Status of seedling establishment pests of *Acacia mearnsii* De Wild. (Mimosaceae) in South Africa

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There are about 106 690 ha of *Acacia mearnsii* (wattle) plantations in South Africa. Wattle was previously grown mainly for the commercial potential of its bark (a source of tannin extract) but is now also managed on a short rotation for pulpwood. Clear-felled sites are continually being regenerated. Although considerable research has been done on the post-establishment insect pests of wattle, little is known about the incidence and status of seedling establishment pests. Fourteen trials were planted, on previous wattle sites, over six growing seasons from 1990/91 to 1999/00. Seedlings were evaluated monthly after planting for one year. Stressed, damaged and dead seedlings were uprooted and inspected to determine the cause of death. About 9% to 51% of seedlings failed to establish during wattle regeneration, and the incidence of damage by seedling pests ranged from about 2% to 30%. At sites where the plantation residue was windrowed and burnt, the average incidence of seedling establishment pests was about 20%, and the average total failure of wattle seedlings to establish was about 34%. Whitegrubs (larvae of Coleoptera: Scarabaeidae: Melolonthinae, Rutelinae) were the dominant and economically most important seedling establishment pests (average incidence of about 13%), followed by cutworms (larvae of Lepidoptera: Noctuidae) whose average incidence of about 4% was similar to that of grasshoppers (Orthoptera: Acrididae, Pyrgomorphidae) (about 2%) and millipedes (Diplopoda: Juliformia) (about 1%). Other seedling establishment pests included termites (Isoptera: Termitidae, Hodotermitidae), tipulid larvae (Diptera: Tipulidae), wireworms (Coleoptera: Elateridae), false wireworms (Coleoptera: Tenebrionidae), crickets (Orthoptera: Gryllidae), ants (Hymenoptera: Formicidae) and nematodes (Nematoda: Heteroderidae, Trichodoridae). Nematodes were sporadically important (about 12%) in an old arable wattle site. Although the prophylactic and corrective application of insecticides was widely used to control these pests at planting, their routine use in certified plantations now contravenes the Forest Stewardship Council guidelines.

Introduction

Acacia mearnsii De Wild. was first introduced into South Africa from Australia in about 1864.[1] It was primarily imported as a shade tree for livestock, for windbreaks and as a source of fuel wood on farms. It was only in 1884 that the commercial potential of wattle bark (a source of tannin extract) was exploited.[1] Commercial wattle plantations now cover 106 687 ha, despite a gradual decrease in the area under wattle of 1.3% per year during the last 20 years.[2] Wattle plantations are now grown and managed for pulpwood, mining timber, poles, bark extracts, charcoal, firewood and, to a lesser extent, for saw logs.

In all, 329 species of invertebrates, mainly insects, spiders and mites, are associated with wattle trees in South Africa,[3] and include 221 species that are phytophagous on wattle.[4] These phytophagous invertebrates represent various feeding guilds (leaf eaters, leaf miners, gallers, sap suckers, flower and bud feeders, seed insects, wood borers, shoot borers, bark feeders and root feeders) and belong to the orders Coleoptera (46.1%), Lepidoptera (35.7%), Hemiptera (11.8%), Isoptera (3.6%), Psocoptera (1.4%), Orthoptera (0.9%) and Thysanoptera (0.5%). All the insect pests that damage wattle in South Africa are indigenous. Most of them had a low pest status before colonizing and exploiting the rich resource provided by the exotic commercial wattle plantations.

There is a limited availability of land and water for agriculture in South Africa[5] and commercial forestry is often in intense competition with other agricultural crops for these valuable resources. To maximize yields in a limited area, there has been a corresponding shift from extensive to intensive silviculture[6] of wattle, hence a renewed interest in the management of wattle pests, especially seedling establishment pests that affect new transplants. Although a failure of seedlings to establish (variable value from about 17% to 31%) has been recorded[7–9] during the regeneration of wattle, the causes of this mortality were only vaguely known.

Annotated checklists of wattle pests have been compiled,[3,4,10,11] which reported on the general incidence of damage and associated pest species. Foresters often replaced dead seedlings when a mortality threshold of greater than 10% was observed. This practice of replanting was usually not coupled with any other corrective action because of a lack of understanding of the causes of mortality. In other instances, surviving and replanted seedlings were treated with an insecticide after mortality was observed. This reaction to seedling damage was often too late because of the seasonality of the pest or even unnecessary because the seedlings were already damaged or killed. There has also been a reluctance to use biological control as a strategy to manage wattle pests in the past because of the view[12] that these indigenous pests already have their complement of natural enemies and are therefore best controlled with the preventative or corrective use of insecticides. This general recommendation of the preventative use of a pesticide at planting is financially wasteful, short sighted (in terms of strategic planning and insecticide resistance management), environmentally hazardous and a practice that is prohibited by the Forest Stewardship Council (FSC) certification guidelines.[13]

The identity, pest status and biology of most plantation seedling establishment pests are poorly understood and in many cases unknown; this has precluded the identification of high-risk areas and the reasons for seedling establishment pest outbreaks. The study reported here fills some of these knowledge gaps and highlights the need for specialist pest management inputs during strategic planning of planting programmes in plantation forestry.

