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This publication includes lecture notes of papers presented at the 2002 New Jersey Turfgrass Expo. Publication of these lectures provides a readily available source of information covering a wide range of topics and includes technical and popular presentations of importance to the turfgrass industry.

This proceedings also includes research papers that contain original research findings and reviews of selected subjects in turfgrass science. These papers are presented primarily to facilitate the timely dissemination of original turfgrass research for use by the turfgrass industry.

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EARTHWORMS AND CASTING CONTROL IN THE UNITED KINGDOM

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The problems associated with casting by earthworms on lawns, golf courses, and sports turf areas are well documented. When casting is heavy the ejected material is unsightly, causes an uneven surface which can interfere with the run of a ball, and forms a moisture retentive playing surface. Furthermore, soil expelled by earthworm activity can act as a seedbed for weed invasion and, in addition, mole activity may also be encouraged by high earthworm populations.

Through the 1970s and 1980s, chemical control based on the highly effective wormkiller chlordane meant that casting problems could be effectively eliminated for periods of up to about 5 years. However, the withdrawal of chlordane in December 1992 followed by the subsequent loss of a number of other pesticides has meant that the only chemicals now permitted for earthworm control in the United Kingdom are carbendazim, carbendazim + chlorothalonil, and thiophanate-methyl. All these materials only give short-term control of casting, and the necessity of more frequent applications means that costs of earthworm control have increased considerably, both in terms of the chemicals used and the labor and machinery required for the extra treatments.

If problems of casting are to be reduced, it is vital that the ecology of the earthworm is understood. This includes factors controlling the size of earthworm populations and consideration of how cultural control, through the manipulation of the soil environment, can reduce the problems caused by casting.

SEVERITY OF CASTING PROBLEMS IN THE UNITED KINGDON

The climate of the United Kingdom greatly favors earthworms. Rainfall is fairly consistent throughout the year and summer temperatures are never very high, so soils tend to stay reasonably moist. Similarly, winter temperatures are such that there are never prolonged periods when the ground is frozen to a depth of more than 100 mm. Earthworm populations are therefore high, and casting is a significant issue in the fall, winter, and early spring.

The severity of the problem was assessed using a questionnaire survey which was sent to golf clubs in April 1997 to coincide with the end of the main period of casting activity (Baker and Binns, 1998). Results indicated that there was indeed a major problem with casting on United Kingdom golf courses and, more importantly, the problem was increasing. The situation was worst in tees and fairways. Of the questionnaire returns, 49% indicated moderate to severe problems on fairways, and for tees the corresponding figure was 42%. Casting was lower on greens, and only 9% of clubs indicated moderate to severe problems on the putting surface.

Nearly two-thirds of respondents suggested that rates of casting had increased compared with the period before December 1992 when chlordane was available, and 22% of responses suggested that casting was a much greater problem. Since the questionnaire survey, any residual effects of chlordane have now disappeared, and with 2 years with above average rainfall, casting rates appear to have increased further.

EARTHWORM POPULATIONS

The questionnaire survey of Baker and Binns (1998) also provided useful information on soil and management factors that may influence earthworm populations and casting activity. Course type had a major influence on earthworm casting and, for ex-

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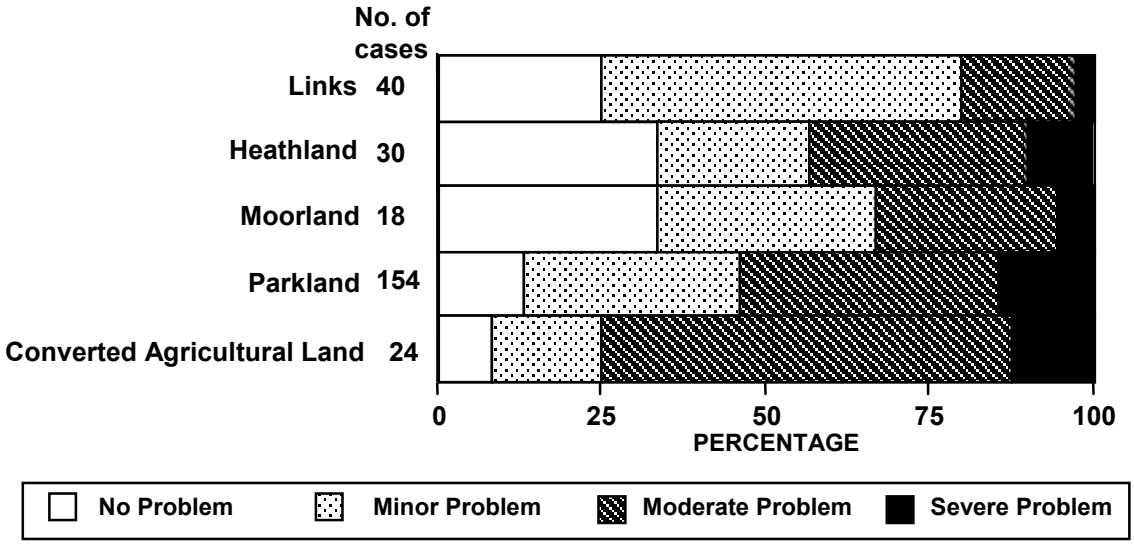

