PESTS

Earthworms

Earthworms are considered to be a major pest on golf courses throughout most of Europe. A relatively recent review has been published by Kirby & Baker (1995) detailing the research carried out into earthworms up until 1995 (within a sports/golfing context). A further review of earthworms (in general) has been written by Edwards & Bohlen (1996). Therefore, these reviews will be referred to for research before 1995.

Earthworm biology

Earthworms are from the class Oligochaeta. They are segmented worms that can vary in colour from red to brown or grey or green. Earthworms are hermaphrodite and can breed at most times of the year although fewer ova are produced in the winter months (Edwards & Bohlen, 1996). Potentially, earthworms can survive for 4-8 years, although in the field, they probably survive no longer than a few months (Edwards and Bohlen, 1996). Their distribution is affected by soil type, rootzone temperature, moisture, pH, inorganic salts, aeration, texture, available food, reproductive potential and dispersive powers of the species. The distribution of earthworm populations has been surveyed in Great Britain on golf courses (Binns *et al.*, 1999), in Scotland on pasture grassland (Boag *et al.*, 1997) and in Sweden on pasture grassland (Lofs-Holmin, 1986).

On pasture land in Scotland, of the 13 species of earthworm observed, the most common were *Aporrectodea longa* and *Lumbricus terrestris* (found on 94% of sites) and *A. caliginosa* (found on 79% of sites) (Boag *et al.*, 1997). Binns *et al.* (1999) also found these three species to be the most common on golf course fairways in Great Britain, with *A. longa*, *L. terrestris* and *A caliginosa* found on 90%, 90% and 81% of fairways, respectively.

Of the three most common species, *A. longa* and *A. caliginosa* were not tolerant of acidic pH but *L. terrestris* could tolerate a wide range of pH (Kirby & Baker, 1995). They were all highly sensitive to soil moisture and casting was severely reduced during dry periods. They have been shown to be most active at temperatures between 10ºC and 15ºC (Kirby & Baker, 1995). A reduction in cutting height has been shown to reduce earthworm numbers, probably as a result of changes in food supply, soil moisture and temperature (Kirby & Baker, 1995). Earthworms would be expected to cast more on heavy soils, as there is less open space within the soil where digested waste could be accumulated. Waste is, therefore, pushed to the surface forming casts. However, compacted areas such as footpaths can have reduced numbers of casts as earthworms dislike compacted soils (Kirby & Baker, 1995).

Benefits of earthworms

Earthworms play a vital role in nutrient recycling and breakdown of organic matter. They feed on dead and decaying organic matter and receive their nutrients by digesting the micro-organisms that are growing on the organic matter (Edwards & Bohlen, 1996). Earthworms will pull fallen leaves into their burrows often storing food for periods when they cannot forage due to adverse surface conditions. Although, it has been shown that some species prefer dung or partially digested herbage to tree leaves (Kirby and Baker, 1995).

Earthworms create open channels in the soil due to their burrowing bringing subsoil to the surface and allowing gaseous exchange to occur improving the aeration of the soil (Edwards & Bohlen, 1996). Preferential flow of water can occur through macropores opened by earthworms improving the drainage potential of soil. They also breakdown organic matter and recycle nutrients.

Problems of earthworms on golf turf

The three species most commonly found on pasture in Scotland and golf courses in Great Britain, *A. longa*, *A. caliginosa* and *L. terrestris*, are also the three species most closely associated with casting (Edwards & Bohlen, 1996). In New Zealand, the most common casting earthworms were *A. caliginosa* and *L. terrestris* (Munro, 2002). Casting causes numerous problems on golf courses. The presence of casts produces an uneven playing surface (Kirby & Baker, 1995; Plate 1). Casts also bring weed seeds to the surface and provide an ideal seedbed for germination. *L terrestris* and *A, longa* preferentially choose *Poa pratensis* and *Poa trivialis* over *Lolium perenne* and *Festuca rubra* showing earthworms to select certain seeds (Edwards & Bohlen, 1996). This selection is probably associated with the size of the seeds as seeds from *Poa* species would be smaller. Although *Poa annua* was not mentioned, it is highly likely that its seeds would be transported to the surface as the amount of *Poa annua* in the seed bank of golf course soils would be high.