Material and methods

Fourteen multi-purpose trials were planted on previous wattle sites, over six growing seasons (1990/91 to 1999/00) to determine, amongst others, the mortality factors affecting the regeneration of wattle. Sites were selected so as to be representative of different plantation residue management practices.[14] Trial 1 (Seven Oaks: 29°12′S, 30°38′E), trial 2 (Umvoti: 29°11′S, 30°27′E), and trial 3 (Melmoth: 28°31′S, 31°17′E) were a randomized complete block design with 12 plots/block (20 trees/plot) in six blocks (1 440

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seedlings). Trial 4 (Pietermaritzburg: 29°32′S, 30°27′E), trial 5 (Richmond: 29°49′S, 30°17′E) and trial 6 (Hilton: 29°34′S, 30°16′E) were each a randomized complete-block design with eight plots/block (20 trees/plot) in six blocks (960 seedlings). Trial 7 (Seven Oaks: 29°11′S, 30°40′E) was a randomized complete-block design with five plots/block (20 trees/plot) in 10 blocks (1000 seedlings). Trial 8 (Pietermaritzburg: 29°33′S, 30°27′E), trial 9 (Pietermaritzburg: 29°33′S, 30°27′E) and trial 10 (Seven Oaks: 29°10′S, 30°39′E) were each two adjacent 5 × 5 Latin-square designs (20 trees/plot) (1000 seedlings). Trial 11 (Pietermaritzburg: 29°32′S, 30°28′E), trial 12 (Iswepe: 26°48′S, 30°37′E) and trial 13 (Iswepe: 26°48′S, 30°37′E) were each a randomized complete-block design of five tree species per block in four blocks with 100 trees/plot. Only one of the five tree species in each trial was wattle (400 seedlings). Trial 14 (Wakkerstroom: 27°21′S, 30°38′E) was a 5 × 5 Latin-square design of five tree species (plot) with 120 trees/plot, and only one of the five tree species was wattle (600 seedlings). Large trials with many trees per plot were planted because of the usual aggregated nature of soil invertebrate distributions.[15,16]

All wattle seedlings and subsequent surviving wattle seedlings were evaluated monthly for one year after planting. During each survey, all stressed, damaged and dead seedlings were dug out together with approximately 0.012 m^3 of the surrounding soil to determine the cause of death. A short frequency of the survey interval was chosen to aid detection of the pest, which also allowed for its associated damage to be recorded. With practice during repeated trial assessments, it became easier to recognize the damage caused by the various seedling establishment pests. Although these mortality factors were confirmed in most instances by the presence of the pest, it was also possible to include symptomatic damage in the diagnosis of mortality, especially when a pest was not present or was responsible for the deaths of several seedlings. Mortality was expressed as a percentage loss of establishment (number of stressed, damaged and dead seedlings per mortality category versus the total number of seedlings planted). The percentage loss of establishment because of damage by seedling establishment pests was equivalent to the percentage infestation of that pest. Although all mortality factors were determined, including an unknown category, only infestations by seedling establishment pests were evaluated in this paper because most other mortality factors can be overcome with a more careful application of existing silvicultural and nursery practices. It was not possible to determine the incidence of pathogens because most seedlings dried out during the monthly survey interval and the isolation for pathogens showed only saprophytes.

The usual practice during wattle regeneration is that residues from the previous harvest are windrowed and burnt and sites are weeded (manual or post-emergent herbicide spray). This residue regime was therefore used as the standard treatment to evaluate the status of seedling establishment pests. One-way ANOVA[17] was used to quantify differences between trials and the dependent mortality variables and the Tukey HSD test was used for all post-hoc analysis. The Statistica version 7 software program was used for analysis.[18]

A previous evaluation[14] of the effect of different plantation residue-management practices [windrowed-burnt-weeded, windrowed-burnt-ripped, fallow (mowed, manual weed), windrowed-burnt-closer spacing, windrowed-'broadcast'-herbicide] on the incidence of seedling establishment pests, allowed for the grouping of similar practices in Table 1. This further allowed for the change in status of seedling establishment pests during differing plantation residue management practices to be compared.

A pest database of extension visits and reported incidences of seedling damage (Pest & Diseases Database, 2002, unpublished data) was begun at the start of these experiments by the author. This was used to supplement the trial data in evaluating the status of seedling establishment pests and allowed for the inclusion of a discussion on pests that were not observed in the trial series.

Results and discussion

The incidence of damage by seedling establishment pests in the trials is shown in Table 1 and the status of the major groups is discussed below. The biology and control of these pests was reviewed in the light of knowledge gained while conducting this study and to collate information from numerous unpublished reports.

Whitegrubs (larvae of Coleoptera: Scarabaeidae: Rutelinae, Melolonthinae).

Status

Whitegrubs were the dominant and most important pests (ANOVA: $F_{9,70} = 31.1$, $P < 0.0000$) that affected the regeneration of wattle seedlings, causing significantly more mortality than any other category of pests (Table 1). An average of about 13% (range 9.2–18.9%) of wattle seedlings failed to establish because of whitegrub damage in sites where the plantation residue was windrowed and burnt. The incidence of whitegrub damage was markedly reduced when the plantation residue was windrowed, burnt and ripped or the site left fallow (average 0.7%) or when the seedlings were planted closer together (average 5.1%) (Table 1).