Figure 1. The effect of course type on the severity of earthworm casting problems.

ample, Figure 1 shows that for fairways, far more problems were reported on converted agricultural land and parkland courses than on links courses. The effects of casting were also greater on heavier soils but, perhaps surprisingly, the relationship between casting activity and acidity was not statistically significant.

On many courses, casting activity was greater on certain areas, and the main reasons for this, listed in order of the number of responses in the questionnaire data, were higher moisture contents (poor drainage), heavier soils, imported topsoil or turf, higher pH/lime application, and low-lying areas.

Table 1 shows species identified from over 8000 earthworms collected from 59 sites at 32 golf courses (Binns et al., 1999). It is an unfortunate fact that the three earthworm species that are most closely associated with casting activity are by far the most abundant species on United Kingdom golf courses. *Aporrectodea longa* is a large, lightly pigmented earthworm, with adults 90 to 170 mm in length. It constructs permanent burrow systems to a depth of about 0.5 m and is common in gardens, pastures, and cultivated soils. *Lumbricus terrestris* is another large earthworm, brown to purplish red above but pale beneath with a flattened, paddle-shaped tail. This is the species that is regularly seen on the surface on mild, moist nights when it emerges either to forage for plant material or for reproduction (hence the name 'nightcrawler' in the United States). *Aporrectodea caliginosa* can be both variable in coloration and size. Small individuals are common in the upper 70 mm of the soil from where they can produce some casting, but it is the larger, deeper burrowing 'nocturna' form that is associated with large surface casts.

With respect to soil texture, the highest natural earthworm populations occur within the soil types that are appropriate for many areas of sports turf (i.e., light sandy soils and light and medium loams). Low populations are associated with gravelly deposits and peat soils.

The acidity of a soil has a major influence on the number of earthworms. This is often apparent on sports fields where an abundance of earthworm activity is seen in areas around line markings, the latter often containing lime. Acidity also affects species composition; most species favor a fairly neutral pH and many are not found where the pH is less than 5.0.

Moisture content affects earthworm distribution and very droughty soils are avoided. Nevertheless, earthworms have considerable ability to survive adverse moisture conditions, either by moving into a more suitable area or becoming dormant until favorable conditions return. Most species of earthworm can survive prolonged periods of submergence, but

in general, saturated soils are avoided. So from the point of view of moisture, most sports turf soils, except perhaps some very sandy constructions, provide ideal conditions for earthworm activity. Grass covered surfaces also produce a favorable temperature regime by insulating against extreme conditions. This maintains optimum conditions for activity, metabolism, growth, respiration, and reproduction.

Food supply is the other main factor influencing population size, species composition, growth rates, and levels of fertility. Grass clippings and thatch material developed from a turf sward meet the nutritional requirements of many earthworm species.

CULTURAL CONTROL

This review of earthworm ecology suggests that these are a large number of factors influencing earthworm populations and casting activity. Management practices can therefore be used to manipulate the soil and turf environment so that conditions are less conducive to earthworm activity. We are currently investigating many of the factors in a major study on earthworm control that has been financed by the Royal and Ancient Golf Club of St. Andrews.

Soil acidity

An important management factor that can influence earthworm activity is through the effects that fertilizer, lime, top dressing, and irrigation water have on soil acidity. Two of the main casting species, *A. longa* and *A. caliginosa* 'nocturna,' are acid-intolerant so a low pH will reduce numbers of these species but may well allow the beneficial effects of other types of earthworm. A pH of about 5.0 represents their lowest tolerance and this can be used as a cultural control on greens and fairways. A much lower pH will affect grass growth but a balance with a slightly acid soil which favors the growth of fine grasses and which decreases, but does not entirely eliminate, earthworms is preferred.

