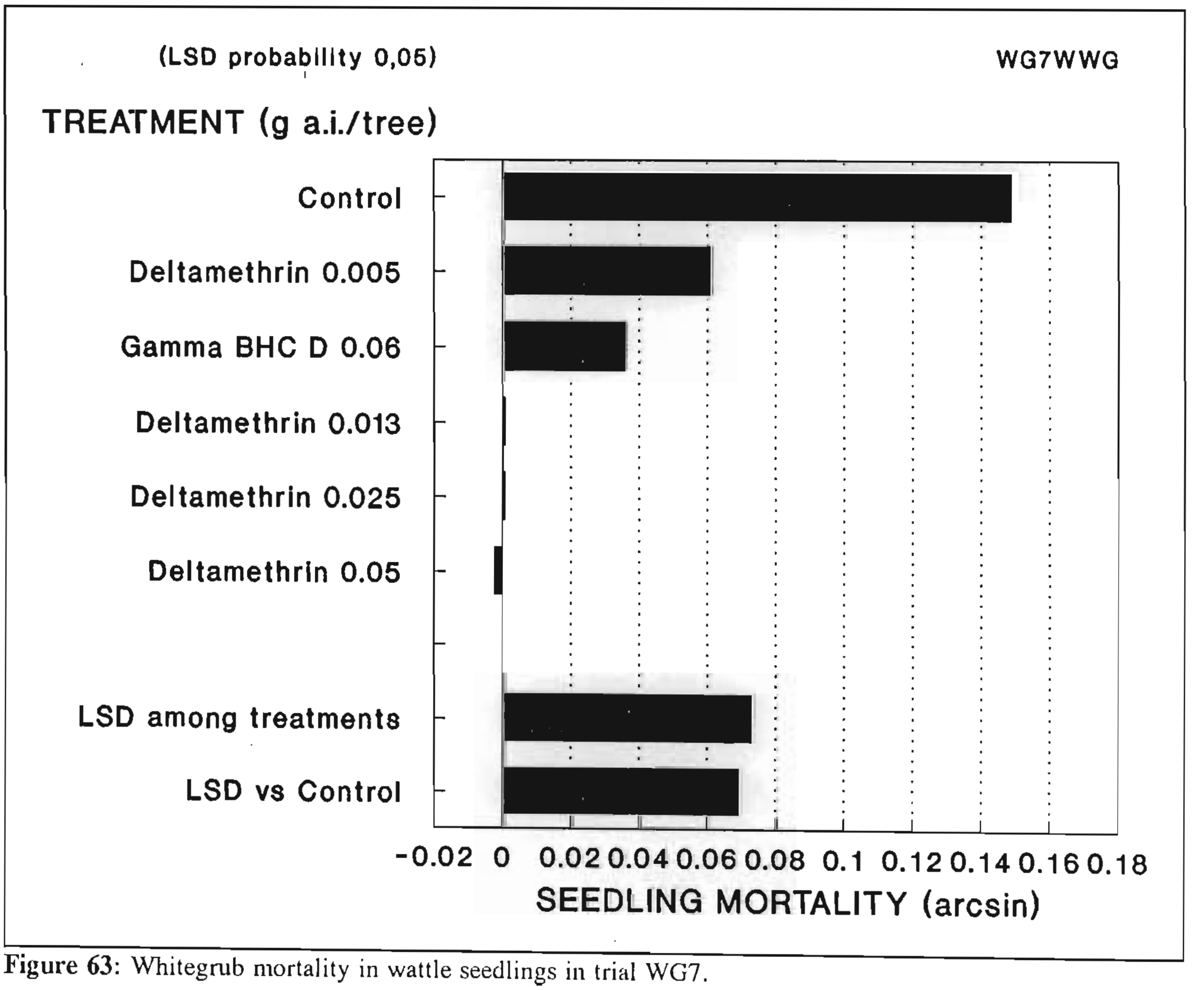


Figure 63: Whitegrub mortality in wattle seedlings in trial WG7.

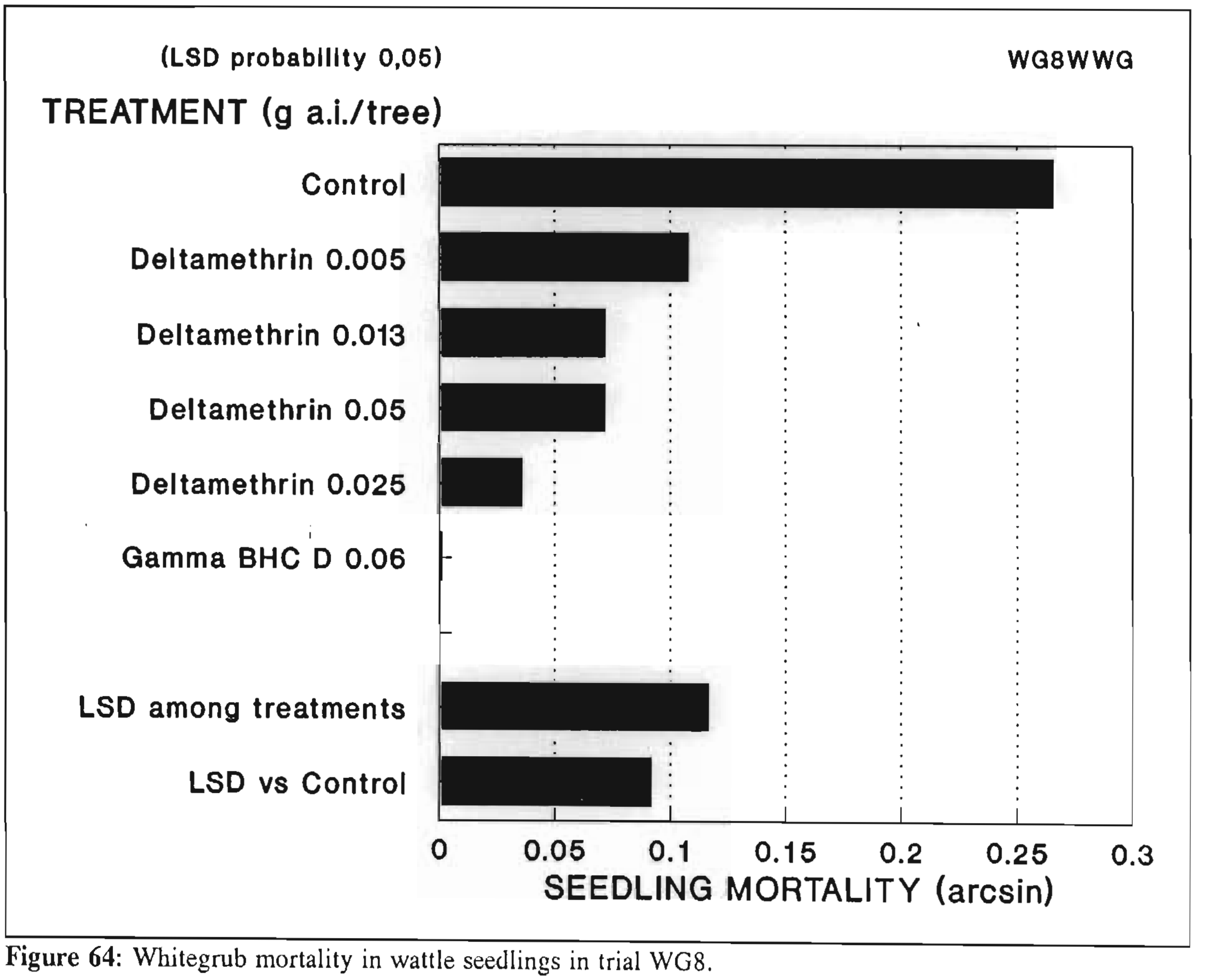


Figure 64: Whitegrub mortality in wattle seedlings in trial WG8.

Eucalyptus grandis

In trial WG7 (***Figure 65***), with a whitegrub infestation of 1,61%, gamma BHC 0,6% D, deltamethrin 5% SC at 0,05 g, 0,013 g and 0,005 g a.i./tree showed significantly less mortality than the control. There were no significant differences between treatments. The ineffectiveness of deltamethrin 5% SC at the higher rate of 0,025 g a.i./tree was probably because of the low, patchy distribution of whitegrubs in this trial.

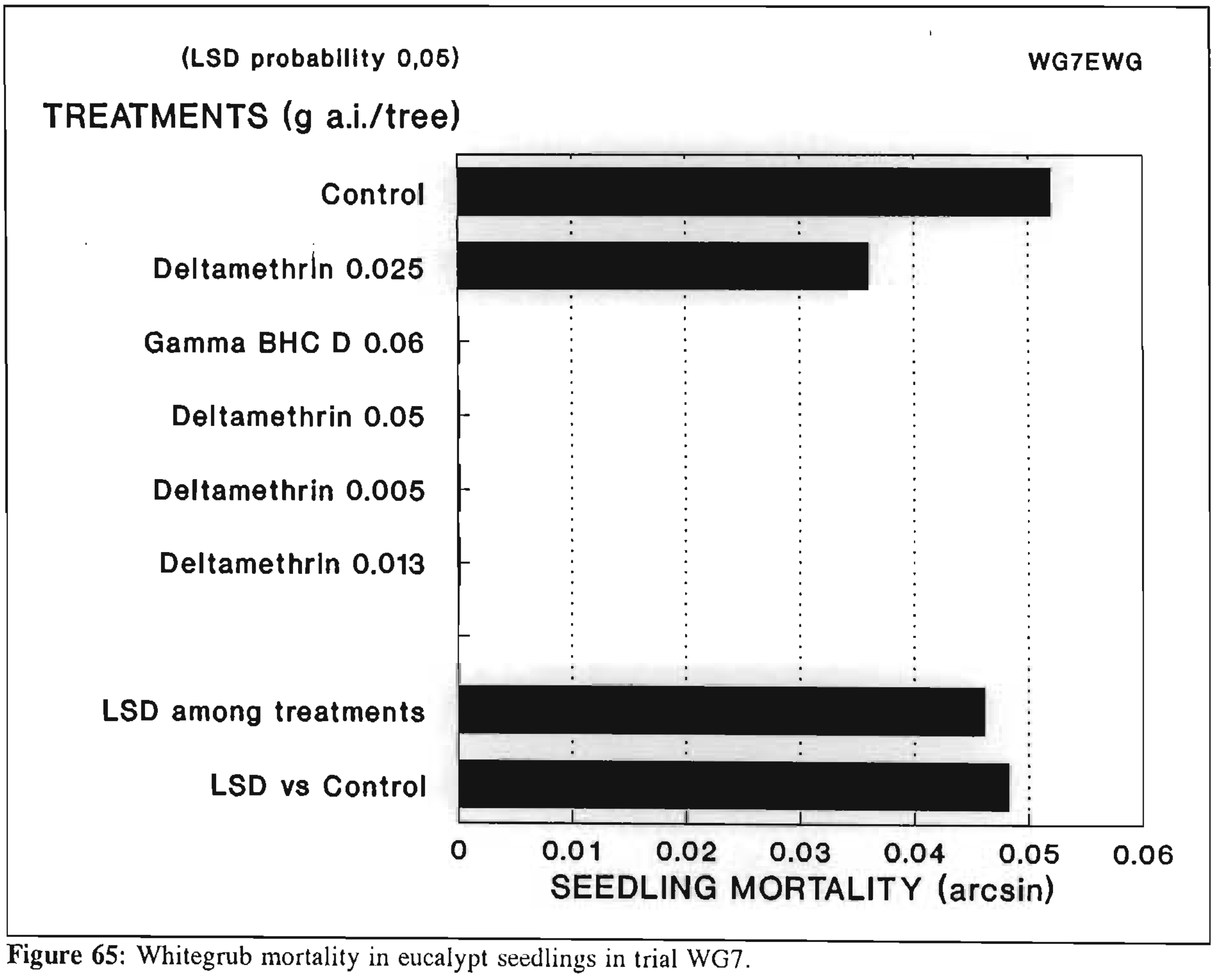


Figure 65: Whitegrub mortality in eucalypt seedlings in trial WG7.

In trial WG8 (***Figure 66***), with a whitegrub infestation of 12,1%, all treatments showed significantly less mortality than the control with the exception of deltamethrin 5% SC at its lowest rate (0,005 g a.i./tree). All treatments showed significantly less mortality than deltamethrin 5% SC at its lowest rate. There was also a rate response to deltamethrin.