Biology

Whitegrub is the common name for larvae of several species of leaf chafer beetles (Coleoptera: Scarabaeidae: Rutelinae, Melolonthinae).[19] Adults of some species defoliate pine and wattle trees. Whitegrubs are C-shaped, have three pairs of well-developed thoracic legs, a sclerotized head and are whitish with a blue tinge where the gut shows through the distended abdominal body wall. Those associated with wattle are 2.6–36.0 mm long, varying according to age and species.[20] A particularly damaging species in the Natal Midlands of KwaZulu-Natal was the large wattle chafer, *Hypopholis sommeri* Burmeister, where both the adults and larvae were pests. Several species of whitegrubs have been recorded as either or both root feeders and defoliators of wattle, while many species remain undescribed. About 26 species of Scarabaeidae that attack wattle were initially recorded[3] and later[4] a further five species were added to the list. Some of the identifiable genera encountered in this study were *Anomala, Adoretus, Hypopholis, Maladera, Schizonycha,* and *Monochelus.*

Wattle scarabaeid larvae tend to occur in soils with a high organic content[21] because the early instars initially feed on organic matter in the soil and switch to root feeding during their second and third instars.[22] Whitegrubs are common during and after wattle rotations in the Natal Midlands.[23]

Eggs are laid in moist soil beneath the host plants, mainly from October to March. The eggs hatch after two to three weeks.[20] There are three larval stages before pupation in the soil. Some species, for example *Adoretus ictericus* Burmeister, have a one-year life cycle[24] but in other species, for example *H. sommeri* and *Schizonycha affinis* Boheman, the life cycle may take up to two years.[22] The resultant overlapping generations result in an almost continuous infestation,[11] which further adds to the economic importance of whitegrubs in the regeneration of wattle.

Damage

Whitegrubs ate the roots and sometimes ring-barked young seedlings up to the root collar region. This caused reduced growth and frequently the death of newly emerged or planted

Table 1. Percentage incidence of seedling establishment pests during the regeneration of wattle seedlings in South Africa. (Clustered according to the similarity of the plantation residue management regime.) (T1 to T 14: trials 1 to 14.)

Seedling establishment pest	Clustered plantation residue management regimes																	
	Windrowed-burnt-weeded; broadcast									Sign.[1]	Fallow; ripped				Espacement			Arable
	T 1	T 4	T 8	T 9	T 11	T 12	T 13	T 14	Avg (%)		T 2	T 5	T 6	Avg (%)	T 3	T 7	Avg (%)	T 10
Whitegrubs	10.70	18.90	10.60	12.89	13.70	9.17	9.17	15.10	12.50	a	0.94	0.88	0.28	0.70	4.73	5.39	5.06	2.37
Cutworms	0.53	0.75	2.97	1.77	11.08	7.00	6.29	1.39	3.97	b	1.96	0.57	1.79	1.44	2.52	1.33	1.93	1.76
Grasshoppers	0.00	0.00	0.00	0.67	2.63	10.3	2.00	1.39	2.12	b,c	0.00	0.14	0.08	0.07	0.00	0.17	0.09	0.74
Millipedes	0.59	3.32	1.78	0.55	0.00	3.75	1.54	0.00	1.44	b,c	0.11	0.17	0.00	0.09	0.88	0.00	0.44	0.33
Crickets	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.76	0.12	c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wireworms	0.00	0.21	0.00	0.29	0.00	0.00	0.13	0.00	0.08	c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66
Termites	0.00	0.14	0.00	0.08	0.25	0.00	0.00	0.00	0.06	c	0.04	0.00	0.00	0.01	0.00	0.17	0.09	0.00
Tipulid larvae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.04	c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nematodes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	c	0.00	0.00	0.00	0.00	0.38	0.00	0.19	11.60
Ants	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	c	0.11	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Total pest incidence (%)	11.82	23.27	15.37	16.41	27.63	30.21	19.13	18.89	20.34		3.16	1.76	2.15	2.36	8.51	7.06	7.79	17.44
Total loss of seedling establishment (all mortality factors) (%)	33.94	33.86	23.15	27.31	40.75	36.50	29.00	50.84	34.42		8.95	12.65	41.03	20.88	30.03	11.83	20.93	23.00

[1]Mortality factors with letters in common indicate no significant difference ($P > 0.01$). Avg, average.

wattle seedlings (especially when the root plug of container seedlings was devoured) (see Figs A–E in supplementary material online for pictures of progressive stages of seedling damage). Older saplings that developed sufficient lateral roots prior to whitegrub infestation were less affected and able to withstand subsequent whitegrub attack. However, it has been observed that those seedlings that were not killed during whitegrub attack generally had stunted growth and this made them more susceptible to frost damage during winter. Whitegrub damage of seedlings in the summer rainfall region began soon after planting (October to April), peaked in February, and diminished towards winter. Transplants are most susceptible to whitegrub damage during December to April.[21] Although numerous whitegrub larvae were present during winter, they were often deeper in the soil in response to soil moisture and temperature[16,25] and were below the root range of seedlings.

