

Efficacy of cultural control measures against the banana weevil, *Cosmopolites sordidus* (Germar), in South Africa

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Abstract

The banana weevil, *Cosmopolites sordidus*, is the most important insect pest of banana and plantain in the world. Cultural control methods were investigated over 2 years in southern KwaZulu-Natal, South Africa. Harvesting at ground level and dissection of remnants (treatment 1), and covering the base of the mat (entire plant consisting of several meristems) with soil and moving debris to the inter-row (treatment 2), were compared to a positive control that involved treatment of plants with a registered pesticide (treatment 3), and a negative control that involved harvesting at 150 cm from the collar with no soil or sanitation amendments (treatment 4). Yield, weevil damage and pseudostem girth of plants were measured from August to November annually, while adult beetle densities were assessed over 4 weeks in October/November and April. Nematode samples were taken and analysed in October/November every year. Damage parameters included the coefficient of infestation, the percentage coefficient of infestation (PCI) at two intervals, the summed PCI value, the percentage cross-sectional damage of the central cylinder and cortex, and the mean cross-sectional damage percentage. A randomized block design with three replicates was used in the trial. The parameters were similar before the onset of the trial. Fruit yield and plant girth, corrected by nematode densities, were not significantly different in any treatment, nor were the nematodes controlled. Soil cover and recession of remnants was the only effective treatment, significantly reducing the CI, but not the adult density or the other damage parameters. Soil cover showed promise as a cultural control method because it only needs to be applied

seasonally and reduced the percentage cross-sectional damage of the central cylinder, the damage parameter most closely related to yield, by 14%.

Introduction

The banana weevil, *Cosmopolites sordidus* (Germar) (Col., Curculionidae), is a major insect pest of banana and plantain in the world (Waterhouse and Norris 1987; Gold et al. 1999). Eggs are usually laid at ground level (Franzmann 1972) in the crown of the rhizome and pseudostem base (Abera et al. 1999). The larvae tunnel into the rhizome and occasionally the pseudostem, interfering with root initiation (Treverrow et al. 1992), plant nutrition (Chavarria-Carvajal and Irizarry 1997) and water transport (Collins et al. 1991), resulting in plant stunting, delayed maturation (Gold et al. 1998), reduced fruit size and bunch weight, and even plant snapping or toppling (Batchelder 1954; Franzmann 1972; Koppenhofer 1993; Rukazambuga 1996). Interior corm damage possibly affects nutrient transport and stem growth (Taylor 1991), while peripheral damage may adversely affect root development (Gold et al. 1994). Morphological and physiological symptoms of infested plants include reduced vigour, leaf chlorosis (Franzmann

1972), choking of the bunch in the pseudostem (Pinese and Elder 2004), decreased vigour of followers (Rukazambuga 1996) and a different proportion of water suckers (Gold et al. 1999). Infestation by banana root nematodes can show similar plant symptoms, including a reduction in vigour, leaf chlorosis, plant toppling and yield reduction (Bujulu et al. 1983; Smith 1995; Willers et al. 2001). Adult weevils feed on plant tissues or crop debris but the resultant damage is considered negligible (Franzmann 1972; Treverrow et al. 1992). In established fields, weevils are patchy distributed (Treverrow et al. 1992), normally move less than 10 m per month (Gold et al. 1999), and only a small proportion will move more than 25 m in 6 months (Gold and Messiaen 2000).

Cultural control is an important strategy for managing the banana weevil in subsistence and organic farming systems (Simmonds 1959). It is based on the manipulation of the weevil habitat to adversely affect the pest and promote the banana plant. Cultural control is applied at the crop establishment (preventative control) and crop management (curative control) stages. The former includes using uninfested plants as propagating material to prevent the spread of the weevil and reduce damage, as eggs and larvae can be disseminated in infested planting material. If suckers are used, rhizomes should be pared (Franzmann 1972; Fogain et al. 2002). Hot water treatment of suckers is also recommended (Gettman et al. 1992), but the relatively long time required (3 h) to mitigate weevil larvae may discourage its use (Gold et al. 1998). In South Africa, commercial growers mainly use in vitro planting material (Robinson 1996). Tissue culture plants are free of banana weevils and nematodes (Robinson 1996), making them ideal to 'start clean, stay clean' (Peasley and Treverrow 1986). All banana plant material should be removed from fields to be replanted and left fallow or used for annual crops for a minimum of 1 year (Seshu Reddy et al. 1993), but 18 months or 2 years are preferred (Treverrow et al. 1992). New plantings should preferably be made in virgin soil and/or removed from infested fields. Deep planting (45–60 cm) delays weevil infestation rates and lowers weevil

incidence (Seshu Reddy et al. 1993). *Tephrosia* spp. and neem (*Azadirachta indica* A. Juss.) have a repellent effect (Walangululu et al. 1993), while the latter also negatively affects the physiology of the weevil (Musabyimana et al. 2001), thereby helping to delay infestation rates of new plantings (Musabyimana 1999; Fogain et al. 2002). Intercropping with coffee has also been reported to reduce weevil numbers, although the mechanism of action is unclear (Kehe 1988). Susceptible banana cultivars and residues can serve as trap crops in multi-cultivar stands (Masanza 2003).