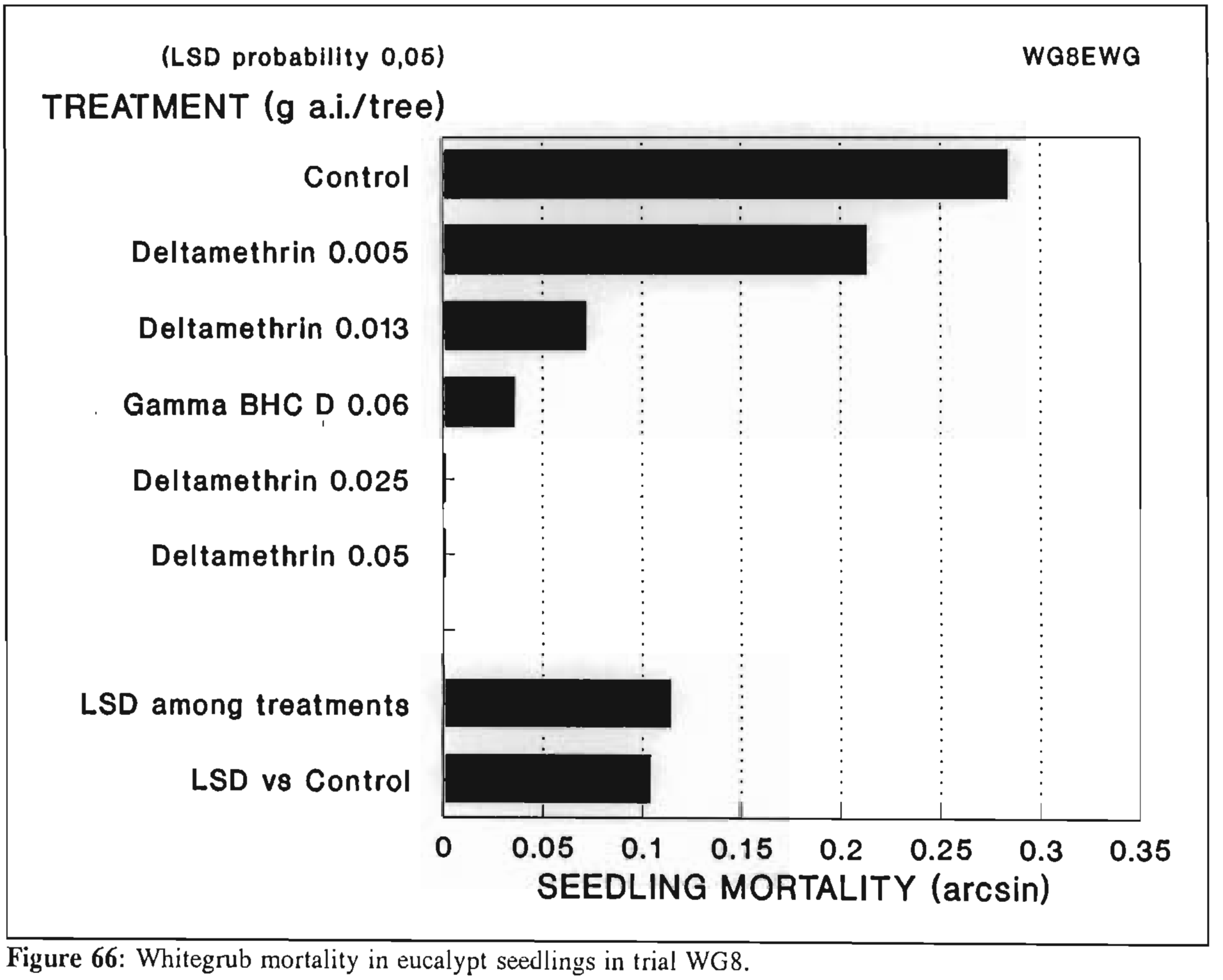


Figure 66: Whitegrub mortality in eucalypt seedlings in trial WG8.

6.2.2.3.2 CUTWORM MORTALITY

Acacia mearnsii

In trial WG7 (*Figure 67*), with a low cutworm infestation of 1,64%, no treatments showed significantly less or more mortality than the control. Despite this and the fact that there were no significant differences between treatments, there was a rate response to deltamethrin.

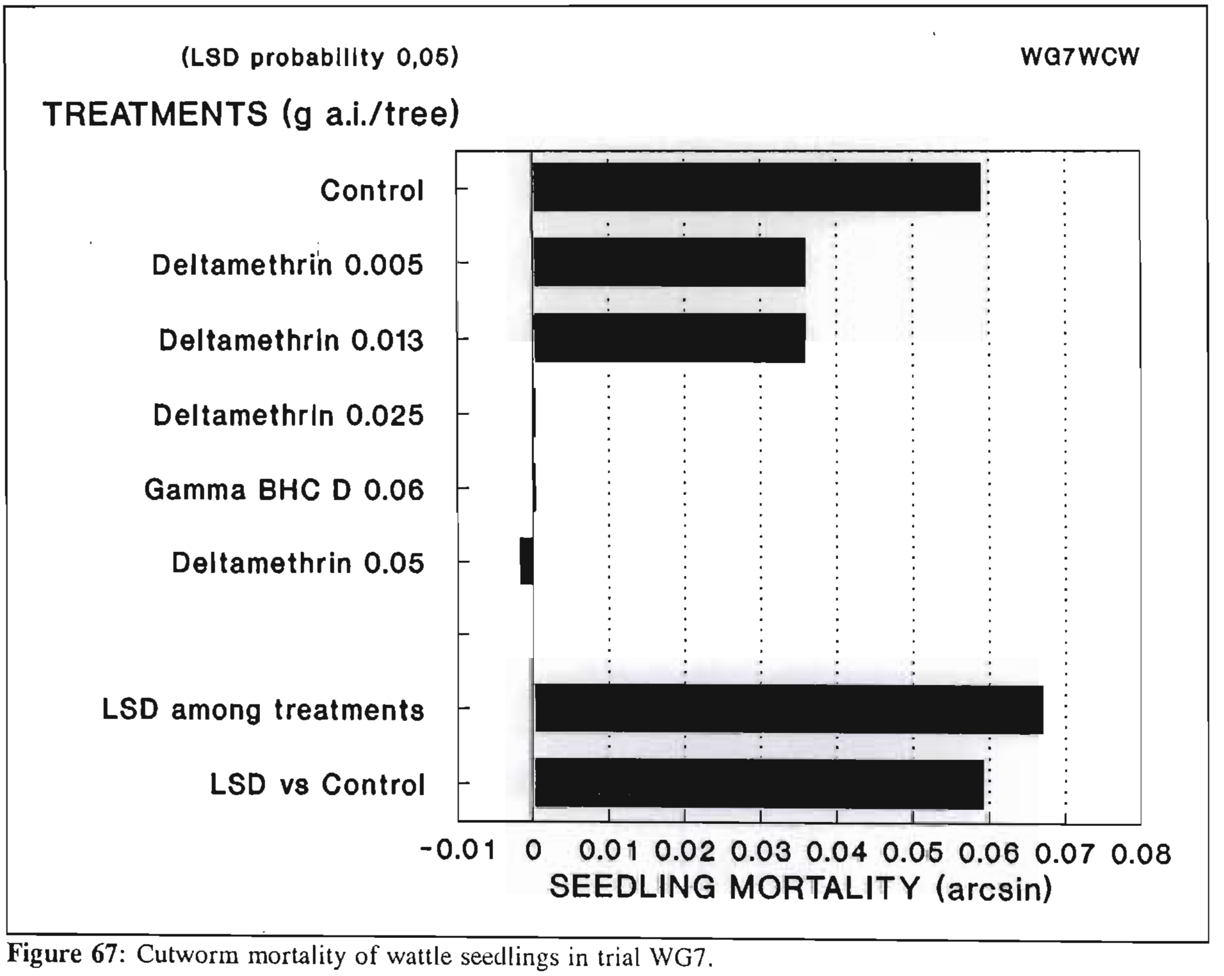


Figure 67: Cutworm mortality of wattle seedlings in trial WG7.

In trial WG8 (***Figure 68***), with a higher cutworm infestation of 3,29%, deltamethrin 5% SC at all rates of application and gamma BHC 0,6% D showed significantly less mortality than the control. There were no significant differences between treatments.

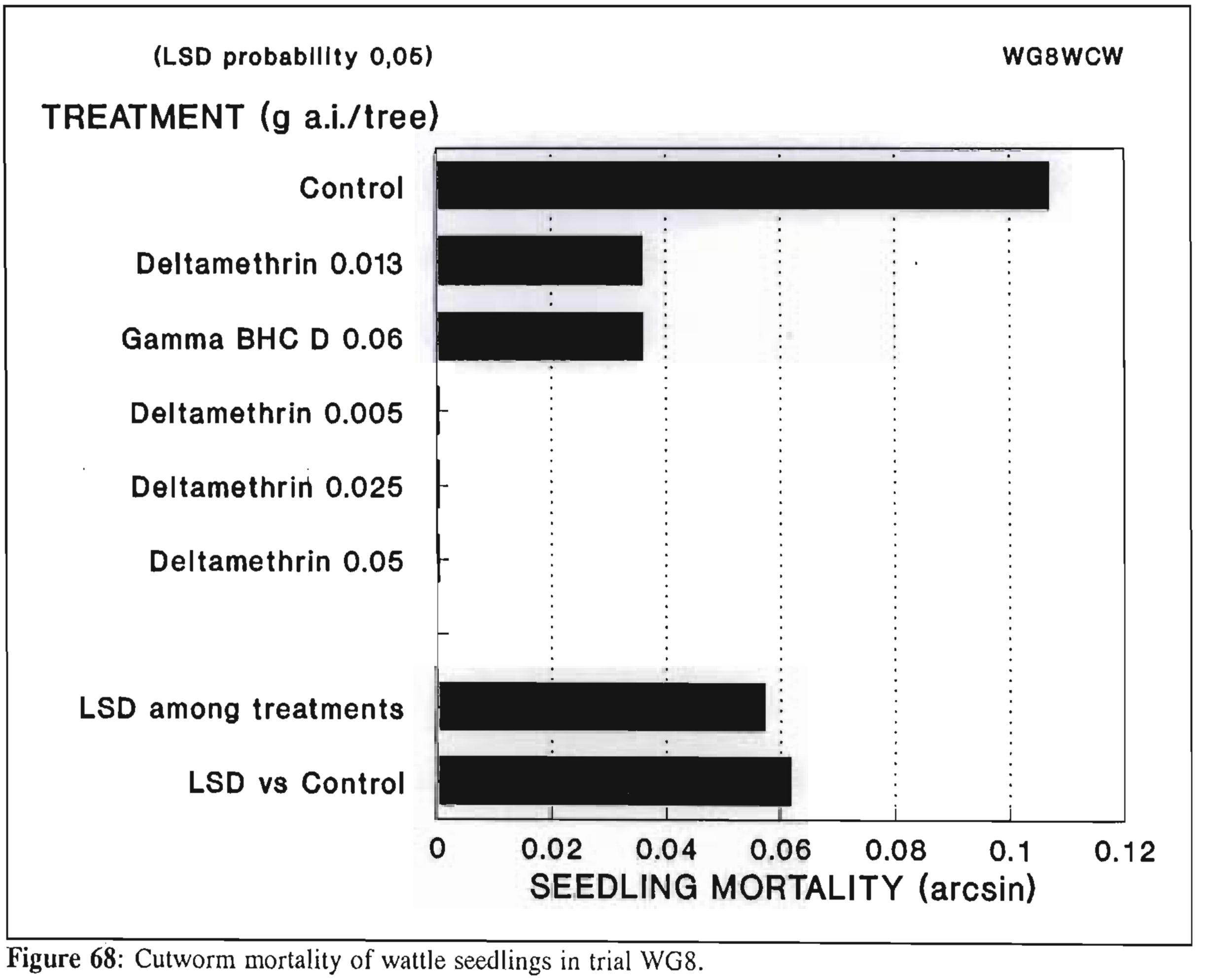


Figure 68: Cutworm mortality of wattle seedlings in trial WG8.

Eucalyptus grandis

In both trials WG7 (infestation of 4,52%) and WG8 (infestation of 1,61%) (*Figures 69 and 70*), no treatments showed significantly less mortality than the control. There were no significant differences between treatments.

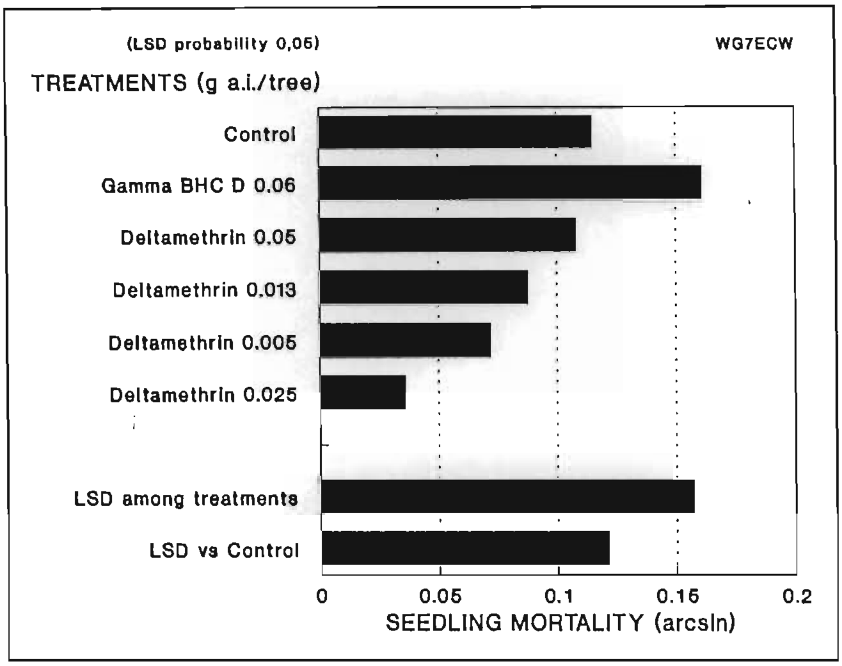


Figure 69: Cutworm mortality of eucalypt seedlings in trial WG7.