Control

Extensive trials have been conducted to evaluate the efficacy, formulations and method of application of insecticides to control whitegrubs at planting.[21,26–28] Three insecticidal treatments were subsequently registered for use against whitegrubs in forestry:[29] deltamethrin 5% SC applied as a drench at 0.025 g active ingredient (a.i.)/seedling at planting in 1 to 2 l of water, gamma BHC 0.6% DP applied around the root plug at 0.06 g a.i./seedling in the planting pit, and carbosulfan 10% CRG applied around the root plug at 1.0 g a.i./seedling in the planting pit. Chlorpyrifos 10% CRG applied around the root plug at planting at 1.0 g a.i./seedling was also effective in trials[21] but has not yet been registered for use against whitegrubs in forestry by its commercial agents. In line-sown wattle (where commercial seeds are sown into a drill line), it was proposed that gamma BHC 0.6% DP be sprinkled into the furrow at the rate of at least 11 kg per hectare and that nursery beds or sleeves be dusted at the rate of 30 g m^{-2} to achieve control of whitegrub.[20] The use of gamma BHC, an organochlorine insecticide, should, however, now be prohibited in terms of FSC regulations.[13]

Cutworms (larvae of Lepidoptera: Noctuidae)

Status

Cutworms were the second-most frequently recorded wattle seedling establishment pest and had similar average incidences to grasshoppers and millipedes (ANOVA: $F_{9,70} = 31.1$, $P < 0.0000$) (Table 1). Cutworm infestations in sites where the plantation residue was windrowed and burnt caused an average of about 4.0% (range 0.5–11.1%) damage to wattle seedlings but had about a threefold lower status than whitegrubs. Although at a lower incidence, cutworms were twice as common (1.4%) as whitegrubs (0.7%) in sites that were left fallow or ripped after being windrowed and burnt (Table 1), presumably because the greater weed biomass that developed during the unplanted interval, favoured the development of cutworm populations.

Biology

Cutworms are the caterpillars of numerous species of *Agrotis* moths (Lepidoptera: Noctuidae). *Agrotis segetum* (Denis & Schiffermüller) and *A. longidentifera* (Hampson) were observed to damage wattle seedlings in these trials. The mature caterpillars were about 35 mm long, dull greyish or brown in colour, lacked secondary setae (hairless, waxy appearance), and curled up into a tight ring when disturbed. The moths have nondescript greyish or brownish forewings and whitish hindwings, are strong nocturnal fliers, and are attracted to light.[22]

Eggs are laid singly or in clusters on the soil or host plants and hatch after 3 to 15 days. An adult female can lay 1000 to 2000 eggs. There are six larval instars lasting from 20 to 128 days and the pupal stage takes 9 to 45 days, both depending on the species and climate.[22] Hence there were from one to four generations during summer and seedlings were therefore susceptible throughout the planting season. Cutworms often over-wintered as larvae.

Damage

Soon after planting, cutworms severed the stems of seedlings at their bases at ground level, dragged them underground, and ate the leaves. Larvae tended to move from plant to plant along the row. Seedlings either died, became vulnerable to frost damage during winter, or growth was retarded for some time while coppicing. Older seedlings, where the bark on the stem had hardened, were often ring-barked at the root collar. Calloused tissue developed around the wound in actively growing seedlings and formed strongly elbowed stems that later broke; hence, cutworm damage had impacts beyond the establishment phase. Some damaged seedlings were out-competed by weeds and died or broke off in the wind. Young cutworm larvae could climb the stems and sever the tender branches of older seedlings. Older larvae tended to feed nocturnally at the root collar, and during the day they sought refuge in the soil or beneath debris around the bases of seedlings.

Cutworm damage was very common; a variable incidence of cutworm damage was observed in all sites irrespective of the plantation residue management regime (Table 1). Their higher average incidence in previously burnt sites was because fire broke the dormancy of wattle seed and resulted in a flush of wattle seedlings that were attractive to ovipositing moths. Poor weed control also appeared to aggravate cutworm damage, because the presence of weeds caused a build-up and supported a larger cutworm population. The earlier instars fed aerially on weeds before becoming subterranean[22] but when these weeds were removed after wattle regeneration, cutworms tended to concentrate their feeding on the newly planted seedlings. Cutworm damage occurred throughout summer into autumn. The younger the seedlings, the more prone they were to cutworm damage.

Control

The same insecticides, formulations and method of application of various insecticides for the control of whitegrubs were also tested against cutworms at planting.[21,26–28] Deltamethrin 5% SC applied as a drench at 0.025 g a.i./seedling in 1 to 2 l of water at planting was subsequently registered for use against both whitegrubs and cutworms in forestry. Several other insecticides are also registered for use against cutworms of other crops, for example, alpha-cypermethrin, beta-cyfluthrin, chlorpyrifos, cyfluthrin, cypermethrin, deltamethrin, endosulfan, esfenvalerate, fenvalerate, lambda-cyhalothrin, permethrin, quinalphos, sodium fluosilicate, tau-fluvalinate, tralomethrin and trichlorfon.[29] An application of these insecticides depends on their formulation, and includes pre- and post-emergence spraying, row application, aerial application and pre-emergence bait application at specified dosages. Spray treatments should preferably be applied when the top three to five centimetres of soil is moist.[29] The traditional practice of sprinkling gamma BHC dusting powder around the seedling[11] was ineffective against cutworms.[21]

Termites (Isoptera: Termitidae, Hodotermitidae)

Status

Termite damage was rare (average 0.06%) during the regeneration of wattle plantations (Table 1). However, when present, especially during first conversion from grassland to forestry, termites caused extensive damage to seedlings.[11]