High weevil densities and inadequate fallow periods in local commercial systems may lead to infestation of new plants by adults surviving in old residual plant remnants. The growing habits (Robinson 1996) and susceptibility of *in vitro* plants to *C. sordidus* may negate their advantage (Nuno and Ribeiro 2002). Deep planting is labour intensive and under these conditions some plant varieties (e.g. plantains) will produce a new rhizome above the previous one (Seshu Reddy et al. 1993). High rates of powdered neem are phytotoxic (Musabyimana et al. 2000) and it is not effective as a curative treatment (Fogain et al. 2002). Moreover, intercropping can reduce banana yield (Uronu 1992) and is troublesome due to the closing of the banana canopy (Seshu Reddy et al. 1993). Most of the mechanisms by which diversified systems can reduce herbivore attack, including higher efficacy of natural enemies, effects on immigration/emigration rates and modification of the micro-environment, are not relevant to the banana weevil (Gold et al. 1999).

Locally, cultural control is more applicable at the crop management stage. Covering the base of stools with soil mounds up to 30 cm high was associated with low weevil infestations in the Ivory Coast (Kehe 1988). The additional soil assists in delaying high mat formation and provides a firm anchorage for the plant (Seshu Reddy et al. 1999), which can have additional benefits in terms of yield by reducing toppling and optimizing nutrient uptake. In Uganda, plants harvested low and covered with soil had lower oviposition (four times less) compared to uncovered plants during the wet season, although the dry season showed a 73% higher oviposition rate between the treatments (Masanza 2003). Felling pseudostems at ground level (Simmonds 1959; Anneck and Moran 1982) and diligent crop hygiene, the destruction or removal of accumulating crop trash and fallen plants, are also recommended to minimize additional sheltering and breeding sites of *C. sordidus* (Peasley and Treverrow 1986; Collins et al. 1991; Treverrow et al. 1992; Fogain et al. 2002). Desiccation rate is enhanced by cutting debris along the longitudinal axis (Treverrow et al. 1992). The rationale for low harvesting of plants is to accelerate desiccation of residues, a condition unfavourable for weevil development. Harvesting low has however been shown to impact negatively on yield by reducing bunch mass (Daniells and O'Farrell 1987). Some nutrients may be lost to a plant from using harvested pseudostems for mulch as opposed to senesced pseudostems that may 'feed' followers through direct nutrient translocation (Wortman et al. 1994). The area around plants should be free of trash and remnants should be placed in the inter-row (Stanton 1994) to attract adults away and reduce surface moisture at the base of the plant. Recession of the mulch to more than 1 m from the pseudostem compared to mulching to the base of the pseudostem over a 3-year period in Uganda, however, did not significantly reduce weevil density or damage to the plant (McIntyre et al. 2003). In Australia, dissection of pseudostems and raking mulch into the mid-row three to four times per year also did not result in a reduction of weevil adults or damage over 3 years (Smith 1995).

The efficacy of cultural control is not well understood and has not been evaluated under local conditions. The aim of the study was to quantify the efficacy of covering the base of banana stools with soil, alternate felling heights and sanitation on weevil population and damage in South Africa. The cultural control treatments were compared to treatment of plants with a chemical (aldicarb) registered for nematode and weevil control in South Africa.

Materials and Methods

Research site

The commercial banana industry in South Africa is based on the production of the Cavendish subgroup of banana cultivars (AAA). Desuckering is used to maintain optimal banana plant density and manageability, and single followers (suckers) are selected between 5 and 10 months after planting, with direction of selection uniform to maintain spatial arrangement (Robinson 1996). In the South Coast region of KwaZulu-Natal, sucker selections are usually made against slopes. Time from planting to harvest varies between 15 and 20 months and harvest-to-harvest from 11 to 13 months (Robinson 1996). As in other banana cropping systems, older ratoon stands are harvested throughout the year. The fruit is cut green and pseudostems felled at approximately 1 to 1.5 m height and left in situ. Each plant (or mat) therefore consists of a harvested stump(s), mother plant (flowering or bunch bearing) and one or two daughter suckers (pre-flowering followers). Plantation care in commercial operations usually also includes irrigation, weed control (herbicides) and leaf removal. Bunches are covered with perforated blue polyethylene bags and plants may be propped. Residual banana materials (mainly leaves) are used as mulch, usually spread randomly within the plantation.