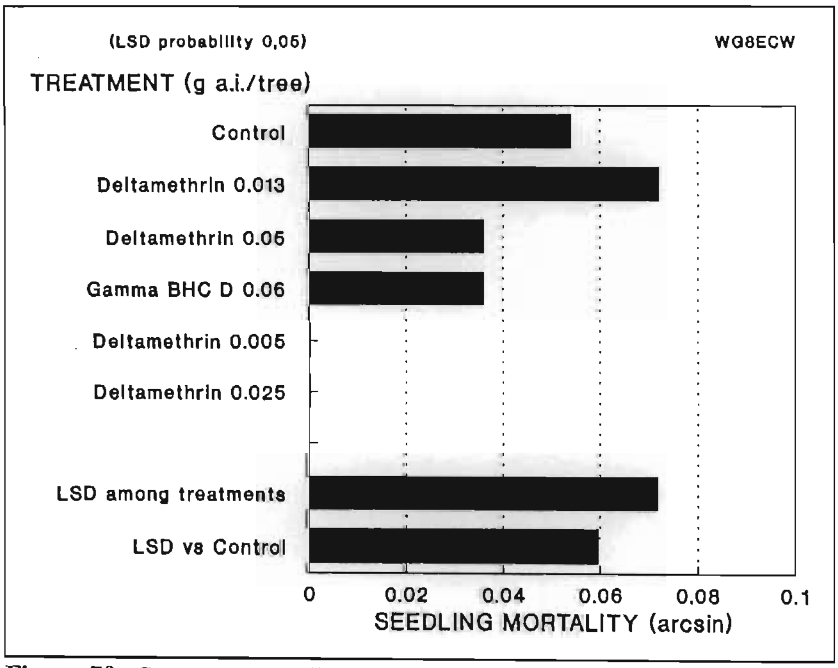


Figure 70: Cutworm mortality of eucalypt seedlings in trial WG8.

6.2.2.3.3 DISCUSSION

Deltamethrin 5% SC at all rates of application (except at its lowest rate of 0,005 g a.i,./tree) successfully controlled whitegrubs. Gamma BHC 0,6% D at 0,06 g a.i./tree was also consistently successful. Persistence of these insecticides was not tested and the rainfall during the 1991/92 season was low.

The success of deltamethrin 5% SC and gamma BHC 0,6% D at controlling cutworms in the wattles of trial WG8 was encouraging but the repeated efficacy of these treatments was lacking and needed to be tested further.

6.2.3 1992/93 SEASON

6.2.3.1 INTRODUCTION

These trials were an elaboration of the research that was conducted in the previous two seasons. The objectives of these trials were to investigate the following:

1. The degree of persistence of selected treatments when applied early in the planting season. Emphasis, in particular for whitegrub control, was placed on the persistence of, or on the continued release of, the active ingredients because trees planted early in the season needed protection from damage later in the season.
2. The effectiveness of deltamethrin 5% suspension concentrate (SC) at application rates lower than 0,05 g a.i./tree.
3. The possibility of one combined treatment for both whitegrubs and cutworms at planting.

6.2.3.2 MATERIALS AND METHODS

Two trials (WG9 [**Appendix 9**] and WG10 [**Appendix 10**]) were planted in October 1992. October is generally the earliest time that seedlings can be planted out. The degree of persistence of insecticidal treatments applied at October plantings could then be tested when pests attacked these seedlings later in the same growing season. Each trial consisted half of *Eucalyptus grandis* and half of *Acacia mearnsii*. Each treatment plot consisted of 16 trees (8 treated and 8 untreated trees). There were five treatments *viz*. gamma BHC 0,6% dust (D) applied at 0,06 g a.i./tree, carbosulfan 10% controlled release granules (CRG) applied at 1,00 g a.i./tree and deltamethrin 5% SC applied at 0,05 g, 0,025 g, 0,013 g a.i./tree. These treatments were replicated ten times for each species in a Latin square trial design; which was split into five replicates each, where the wattle block alternated with the eucalypt block. Trials were surveyed once a month to assess and determine the causes of mortality.

6.2.3.3 RESULTS

6.2.3.3.1 WHITEGRUB MORTALITY

Acacia mearnsii

In trial WG9 (***Figure 71***), with a 13,06% whitegrub infestation, carbosulfan CRG, gamma BHC and deltamethrin SC at 0,025 g a.i./tree showed significantly less mortality than the control. Carbosulfan CRG showed significantly less mortality than deltamethrin SC at 0,05 and 0,013 g a.i./tree.

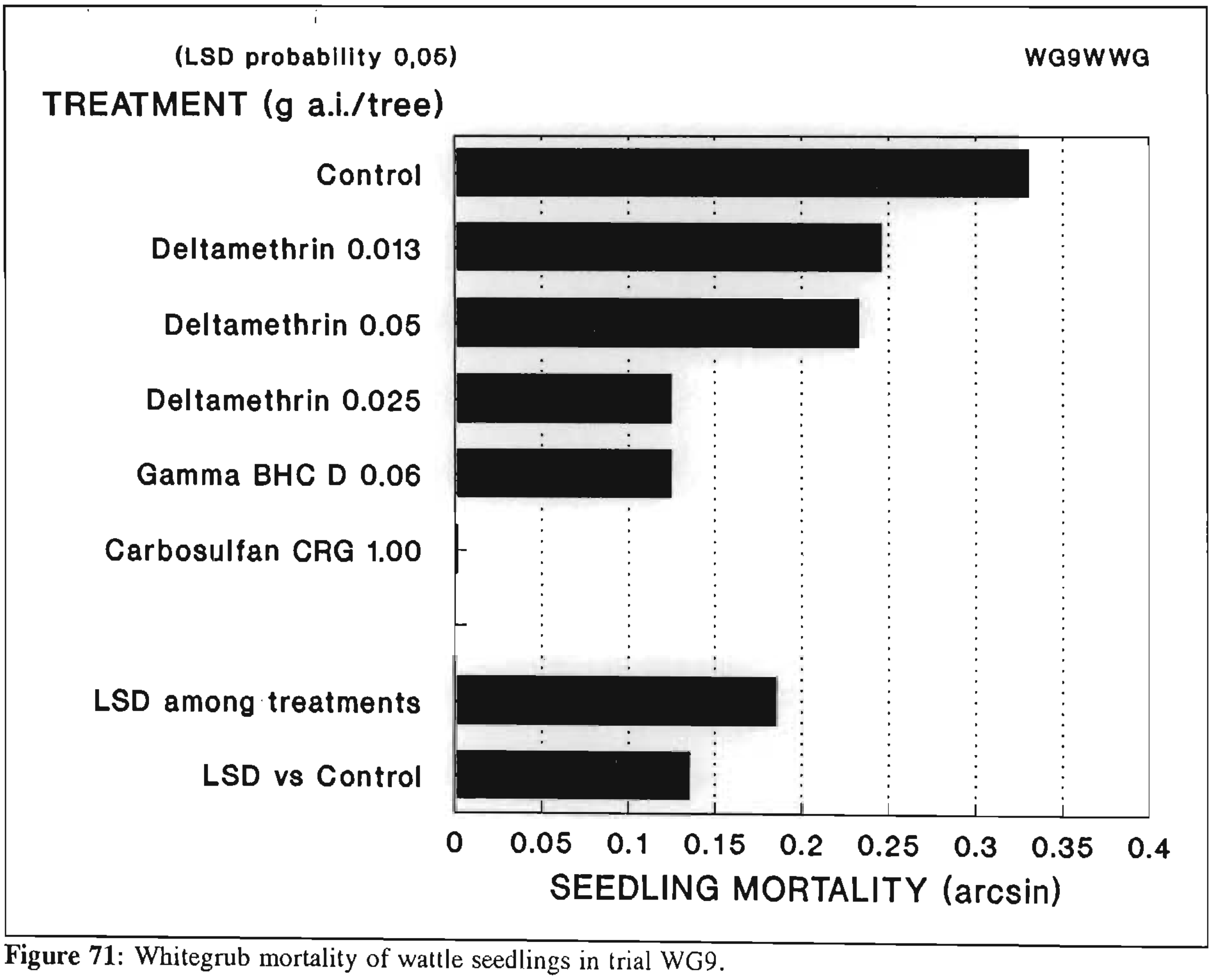


Figure 71: Whitegrub mortality of wattle seedlings in trial WG9.

In trial WG10 (*Figure 72*), no treatments showed significantly less mortality than the control because of the low incidence of whitegrub damage (2,58% infestation). There were no significant differences between treatments.

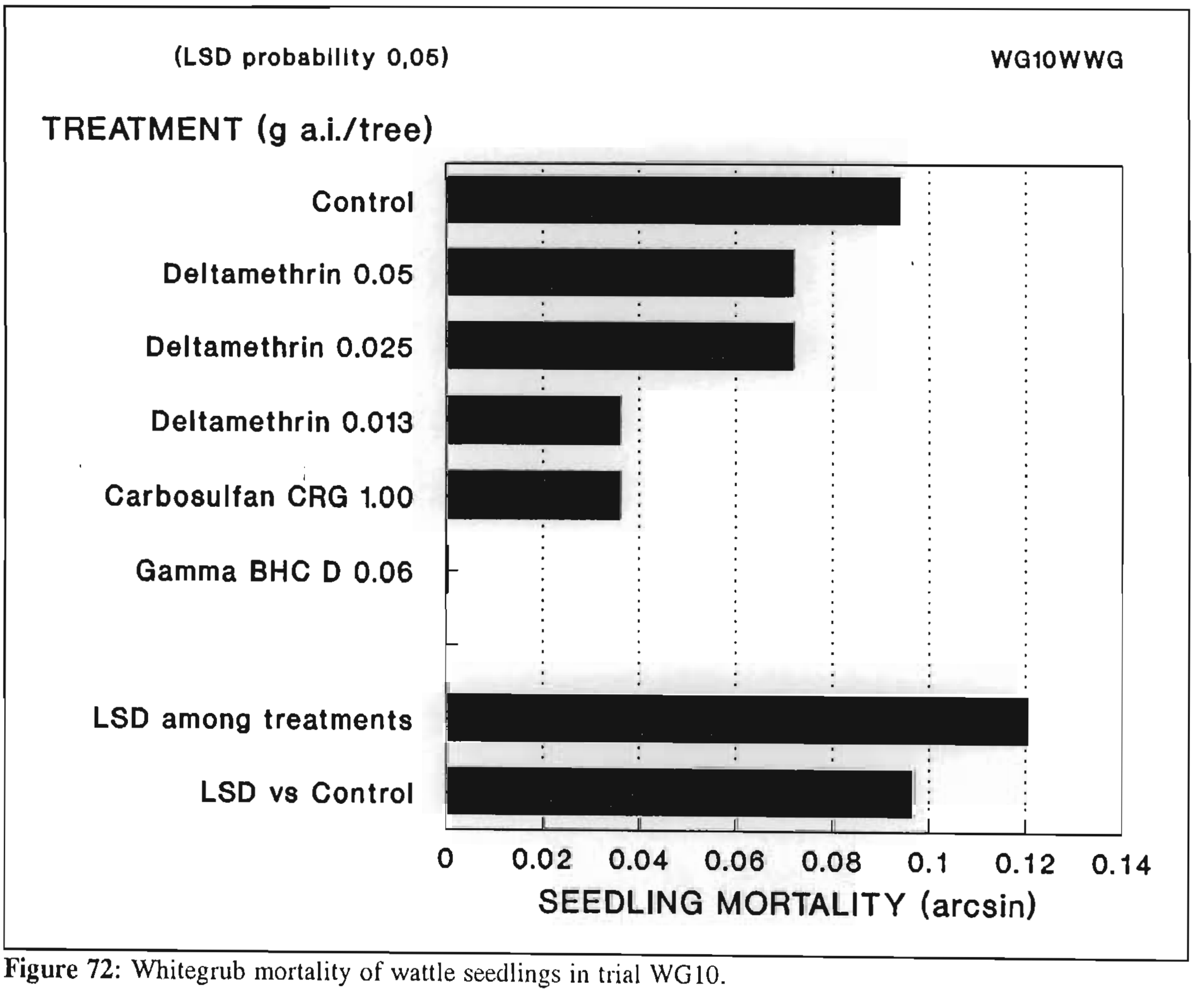


Figure 72: Whitegrub mortality of wattle seedlings in trial WG10.

Eucalyptus grandis

In trial WG9 (***Figure** 73*), all treatments showed significantly less mortality than the control. The incidence of whitegrub damage was high (20,48% of all eucalypts planted), hence the effect of the different treatments were better evaluated. There were no significant differences between treatments. In trial WG10 (***Figure** 74*), all treatments except deltamethrin SC at its lowest rate of 0,013 g a.i./tree showed significantly less mortality than the control. All treatments showed significantly less mortality than deltamethrin SC at 0,013 g a.i./tree.

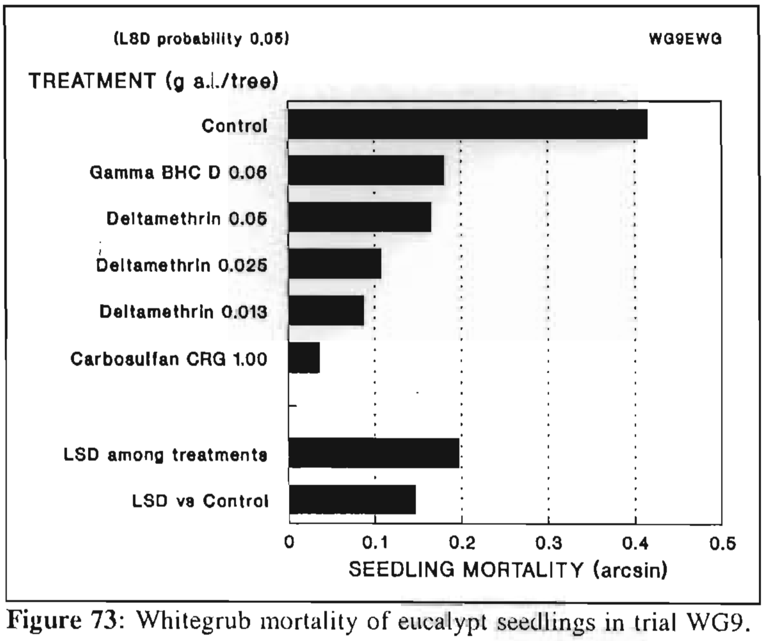


Figure 73: Whitegrub mortality of eucalypt seedlings in trial WG9.