Biology

Termites (Isoptera: Termitidae, Hodotermitidae) are social insects with four different castes. The fungus-growing termites, namely, *Macrotermes natalensis* (Haviland), *Macrotermes falciger* (Gerstäcker) and *Macrotermes mossambicus* (Hagen) usually caused the most damage.[12] Adult workers of the fungus grower termites gathered plant fibre and this digested vegetable matter, which was produced as faecal pellets formed the basis of a fungus garden that was constructed within the nest and was tended by workers. Termites appeared to be associated with deep, well-drained soils in warmer (north of 30°S, below 1300 m altitude) and drier areas (less than 900 mm mean annual rainfall).[30] *Macrotermes natalensis* was by far the most common species and their hard conical mounds were characteristic of the drier areas of KwaZulu-Natal and Mpumalanga. *Odontotermes* sp. was occasionally involved in damage of wattle along the south coast of KwaZulu-Natal but very rarely *Microtermes*.[11] *Hodotermes mossambicus* (Hagen) was also reported to cause damage to wattle in the Eastern Cape, KwaZulu-Natal and southeastern Mpumalanga.[3,10,11]

Damage

Termites ate the roots, root collar and bark of living plantation trees. Trees were ring-barked and the wood was whittled away so that the damaged tap and lateral roots had a tapered and roughly sand-papered appearance. Seedlings were killed and young wattle trees were attacked throughout the year for up to two years. Trees consequently could not be firmly anchored in the soil, and this led to wind throw and a resultant reduction in plant density.[11] Damage usually ceased when the canopy closed[31] and, although nests could survive canopy formation, damage to subsequent rotations was rare. Termite damage to wattle was extensive when trees were first planted in ex-grassland sites.[11] Termite activity could be detected before land preparation, not only by the presence of visible nests but also by the soil sheeting constructed over stumps, twigs, dry grass stems and dry cattle dung.

Control

Carbosulfan 10% CRG applied around the root plug in the planting pit at a rate of 1.00 g a.i./seedling is the only treatment registered for use against termites in forestry.[29] The exorbitant cost of carbosulfan and its limited availability in South Africa are two important limits on its application. The traditional practice of nest fumigation during or before land preparation[11] is not recommended because not all nests are visible above ground as mounds, and this practice also has an adverse environmental impact in that termites also serve a useful function in nutrient recycling. The seedlings themselves should rather be protected with insecticide until canopy closure, when the trees are no longer attacked.

Grasshoppers (Orthoptera: Acrididae, Pyrgomorphidae)

Status

Grasshoppers were sometimes recorded as a low occurrence (2%) pest of wattle seedlings (Table 1). A maximum of about 10% of seedlings were killed where the plantation residue was windrowed and only broadcast prior to planting, allowing grass and weeds to accumulate on the site. This allowed a build-up of grasshoppers and also the migration of grasshoppers from an adjacent site that was windrowed and burnt (Table 1). A more appropriate average incidence of grasshopper damage would be about 0.9%, when the result from the 'broadcast' site was excluded (Table 1).

During numerous extension visits, it was observed that grasshoppers increased in numbers during the period in between harvesting and replanting. Hence when these areas were treated with herbicide prior to planting, the resident orthopteran population concentrated its feeding on the wattle seedlings. This association with the weed ground cover was similar to that of cutworms and supported their similar pest status (Table 1).

Biology

Numerous species of phytophagous short-horned grasshoppers, for example *Duronia chloronota* (Stål) (Orthoptera: Acrididae), attack wattle seedlings[3] but the most commonly observed pest was the elegant grasshopper, *Zonocerus elegans* (Thunberg) (Orthoptera: Pyrgomorphidae). *Zonocerus elegans* was very common in sparse vegetation and often occurred on bare soil. They were aposematically coloured in red, yellow, green or blue and produced repugnatorial secretions.

Each female *Z. elegans* can lay about three egg packets (between 30 and 100 eggs per packet) in loose soil during late summer (March to April). These eggs overwinter and hatch when the temperature increases and after the first spring rains.[22] Nymphs and adults were present for about six months, coinciding with the planting season in the summer rainfall area. Therefore, the blanket treatment of competing vegetation and weeds with herbicides prior to planting coupled with the policy of minimum tillage[32] accentuated grasshopper damage of wattle seedlings.

Damage

Grasshoppers severed the young stems and branches of seedlings. In instances where the stem had been partly damaged, the stems often snapped off at these weak spots. Late detection of this type of damage could be confused with damage by cutworms or duiker browsing.

Control

Although no insecticides are registered for use against grasshoppers in forestry, several insecticides are registered for use against these pests affecting other crops.[29] Various formulations of carbaryl, for example, carbaryl 85% WP (wettable powder) at 127.5 g a.i./100 l water, sprayed from a knapsack applicator, can be used against the elegant grasshopper. Deltamethrin 5% SC at 0.15 g a.i./100 l water was used to control short-horned grasshoppers. It was reported that the tannins present in wattle leaves and stems have a toxic effect and exerted control on *Schistocerca gregaria* Forsk. in Morocco.[11]

Millipedes (Diplopoda: Juliformia)