The banana weevil cultural control trial was conducted on a commercial farm at the South Coast of KwaZulu-Natal, South Africa. Soil in the area is a Glenrosa form, with an orthic A and lithocutanic B zone. It is a sandy loam soil with 16% clay, 30% loam and 54% sand (Dochez 1998). The trial site was in Ramsgate (30°52'33'S; 30°19'28'E), 130 m above sea level. The trial was conducted from August 2003 to November 2005. The site is in a summer rainfall area (750–1000 mm per year), and during the trial the ambient temperature ranged from 12 to 25°C. The Cavendish cultivar, Grand Nain (AAA group), was grown at the trial, planted in November 2000 at a density of 2222 plants ha⁻¹ (3 m between rows × 1.5 m between plants). High mat was evident in the plantation, with the collar (junction between pseudostem and rhizome) commonly more than 10 cm above ground level. The plantation was sprinkler irrigated with 2 cm water per week, a practice only suspended if rainfall exceeded that value in the particular week. The site was treated at planting with the oxime carbamate, aldicarb (Temik 15% GR), at the registered dosage of 2.025 g.a.i./mat, to provide nematode and weevil control (Nel et al. 2002; Anonymous 2005). Regular chemical weed control with glyphosate (Roundup), leaf removal, desuckering and propping of bunch-bearing plants were practised. Pre-trial plant inspections revealed light to moderate rhizome tunnel damage by *C. sordidus*.

Trial design

Four treatments were compared: harvesting at ground level and longitudinal dissection of all remnants (including the harvested stump and any old decayed stumps) (treatment 1), covering the base of the mat with soil up to 30 cm from the collar and moving all debris to the inter-row (treatment 2), application of aldicarb at the registered dosage (treatment 3) and the standard practice of harvesting at 1.5 m with no debris management or covering of the mat (treatment 4 – control). The mat in treatment 2 consisted of a 1.5 m high harvested stump, one (two in the second season of the study) old decayed stump(s) of previous retons, the mother plant and daughter sucker(s). The layout of the trial followed a randomized block design with three replicates. Each plot consisted of 72 plants (6 rows and 12 plants per row; 324 m²). The layout and design of the trial was similar to that of Smith (1995) and McIntyre et al. (2003), but used more plants per plot and also included a 6-m barrier area between plots. To standardize for abiotic influences, replicates were orientated perpendicular to the sea/land breeze and moisture gradient in the field. Weevil flight is very rare and natural adult dispersal slow (Simmonds 1959; Treverrow et al. 1992; Gold et al. 1999; Gold and Messiaen 2000). Pre-trial yield, plant girth, nematode counts, adult weevil numbers and larval damage sampling was carried out to ensure homogenous damage levels between plots at the onset of the trial. It was assumed that adult migration caused no significant effects on the outcome of the trial. A similar trial design used for a chemical study provided significant treatment effects between pesticides and controls in terms of damage parameters and adult numbers (J. de Graaf, A. S. Schoeman, P. Govender, A. Viljoen, unpublished data; SA Patent Application Number 2007/01262), supporting the assumption that adult migration does not mask effective treatment.

The cultural treatments were maintained monthly in summer and bi-monthly in winter (soil cover was maintained seasonally) and the chemical applied to the soil, as recommended by the manufacturers, in October/November and March. Yield, damage parameters and pseudostem girth of plants felled during a 3-month period (August–November) in 2003 to 2005 were measured, while adult densities were assessed over 4 weeks in October/November (2003–2005) and April (2004–2005). To consider the effect of nematode damage on research results, nematode samples were analysed in October/November 2003–2005. Root samples were collected from three randomly selected mother plants per plot, and sent to the ARC – Institute for Tropical and Subtropical Crops (Nelspruit, Mpumalanga) – where 30 g of roots (randomly selected per plot) were examined for nematodes. The initial data were recorded before any of the treatments were applied.

Yield was determined at the pack-house by weighing of bananas (bunches excluding the peduncle). Mother plants were sampled for weevil damage and girth within a week of harvest. The coefficient of infestation (CI) was determined by paring the corm and scoring the proportion of the rhizome circumference with weevil galleries (Vilardebo 1973). Intervals of 2.5% were included up to a level of 10% damage. Damage was also rated by the percentage coefficient of infestation (PCI) (Mitchell 1978, 1980), which involved scoring the presence/absence of peripheral damage for ten sections, each covering 18° of the corm surface. The latter was determined at 5 cm

(Gold et al. 1994) and between 5 and 20 cm from the collar. These two PCI values were summed to provide a total PCI value. A cross section of the corm was made at 10 cm from the collar and the percentage damage of the cortex (XO) and central cylinder (XI) scored at 10% intervals, using a transparent circular grid divided into 36° sections (modified from Gold et al. 1994; Kiggundu 2000). The two cross section values were averaged to provide the mean cross-sectional damage (X mean). The circumference of harvested plants was measured at 100 cm from the collar.

Three split-pseudostem traps, placed individually next to three plants in the middle of each plot (traps between plots separated by a minimum of 20 m), were used to sample adult numbers at the base of plants. Trap material was randomly selected from plants harvested within 2 weeks before trap preparation at a plantation similar to but isolated (by a dirt road) from the specific trial site. Only one trap was prepared from each plant and pseudostems with internal damage/tunnels were discarded. Pseudostem traps were 30 cm in length (pseudostem section 30–60 cm above the collar), bisected longitudinally and each half placed (with the cut surface ventrally) directly next to the mat of the plant. The two halves were placed on opposite sides of the mat and regarded as one trap. The split pseudostems were covered with mulch to delay desiccation and decomposition. Traps were replaced once a week, when the samples per trap were counted and destroyed.

