Plant parasitic nematodes: a new turf war?

Plant parasitic nematodes cause crop losses around the world but particularly in tropical and subtropical regions. In recent years, increasing levels of nematode damage have been observed in the UK and Irish sports turf industries, with golf courses and soccer pitches severely affected throughout the British Isles. What are the causes of this activity and does it herald greater problems for European agriculture and horticulture?

Regular viewers of televised soccer matches in Britain will have noticed the poor condition of many football pitches. Increasingly, we are seeing playing surfaces that lift and cut-up excessively during games as well as yellowing turf that deteriorates throughout the season. Eventually grass cover is lost, leaving the pitches requiring extensive re-turfing or re-seeding. Close examination of this turf will show chlorotic, stunted grass plants with shallow, sparse root systems. These are typical symptoms of plant parasitic nematode attack, and the poor state of pitches in many of Britain’s football stadiums can be attributed to the feeding actions of these highly specialised parasites. Plant pathologists have noticed similar symptoms appearing on golf courses and in commercial turf nurseries throughout northwestern Europe. However, turf managers, facing a new and unfamiliar problem, are starting to fight back.

How plant parasitic nematodes attack plants
Plant parasitic nematodes are microscopic roundworms (adults are 400-3000 µm in length and 25-100 µm in diameter). Most of the 4,100 described species live in the
soil, where they feed on plant roots using a well-developed digestive system. The heads of plant-feeding nematodes contain a hollow spear or stylet with which they pierce root cell walls and ingest the cell contents. Two major types of nematode parasitise turfgrass.

**Ectoparasitic** species migrate along root surfaces, feeding on root cells. Species with short stylets attack the outer root cells while those bearing longer stylets can feed on cells deeper inside the root (Figure 1A).

**Endoparasitic** nematodes actually enter the root, where they migrate through the plant, often reaching the vascular tissue before starting to feed. Some specialised endoparasitic species such as *Meloidogyne* (root-knot nematodes) establish and maintain complex feeding sites where they manipulate root physiology and morphology to support their parasitic way of life. *Meloidogyne* second stage juveniles (Figure 1B) are attracted to roots by following gradients of plant chemicals and carbon dioxide in the soil. The juveniles penetrate the root tips and move inter-cellularly to the region of cell differentiation in the cortex where they select 2-12 phloem or parenchymal cells into which they inject secretions. This stimulates the cells to divide (without the formation of new cell walls) and develop into specialised nematode feeding sites (giant cells).

The giant cells have elevated metabolic activity and are maintained by the nematode to supply the food necessary for development and reproduction (Figure 2). The surrounding root tissues undergo hypertrophy and hyperplasia, resulting in the root knots or root galls typical of *Meloidogyne* attack (Jones and Payne, 1978).

Nematode infested roots become stunted and bushy, develop lesions and may exhibit galling. In turfgrass, this feeding activity results in rather non-specific above-ground symptoms which are indicative of the damaged root systems and made worse by both biotic and abiotic factors including disease, low light levels (as is evident in many of our larger sports stadiums) and high temperature. An affected turf typically displays reduced vigour, wilts easily in dry conditions, responds slowly to nutrient application, becomes stunted and chlorotic and may eventually die (Crow, 2005a).

**New problems for golfers**

The British Isles are renowned for the standard and diversity of their golf courses, with many traditional links, heath and parkland courses in existence for over a century. However the last 15 years have seen a rapid growth in golf greens built to United States Golfing Association specifications. These generally feature sand-based putting greens seeded with creeping bentgrass (*Agrostis stolonifera var. stolonifera*) and it was in these greens that a new ‘disease’ first appeared in the late 1990s.

One to two years after seeding, small yellow patches appeared in the turf (Figure 3A). Within the patches, root systems were severely damaged and showed the characteristic signs of root-knot nematode attack – stunted, galled roots (Figure 3B). As this yellowpatch disease progressed, patches increased in size, leaf density decreased and turf eventually thinned out (Figure 3C). Where greens were exposed to additional stresses such

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**Figure 1. (A) Sheath nematodes (Hemicycliophora) are ectoparasites commonly found feeding in turfgrass root systems. (B) Infective second stage juveniles of the most damaging endoparasite in European turfgrass, *Meloidogyne minor*.**

**Figure 2. *Meloidogyne minor* lifecycle.**

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**Figure 3.**
as high temperatures, wind or high salt levels, turf loss became extensive (Figure 3D).