Status

Millipedes were a recurrent but low status pest of wattle seedlings, with average damage of about 1.4% in sites where the plantation residue was windrowed and burnt. The highest incidence (3.8%) of millipede damage was recorded in the site where the plantation residue was broadcast (Table 1). Their status is likely to increase with the move towards the broadcasting of plantation residue because the accumulation of leaf litter following such practices favours their breeding.[33]

Biology

Millipedes (Diplopoda: Juliformia) were usually found in soil, debris, under stones or bark and often accumulated under brush piles in forestry. They were active after summer rains. Eggs were laid in small nests made of hard earth, over which the female kept guard. Several morphospecies have been observed but only the identity of *Orthoporoides pyrrocephalus* Krabb., which is widely distributed in localized areas of South Africa,[34] has been confirmed. *Orthoporoides pyrrocephalus* was reported to show little discrimination in its choice of food. However, there is a view that millipedes should not be regarded as pests of primary importance[34] and that in general they preferred plants already damaged (by other seedling establishment pests) and decayed plant tissue (by soil pathogens) as food. Millipede attack should therefore be construed as a symptom rather than a cause of damage.

Damage

There is still some uncertainty about the exact nature of the damage that millipedes caused. The roots of seedlings were damaged or destroyed, either mechanically by burrowing into the root plug, or by feeding. Where damage had already begun by other seedling establishment pests, millipedes were present in sufficient numbers to aggravate the injury. There have been reports that millipedes emerged from brush piles in summer and moved along the rows of seedlings, chewing the stems at or above soil level.[12] The stems were severed, or broken at the calloused wound or the seedlings were ring-barked (similar to cutworm damage). Similarly in western Nigeria, an *Odontopyge* species had been reported as a pest in nursery beds of *Gmelina arborea* Roxburgh (yemane trees) and *Tectona grandis* Linnaeus (teak trees) in the high forest zone, where it also destroyed young seedlings by eating through the stems.[35]

Control

Although no insecticides are registered for use against millipedes in forestry, a bait formulation was registered for use against this pest in other crops.[29] Methiocarb 80% WP can be prepared as a soft porridge bait at 200 g a.i./bait mixture (with 10 kg bran and 15 l water). This bait was strategically distributed in the field during the late afternoon when the pests became active.

Nematodes (Nematoda: Heteroderidae, Trichodoridae)

Status

Nematodes were not normally encountered as pests of wattle (in 2 of 14 trials) but when present in large numbers, especially on old arable land, they caused extensive damage (12%) (Table 1). An accurate estimation of the status of nematodes was difficult because wattle seedlings were seldom killed but showed stunted growth with sparse and chlorotic foliage, which could also be attributed to other silvicultural causes.

Biology

The plant parasitic nematodes (Nematoda), commonly called eelworms, are microscopic, slender, transparent worms living in the soil. Most are free-living and feed on the roots of plants, while others are parasitic in the roots. *Meloidogyne javanica* (Treub) (Heteroderidae) caused root knots, wherein the females are obligate parasites.[11] *Paratrichodorus* (Trichodoridae) was another debilitating ectoparasitic nematode that accumulated at and fed on the growing tips of roots, resulting in root necrosis and terminal thickening of the roots. Other genera found attacking wattle seedlings included *Pratylenchus, Helicotylenchus* and *Xiphinema.*[28]

Damage

Plant parasitic nematodes seldom killed the plant but debilitated it, and fungal pathogens may gain access through the lesions they cause. Nematodes damaged the roots of seedlings, which interferes with the normal functioning of the root system and this caused stunted growth. Damage by *M. javanica* resulted in the formation of small nodules, galls or knots that were different to the nitrogen-fixing rhizobium nodules, which had distinct stalks.

Control

Although no nematicides are registered for use in forestry, aldicarb 15% GR applied at the rate of 0.75 g a.i./m^2, is registered for use against this pest affecting other crops.[29] Aldicarb, like most systemic nematicides, may be phytotoxic, so caution needs to be exercised in trying to adapt this recommendation for use in forestry. Carbosulfan 10% CRG at 1 g a.i./seedling, although not registered against nematodes in forestry, effectively controlled nematodes under experimental conditions.[28] Nematode damage was more prevalent in sandy soils with a low organic content but when the humic content of the soil had been built up by the broadcasting of plantation residue, wattle seedlings were seldom affected by nematodes.[11] Decomposition of organic matter promoted the build-up of nematophagous fungi and predatory nematodes that can suppress parasitic nematode populations.[36]

Tipulid larvae (Larvae of Diptera: Tipulidae)

Status

Tipulid larvae were very infrequent, low status pests of wattle seedlings. In only one out of 14 trials was tipulid larval damage (actual infestation of 0.3%, average 0.04%) recorded during the regeneration of wattle plantations (Table 1).

Biology

Tipulid or crane fly larvae (Diptera: Tipulidae), commonly called 'leather jackets', were seldom encountered as pests. However, the larvae of some soil-inhabiting species can be destructive feeders on subterranean parts of plants.[19] *Nephrotoma* spp. have been recorded in association with wattle in South Africa.[3] *Nephrotoma sodalis* Loew stripped the bark from the roots of *Pinus strobus* Linnaeus seedlings and was recorded as a pest in North America.[35] *Tipula paludosa* Meigen is an introduced pest that attacks white spruce seedlings in the coastal areas of British Columbia.[37]

Damage

Tipulid larvae girdled the stem above and below the soil line, thereby affecting water transport to the shoots. They also consumed some of the upper roots.