Statistical analysis

Analysis of covariance (ancova) (Sokal and Rohlf 1997) was used to quantify yield and girth over time, among treatments and between the interactions of time and treatment. The nematode numbers of all the species were combined and entered as a covariate. Nematode densities over time and between treatments were ascertained by factorial anova, while the pre-treatment densities were compared by one-way anova (Sokal and Rohlf 1997). The seven parameters used for damage estimation were compared over time, between treatments and among the interactions of time and treatment using repeated measures anova. One-way anova (Sokal and Rohlf 1997) was used to ascertain pre-trial differences in adult densities. Differences of adult densities over time, between treatments and between the interactions of the independent variables were determined by factorial anova (Sokal and Rohlf 1997). The Tukey HSD test (Sokal and Rohlf 1997) was used for all post hoc analysis. Percentage data were arcsine-transformed for statistical analysis and back-transformed before presentation. The statistica Version 7 (Statsoft Inc. 2004) software program was used for analysis.

Results

Yield, girth and nematodes

No differences were found in yield ($F_{3,7} = 0.14$, $P = 0.934$) or plant girth ($F_{3,7} = 0.65$, $P = 0.607$) between plots before the onset of the trial (spring 2003). The initial nematode densities between plots were also similar ($F_{3,8} = 0.07$, $P = 0.973$). While the average bunch weight increased from 2004 [29.7 ± 0.5 (SE) kg per bunch] to 2005

[32.1 ± 0.82 (SE) kg per bunch], no significant difference in yield was found ($F_{1,15} = 4.40$, $P = 0.053$). The bunch yield for the different treatments (range: 30.6–31.1 kg per bunch) was similar ($F_{3,15} = 0.01$, $P = 0.998$) and no interaction between the independent variables was found ($F_{3,15} = 0.29$, $P = 0.835$). Plant girth showed no significant effect of time [2004: 67.2 ± 0.8 (SE) cm, 2005: 67.8 ± 0.8 (SE) cm] ($F_{1,15} = 0.06$, $P = 0.809$), treatment (range: 66.6–68.7 cm) ($F_{3,15} = 1.61$, $P = 0.229$), or interaction between time and treatment ($F_{3,15} = 0.57$, $P = 0.642$).

The density of the nematode complex was similar in October/November of 2004 and 2005 ($F_{1,16} = 0.46$, $P = 0.507$). The average number of nematodes per 30 g roots ranged from 700.0 to 1316.7 for the aldicarb and low harvest-and-remnant destruction treatments respectively. No significant difference was, however, found between the treatments ($F_{3,16} = 2.24$, $P = 0.123$) or the interaction between time and treatment ($F_{3,16} = 0.15$, $P = 0.926$). The annual samples (2003–2005) mainly comprised spiral nematodes (*Helicotylenchus* spp.), while relatively low numbers of root knot (*Meloidogyne* spp.) and lesion nematodes (*Pratylenchus* spp.) were present. No burrowing nematodes (*Radopholus similis* (Cobb)) were found during the study.

Damage parameters

The pre-trial plant damage estimations of the PCI (0–5 cm), PCI (5–20 cm), total PCI, CI, XO, XI and X mean were similar between plots ($F_{3,8} = 0.09$, $P = 0.963$; $F_{3,8} = 0.18$, $P = 0.907$; $F_{3,8} = 0.07$, $P = 0.974$; $F_{3,8} = 0.11$, $P = 0.951$; $F_{3,8} = 0.13$, $P = 0.942$; $F_{3,8} = 0.39$, $P = 0.766$; and $F_{3,8} = 0.13$, $P = 0.938$ respectively). No temporal effect was found for any of the dependent variables between 2004 and 2005 ($0.002 < F_{1,16} < 1.66$, $0.216 < P < 0.962$). A significant treatment effect was only found for CI ($F_{3,16} = 4.17$, $P = 0.023$). Post-anova analysis showed that treatment 2 significantly reduced the damage parameter compared to the control (fig. 1). The former treatment also showed the lowest values for the three PCI damage parameters (fig. 1). Relative to control plants, treatment 2 caused the greatest reduction in the percentage damage to the cortex and X mean, while aldicarb application showed the greatest reduction in the XI (fig. 2).