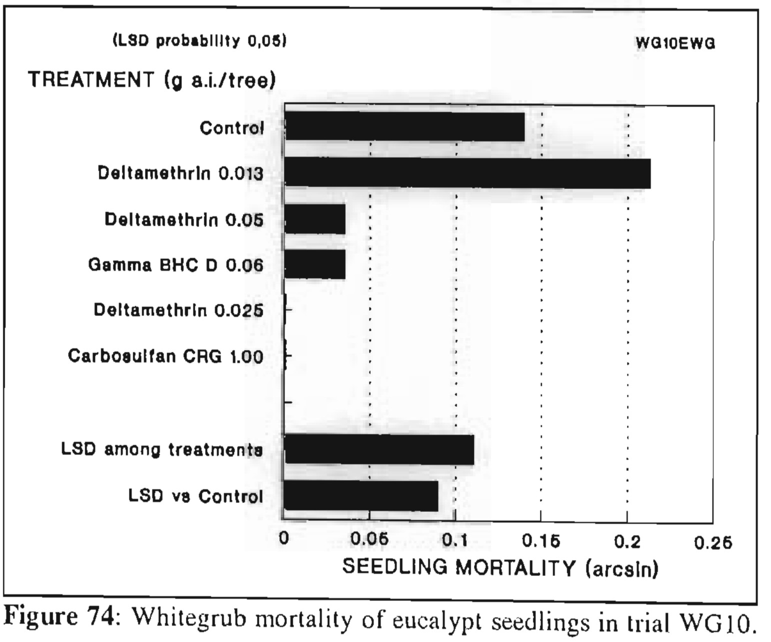


Figure 74: Whitegrub mortality of eucalypt seedlings in trial WG10.

6.2.3.3.2 CUTWORM MORTALITY

In trial WG9 (4,35% infestation), where treatments were assessed for the control of cutworm in eucalypts (***Figure 75***), deltamethrin SC at all rates of application and carbosulfan CRG showed significantly less mortality than the control. Deltamethrin SC at 0,013 g a.i./tree showed significantly less mortality than the ineffective gamma BHC 0,6% D. Trial WG9 was planted on a site that received higher rainfall than trial WG10. The top soil in trial WG9 had a slightly higher available water capacity because of its higher organic carbon and percentage clay content throughout the profile (***Appendix 9***)). A high organic matter content in flooded soils accelerates the hydrolysis of carbosulfan to carbofuran (Sahoo *et al.*, 1993). Hence in trial WG9 there was a higher concentration of the active ingredient carbosulfan/carbofuran in the top soil to control cutworms. In trial WG10 where the incidence of cutworm damage on eucalypts was higher (5,59%), only deltamethrin SC at its lowest rate of application (0,013 g a.i./tree) showed significantly less mortality than the control (***Figure 76***). There were no significant differences between treatments.

The incidence of cutworm damage on wattle was low in both trial WG9 (***Figure 77***), (2,26%) and trial WG10 (***Figure 78***), (2,10%). Although similar trends were noticed in the effects of treatments on cutworm, the low incidence of cutworm damage resulted in a high LSD value. Therefore no treatments showed significantly less mortality than the controls.

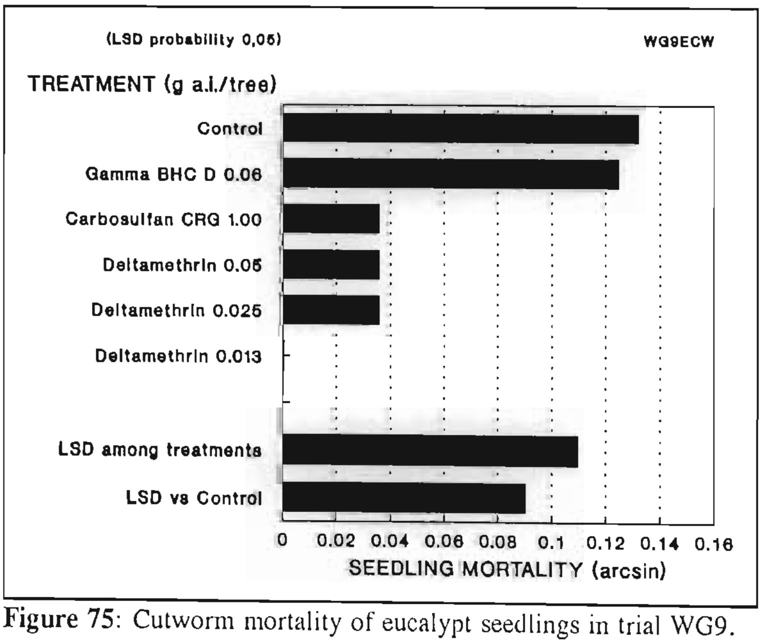


Figure 75: Cutworm mortality of eucalypt seedlings in trial WG9.

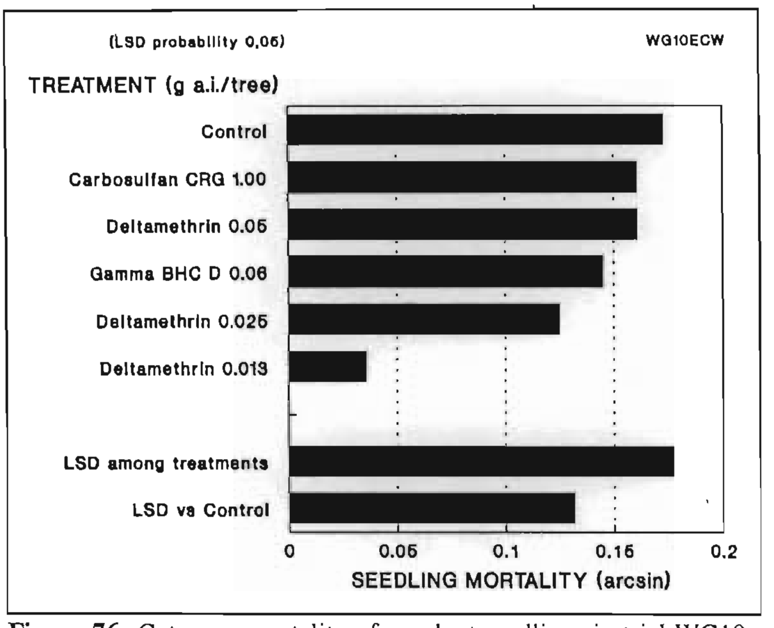


Figure 76: Cutworm mortality of eucalypt seedlings in trial WG10.

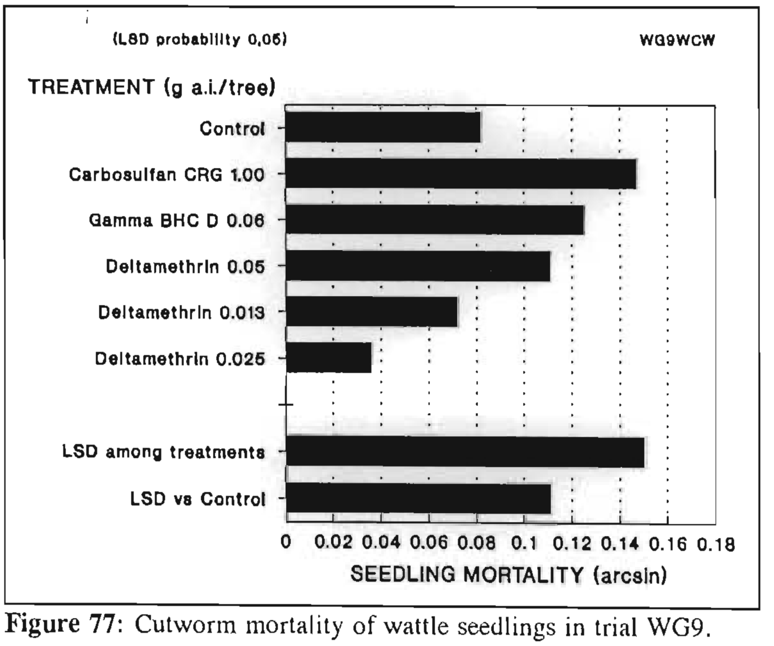


Figure 77: Cutworm mortality of wattle seedlings in trial WG9.

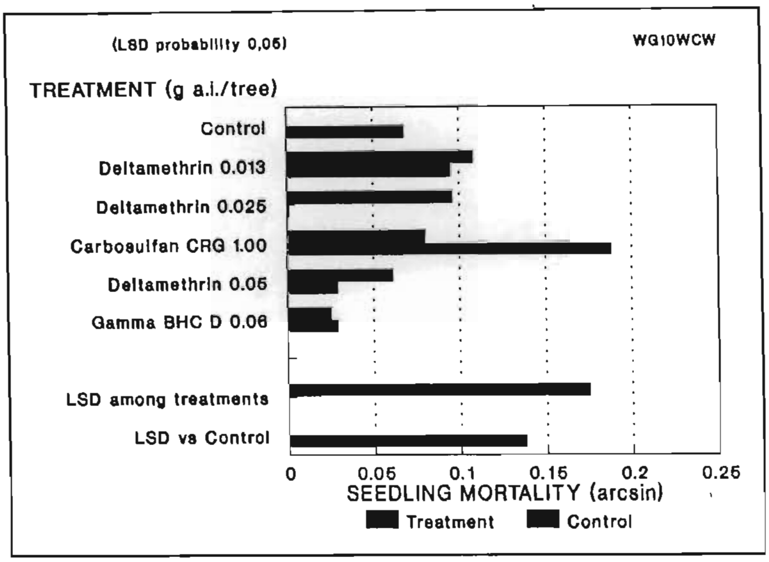


Figure 78: Cutworm mortality of wattle seedlings in trial WG10.

6.2.4 CONCLUSIONS

Gamma BHC 0,6% dust applied at 0,06 g a.i./tree was effective against whitegrubs and persistent enough to be applied as early as October in the planting season. However, this was under low rainfall conditions. Gamma BHC 0,6% D was ineffective against cutworms, contrary to the recommendation by Sherry (1971) and the general practice of some foresters who use gamma BHC 0,6% D for pests in general. Carbosulfan 10% controlled release granules and chlorpyrifos 10% CRG applied at 1,00 g a.i./tree were effective against whitegrubs. Under moist soil conditions, in highly organic soils, carbosulfan CRG applied at 1,00 g a.i./tree was also effective against cutworm. Deltamethrin 5% suspension concentrate applied at 0,025 g a.i./tree was effective against whitegrubs and cutworm. This treatment was persistent enough to be applied early in the planting season and was suitable to be used as a combined treatment for the control of whitegrubs and cutworm at planting. Deltamethrin SC applied at 0,013 g a.i./tree was effective when the incidences of whitegrubs and cutworms are high. The persistence and efficacy of these selected treatments, especially at the lower rates of application, still needs to be investigated under higher rainfall conditions. The rate, method of application and efficacy of deltamethrin 5% SC some time after planting (when foresters generally notice whitegrub damage) requires investigation.

6.3 CHOICE AND COST OF INSECTICIDAL TREATMENTS

The choice of insecticidal treatments on a preventative basis will depend on the pest or pests that one wishes to control and on economic constraints. Carbosulfan 10% CRG can simultaneously control whitegrubs and termites in those areas where both pests are a problem. The advantages of carbosulfan 10% CRG are that: it is already registered for termite control in forestry, where it provides protection for up to two years and is readily available; it can be used on all types of mineral and organic soils; it affords protection against a wide range of soil pests (including nematodes); and it is used as a systemic, stomach poison and contact insecticide (Thomson, 1992). The disadvantages of carbosulfan are its excessive costs (***Table 12***), that its efficacy depends on soil moisture, that is provides the seedling with protection around the root plug and not the lateral roots, and that as a systemic its active metabolites require about 30 days to build up to maximum levels in the stem (Thomson, 1992).

Chlorpyrifos 10% CRG can also control whitegrubs. The advantages of chlorpyrifos 10% CRG are that it has a persistence of 60 to 120 days and is very resistant to leaching in the soil. However, its activity is reduced in organic soils and it has no systemic activity (used as a contact and stomach poison insecticide) (Thomson, 1992). The disadvantages of chlorpyrifos are its excessive costs (***Table 12***), and that its efficacy depends on soil moisture.

The controlled release granule formulations have non persistent chemical residues, which show no potential for accumulating in food chains. They have a short half life and low vapour pressure, characteristics which minimise their impact on the environment. The controlled release granules minimise environmental exposure by releasing the total dose, at a controlled rate, over a period of time. This minimises the level of active ingredient in the soil at any one time. In forestry their application is confined to the planting hole, where protection is needed, which minimises the impact of the insecticide on non target organisms. These dry, dust free granules provide safety benefits to users by reducing both oral and dermal toxicity (Canty, 1991).

The most cost effective treatment for whitegrubs is gamma BHC 0,6% D (***Table 12***). This is an organochlorine insecticide which is broad spectrum and has long residual effects. It is used as a contact and stomach poison insecticide (Thomson, 1992). Some isomers of gamma BHC D have been withdrawn and the future availability of gamma BHC D is uncertain.