Adding lime to turf areas can dramatically increase earthworm casting. For example, Escritt and Lidgate (1964) found that the application of lime at 135 g/m^2 per year increased casting by over 50% after 2 years, and after 14 years the turf was at times almost impossible to mow because of the perfusion of casts. As well as intentional applications (e.g., of ground limestone), lime can be applied inadvertently through top dressing and also in irrigation water. Again, early trials at the STRI vividly demonstrated the effect, and Ferro (1937) reported that casting rates were almost twice as high when top dressing was based on a sea sand containing 4.3% lime compared to a lime-free river sand. Our current recommendation is that rootzone materials and top dressings should contain no more than 0.5% calcium carbonate because of the risks of disease, weed invasion, and earthworm activity.

Table 1. Earthworm species found on golf courses in the United Kingdom.

Species	Percentage of all earthworms collected	Samples containing species (%)
Aporrectodea longa	39	98
Lumbricus terrestris	22	98
Aporrectodea caliginosa	26	88
Allolobophora chlorotica	3	56
Aporrectodea rosea	3	54
Octolasion cyaneum	3	42
Lumbricus rubellus	2	27
Lumbricus festivus	2	24
Lumbricus castaneus	<1	10
Dendrodrilus rubidus	<1	5
Aporrectodea icterica	<1	3
Octolasion tyrtaeum tyrtaeum	<1	2
Satchellius mammalis	<1	2

The effect of fertilizer on soil pH is also very important. Acidifying fertilizers such as ammonium sulfate, ammonium nitrate, and iron sulfate can substantially reduce earthworm activity. Conversely, materials such as nitrochalk, sodium nitrate, or basic slag which tend to induce alkalinity or a neutral reaction are often associated with higher levels of earthworm activity.

Recent work at the STRI has also examined the effectiveness of soil acidification using sulfur and aluminum sulfate and substantial reduction in casting can be achieved. For example, Baker et al. (1996) found that, on a sandy clay loam soil with an initial pH of 5.7, a total application of 65 g/m^2 of sulfur and 360 g/m^2 of aluminum sulfate applied in up to four dressings was sufficient to reduce casting by 50%. Similarly, Baker et al. (1998) found that 40 g/m^2 of sulfur, applied to a clay loam soil as an aqueous suspension, reduced the pH of the surface 25 mm from 5.8 to 5.2, and the pH at the 25 to 75 mm depth fell from 6.7 to 6.4. Casting was substantially reduced by sulfur, and 1 year after the initial application, rates of casting relative to the untreated turf were 48% and 36%, respectively, for total sulfur applications of 20 g/m^2 and 40 g/m^2.

The use of sulfur is not without its risks because of the problem of scorch and because over-acidity may in the long term impair healthy grass growth. In consequence, a series of trials were established at eight separate sites to help us predict with greater certainty the effects of sulfur on a wide range of soil types. This work will be published in 2003 but has suggested that light dressings of 20 to 30 g/m^2 applied 2 to 3 times per year is more effective than heavier dressings, although the program must be carefully monitored for effects on pH and turf quality.

Food supply

The size of the earthworm population is dependent on food supply, and this can be influenced by fertilizer type, aeration policies, thatch control, and mowing practices.

The use of inorganic fertilizers rather than organic forms reduces available food supply. Materials such as dried blood, hoof and horn meal, and dried poultry manure, which were used more extensively in the past, are easily assimilated food for earthworms, and heavy rates of casting on areas treated with these forms of fertilizer were regularly observed (Escritt and Arthur, 1948; Escritt and Legg, 1969). In addition, management practices such as regular aeration and scarification to reduce the amount of thatch should also restrict food supply.

Mowing Practices

Baker et al. (2000) examined the effects of clipping removal to see how this affects casting rates. Three possibilities were considered: (a) letting clippings fly all year; (b) boxing off all clippings; and (c) an intermediate treatment whereby clippings are removed during the spring and autumn when earthworms are most active, but allowed to fly in the summer when earthworms are dormant, especially in very dry conditions. This latter strategy would in theory substantially reduce the amount of clippings needing disposal but still allow some nutrient recycling associated with the breakdown of mown leaf tissue.