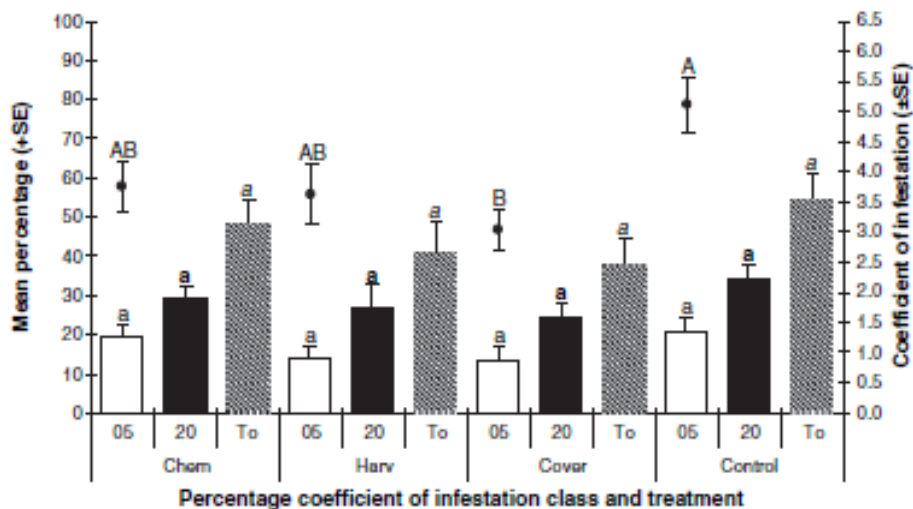


Fig. 1 The mean percentage of the percentage coefficient of infestation (PCI) and coefficient of infestation (secondary axis) damage parameters of untreated (control) plants and plants treated with aldicarb, and the two cultural control treatments, from October/November 2003 to October/ November 2005 at Ramsgate (KZN, South Africa). For each dependent variable, means with letters in common are not significantly different ($P > 0.05$) and upper-case letters refer to the secondary axis. 05 = PCI from 0 to 5 cm from the collar, 20 = PCI from >5 to 20 cm from the collar, T_0 = summed total PCI, Chem = Aldicarb, Harv = low harvesting and destroying remnants, Cover = soil cover and movement of debris to the inter-row.

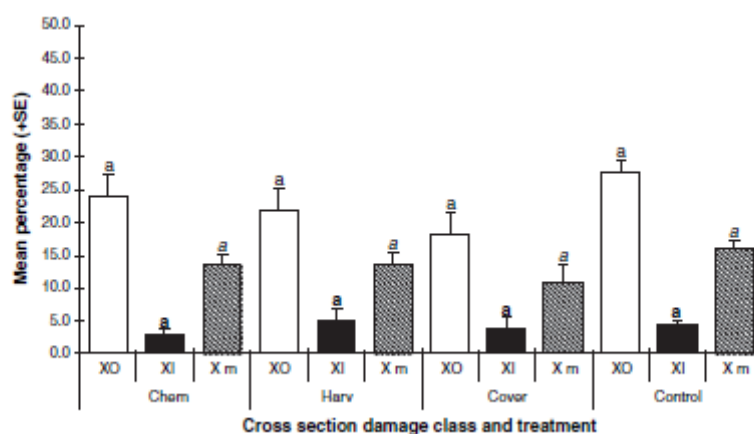


Fig. 2 The mean percentage of the cross-sectional damage parameters of untreated (control) plants and plants treated with aldicarb, and the two cultural control treatments, from October/November 2003 to October/November 2005 at Ramsgate (KZN, South Africa). For each dependent variable, means with letters in common are not significantly different ($P > 0.05$). XO = cross-sectional damage percentage of the cortex, XI = cross-sectional damage percentage of the central cylinder, X mean = average cross-sectional damage of the corm, Chem = Aldicarb, Harv = low harvesting and destroying remnants, Cover = soil cover and movement of debris to the inter-row.

Adult densities

The pre-trial adult densities were not different between plots ($F_{3,8} = 1.92$, $P = 0.206$). Subsequent collections showed a significant difference in the number of adults collected ($F_{3,32} = 6.96$, $P = 0.001$). There were no significant treatment effects or an interaction between time and treatment ($F_{3,32} = 0.79$, $P = 0.506$; $F_{9,32} = 1.52$, $P = 0.184$ respectively). The Tukey post hoc test showed that the mean number of adults collected in April 2005 [11.5 ± 1.0 (SE)], was significantly less than the numbers in October/November 2005 [19.1 ± 1.8 (SE)], April 2004 [19.1 ± 1.6 (SE)] and October/November 2004 [19.2 ± 1.6 (SE)], which were all statistically similar. Treatment 2 caused a slight reduction in the number of beetles collected in the pseudostem traps (fig. 3).

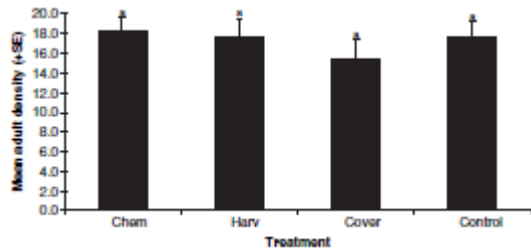


Fig. 3 The mean number of adult weevils captured from untreated (control) plots and plots treated with aldicarb, and the two cultural control treatments, from October/November 2003 to October/ November 2005 at Ramsgate (KZN, South Africa). For each dependent variable, means with letters in common are not significantly different ($P > 0.05$). Chem = Aldicarb, Harv = low harvesting and destroying remnants, Cover = soil cover and movement of debris to the inter-row.