Deltamethrin 5% SC will offer simultaneous control of whitegrubs and cutworms at an intermediate cost between carbosulfan 10% CRG and gamma 0,6% BHC D (***Table 12***). The suspension concentrate formulation appears to be more persistent than the emulsifiable concentrate (B Goodwin, personal communication). Deltamethrin 5% SC is broad spectrum and has more flexibility than the other formulations, in that it allows treatment after an infestation has developed. Deltamethrin is the most powerful of the synthetic pyrethroids and is fast acting, hence its suitability for after-planting application. As a drench it is more mobile in the soil than the CRG formulation. Deltamethrin is a contact and stomach poison insecticide with no systemic activity. Its effectiveness and persistence is reduced at temperatures greater than 35^0 C (Thomson, 1992).

TABLE 12: The cost (in Rands) of insecticidal treatments per hectare.

Treatment	Product/tree	g a.i./tree	Unit price	Wattle at 2222 stems/ha		Eucalypts at 1666 stems/ha	
				Product/ha	Price R/ha	Product/ha	Price R/ha
Carbosulfan 10% CRG	10,0 g	1,000	R31,50/kg	22,22 kg	R699,93	16,66 kg	R524,79
Chlorpyrifos 10% CRG	10,0 g	1,000	R31,50/kg	22,22 kg	R699,93	16,66 kg	R524,79
Deltamethrin 5% SC	0,5 ml	0,025	R212,72/*l*	1,11 *l*	R236,12	0,833 *l*	R177,20
Gamma BHC 0,6% D	10,0 g	0,060	R69,54/25 kg	22,22 kg	R61,81	16,66 kg	R46,34

6.4 RECOMMENDATIONS

Wattle and eucalypt seedlings can be preventatively treated for the control of whitegrubs by the application of gamma BHC 0,6% dust at 0,06 g a.i./tree or carbosulfan 10% CRG at 1,00 g a.i./tree or chlorpyrifos 10% CRG at 1,0 g a.i./tree or deltamethrin 5% SC at 0,025 g a.i./tree. Wattle and eucalypt seedlings can be preventatively treated for the control of cutworm by the application of deltamethrin 5% SC at 0,025 g a.i./tree.

The above recommendations are tentative, pending the registration of these treatments on the specific crop and pest or pests with the Registrar (Department of Agriculture).

CHAPTER 7: ESTIMATES OF ANNUAL DAMAGE IN THE NATAL MIDLANDS BY WHITEGRUBS AND CUTWORMS AND COST IMPLICATIONS OVER THE THREE YEAR STUDY PERIOD

7.1 ESTIMATES OF NEWLY PLANTED AREAS THAT FAILED TO ESTABLISH

The total area planted to hardwoods and softwoods in the Natal Midlands during the 1990/91 season was 10 910 ha and 6067 ha respectively, during the 1991/92 season was 9264 ha and 2506 ha respectively, and during the 1992/93 season was 7560 ha and 1471 ha respectively (***Table 13***). This represents an annual decrease of about 37% per annum of newly planted commercial plantations in the Natal Midlands over the three year study period. South Africa is presently experiencing a severe drought, which accounts for the above reduced planting. Consequently, in the Natal Midlands, a total of 11 139 ha was unplanted in the 1990/91 season; a total of 13 960 ha was unplanted in the 1991/92 season and a total of 13 577 ha was unplanted in the 1992/93 season. This represents an annual increase of about 8,7% p.a. of the area that was unplanted because of the drought over the three year study period. The permanent labour force was instead largely used to clear existing wattle jungles; the area to wattle jungles having declined by about 13,6% p.a. during the three year study period.

The percentages of seedlings that failed to establish in the ten trials that were planted during the three-year study period were averaged and expressed as a factor per hectare (i.e. 0,22714). Using this averaged factor as a tool, it is estimated that in the Natal Midlands, 2478 ha, 2104 ha, 1717 ha of hardwoods and 1378 ha, 569 ha, 334 ha of softwoods failed to establish during the 1990/91, 1991/92 and 1992/93 seasons respectively. This estimation of susceptibility excludes damage by termites, which are associated with different soil types as compared to whitegrubs and cutworms. Under higher rainfall conditions, the area planted to exotic forestry tree species would increase and one can expect the above estimates of crop failure to be higher.

7.2 ESTIMATES OF WHITEGRUB AND CUTWORM DAMAGE IN AREAS THAT WERE CONVERTED FROM WATTLE TO OTHER PLANTATION CROPS AND AREAS RE-ESTABLISHED TO WATTLE DURING THE STUDY PERIOD

Each season a large area is converted from previous wattle plantation or wattle jungle to other plantation species or re-established to wattle (***Table 14***). These wattle plantations have humic soils with a high organic carbon content and hence the complement of indigenous soil pests. During the three-year study period a total of 8293 ha were converted to other plantation species and re-established to wattle. The percentages of seedlings that were damaged by whitegrubs and cutworm in the ten trials planted during the three-year study period were averaged and expressed as factors per hectare (i.e. 0,07937 for whitegrubs and 0,02199 for cutworms). Using these factors, it is estimated that 232,3 ha, 187,2 ha, 238,8 ha were damaged by whitegrubs and 64,34 ha, 51,8 ha, 66,2 ha were damaged by cutworms during the 1990/91, 1991/92 and 1992/93 season respectively. It is estimated that, in total, 664,7 ha, 535,8 ha and 683,2 ha failed to establish during the 1990/91, 1991/92 and 1992/93 seasons respectively.

TABLE 13: Area (in hectares) of commercial plantations in the age class 0 to 1 year, planted during the 1990/91, 1991/92 and 1992/93 seasons.

TYPE	PLANTED				WATTLE JUNGLE				UNPLANTED				ESTIMATED AREA DAMAGED			
	1990/91 *	1991/92 **	1992/93 ***	Total	1990/91 *	1991/92 **	1992/93 ***	Total	1990/91 *	1991/92 **	1992/93 ***	Total	1990/91	1991/92	1992/93	Total
Hardwoods	10 910	9 264	7 560	27 734	706	653	536	1 895	7 952	8 231	7 353	23 536	2 478	2 104	1 717	6 299
Softwoods	6 067	2 506	1 471	10 044	10	10	20	40	3 187	5 729	6 224	15 140	1 378	569	334	2 281
Total	16 977	11 770	9 031	37 778	716	663	556	1 935	11 139	13 960	13 577	38 676	3 856	2 673	2 051	8 580

* Department of Water Affairs and Forestry (1992)
** Department of Water Affairs and Forestry (1993)
*** Department of Water Affairs and Forestry (1994)

TABLE 14: Area (in hectares) converted from wattle to other plantation crops and re-established to wattle during the 1990/91, 1991/92 and 1992/93 seasons and estimated damage by whitegrubs and cutworms.

CROP AFFECTED	TOTAL AREA CONVERTED				ESTIMATED WHITEGRUB DAMAGE				ESTIMATED CUTWORM DAMAGE				FAILURE TO ESTABLISH			
	1990/91 *	1991/92 **	1992/93 ***	Total	1990/91	1991/92	1992/93	Total	1990/91	1991/92	1992/93	Total	1990/91	1991/92	1992/93	Total
Wattle	2 133	1 831	2 473	6 437	169,3	145,3	196,3	510,9	46,90	40,3	54,4	141,60	484,5	415,9	561,7	1 462,1
Pine	178	43	130	351	14,1	3,4	10,3	27,8	3,90	0,9	2,9	7,70	40,4	9,8	29,5	79,7
E. grandis	180	197	184	561	14,3	15,6	14,6	44,5	4,00	4,3	4,1	12,40	40,9	44,7	41,8	127,4
Other gum	65	82	79	226	5,2	6,5	6,3	18,0	1,40	1,8	1,7	4,90	14,8	18,6	17,9	51,3
Other hardwood	2	-	-	2	0,2	-	-	0,2	0,04	-	-	0,04	0,5	-	-	0,5
Agriculture	368	206	142	716	29,2	16,4	11,3	56,9	8,10	4,5	3,1	15,70	83,6	46,8	32,3	162,7
TOTAL	2 926	2 359	3 008	8 293	232,3	187,2	238,8	658,3	64,34	51,8	66,2	182,34	664,7	535,8	683,2	1 883,7

* Department of Water Affairs and Forestry (1992);
** Department of Water Affairs and Forestry (1993);
*** Department of Water Affairs and Forestry (1994)

7.3 ESTIMATES OF WHITEGRUB AND CUTWORM DAMAGE IN NEWLY AFFORESTED AREAS DURING THE STUDY PERIOD

During the annual expansion of forestry in the Natal Midlands large areas of grassland and ex-agricultural land become afforested (***Table 15***). These areas also have humic soils with a high organic carbon content and an endemic indigenous soil pest population. A total of 8491 ha, 7791 ha and 3435 ha were newly afforested during the 1990/91, 1991/92 and 1992/93 seasons respectively. Only trial WG5 closely resembled a newly afforested area. The whitegrub and cutworm damage from trial WG5 was therefore expressed as factors per hectare (i.e. 0,0117 for whitegrubs and 0,0063 for cutworms). Using these factors, it is estimated that 99,32 ha, 91,11 ha, 40,2 ha were damaged by whitegrubs and 53,11 ha, 48,67 ha, 21,4 ha were damaged by cutworms during the 1990/91, 1991/92 and 1992/93 seasons respectively. It is estimated that, in total, 1 020,2 ha, 936,2 ha and 412,8 ha failed to establish during the 1990/91, 1991/92 and 1992/93 seasons respectively.

Combining the estimates for areas converted from previous wattle plantation, re-established to wattle and newly afforested areas, it is estimated that, 331,6 ha, 278,3 ha, 279 ha were damaged by whitegrub and 117,5 ha, 100,5 ha, 87,6 ha were damaged by cutworm during the 1990/91, 1991/92 and 1992/93 reduced (because of the drought) planting season respectively. One can therefore generalise that between about 367 ha and about 449 ha (average of 398 ha) are annually damaged and killed by whitegrubs and cutworms in the Natal Midlands. The estimates calculated above exclude damage by whitegrubs to established saplings where the trees are not killed but have reduced growth. The incidence of whitegrub damage in the re-establishment of pine plantations and in the conversion of pine to other plantation species was occasionally observed but because of its sporadic occurrence, it was not included in the above estimate.

TABLE 15: Area (in hectares) of new afforestation during the 1990/91, 1991/92 and 1992/93 seasons, and an estimate of whitegrub and cutworm damage.

SPECIES	TOTAL AREA AFFORESTED				ESTIMATED WHITEGRUB DAMAGE				ESTIMATED CUTWORM DAMAGE				FAILURE TO ESTABLISH			
	1990/91 *	1991/92 **	1992/93 ***	Total	1990/91	1991/92	1992/93	Total	1990/91	1991/92	1992/93	Total	1990/91	1991/92	1992/93	Total
Pine	5121	4335	1434	10 890	59,90	50,70	16,8	127,40	32,00	27,10	9,0	68,10	615,3	520,9	172,3	1 308,5
E. grandis	1070	1238	54	2 362	12,50	14,50	0,6	27,60	6,70	7,70	0,3	14,70	128,6	148,8	6,5	283,9
Other gum	1663	922	807	3 392	19,50	10,80	9,4	39,70	10,40	5,80	5,0	21,20	199,8	110,8	97,0	407,6
Wattle	635	1284	1108	3 027	7,40	15,00	13,0	35,40	4,00	8,00	6,9	18,90	76,3	154,3	133,1	363,7
Poplars	2	11	18	31	0,02	0,10	0,2	0,32	0,01	0,07	0,1	0,18	0,2	1,3	2,2	3,7
Other hardwood	-	1	14	15	-	0,01	0,2	0,21	-	-	0,1	0,10	-	0,1	1,7	1,8
TOTAL	8491	7791	3435	19 717	99,32	91,11	40,2	230,63	53,11	48,67	21,4	123,18	1 020,2	936,2	412,8	2369,2

* Department of Water Affairs and Forestry (1992)
** Department of Water Affairs and Forestry (1993)
*** Department of Water Affairs and Forestry (1994)

7.4 COST IMPLICATIONS OF WHITEGRUB AND CUTWORM DAMAGE

Atkinson and de Laborde (1993) used a discounted cash flow procedure to determine the loss per hectare of eucalypt and wattle plantations because of damage by soil pests. A 10% to 30% level of eucalypt seedling mortality per hectare (assuming no blanking/replanting) resulted in a loss of R450 to R1 340 per hectare (over a ten year rotation period). Assuming the dead seedlings were blanked within one month and they were 10% smaller at harvest, then a 10% to 50% tree mortality would result in a loss of R100 to R427 per hectare. Similarly, if one assumes a 14% wattle seedling mortality at planting (this translates to a 10% net mortality after thinning), then the loss per hectare is R722 (Atkinson and de Laborde, 1993).

The estimated total areas in the Natal Midlands that were damaged by whitegrubs and cutworms (extracted from ***Tables 14 and 15***) were combined and presented for each year of the study period and for each of the plantation tree species (***Table 16***). The annual forestry costs for each province and each plantation tree species were determined by the Forestry Economics Services (South African Timber Growers' Association). These costs were used to estimate the loss in establishment costs and additional blanking costs because of mortality by whitegrubs and cutworms. It is therefore estimated that in total during the 1990/91 season in the Natal Midlands, about R290 976 of the initial establishment costs were lost and it cost about a further R627 856 to blank (replant) these seedlings (Rusk *et al.*, 1992). Similarly, it is estimated that in total during the 1991/92 season in the Natal Midlands, about R405 642 of the initial establishment costs were lost and it cost about a further R965 576 to blank these seedlings (Rusk *et al*, 1993). Similarly it is also estimated that in total during the 1992/93 season in the Natal Midlands, about R526 498 of the initial establishment costs were lost and it cost about a further R1 056 930 to blank these seedlings (Rusk *et al*, 1994). These additional blanking costs exclude the costs of insecticides and their application. The Forest Industry of the Natal Midlands has therefore lost about 1,22 million rands of establishment costs and about a further 2,65 million rands in blanking costs over the three year study period because of damage by whitegrubs and cutworms. These losses further illustrate the economic importance and the pest status of whitegrubs and cutworms in the forest industry.