This trial started in October 1996 on fairway type turf mown at 13 mm growing on a sandy clay loam soil with a pH of 5.7. Results for the main period of casting from September 1997 to March 1998 are shown in Figure 2. Apart from March 1998, when casting activity had already slowed down, the boxing off of clippings consistently reduced the rate of casting by an average of nearly 30% over the whole year. Selective removal of clippings in the spring and autumn only brought about a significant reduction in casting on one occasion. Unfortunately, it would therefore appear that the overall productivity of organic material is more important than the time when clippings are added or removed from the surface.

Removal of clippings means that nutrient cycling is reduced, so we included light fertilizer dressings of 25 and 50 kg/ha per year of nitrogen in the experiment (applied as two dressing in the spring and summer). This compensated for an estimated loss of about 30 to 45 kg/ha per year of nitrogen through clipping removal. Ammonium sulfate was used because of its acidifying effect, and when applied at 50 kg/ha per year the ammonium sulfate reduced casting by 26% when averaged over all mowing regimes. However when comparison is made of the use of 50 kg/ha per year of ammonium sulfate on turf where the clippings are removed against turf with no acidifying fertilizer and clippings returned, the reduction in casting was 48%. Some care is needed in this policy as acidification can go too far, but adjustment of mowing regimes and fertilizer practices will certainly influence casting actively. It may not be practical to re-

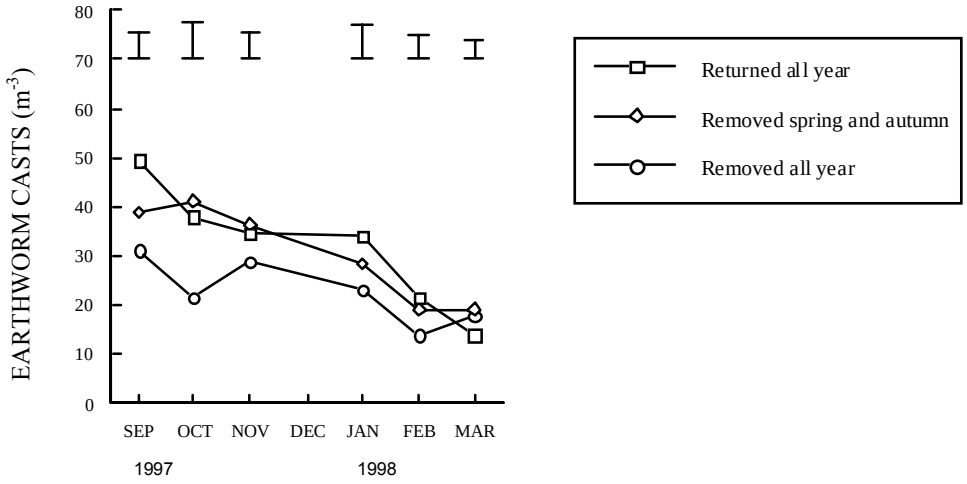

Figure 1. Rates of casting in relation to mowing treatments with return and removal of clippings (the vertical bars show the least significant difference).

move clippings on all parts of the course but it should be considered where possible for more sensitive areas such as landing zones and approaches, as well as tees and greens.

Soil moisture content

Earthworm casting falls rapidly in dry conditions, but at the same time earthworms have considerable ability to survive drought, either moving into moister soil lower in the profile, by curling up in a mucus-lined chamber, or by ceasing feeding and existing in a dormant state. Our work has shown that wet areas on a golf course have higher earthworm populations. Furthermore, the effects of casting are probably more severe in wet areas because the cast soil is more easily smeared. In consequence improved drainage may reduce the effects of casting problems.

Turf needs at least moderate rainfall or supplementary irrigation for its survival, and it is unlikely that moisture content is one of the main factors limiting the presence of earthworms on golf courses. However the consequence of factors such as fairway irrigation in areas with potentially high earthworm populations must be considered because of the twin effects of higher moisture contents and greater organic matter production. Both properties are associated with increased earthworm populations and casting. More research work in this area is required.

THE OUTLOOK

In the absence of persistent pesticide materials such as chlordane (now withdrawn from use), no single factor is going to bring about total control of earthworm casting. Indeed it is highly unlikely that even in combination the good management practices discussed above can bring about a complete cessation of casting. However it should be possible to bring about reasonable suppression of casting using cultural control techniques, so that only the worst areas on the course need pesticide applications for casting control.

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