Control

No control measures have been developed for tipulid larvae in South Africa. Tipulid larvae have survived in fallow moist soil by feeding on decaying seedling roots and weed roots in British Columbia; so larvae are susceptible to desiccation.[37] Discing or shallow ripping of the soil and keeping a site weed free would reduce tipulid larvae infestations.

Wireworms and false wireworms (Coleoptera: Elateridae, Tenebrionidae)

Status

Wireworms were low status, occasional pests of wattle seedlings, especially in sites where the plantation residue was windrowed and burnt. The average incidence of wireworm damage was 0.08% with a maximum of 0.7% in an old arable site (Table 1).

Biology

Four species of wireworms (Coleoptera: Elateridae) were listed as being associated with wattle, but only the larvae of *Agriotes* spp. were recorded as a pest of wattle seedlings.[3] The larvae of some species of *Agriotes* are major agricultural pests in Europe and the United States but only occasionally attacked the roots of wheat and potato tubers in South Africa.[19]

False wireworm larvae (Coleoptera: Tenebrionidae) are pests on the roots of various cultivated crops in South Africa.[19] The larvae of *Somaticus varicollis varicollis* Koch and adults and larvae of *Gonocephalum simplex* (Fabricus) are pests of maize in KwaZulu-Natal.[38] *Gonocephalum simplex* has also been recorded on a wide spectrum of field crops in Zimbabwe.[39] Larvae of *Somaticus angulatus* Fahraeus were regarded as one of the most economically important pests of maize and groundnuts in South Africa.[40–42] Hence the occurrence of wireworm and false wireworm damage can be expected in new afforestation of ex-arable lands. Although many of the species found in agricultural lands are known, the species present in forestry soils still requires identification.

Damage

Adult tenebrionids chewed the bark off stems and sometimes wattle seedlings were ring-barked at ground level, whereas the larvae damaged the subterranean parts of seedlings, especially the roots.

Control

No insecticides are registered for use in forestry. However, gamma BHC 0.6% DP applied at a rate of 40 kg/ha for wireworm and false wireworm larvae, and quinalphos 0.5% RB applied at 5 kg/ha for adult tenebrionids, are registered for use against these pests in other crops.[29]

Crickets (Orthoptera: Gryllidae)

Status

Crickets were low status, occasional pests of wattle seedlings. The incidence of damage averaged about 0.1%, with a maximum of 0.8% in sites that were windrowed and burnt (Table 1). Most instances of cricket damage occurred during dry conditions following broad-spectrum herbicide applications.

Biology

Crickets (Orthoptera: Gryllidae) are widespread, nocturnal insects that live in and on the ground, under stones or logs or among fallen leaves by day, emerging at night to feed on seedlings of cultivated crops.[19] The shiny black cricket, *Gryllus bimaculatus* de Geer, is about 25 mm long and usually has a conspicuous yellowish mark on either side at the base of the forewing. *Brachytrypes membranaceus* (Drury) has also been identified as damaging to wattle plantations.[3]

Damage

Crickets stripped the bark off the stems of seedlings at ground level and fed on the underlying tissue. Late detection diagnosis presented as a dried, frayed and ring-barked stem.

Control

Although no insecticides are registered for use against crickets in forestry, mercaptothion 50% EC at 12.5 g a.i./10 l water, as a full-cover spray, is registered for use in ornamental plants, flowers and lawns against crickets.[29]

Ants (Hymenoptera: Formicidae)

Status

In only one trial ants were implicated in the indirect mortality of regenerated wattle seedlings, with an infestation of 0.1% (Table 1).

Biology

While *Anoplolepis custodiens* Smith (Hymenoptera: Formicidae) was usually associated with honeydew secreting scale insects on wattle,[3] *Myrmicaria natalensis* (Smith) was observed to mine soil from the planting pits of wattle seedlings.

Damage

Ants were observed to mine the soil from seedling planting pits, thereby creating air pockets around the root plug.

Control

No control measures are warranted.

Other wattle establishment pests

Several other pests that were recorded over a 14-year period from extension visits and samples submitted for diagnosis or identification (Pest & Diseases Database, 2002, unpublished data), affected the establishment of wattle seedlings, but were not encountered in this study. Adults of various leaf beetles

(Coleoptera: Chrysomelidae), for example *Peploptera curvilinae* Jacoby, *Colasposoma semihursutum* Jacoby, and several closely related species defoliated wattle seedlings, whereas their larvae fed on the roots. Curculionid adults of *Ellimenistes laesicollis* Fåhraeus, *Catamonus melancholicus* Boheman and *Protostrophus lugubris* Marshall defoliated and chewed the bark of wattle seedlings, causing the stems to break. The brown wattle mirid, *Lygidolon laevigatum* Reuter (Hemiptera: Miridae), also caused serious defoliation of wattle seedlings.