TABLE 16: The estimated loss in establishment costs (in Rands) and additional blanking costs as a result of whitegrub and cutworm damage during the 1990/91, 1991/92 and 1992/93 seasons.

CROP AFFECTED	TOTAL AREA SUSCEPTIBLE				COMBINED ESTIMATE OF WHITEGRUB AND CUTWORM DAMAGE				ESTIMATED LOSS IN ESTABLISHMENT COSTS (Rands)				ESTIMATED ADDITIONAL BLANKING COSTS (Rands)			
	1990/91 *	1991/92 **	1992/93 ***	Total	1990/91	1991/92	1992/93	Total	1990/91	1991/92	1992/93	Total	1990/91	1991/92	1992/93	Total
Wattle	2 768	3 115	3 581	9 464	227,6	208,6	270,6	706,8	179 943	240 969	430 119	851 031	139 784	256 770	650 668	1 047 222
Pine	5 299	4 378	1 564	11 241	109,9	82,1	39,0	231,0	56 603	86 899	37 161	180 663	305 699	457 808	193 107	956 614
Eucalypts	2 978	2 439	1 124	6 541	74,0	67,0	42,0	183,0	54 430	77 774	59 218	191 422	182 373	250 998	213 155	646 526
TOTAL	11 045	9 932	6 269	27 246	411,2	357,7	351,6	1120,8	290 976	405 642	526 798	1 223 116	627 856	965 576	1 056 930	2 650 362

* Department of Water Affairs and Forestry (1992)
** Department of Water Affairs and Forestry (1993)
*** Department of Water Affairs and Forestry (1994)

CHAPTER 8: SUMMARY

Amongst the members of the indigenous soil pest complex that affect the establishment of *Acacia mearnsii* and *Eucalyptus grandis* seedlings, from most important pest status to least important were whitegrubs (7,9% infestation), nematodes (6,2% infestation), cutworms (2,5% infestation), millipedes (0,6% infestation) and grasshoppers/crickets (0,3% infestation). Nematode, millipede and grasshopper/cricket infestations were very sporadic. Only whitegrub and cutworm infestations occurred regularly. The most frequent and important soil pests are therefore whitegrubs, followed by cutworms. Termites, unlike whitegrubs and cutworms, are associated with deep, well drained soils, high in clay but low in humic content.

Whitegrubs fed on the young and tender roots of the lateral roots; in severe cases the root plugs of transplants were completely devoured. Whitegrub damage began soon after planting, followed a bell shaped curve, peaked in February and tailed off sharply towards June. Transplants in the summer rainfall region were most susceptible to whitegrub damage from December to April. The percentage of whitegrub infestation was strongly correlated with the percentage of organic carbon in the topsoil. Soils with a humic phase are more likely to develop whitegrub infestations than soils with an orthic phase. High risk areas (previous wattle or ex-agricultural land with humic topsoils) can therefore be identified to preventatively treat seedlings with insecticides at planting.

Cutworms cut off the tender stems of young transplants at ground level. The growing tips and foliage were dragged below ground and fed upon. Cutworm damage began soon after planting and the seedlings were most susceptible during the first two months after planting, before the stem became woody.

Whitegrub feeding also affects the growth of established insecticide treated seedlings. Gamma BHC 0,6% D and carbosulfan 10% CRG provided the established seedlings with localised protection around the root plug, while deltamethrin 5% SC was applied as a drench and dispersed to the region of the lateral roots where protection was needed. Established wattle trees are more tolerant to damage by whitegrubs in shallow, marginal sites and grow more uniformly than eucalypts.

Carbosulfan 10% CRG and chlorpyrifos 10% CRG applied at 1,0 g a.i./tree were effective against whitegrubs. Under moist soil conditions, in highly organic soils, carbosulfan 10% CRG at 1,0 g a.i./tree was also effective against cutworm. Isazofos 10% CRG showed promise for the control of whitegrubs. Cadusafos 10% G at 1,2 g a.i./tree was phytotoxic to both wattle and eucalypt seedlings; eucalypts appeared to be more sensitive than wattle. Ethoprofos 20% EC at 1,0 g a.i./tree was extremely phytotoxic to both wattle and eucalypts. Alphamethrin 10% SC was successful at controlling whitegrubs but at the unrealistically high rate of 0,55 g a.i./tree. Gamma BHC 0,6% D applied at 0,06 g a.i./tree was effective against whitegrubs and persistent enough to be applied as early as October in the planting season. Gamma BHC was ineffective against cutworms. Deltamethrin 5% SC applied at 0,025 g a.i./tree was effective against whitegrubs and cutworms. This treatment was persistent enough to be applied early in the planting season and was suitable to be used as a combined treatment for the control of whitegrubs and cutworms at planting.

Within a range of about 367 ha to 449 ha (average of 398 ha) were annually damaged by whitegrubs and cutworms in the Natal Midlands. This estimate excluded damage by whitegrubs to established saplings (where the trees were not killed but had reduced growth), whitegrub damage in the re-establishment of pine plantations and the conversion of pine to other plantation species. The total estimated loss in establishment costs and the additional blanking costs because of mortality by whitegrubs and cutworms was R1,22 and R2,65 million, respectively, over the three year study period.

REFERENCES

ABBOTT, I. 1993. Insect pest problems of eucalypt plantations in Australia. 6.Western Australia. Australian Forestry 56(4). p381-384.

ALLSOPP, P G and BULL, R M. 1989. Spatial pattens and sequential sampling plans for melolonthine larvae (Coleoptera : Scarabaeidae) in southern Queensland sugarcane. Bulletin of Entomological Research 79(2). p251-258.

ALLSOPP, P G and CHANDLER, K J. 1990. Cane grub research and control in Australia since 1970. Unpublished report. Bureau of Sugar Experiment Stations. Australia. 15pp.

ANNECKE, D P and MORAN, V C. 1982. Insects and mites of cultivated plants in South Africa. Durban:Butterworths. 383pp.

ATKINSON, P R. 1991. Rate of attack by termites on eucalypts. In Institute for Commercial Forestry Research Annual Research Report. p167-168.

ATKINSON, P R. 1994. Institute for Commercial Forestry Research. Pietermaritzburg. Personal communication.

ATKINSON, P R. 1994. Millipedes. In Brochure of wattle pests and diseases. Institute for Commercial Forestry Research. 28pp.

ATKINSON, P R and DE LABORDE, R M. 1993. Estimates of the extent of, and the potential losses from, infestations of common forestry pests in South Africa. ICFR Bulletin Series 19/93. 10pp.

ATKINSON, P R, TRIBE, G D and GOVENDER, P. 1991. Pests of importance in the recent expansion of *Eucalyptus* plantings in South Africa. In Proceedings IUFRO Symposium. Intensive Forestry: The role of eucalypts 2, p728-738.

ATKINSON, P R, VAN DEN BERG, E and VAN RENSBURG, N J. 1991. Response of *Eucalyptus* to aldicarb in coastal sandy soils in Natal, South Africa. South African Forestry Journal 158. p5-9.

BAKER, A N. 1974. Some aspects of the economic importance of millipedes. In Symposium of the Zoological Society of London No. 32. p621-628.

BAKSHA, M W and ISLAM, M R. 1990. Summary of recent activities on forest insects in Bangladesh. In Proceedings IUFRO Workshop: Pests and diseases of forest plantations. RAPA Publication 1990/9. p43-44.

BANDARA, P D M G D. 1990. Insects and diseases of forest plantations in Sri Lanka. In Proceedings IUFRO Workshop: Pests and diseases of forest plantations. RAPA Publication 1990/9. p43-44.

BASHFORD, R. 1993. Insect pest problems of eucalypt plantations in Australia. 4.Tasmania. Australian Forestry 56(4). p375-377.

BLAIR, B W. 1973. A new look at cutworm control. Rhodesian Agricultural Journal 70. p163-164.

BOHLEN, P J and BARRETT, G W. 1990. Dispersal of the Japanese Beetle (Coleoptera: Scarabaeidae) in strip-cropped soybean agroecosystems. Environmental Entomology 19(4). p955-960.

BORTHWICK, R B. 1990a. Cutworms. Institute for Commercial Forestry Research Leaflet Series. Pietermaritzburg. 3pp.

BORTHWICK, R B. 1990b. Whitegrub. Institute for Commercial Forestry Research Leaflet Series. Pietermaritzburg. 3pp.

BOVING, A G. 1942. Descriptions of the larvae of some West Indian Melolonthinae beetles and a key to the known larvae of the tribe. Proceedings of the United States National Museum 92. p167-178.

BRITS, D. 1992. Hops Industry. Cape Province. Personal communication.

BROWNE, F G. 1968. Pests and diseases of forest plantation trees. Clarendon Press. London. 1330pp.

BULL, R M. 1986a. *Lepidiota picticollis* Lea, an increasing cane grub pest problem in the Bundaberg District. Proceedings of Australian Society of Sugar Cane Technologists 8. p141-147.

BULL, R M. 1986b. New chemicals for the control of cane grubs. Proceedings of the International Society of Sugar Cane Technologists 19. p626-636.

BULL, R M and ALLSOPP, P G. 1988. Control problems with *Lepidiota noxia* Britton in Southern Queensland. Proceedings of Australian Society of Sugar Cane Technologists 10. p179-184.

BURLEY, J, ARMITAGE, F B, BARNES, R D, GIBSON, G L, HARDCASTLE, P D, HUGUET, L, PLUMPTRE, R A and WOOD, P J. 1989. Forestry research in eastern and southern Africa. Tropical Forestry Papers No. 19. Oxford Forestry Institute. London.

CACKETT, K E. 1990. 3500/20 Bio-assay Trial. Unpublished report. Zimbabwe Sugar Association Experiment Station. 4pp.

CANTY, C. 1991. Controlled release granules protect *Eucalyptus* trees from termite attack. In: Proceedings IUFRO Symposium. Intensive Forestry : The role of eucalypts 2, p739-748.

CARNEGIE, A J M. 1974. Sugarcane white grubs (Scarabaeoidea) and their control in South Africa. Proceedings of the International Society of Sugar Cane Technologists XV. p498-512.

CARNEGIE, A J M. 1988. White grubs (Scarabaeoidea) continue to cause sporadic damage to sugarcane in South Africa and Swaziland. Proceedings of the South African Sugarcane Technologists Association 62. p161-163.

DEGROOT, R and VALVASORI, M. 1989. Use of suSCon Blue as alternative to persistent organochlorine insecticides for soil pests of sugar cane. International Sugar Journal 91. p210-212.

DEPARTMENT OF AGRICULTURE. 1993. A guide to the use of pesticides and fungicides in the Republic of South Africa. Government Printer. Pretoria. 332pp.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1992. Report on commercial timber resources and roundwood processing in South Africa, 1990/1991. Pretoria. 130p.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1993. Report on commercial timber resources and roundwood processing in South Africa, 1991/1992. Pretoria. 130p.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1994. Report on commercial timber resources and roundwood processing in South Africa, 1992/1993. Pretoria. 130p.

DRINKWATER, T W. 1980. Cutworms in maize. Farming in South Africa. Maize Series D5/1980. p1-4.

DRINKWATER, T W. 1989. Occurrence of soil-inhabiting Tenebrionidae (Coleoptera) in maize fields in South Africa. Phytophylactica 21. p397-398.

DRINKWATER, T W and GILIOMEE, J H. 1991. The life-cycle and seasonal history of the false wireworm, *Somaticus angulatus* (Coleoptera: Tenebrionidae), in maize fields in the North-Western Orange Free State. Phytophylactica 23. p261-264.

DRINKWATER, T W and VAN RENSBURG, J B J. 1992. Association of the common cutworm, Agrotis segetum (Lepidoptera:Noctuidae), with winter weeds and volunteer maize. Phytophylactica 24. p25-28.

FLEMING, W E. 1972. Biology of the Japanese beetle. United States Department of Agriculture Technical Bulletin No. 1449. 129pp.

GOODWIN, B. 1991. Hoechst Chemicals. Johannesburg. Personal communication.

GORDON, R D and CARTWRIGHT, O L. 1988. North American representatives of the tribe Aegialiini (Coleoptera: Scarabaeidae: Aphodiinae). Smithsonian Contributions to Zoology No. 461. 37pp.

GOVENDER, P. 1993. Pests of establishment of eucalypts and wattle. In Institute for Commercial Forestry Research Annual Research Report. p161-170.

GOVENDER, P and ATKINSON, P R. 1992a. Pests of establishment of eucalypts and wattle. In Institute for Commercial Forestry Research Annual Research Report. p178-181.

GOVENDER, P and ATKINSON, P R. 1992b. Pests of establishment in ex-croplands. In Institute for Commercial Forestry Research Annual Research Report. p182-184.

GOVENDER, P and ATKINSON, P R. 1993. The soil pest complex and its control in the establishment of commercial eucalypt and wattle plantations in South Africa. ICFR Bulletin Series No. 18/93. 8pp.

HANULA, J L and ANDREADIS, T G. 1988. Parasitic microorganisms of Japanese beetle (Coleoptera: Scarabaeidae) and associated scarab larvae in Connecticut soils. Environmental Entomology 17(4). p709-714.

HAYES, W P. 1929. Morphology, taxonomy and biology of larval Scarabaeoidea. Illinois Biological Monographs 12(2). p1-119.