Discussion

Neither the cultural control methods investigated in this study, nor the chemical registered for control of the banana weevil in South Africa, caused a significant increase in plant yield or plant girth after 2 years. Cultural treatments and chemical application did not significantly reduce adult beetles or any of the damage parameters either, except when the mat was covered with soil and remnants were moved to the inter-row, which resulted in lower damage to the periphery of plants. Adult trapping may not give accurate estimates (Seshu Reddy et al. 1993). Trapped beetles only provided an indication of the adult activity at the base of the plant, and were not considered a measure of adult density per plot. It was interesting that neither the weevil number, nor root infestation by nematodes, was reduced by aldicarb, a chemical registered for this purpose (Jones and Dieckmann 1982; De Jager et al. 1991). The data support regular grower reports of aldicarb treatment failures in the area. Any possible beneficial plant growth effects of covering the collar area in soil may have been offset by removing remnants (nutrients) from the base of the plant. The beneficial mechanism of a soil cover for weevil damage control may be related to weevil oviposition and/or an increase in plant vigour. The soil may provide a moist area at the base of the pseudostem attractive to adults, but residues in the field may be more attractive and the physical soil barrier may hinder location of favoured oviposition sites at the collar area. Based on previous research (Smith 1995; McIntyre et al. 2003), the most effective component of the combined soil cover and residue recession treatment appears to be the former, but an interaction effect between the treatments cannot be discounted. The application of cultural methods is usually problematic because of labour costs (Dochez 1998). Soil cover of plant bases only needs to be applied seasonally, because plant roots grow into and attach the additional soil to the rhizome. Based on the results, covering stools with soil are recommended in South Africa in the short term.

Daniells and O'Farrel (1987) found that harvesting at a 200 cm vs. 10 cm height increased bunch mass on the follower by 12% and decreased time to the next harvest by 5%. In this study, the significant reduction in weevil damage could have

compensated for the yield loss that one would have expected. The damage, however, remained relatively constant under low harvest conditions, suggesting that the effect of felling height on yield may vary between cropping systems, or that more than two seasons are required before the effect is evident. The efficacy of banana crop sanitation is questionable because residual corms, that are the most important source of pest populations, are not amendable to the practice of crop hygiene (Nanne and Klink 1975; Treverrow and Maddox 1993). Removal of the rhizome is labour intensive and will weaken followers by reducing the support of the mat. Residues can serve as traps and in some varieties it is more attractive to egg-laying females than standing plants (Waterhouse and Norris 1987; Gold et al. 1999; Masanza 2003). Poor sanitation can, however, increase weevil damage and the beetle population (Masanza 2003; Masanza et al. 2005b). Double the number of weevils complete development in toppled compared to standing plants, because of greater ovipositional accessibility to softer corm material and an increased oviposition area (Treverrow et al. 1992). The developmental rate may also be positively related to residue age (Masanza 2003), although fresh residues are usually more attractive (Masanza et al. 2005a). Sanitation over a long, extended period provided beneficial effects in Uganda (Masanza 2003; Masanza et al. 2005b).

Plants were propped during the trial and plant loss, which can contribute more to yield loss than reduction in bunch weight (Rukazambuga 1996), was not considered. The damage parameter of Cavendish bananas that is most closely related to effective bunch weight (fruit weight) is the percentage damage to the central cylinder (J. De Graaf et al., unpublished data). Under certain conditions, however, the mean percentage damage to the cortex and central cylinder of the corm is also important (J. De Graaf et al., unpublished data). Soil cover and recession of remnants reduced the respective parameters by 14% and 32% respectively.

In South Africa, cultural control over 2 years could not compare to the high efficacy of injecting pesticides into plants to control banana weevil damage (J. De Graaf et al. unpublished data; SA Patent Application Number 2007/01262). Nevertheless, the movement of remnants to the inter-row combined with covering the entire mat of a plant with soil showed promise as a control method and reduced peripheral larval damage after 2 years in a South African cropping system.

References

- Abera AMK, Gold CS, Kyamanywa S, 1999. Timing and distribution of attack by the banana weevil (Coleoptera: Curculionidae) in East African highland banana (*Musa* spp.). Fla. Entomol. 82, 631–641.
- Annecke DP, Moran VC, 1982. Insects and mites of cultivated plants in South Africa. Butterworths, Durban.
- Anonymous, 2005. Agricultural remedies. National Department of Agriculture [WWW document]. URL <http://0-www.nda.agric.za.innopac.up.ac.za:80/act36/AR/Insecticides.htm> [accessed on 19 November 2007].