PLATE 1: Wormcasts create an uneven playing surface

Where casting is heavy, the pore saturation in the upper 30mm is high and the soil strength is reduced (Kirby & Baker, 1995). Earthworms have also been implicated in the movement of plant pathogens such as *Fusarium* and *Pythium* and plant parasitic nematodes (Edwards & Bohlen, 1996). However, it has also been shown that earthworms have the ability to disperse biological control agent, such as the bacteria *Pseudomonas corrugata*, that infects wheat roots and protects against *Gaeumannomyces graminis* var. *tritici* (the cause of take-all in wheat). Earthworms, including *L. terrestris* have also been implicated in the movement of the entomopathogenic nematode *Steinernema carpocapsae* (Edwards & Bohlen, 1996), which is used in the US as a biocontrol agent for many insect pests including armyworms, cutworms, webworms and billbugs (Grewal, 2001).

In a survey of 297 golf courses, Baker and Binns (1998) reported casting to be more of a problem on tees and fairways than on greens. On fairways, parkland courses and converted agricultural land suffered more problems with casting than links or moorland courses. However, less problems with casting were associated with sandy fairways and more with clay or clay/loam soils. There was no significant difference in casting rates and pH of the fairway soil. On tees, there was no significant difference in casting rates for the type of course, the pH of the soil or the soil texture.

Earthworms were the most common and widespread pest of golf course greens in a later survey of 190 golf courses (Mann, 2003). There was no significant difference in spread of earthworms across the UK and Ireland. The distribution of earthworms between different soil types was not significant either. Earthworms were also the most common pest on fairways (unpublished information from the STRI pests and disease survey). Again, there was no significant difference in the spread of earthworms over the UK and Ireland or between different soil types. However, in this survey, severity of earthworm casting was not taken into account, only the presence of earthworms. Therefore, although casting severity may have been less on sandy soils, it still occurred.

Past chemical control measures

Expellants

Kirby & Baker (1995) identified six expellant materials that have been used to control earthworms. Mowrah meal was probably the most widely used and could control earthworms for up to two years. Rotenone (derris dust) was effective for longer than two years. Both mowrah meal and rotenone are toxic to fish and so could not be used near water sources. Mercuric chloride has also been used although it is very toxic to man. Potassium permanganate provides a similar duration of control to Mowrah meal but can stain the grass (Kirby & Baker, 1995). Formaldehyde and mustard powder have also been used to collect earthworms. However, there is evidence that both may scorch the grass (Kirby & Baker, 1995).

Further work by Cook *et al*. (1997) showed that mustard powder, rotenone, detergent, potassium permanganate and formaldehyde were not suitable as earthworm expellants. Expellants should have high expellant activity and result in suppression of casting for a long period after application. However, none of the products tested demonstrated both these characteristics. Mustard and formaldehyde produced the highest numbers of expelled earthworms but also caused the grass to scorch. The other active ingredients were not as effective at expelling the earthworms. Rotenone did reduce casting but did not expel earthworms suggesting that it killed the worms underground.

One other problem with expellants that must be considered is the high amount of water that is required to wash these products into the soil. With the current European Union Water Framework Directive, it is possible that the amount of water that can be used by golf courses in the future will be more restricted than at present. Therefore, products that require a large throughput of water would not be suitable for future control measures.

Lumbricides

The two most widely used chemicals were lead arsenate and chlordane (Kirby & Baker, 1995). Lead arsenate controlled earthworms for 5-6 years. Chlordane has also been widely used due to its persistence and longevity of control. Chlordane was banned in 1992 as a result of its persistence in the soil. Baker & Binns (1998) suggested that there may have been a residual effect from chlordane applied up to six years previously and that casting was not reported as a problem on golf course greens partly as a result of the last application of chlordane. Some greenkeepers believe they are only now starting to see casting problems return and that chlordane has still been having some effect 10 years after the last application (Pers comm. Derek Green, 2002). However, the most recent survey of golf courses in the UK and Ireland (Mann, 2003) suggests that earthworms were the most common pests on golf courses.

Other chemicals that showed good control of earthworms in turf included parathion, aldrin, lindane and carbaryl. Carbaryl, lindane and parathion are still available in some areas of Europe and have been considered in the EU review – Directive 91/414. Lindane and parathion have not been included on Annex 1. The decision on carbaryl has not yet been taken.

Present chemical control measures

Some fungicides have shown activity against earthworms and have been used to control casting. Carbendazim and thiophanate-methyl effectively suppress casting. It was suggested that these active ingredients prevented the earthworms from feeding at the surface but did not kill them as similar numbers of earthworms were extracted from treated and non-treated areas

(Kirby & Baker, 1995). However, other work has shown carbendazim to be more toxic and the actual effect of these active ingredients on earthworms needs to be established.