HEPBURN, G A. 1966. A revised list of wattle insects and spiders of southern Africa. Annual Report of the Wattle Research Institute, 1965-1966. p67-83.

HERBERT, M A. 1993. Institute for Commercial Forestry Research. Personal communication.

HITCHCOCK, B E, BULL, R M, ALLSOPP, P G and McGILL, N G. 1989. Control of *Lepidiota squamulata* Waterhouse larvae by single and double applications of controlled release insecticides. Proceedings of Australian Society of Sugar Cane Technologists 11. p147-150.

HITCHCOCK, B E, CHANDLER, K J and STICKLEY, B D A. 1984. Controlled release pesticides for soil insect control in sugar cane. Proceedings of Australian Society of Sugar Cane Technologists 6. p87-94.

KARD, B M R, HAIN, F P and BROOKS, W M. 1988. Field supression of three whitegrub species (Coleoptera: Scarabaeidae) by the entomogenous nematodes *Steinernema feltiae* and *Heterorhabditis heliothidis*. Journal of Economic Entomology 81(4). p1033-1039.

KUNZ, R. 1994. Institute for Commercial Forestry Research, Pietermaritzburg. Personal communication.

LAWRENCE, R F. 1984. The centipedes and millipedes of Southern Africa. Cape Town: Balkema. 148pp.

LONGWORTH, J F. 1976. Insect viruses and pest control: the search for alternatives. New Zealand Journal of Agriculture 132(6). p16-17, 19.

MARAIS, M and BUCKLEY, N H. 1993. Plant-parasitic nematodes in forest soils in the Transvaal and Natal, South Africa. South African Forestry Journal 166. p9-16.

NATAWIRIA, D. 1990. Insect pests in plantation forests of Indonesia. In Proceedings IUFRO Workshop: Pests and diseases of forest plantations. RAPA Publication 1990/9. p56-61.

NEUMANN, F G. 1993. Insect pest problems of eucalypt plantations in Australia. 3.Victoria. Australian Forestry 56(4). p370-374.

NICHOL, N S. 1992. Institute for Commercial Forestry Research. Pietermaritzburg. Personal communication.

NICHOL, N S. 1993. Common nursery pathogens of commercial tree species. In Institute for Commercial Forestry Research Annual Research Report. p155-157.

OBERHOLZER, J J. 1959. A morphological study of some South African Lamellicorn larvae. 1-Descriptions of the third instar larvae. South African Journal of Agricultural Science 2(1). p41-74.

OHMART, C P. 1990. Insect pests in intensively-managed eucalypt plantations in Australia: some thoughts on this challenge to a new era in forest management. Australian Forestry 53(1). p7-12.

OMER-COOPER, J, WHITNALL, A B M and FENWICK, E M. 1942. The insect and the golfer. South African Golf. June 1941 to April 1942. 20pp.

OMER-COOPER, J, WHITNALL, A B M and FENWICK, E M. 1948. Notes on four species of Coleoptera attacking turf in the eastern Cape Province. South African Journal of Science 44. p125-134.

PETERSON, A. 1955. A manual of entomological techniques. Edward Brothers, Ohio. 88pp.

PHILLIPS, C L. 1993. Insect pest problems of eucalypt plantations in Australia. 5.South Australia. Australian Forestry 56(4). p378-380.

PILLAI, G B. 1987. Integrated pest management in plantation crops. Proceedings of the workshop on The Insect Pest Management Strategies in coffee, Cardamom and tea cropping systems. Suppl. JCR 17. p150-153.

PRAKASAN, C B. 1987. Biological control of coffee pests. Proceedings of the workshop on The Insect Pest Management Strategies in coffee, Cardamom and tea cropping systems. Suppl. JCR 17. p114-117.

PRINS, A J. 1965. Notes on the biology and morphology of the wattle chafers *Monochelus calcaratus* Burm. (Melolonthidae), *Hypopholis sommeri* Burm. (Melolonthidae), and *Adoretus ictericus* Burm. (Rutelidae) with some references to natural enemies (Coleoptera: Lamellicornia). Entomology Memoirs Vol. 9. Department of Agricultural Technical Services. Republic of South Africa. 55p.

PRINS, A J. 1984. Morphological and biological notes on some South African arthropods associated with decaying organic matter. Part 3. The families Dermestidae, Cantharidae, Melyridae, Tenebrionidae and Scarabaeidae (Coleoptera). Annals of the South African Museum 94(4). p203-304.

RITCHER, P O. 1943. The Anomalini of eastern North America with descriptions of the larvae and a key to species (Coleoptera : Scarabaeidae). Kentucky Agricultural Experiment Station Bulletin 442. University of Kentucky. 27pp.

RITCHER, P O. 1945a. Rutelinae of eastern North America with descriptions of the larvae of *Strigodermella pygmaea* (Fab.) and three species of the tribe Rutelini (Coleoptera : Scarabaeidae). Kentucky Agricultural Experiment Station Bulletin 471. University of Kentucky. 19pp.

RITCHER, P O. 1945b. North American Cetoniinae with descriptions of larvae and keys to genera and species (Coleoptera : Scarabaeidae). Kentucky Agricultural Experiment Station Bulletin 476. University of Kentucky. 39pp.

RITCHER, P O. 1945c. Coprinae of eastern North America with descriptions of larvae and keys to genera and species (Coleoptera : Scarabaeidae). Kentucky Agricultural Experiment Station Bulletin 477. University of Kentucky. 23pp.

RITCHER, P O. 1947. Larvae of Geotrupinae with keys to tribes and genera (Coleoptera : Scarabaeidae). Kentucky Agricultural Experiment Station Bulletin 506. University of Kentucky. 27pp.

RITCHER, P O. 1966. Whitegrubs and their allies. A study of North American scarabaeoid larvae. Oregon State Monographs. Studies in Entomology No. 4. Oregon State University Press. 219pp.

RUSK, G D, PENNEFATHER, M and CRONJE, C A. 1992. Forestry costs in South Africa: 1991. Forestry Economics Services Document No. 28/1992. South African Timber Growers' Association.

RUSK, G D, PENNEFATHER, M and CRONJE, C A. 1993. Forestry costs in South Africa: 1992. Forestry Economics Services Document No. 39/1993. South African Timber Growers' Association.

RUSK, G D, PENNEFATHER, M and CRONJE, C A. 1994. Forestry costs in South Africa: 1993. Forestry Economics Services Document No. 49/1994. South African Timber Growers' Association.

SAHOO, A, ADHYA, T K, BHUYAN, S and SETHUNATHAN, N. 1993. Effect of moisture regime, temperature, and organic matter on soil persistence of carbosulfan. Bulletin of environmental contamination and toxicology 50(1). p29-34.

SCHöNAU, A P G. 1968. Annual Report of the Wattle Research Institute, 1967-1968. p17.

SCHöNAU, A P G. 1990. Role of eucalypt plantations in timber supply and forest conservation in sub-Saharan Africa. Proceedings of 19th IUFRO World Congress, Section 2. p311-319.

SCHöNAU, A P G, BODEN, D I and LOURENS, M J. 1980. Annual Report of the Wattle Research Institute, 1979-1980. p31-32.

SHERRY, S P. 1971. The black wattle, *Acacia mearnsii* de Wild. University of Natal Press. Pietermaritzburg. 402pp.

SHERRY, S P and SCHöNAU, A P G. 1966. Annual Report of the Wattle Research Institute, 1965-1966. p16-17.

SHETLAR, D J, SULEMAN, P E and GEORGIS, R. 1988. Irrigation and use of entomogenous nematodes, *Neoaplectana* spp. and *Heterorhabditis heliothidis* (Rhabditida: Steinernematidae and Heterorhabditidae) for control of Japanese beetle (Coleoptera: Scarabaeidae) grubs in turfgrass. Journal of Economic Entomology 81(5). p1318-1322.

SMITH, C W. 1994. Institute for Commercial Forestry Research. Pietermaritzburg. Personal communication.

SPAULL, V W. 1993. South African Sugar Association Experiment Station. Personal communication.

SPEERS, C F and SCHMIEGE, D C. 1961. White grubs in forest tree nurseries and plantations. United States Department of Agriculture Forest Pest Leaflet 63. 4pp.

STONE, C. 1993. Insect pest problems of eucalypt plantations in Australia. 2.New South Wales. Australian Forestry 56(4). p363-369.

STONE, J D and BUENO, R. 1987. Effect of larval density and soil type on the vertical distribution and survival of *Phyllophaga crinita*. The Southwestern Entomologist 12(2). p101-106.

SUTHERLAND, J R and GLOVER, S G. (Ed). 1991. Proceedings of the first meeting of IUFRO Working Party S2.07-09. Diseases and insects in forest nurseries. British Columbia. Canada. 298pp.

SUTHERLAND, J R and VAN EERDEN, E. 1980. Diseases and insect pests in British Columbia forest nurseries. British Columbia Ministry of Forests / Canadian Forestry Service, Joint Report No. 12. 55pp.

SWAIN, V M and PRINSLOO, G L. 1986. A list of phytophagous insects and mites on forest trees and shrubs in South Africa. Entomology Memoir No. 66. Department of Agriculture and Water Supply. Republic of South Africa. 91pp.

SWEENEY, C. 1967. The Scarabaeoidea associated with sugarcane in Swaziland. An account of preliminary investigations into the bionomics and control. August 1965 - June 1967. Swaziland Ministry of Agriculture Research Bulletin No. 16. 163pp.

TASHIRO, H. 1990. Insecta: Coleoptera Scarabaeidae larvae. In: DINDAL, D L. (Ed) Soil Biology Guide. John Wiley and Sons: New York. p1191-1209.

THOMSON, W T. 1992. Agricultural chemicals, Book 1 : Insecticides, acaricides and oricides. Thomson Publications. United States of America. 301pp.

VAN EEDEN, C F, VAN RENSBURG, J B J, and VAN DER LINDE T C de K. 1991. A check list of insects occurring in groundnut (*Arachis hypogaea*) fields in the Highveld Region. Phytophylactica 23. p255-259.

VAN EEDEN, C F, VAN RENSBURG, J B J, and VAN DER LINDE T C de K. 1994a. Nature and importance of subterranean insect damage to pre-harvest groundnuts. South African Journal of Plant and Soil 11(2). p59-63.

VAN EEDEN, C F, VAN RENSBURG, J B J, and VAN DER LINDE T C de K. 1994b. Damage caused by the false wireworm, *Somaticus angulatus* (Fahraeus) (Coleoptera: Tenebrionidae), to pre-harvest groundnuts in the greenhouse. Applied Plant Science 8(2). p57-60.

VEERESH, G K. 1977. Studies on the root grubs in Karnataka. U A S Monograph Series 2. University of Agricultural Sciences. Bangalore. India. 87pp.

VEERESH, G K. 1980. Larval taxonomy of white grubs with special reference to Melolonthine beetles. Final report of the ICAR ad-hoc project on larval taxonomy of Melolonthine beetles, 1977-1980. Hebbal Agricultural College. Bangalore. India. 93pp.

VILLANI, M G and WRIGHT, R J. 1988. Entomogenous nematodes as biological control agents of European chafer and Japanese beetle (Coleoptera: Scarabaeidae) larvae infesting turfgrass. Journal of Economic Entomology 81(2). p484-487.

WYLIE, F R and PETERS, B C. 1993. Insect pest problems of eucalypt plantations in Australia. 1.Queensland. Australian Forestry 56(4). p358-362.

APPENDIX 1 : TRIAL WG1

Name of company:	Mondi
Name of estate:	Mistley
District:	Seven Oaks
Province:	KwaZulu/Natal
Latitude:	29^0 12' 12" S
Longitude:	30^0 38' 24" E
Altitude:	1 110 m
Mean annual rainfall:	837 mm

Planting date: 23 - 25 October 1990

Soil Classification: Kranskop (Stonyhill 2100)

Description of soil profile in trial WG1:

HORIZON	DEPTH (cm)	FORM	% Particle Size Analysis			% Organic Carbon
			SAND	SILT	CLAY	
A1	0 -25	clay	42	16	42	3,005
A2	25 - 50	clay	40	19	41	2,633
B1	50 - 65	clay	40	18	42	2,263
B2	65 +	clay	32	21	47	1,880

Previous vegetative cover: wattle

Slash management and land preparation:
Slash was windrowed and burned, then manually pitted with a mattock and planted at an espacement of 3 m x 2 m.

Trial design: Randomised block with 12 treatments and six replicates for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Deltamethrin 5% SC (Bitam) at 1 ml
2. Deltamethrin 5% SC (Bitam) at 2 ml
3. Ethoprofos 20% EC (Exp. 05927A) at 1 ml
4. Alphamethrin 10% SC (Fastac) at 1 ml
5. Alphamethrin 10% SC (Fastac) at 5,5 ml
6. Carbosulfan 10% CRG (Marshall suSCon) at 10 g
7. Carbosulfan 10% CRG (Marshall suSCon) at 5 g
8. Cadusafos 10% G (Rugby) at 12 g
9. Cadusafos 10% G (Rugby) at 6 g
10. Chlorpyrifos 10% G (suSCon Blue/Green) at 10 g
11. Chlorpyrifos 10% G (suSCon Blue/Green) at 5 g
12. Gamma BHC 0,6% D (Bexadust) at 10 g

APPENDIX 2 : TRIAL WG2

Name of company:	Masonite
Name of estate:	Rustig
District:	Umvoti
Province:	KwaZulu/Natal
Latitude:	29^0 11' 55" S
Longitude:	30^0 27' 04" E
Altitude:	820 m
Mean annual rainfall:	774 mm

Planting date: 3 - 6 December 1990

Soil Classication: Hutton (Hayfield 2100)

Description of soil profile in trial WG2:

HORIZON	DEPTH (cm)	FORM	% Particle Size Analysis			% Oganic Carbon
			SAND	SILT	CLAY	
A1	0 -25	clay	18	26	56	2,195
A2/B1	25 - 40	clay	21	21	58	1,764
B1/B2	40	clay	19	23	58	1,485

Previous vegetative cover: wattle (harvested in September 1990)

Slash management and land preparation:
Slash was windrowed and burned, then ripped with a single tyne to a depth of 50 cm, into rows, 3 m apart. Seedlings were planted in the ripline at an espacement of 3 m by 2 m.