- Batchelder CH, 1954. Experimentos con insecticidas para combater el picudo negro, *Cosmopolites sordidus* (Germar), en plantaciones de abaca. Turrialba 4, 88–93.
- Bujulu J, Uronu B, Cumming CNC, 1983. The control of banana weevils and parasitic nematodes in Tanzania. *East Afr. Agric. Forest. J.* 49, 1–13.
- Chavarria-Carvajal JA, Irizarry H, 1997. Rates, application intervals and rotation of four granular pesticides to control nematodes and the corm-weevil (*Cosmopolites sordidus* Germar) in plantain. *J. Agric. Univ. Puerto Rico* 81, 43–52.
- Collins PJ, Treverrow NL, Lambkin TM, 1991. Organophosphorus insecticide resistance and its management in the banana weevil borer, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), in Australia. *Crop Prot.* 10, 215–221.
- Daniells JW, O'Farrel PJ, 1987. Effect of cutting height of the parent pseudostem on yield and time of production of the following sucker in banana. *Sci. Hortic.* 31, 89–94.
- De Jager K, Rabie EC, Anderson SH, 1991. Chemiese beheer van die piesangwortelboorder, *Cosmopolites sordidus* en aalwurms, veral die booraalwurm, *Radopholus similis*. *Int. Bull. Citrus Subtropical Fruit Res. Inst.* 228, 17–20.
- Dochez C, 1998. Study on pest status and control of *Cosmopolites sordidus* (Germar) in South Africa. MSc Thesis, Heriot-Watt University, Scotland.
- Fogain R, Messiaen S, Foure E, 2002. Studies on the banana borer weevil in Cameroon. *Infomusa* 11, 8–9.
- Franzmann BA, 1972. Banana weevil borer in North Queensland. *Qld Agric. J.* 98, 319–321.
- Gettman AD, Mitchell WC, Li P, Mau RFL, 1992. A hot water treatment for control of the banana root borer, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) in banana planting stock. *Proc. Haw. Entomol. Soc.* 31, 59–63.
- Gold CS, Messiaen S, 2000. The banana weevil, *Cosmopolites sordidus*. *Musa Pest Fact Sheet No. 4*, INIBAP, Montpellier.
- Gold CS, Speijer PR, Karamura EB, Tushemereirwe WK, Kashaija IN, 1994. Survey methodologies for banana weevil and nematode damage assessment in Uganda. *Afr. Crop Sci. J.* 2, 309–321.
- Gold CS, Night G, Abera A, Speijer PR, 1998. Hot-water treatment for the control of the banana weevil, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae), in Uganda. *Afr. Entomol.* 6, 215–221.
- Gold CS, Rukazambuga NDTR, Karamura EB, Nemeye P, Night G, 1999. Recent advances in banana weevil biology, population dynamics and pest status with emphasis on East Africa. In: *Proceedings of a Workshop on Banana, IPM, Nelspruit, South Africa, November 1998*, 33–50.
- Jones RK, Dieckmann F, 1982. Control of the banana root borer, *Cosmopolites sordidus* Germar. *Inf. Bull. Citrus Subtropical Fruit Res. Inst.* 115, 13–17.
- Kehe M, 1988. Le charançon du bananier (*Cosmopolites sordidus*), les aquis et les perspectives de la recherche: contribution de L'IRFA-CIRAD/Cote d'Ivoire. In: *Nematodes and the borer weevil in bananas: present status of research and outlook*. Ed. by INIBAP, *Proceedings of a Workshop in Bujumbura, Burundi. December 1987*. INIBAP, Montpellier, 47–51.

- Kiggundu A, 2000. Host plant reactions and resistance mechanisms to banana weevil, *Cosmopolites sordidus* (Germar) in Ugandan *Musa* germplasm. MSc Thesis, Orange Free State University, South Africa.
- Koppenhofer AM, 1993. Observation on egg laying behaviour of the banana weevil, *Cosmopolites sordidus* (Germar). *Entomol. Exp. Appl.* 68, 187–192.
- Masanza M, 2003. Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) populations and associated damage. PhD Thesis, Wageningen University, Wageningen, The Netherlands.
- Masanza M, Gold CS, Van Huis A, Ragama PE, 2005a. Effects of covering highland banana stumps with soil on banana weevil *Cosmopolites sordidus* (Coleoptera: Curculionidae) oviposition. *Int. J. Trop. Insect Sci.* 25, 19–24.
- Masanza M, Gold CS, Van Huis A, Ragama PE, Okech SHO, 2005b. Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) populations and crop damage in farmers' fields in Uganda. *Crop Prot.* 24, 275–283.
- McIntyre BD, Gold CS, Ssali H, Riha SJ, 2003. Effects of mulch location on banana weevil, soil and plant nutrients, soil water and biomass in banana fields. *Biol. Fertil. Soils* 39, 74–79.
- Mitchell G, 1978. The estimation of banana borer population and resistance levels. Technical Bulletin 2. Windward Island Banana Growers Association (WINBAN), St Lucia.
- Mitchell G, 1980. Banana entomology in the Windward Islands. Final report 1974–1978. Centre for Overseas Pest Research, London.
- Musabyimana T, 1999. Neem seed for the management of the banana weevil, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) and banana parasitic nematode complex. PhD Thesis, Kenyatta University, Kenya.
- Musabyimana T, Saxena RC, Kairu EW, Ogol CKPO, Khan ZR, 2000. Powdered neem seed and cake for management of the banana weevil, *Cosmopolites sordidus*, and parasitic nematodes. *Phytoparasitica* 28, 321–330.
- Musabyimana T, Saxena RC, Kairu EW, Ogol CPKO, Khan ZR, 2001. Effects of neem seed derivatives on behavioural and physiological responses of the *Cosmopolites sordidus* (Coleoptera: Curculionidae). *J. Econ. Entomol.* 94, 449–454.
- Nanne HW, Klink JW, 1975. Reducing banana root weevil adults from an established banana plantation. *Turrialba* 25, 177–178.
- Nel A, Krause M, Khelawanlall N, 2002. A guide for the control of plant pests. 39th edition. Directorate, Agricultural Production Inputs, Department of Agriculture, Pretoria.
- Nuno L, Ribeiro VP, 2002. *Cosmopolites sordidus* in the autonomous region of Madeira. *Infomusa* 11, 10.
- Peasley D, Treverrow N, 1986. Count, cut and dry: management of banana weevil borer in bananas. Agdex 231/62Z. NSW Agriculture and Fisheries, Sydney.
- Pinese B, Elder R, 2004. Banana weevil borer. Queensland Government, Department of Primary Industries and Fisheries, Horticulture and Fresh Produce [WWW document]. URL <http://0-www2.dpi.qld.gov.au.innopac.up.ac.za:80/horticulture/2507.html>.
- Robinson JC, 1996. Bananas and plantains. CAB International, Wallingford.