Respondents to the survey of Baker & Binns (1998) indicated that there was no significant difference in the length of casting suppression by carbendazim, gamma-HCH + thiophanate-methyl and carbaryl. However, 70% of respondents indicated that suppression by lumbricides lasted for three months or less.

Conversely, in experimental plots, Baker *et al*. (1998) showed carbendazim (applied at the recommended rate for earthworm control) reduced casting to 35% of the control at a site where the organic matter content was 8.4% and pH was 7.3. A further site with an organic matter content of 9.8% and a pH of 5.3 showed a reduction in casting to 13% of the control when carbendazim was applied. Significant effects on casting were still apparent 12-15 months after application.

The active ingredients that are currently available as lumbricides, in the UK, are carbendazim and thiophanate-methyl. Products commonly used containing these lumbricides are Turfclear (carbendazim) and Mildothane Turf Liquid (thiophanate-methyl). On the product label for Turfclear it is stated that it should be re-applied every 4 months for earthworm control. The product label for Mildothane Turf Liquid states that the expected duration of suppression of casts is 6-13 weeks and it should be reapplied as necessary to suppress casting. It is possible that the respondents to the survey of Baker & Binns (1998) have been influenced by the suggested duration of suppression on the product labels (3 months or less) even though much longer periods of suppression have been demonstrated experimentally.

The use of fungicides to suppress earthworm casting may have detrimental effects on disease control. Both of the afore mentioned fungicides can be used in the UK (at a higher rate of application) to control certain diseases. Carbendazim is used to control fusarium patch (*Microdochium nivale*) and dollar spot (*Sclerotinia homoeocarpa*). Thiophanate-methyl is used to control microdochium patch, red thread (*Laetisaria fuciformis*) and dollar spot. Carbendazim and thiophanate-methyl are from the same chemical group of fungicides, called the methyl benzimidazole carbamates (MBC's). They are site-specific fungicides that affect cell division and so disrupt germination and growth of the pathogen. The chance of resistance occurring to the MBC's is high as the resistant isolates are fit for survival (i.e. they are not out-competed by sensitive isolates in the absence of the fungicide) and so the resistant population does not reduce even if the use of the MBC's discontinues. There is also a high risk of cross-resistance between the fungicides in the MBC group and so they should not be used successively to control disease. Applying fungicides for earthworm control at reduced doses and then applying the same chemicals for disease control will exacerbate any resistance problems.

In some areas of the EU, sulphur is considered to be a chemical control and in others it is considered as a cultural control. This will depend on the specific country. However, for the purpose of this review, it is assumed the application of sulphur is a chemical control. Baker *et al*. (1996) showed that application of sulphur or aluminium sulphate reduced casting. Higher rates of the active ingredient reduced the amount of casting more than lower rates. It was estimated that 65 g m^{-2} sulphur and 360 g m^{-2} aluminium sulphate would be required to reduce the casting to 50% of the untreated control. However, rates of 160 g m^{-2} aluminium sulphate, significantly reduced the turf quality. Therefore, it is unlikely that aluminium sulphate would provide acceptable control. Sulphur did not cause scorching up to a rate of 45 g m^{-2}, although from this work it is unknown if 65 g m^{-2} would reduce turf quality. Philips *et* *al*. (2001) showed a great reduction in turf quality between sulphur application rates of 54 g m^{-2} and 75 g m^{-2}. As 65 g m^{-2} lies between these two rates, it would be prudent to determine the effect of this rate on turf quality before suggesting its use for suppression of casting.

Other chemicals will affect the earthworm population although they may not be specifically used for earthworm control. Non-target effects of many of the fungicidal, insecticidal and herbicidal groups are discussed in Edwards and Bohlen (1996), although most of the chemicals mentioned as being toxic to earthworms are no longer approved for use. At present carbaryl is approved for the control of insects in Italy. Carbaryl is effective in reducing earthworm populations.

Cultural control measures

Many researchers have shown various aspects of turfgrass management to suppress earthworm casting. Removal of food supply by boxing off clippings, aeration and scarification can reduce casting (Kirby & Baker, 1995; Edwards & Bohlen, 1996). However, if compaction has been a problem, aeration may increase the rate of casting in certain instances as earthworms dislike compacted areas.