Trial design: Randomised block with 12 treatments and six replicates for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Deltamethrin 5% SC (Bitam) at 1 ml
2. Deltamethrin 5% SC (Bitam) at 2 ml
3. Ethoprofos 20% EC (Exp. 05927A) at 1 ml
4. Alphamethrin 10% SC (Fastac) at 1 ml
5. Alphamethrin 10% SC (Fastac) at 5.5 ml
6. Carbosulfan 10% CRG (Marshall suSCon) at 10 g
7. Carbosulfan 10% CRG (Marshall suSCon) at 5 g
8. Cadusafos 10% G (Rugby) at 12 g
9. Cadusafos 10% G (Rugby) at 6 g
10. Chlorpyrifos 10% G (suSCon Blue/Green) at 10 g
11. Chlorpyrifos 10% G (suSCon Blue/Green) at 5 g
12. Gamma BHC 0,6% D (Bexadust) at 10 g

APPENDIX 3 : TRIAL WG3

Name of company:	Mondi
Name of estate:	Garfield
District:	Melmoth (near Kataza)
Province:	KwaZulu/Natal
Latitude:	28^0 31' 50" S
Longitude:	31^0 17' 49" E
Altitude:	1050 m
Mean annual rainfall:	972 mm

Planting date: 10 - 12 December 1990
Weather overcast, soil moist from rain the previous week (about 40 mm)

Soil Classication: Kranskop

Soil Profile details: A1 depth 0-40 cm, Particle Size Analysis % clay: 30, % Organic C: 3,00 (C. Smith, personal communication)

Previous vegetative cover: wattle (harvested about September 1990)

Slash management and land preparation:
Slash was windrowed and burned the week before planting; unripped. Then manually pitted with a mattock and planted at an espacement of 2 m by 2 m.

Trial design: Randomised block with 12 treatments and six replicates for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rates product/tree):

1. Deltamethrin 5% SC (Bitam) at 1 ml
2. Deltamethrin 5% SC (Bitam) at 2 ml
3. Ethoprofos 20% EC (Exp. 05927A) at 1 ml
4. Alphamethrin 10% SC (Fastac) at 1 ml
5. Alphamethrin 10% SC (Fastac) at 5.5 ml
6. Carbosulfan 10% CRG (Marshall suSCon) at 10 g
7. Carbosulfan 10% CRG (Marshall suSCon) at 5 g
8. Cadusafos 10% G (Rugby) at 12 g
9. Isazofos 10% CRG (Miral) at 10g
10. Chlorpyrifos 10% G (suSCon Blue/Green) at 10 g
11. Chlorpyrifos 10% G (suSCon Blue/Green) at 5 g
12. Gamma BHC 0,6% D (Bexadust) at 10 g

APPENDIX 4 : TRIAL WG4

Name of company:	South African Wattle Growers Union
Name of estate:	Bloemendal Field Experiment Station
Compartment number:	Block 28C
District:	Pietermaritzburg
Province:	KwaZulu/Natal
Latitude:	29° 32' 38" S
Longitude:	30° 27' 57" E
Altitude:	930 m
Mean annual rainfall:	875 mm

Planting date: 14 - 16 January 1991
Extreme heat wave during planting, but good rains on completion of trial.

Soil Classication: Inanda

Description of soil profile in trial WG4:

HORIZON	DEPTH (cm)	FORM	% Particle Size Analysis			% Organic Carbon
			SAND	SILT	CLAY	
A1	0 -30	clay	2	30	68	4,519
B1	30 - 80	clay	1	29	70	3,258
B2	80 +	clay	1	24	75	2,661

Previous vegetative cover: 10 year old, harvested in November and December 1989

Slash management and land preparation:
Debris was windrowed and burnt. Larger slash was used to make a duiker proof fence around the trial. Then manually pitted with a mattock and planted.

Trial design: Randomised block with 8 treatments and six replicates for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Deltamethrin 5% SC (Bitam) at 2 ml
2. Ethoprofos 20% EC (Exp. 05927A) at 5 ml
3. Alphamethrin 10% SC (Fastac) at 1 ml
4. Alphamethrin 10% SC (Fastac) at 5,5 ml
5. Carbosulfan 10% CRG (Marshall suSCon) 10 g
6. Chlorpyrifos 10% G (suSCon Blue/Green) at 10 g
7. Cadusafos 10% G (Rugby) at 12 g
8. Gamma BHC 0,6% D (Bexadust) at 10 g

APPENDIX 5 : TRIAL WG5

Name of company:	Mondi
Name of estate:	Greenhill
District:	Richmond
Province:	KwaZulu/Natal
Latitude:	29° 49' 44" S
Longitude:	30° 17' 33" E
Altitude:	1020 m
Mean annual rainfall:	1019 mm
Planting date:	11 - 14 February 1991 Weather hot and sunny. Soil moist.
Soil Classication:	Hutton
Soil profile details:	A1 depth: 0-30 cm, Particle Size Analysis % clay: 40, % Organic Carbon : 2,00 (C. Smith, personal communication)
Previous vegetative cover:	wattle, harvested a long time back and left to weeds (tall, broadleaf and grasses).

Slash management and land preparation:
Weeds mowed but not disced, and pitted for planting at 3 m by 2 m.

Trial design: Randomised block with 8 treatments and six replicates for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Isazofos 10% CRG (Miral) at 10 g
2. Ethoprofos 20% EC (Exp. 05927A) at 5 ml
3. Alphamethrin 10% SC (Fastac) at 1 ml
4. Alphamethrin 10% SC (Fastac) at 5,5 ml
5. Carbosulfan 10% CRG (Marshall suSCon) at 10 g
6. Chlorpyrifos 10% G (suSCon Blue/Green) at 10 g
7. Cadusafos 10% G (Rugby) at 12 g
8. Gamma BHC 0,6% D (Bexadust) at 10 g

APPENDIX 6 : TRIAL WG6

Hilton:	Mondi's Mountain Home Estate
Name of company:	Mondi
Name of estate:	Mountain Home
District:	Hilton
Province:	KwaZulu/Natal
Latitude:	29^0 34' 34" S
Longitude:	30^0 16' 12" E
Altitude:	1560 m
Mean annual rainfall:	1 111 mm
Planting date:	14 - 15 March 1991 Weather cool and sunny/cloudy. Soil moist.
Soil Classication:	Inanda
Soil profile details:	A1 depth: 0-30 cm, Particle Size Analysis % clay: 50, % Organic carbon : 2,5 (C. Smith, personal communications)
Previous vegetative cover:	wattle, harvested in April 1990, and left to weeds

Slash management and land preparation:

The site was burnt after harvesting but left to weeds. Weeds were sprayed with herbicide prior to planting. Pitted for planting at 3 m by 2 m and weeds line cleaned.

Trial design:	Randomised block with 8 treatments and six replicates for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Isazofos 10% CRG (Miral) at 10 g
2. Ethoprofos 20% EC (Exp. 05927A) at 5 ml
3. Alphamethrin 10% SC (Fastac) at 1 ml
4. Alphamethrin 10% SC (Fastac) at 5,5 ml
5. Carbosulfan 10% CRG (Marshall suSCon) at 10 g
6. Chlorpyrifos 10% G (suSCon Blue/Green) at 10 g
7. Cadusafos 10% G (Rugby) 12 g
8. Gamma BHC 0,6% D (Bexadust) at 10 g

APPENDIX 7 : TRIAL WG7

Name of company:	Mondi
Name of estate:	Mistley
District:	Seven Oaks
Province:	KwaZulu/Natal
Latitude:	29⁰ 11' 26" S
Longitude:	30⁰ 40' 05" E
Altitude:	1 110 m
Mean annual rainfall:	754 mm

Planting date: 4 - 5 December 1991
Planted in and after good rain with good seedlings from Harden Heights Nursery.

Soil Classication: Magwa (Connemara 1200)

Description of soil profile in trial WG7:

HORIZON	DEPTH (cm)	FORM	% Particle Size Analysis			% Organic Carbon
			SAND	SILT	CLAY	
A1	0-40	sandy clay loam	48	24	28	2,068
B1	40-90	sandy clay loam	46	17	37	1,602

Previous vegetative cover: wattle, harvested in about March 1991.

Slash management and land preparation:
The brush rows were burnt in the spring of 1991. Then planted to wattle in October 1991; this was removed and new seedlings planted in the same pits, spaced at 3 m by 1,5 m.

Trial design: Randomised block with 5 treatments and ten replicates for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Gamma BHC 0,6% D (Bexadust) at 10 g
2. Deltamethrin 5% SC (Bitam) at 1 ml
3. Deltamethrin 5% SC (Bitam) at 0,5 ml
4. Deltamethrin 5% SC (Bitam) at 0,1 ml
5. Deltamethrin 5% SC (Bitam) at 0,25 ml

APPENDIX 8 : TRIAL WG8

Name of company:	South African Wattle Growers' Union
Name of estate:	Bloemendal Field Experiment Station
Compartment number:	20B2
District:	Pietermaritzburg
Province:	KwaZulu/Natal
Latitude:	29^0 33' 03" S
Longitude:	30^0 27' 15" E
Altitude:	840 m
Mean annual rainfall:	990 mm

Planting date: 13 - 16 January 1992

Soil Classication: Magwa

Description of soil profile in trial WG8:

HORIZON	DEPTH (cm)	FORM	% Particle Size Analysis			% Organic Carbon
			SAND	SILT	CLAY	
A1	0 -25	silty clay loam	10	50	40	4,027
B1	25 - 60	clay	3	37	60	3,036
B2	60 - 80	clay	4	40	56	2,322

Previous vegetative cover: wattle

Slash management and land preparation:

Debris was windrowed and burnt. Larger slash was used to make a duiker proof fence around the trial. Then manually pitted with a mattock and planted.

Trial design: Latin square with 5 treatments and 10 replicates; twice for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Gamma BHC 0,6% D (Bexadust) at 10 g
2. Deltamethrin 5% SC (Bitam) at 1 ml
3. Deltamethrin 5% SC (Bitam) at 0,5 ml
4. Deltamethrin 5% SC (Bitam) at 0,25 ml
5. Deltamethrin 5% SC (Bitam) at 0,10 ml

APPENDIX 9 : TRIAL WG9

Name of company:	South African Wattle Growers Union
Name of estate:	Bloemendal Field Experiment Station
Compartment number:	21B
District:	Pietermaritzburg
Province:	KwaZulu/Natal
Latitude:	29° 33' 11" S
Longitude:	30° 27' 20" E
Altitude:	900 m
Mean annual rainfall:	990 mm

Planting date: 19 - 21 October 1992

Soil Classication: Inanda

Description of soil profile in trial WG9:

HORIZON	DEPTH (cm)	FORM	% Particle Size Analysis			% Organic Carbon
			SAND	SILT	CLAY	
A1	0-30	silty clay	3	44	53	4,122
B1	30-50	clay	3	38	59	4,232

Previous vegetative cover: wattle

Slash management and land preparation:

Debris was windrowed and burnt. Larger slash was used to make a duiker proof fence around the trial. Then manually pitted with a mattock and planted.

Trial design: Latin square with 5 treatments and 10 replicates; twice for each of wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Gamma BHC 0,6% D (Bexadust) at 10 g
2. Carbosulfan 10% CRG (Marshall suSCon) at 10 g
3. Deltamethrin 5% SC (Bitam) at 1 ml
4. Deltamethrin 5% SC (Bitam) at 0,5 ml
5. Deltamethrin 5% SC (Bitam) at 0,25 ml

APPENDIX 10 : TRIAL WG10

Name of company: Mondi
Name of estate: Mistley
District: Seven Oaks
Province: KwaZulu/Natal
Latitude: 29^0 10' 50" S
Longitude: 30^0 39' 25" E
Altitude: 1020 m
Mean annual rainfall: 708 mm

Planting date: 26 - 28 October 1992

Soil Classication: Hutton (Lillieburn 1100)

Description of soil profile in trial WG10:

HORIZON	DEPTH (cm)	FORM	% Particle Size Analysis			% Organic Carbon
			SAND	SILT	CLAY	
A1	0 -25	clay loam	49	23	28	2.00
A2	25 - 50	sandy clay	49	15	36	1.72
B1	50 - 65	sandy clay	46	16	38	1.43
B2	65 +	clay	43	16	41	1.24

Previous vegetative cover: wattle

Slash management and land preparation:
The brush rows were burnt. New seedlings planted in pits, spaced at 3 m by 2 m.

Trial design: Latin square with 5 treatments and 10 replicates; twice for wattle and eucalypts. Each treatment plot has 16 trees (8 treated and 8 untreated trees).

Treatments (rate product/tree):

1. Gamma BHC 0,6% D (Bexadust) at 10 g
2. Carbosulfan 10% CRG (Marshall suSCon) at 10 g
3. Deltamethrin 5% SC (Bitam) at 1 ml
4. Deltamethrin 5% SC (Bitam) at 0,5 ml
5. Deltamethrin 5% SC (Bitam) at 0,25 ml