- Rukazambuga NDTM, 1996. The effects of banana weevil (*Cosmopolites sordidus* Germar) on the growth and productivity of bananas (*Musa* AAA EA) and the influence of host vigour on weevil attack. PhD Thesis, University of Reading, UK.
- Seshu Reddy KV, Koppenhofer AM, Uronu B, 1993. Cultural practises for the control of the banana weevil. In: Biological and integrated control of highland banana and plantain pests and diseases. Ed. by Gold CS, Gemmil B. Proceedings of a Research Coordination Meeting in Cotonou, IITA, Benin, 140–146.
- Seshu Reddy KV, Gold CS, Ngode L, 1999. Cultural control strategies for the banana weevil, *Cosmopolites sordidus* Germar. In: Proceedings of a workshop on banana. IPM, Nelspruit, South Africa, November 1998, 51–57.
- Simmonds NW, 1959. Bananas. 1st edition. Longmans Press, London.
- Smith D, 1995. Banana weevil borer control in south-eastern Queensland. *Aust. J. Exp. Agric.* 35, 1165–1172.
- Sokal RR, Rohlf FJ, 1997. Biometry. W.H. Freeman and Company, New York.
- Stanton JM, 1994. Status of nematode and weevil borer problems affecting banana in Australia. In: Proceedings of banana nematode/borer weevil conference in Los Banos. Ed. by Valmayor RV, Davide RG, Stanton JM, Treverrow NL, Roa VN, INIBAP, Philippines, 48–56.
- Statsoft Inc., 2004. Statistica. Version 7. Statsoft Inc., Tulsa, OK, USA.
- Taylor B, 1991. Research field work on upland bananas, *Musa* spp., principally acuminata triploid AAA types, in the Kagera region of Tanzania with observations on growth and on the causes of decline in crop yield. *Rev. Agric. Subtrop. Trop.* 85, 349–392.
- Treverrow N, Maddox C, 1993. The distribution of *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) between various types of banana plant material in relation to crop hygiene. *Gen. Appl. Entomol.* 23, 15–20. Links
- Treverrow N, Peasley D, Ireland G, 1992. Banana weevil borer, a pest management handbook for banana growers. Banana Industry Committee, New South Wales Agriculture, NSW, Australia.
- Uronu BEMA, 1992. The effect of plant resistance and cultural practises on the population densities of banana weevil *Cosmopolites sordidus* (Germar) and on banana yield. PhD Thesis, Kenyatta University, Kenya.
- Vilardebo A, 1973. Le coefficient d'infestation, critere d' evaluation du degre d'attaques des bananeraies par *Cosmopolites sordidus* Germar le charancon noir du bananier. *Fruits* 28, 417–431.
- Walangululu M, Litucha BM, Musasa M, 1993. Potential for the control of the banana weevil *Cosmopolites sordidus* Germar with plants reputed to have an insecticidal effect. *Infomusa* 2, 9.
- Waterhouse DF, Norris KR, 1987. *Cosmopolites sordidus* (Germar). In: Biological control: Pacific prospects. Ed. by Waterhouse DF, Norris KR, Inkata Press, Melbourne, 152–158.
- Willers P, Daneel MS, De Jager K, 2001. Banana. In: Pests and beneficial arthropods of tropical and non-citrus subtropical crops in South Africa. Ed. by Van den Berg MA, De Villiers EA, Joubert PH. ARC – Institute for Tropical and Subtropical Crops. Ad Dynamics, Nelspruit, 34–43.
- Wortman CS, Karamura EB, Gold CS, 1994. Nutrient flows from harvested banana pseudostems. *Afr. Crop Sci. J.* 2, 179–182.