As earthworms feed on organic matter, it would be expected that the removal of clippings would reduce the level of casting due to the reduction in food supply. Numerous studies have shown a reduction in casting with the removal of food sources like grass clippings, tree leaves and dung (Edwards & Bohlen, 1996). Baker *et al*. (2000) demonstrated, in a fairway trial, that the removal of clippings all year significantly reduced casting. More casting occurred in plots where clippings were continuously returned and where clippings were returned in the summer but removed in the spring and autumn. However, the removal of clippings from the fairway encouraged the ingress of moss, especially if the loss of nutrients resulting from the removal of clippings was not replaced with fertiliser. However, Backman *et al*. (2001) did not observe a significant reduction in earthworm casts by *L. terrestris* when clippings were removed from a fairway trial over a three year period compared to plots where clippings were returned. It was concluded that other organic matter may have provided the food source and the same population of earthworms was sustained even with the loss of some of the food supply.

The application of alkaline materials such as lime, irrigation water, top dressing and alkaline fertiliser (urea, potassium nitrate) have all been shown to increase casting, probably as a result of increased pH levels in the soil. The application of acidifying materials such as acidifying fertilisers (ammonium sulphate, ammonium nitrate) and iron sulphate have been shown to reduce casting probably by reducing the pH of the soil. Numerous studies have shown that reducing the pH of the soil reduced the number of casts (Kirby & Baker, 1995; Edwards & Bohlen, 1996). The application of 50 kg ha^{-1} of ammonium sulphate significantly reduced casting by up to 50% of an unfertilised area (Baker *et al*., 2000). Similarly, trials in New Zealand showed a reduction in casting when the pH was reduced from 5.5 to 5.0 (Munro, 2002). However, Backman *et al*. (2001) suggested that the application of acidifying fertilisers which reduced the pH of the top 60mm of soil did not decrease the rate of casting. He also did not observe an increase in casting following the application of alkaline fertilisers that increased the pH of the soil. *Lumbricus terrestris*, the species of earthworm that was identified in the study by Backman *et al*. (2001) has been shown to occur in a wide range of pH conditions. The other two species commonly found in the UK (*A. longa* and *A, calignosa*) are more strongly affected by pH. It is possible that the reduction in casting found in the other studies was as a result of a reduction in the activity of these two species rather than a total reduction in all earthworm species. Further work would be required to establish which species of earthworm are responsible for casting after application of acidifying products.

Earthworms seem to dislike soils with a high sand content probably due to the lower moisture content and abrasiveness of the sand particles. Backman *et al*. (2002) showed that applying sand topdressing to a fairway trial decreased casting by *L. terrestris* over three years. Six sand applications of 6mm (high sand) or 3mm (low sand) were made over a 4 month period in the summer of 2000. Casting was significantly reduced by both treatments compared to untreated areas for up to 12 months. However, Munro (2002) suggests that casting is still a significant problem on sports fields regularly top dressed with sand in New Zealand. It is possible that the amount of sand applied (24mm for high sand or 12mm for low sand) in the study by Backman *et al*. (2002) created a surface layer that earthworms disliked. This may have been due to the sand particles being too dry or too abrasive. Earthworms may have dispersed their casts into this layer of sand as it would have enough pore space to accommodate this waste rather than at the surface.

Brushing, switching or drag matting daily during periods of heavy casting will disperse the casts and should be considered as a method of control that will allow the beneficial effects of earthworms on the soil but reduce the problems associated with the casts. However, on fine turf areas rolling may also be required after switching and before mowing to avoid blunting the cutting edge on the area raised by the cast. The success of this approach will be affected by surface conditions. If wet, the casts will smear and in so doing will have negative effects of the health, playing quality and appearance of the surface.

Biological control measures

There is no known agent at present that would be suitable as a biological control for earthworms (Kirby & Baker, 1995). The main predators of earthworms (birds, badgers, hedgehogs and moles) would cause further problems on golf courses. There are also predatory invertebrates (beetles, leeches, slugs and flatworms). However, it would be impossible to consider the use of these as escape to agricultural land, where earthworms are highly desirable, would be a certainty.

Practical control of earthworms at present

The suppression of earthworm casting at present should include a mixture of the following-:

- The use of acidifying fertilisers. However, careful monitoring of pH reductions would be required to ensure the pH did not become too acidic and reduce the quality of the turf.
- Removal of the food supply by boxing off clippings.
- Applying sand top dressings to dilute the effects of casts at the surface.
- Preventing application of alkaline products (fertilisers, lime etc) or alkaline irrigation water.
- The application of sulphur.
- In certain areas of Europe effective lumbricides are still available
- Some fungicides, that also control earthworms, are available in some areas of Europe such as carbendazim and thiophanate-methyl. At present there are no concerns over either of these two products in the EU review (The companies that market them are reasonably confident that they will still be around for the foreseeable future). However, until they are placed on Annex 1, we cannot be certain of their future.

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