Damage by seedling establishment pests created wounds, which permitted the entry of fungal pathogens, for example, *Fusarium* spp., *Phytophthora* spp. and *Cylindrocladium* spp. (Pest & Diseases Database, 2002, unpublished data) or seedlings became stressed and secondary pathogen invasion caused their death. Factors that impeded rapid growth such as poor site quality, drought, frost and weed competition also increased exposure to and delayed the recovery from insect pests and diseases.[43]

Conclusions

About 14 broad groupings of various species of indigenous pests were identified as the cause of about 60% of the mortality of wattle seedlings during regeneration. Whitegrubs were the dominant pests, that represented an average of about 65% of the total pest incidence. The type of damage they inflicted on wattle seedlings often led to mortality and further contributed to their economic importance. Other less important pests of equivalent status included the cutworms, grasshoppers and millipedes, which accounted for 5–20% of the total pest incidence. An insecticide for the combined treatment of whitegrubs and cutworms at planting was registered for use in forestry but the issues of insecticide resistance management and the prophylactic use of insecticides in certified forests still requires attention.

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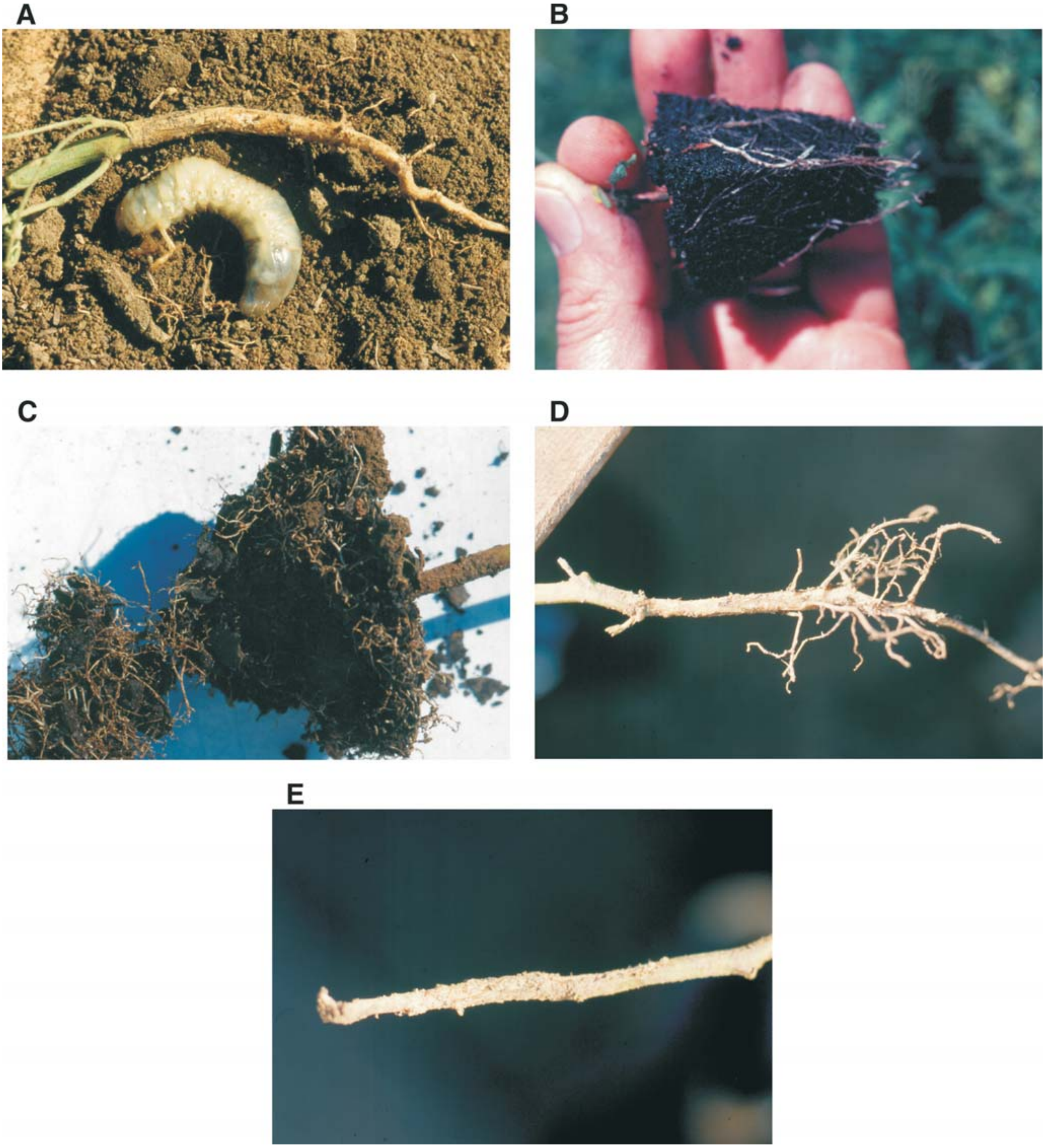
Supplementary material to:

Govender P. (2007). Status of seedling establishment pests of *Acacia mearnsii* De Wild. (Mimosaceae) in South Africa. *S. Afr. J. Sci.* **103**, 141–147.



Figs A–E. Whitegrubs were the dominant and most important pest that affected the regeneration of wattle seedlings. These pictures illustrate progressive stages of the damage they caused to the roots of seedlings. **A**, Whitegrub and associated damage to the roots of a wattle seedling; **B**, intact rootplug of a container-grown wattle transplant; **C**, intermediate whitegrub damage to a wattle rootplug; **D**, absence of fine roots because of whitegrub feeding on a wattle seedling; **E**, extensive and repeated feeding by whitegrub larvae that have resulted in the seedling being stripped off its roots.