While this nematode damage affected the visual appearance of the greens, more significantly (and especially to golfers facing a fast downhill four foot putt!), putting quality was also reduced, with the 'ball roll' affected within the thinning patches. The shallow rooting also meant that turf responded badly to normal maintenance procedures such as aeration, and was unable to withstand normal levels of wear and tear during play (Entwistle, 2003).

The common root-knot nematode species attacking grasses throughout north-western Europe is *Meloidogyne naasi*. However, it became clear that these greens were being attacked by a new species, subsequently described as *Meloidogyne minor* (Karssen *et al.*, 2004). Development rates in plant parasitic nematodes are dependent on soil temperatures, so *M. minor* can complete up to three generations each year. From low initial levels, populations can build up quickly in golf courses and especially in soccer pitches, where under-soil heating is used during the winter.

The discovery of a new root-knot nematode species in golf turf initially raised the suspicion of an accidental alien introduction, perhaps introduced on golf shoes, with the large number of golfing tourists from North America identified as prime suspects. However, *M. minor* was then detected in natural sand dunes around the British Isles suggesting that this nematode was actually a previously unknown 'European native'. The rapid spread of *M. minor* to golf courses (in Ireland, 90% of sand-based golf greens built since 1997 are infested) and soccer pitches seems
linked to the movement of the sand used for root-zone construction.

**Turfgrass**

Turfgrass is an unusual ‘crop’ because in order to optimise its structure and playability, it must be mown regularly (daily for golf greens) and maintained at what can be extremely low cutting heights. This means that the plants are often in a stressed state and therefore easily damaged by the feeding activities of nematodes. Despite this, historical reports of nematode damage to turf in the British Isles have been rare, with few greenkeepers even aware of the existence of the pests. In fact, most current knowledge relating to turfgrass nematodes comes from studies in the USA, where there is a multi-billion dollar sports turf industry and a long history of turfgrass nematode problems.

Coincident with the spread of the *M. minor* yellowpatch disease in the British Isles, increasing numbers of turf samples submitted for analysis have shown signs of attack by other nematode species (Table 1). During 2006, extreme damage was caused to many bent (*Agrostis* sp.) and fescue (*Festuca* sp.) golf greens by the spiral nematode, *Helicotylenchus pseudorobustus*. This species is a common resident of UK soils but the symptoms and population levels in turf were unprecedented, with experienced greenkeepers shocked by the level of damage seen (Figure 4a). Another species with an emerging pest status, *Pratylenchoides crenicauda*, was found causing damage to ryegrass and creeping bentgrass golf turf during 2006. This species is endoparasitic and examination of the roots of infested turf showed cortical cells sloughing off, as large numbers of worms fed around the vascular tissues (Figure 4b). Affected plants had little or no root mass and turf structure was weakened to the point that it could not withstand foot traffic from golfers.

While greenkeepers favour the cultivation of fine turf species such as bents and fescues, most golf greens in the British Isles are dominated by annual meadowgrass (*Poa annua*). *Poa* turf has not escaped the attentions of plant parasitic nematodes, with increasing numbers of meadowgrass greens showing yellow patches and turf loss. In this case, the nematode responsible is *Subanguina radicicola*, whose juveniles invade root tips, migrate to the cortex and cause cells to enlarge. Infested *Poa* plants

<table>
<thead>
<tr>
<th>Genus (common name)</th>
<th>Type</th>
<th>Occurrence (no. of samples)</th>
<th>No. of samples above damage threshold*</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Helicotylenchus</em> (spiral)</td>
<td>Ecto-endoparasite</td>
<td>183</td>
<td>102</td>
</tr>
<tr>
<td><em>Meloidogyne</em> (root knot)</td>
<td>Endoparasite</td>
<td>112</td>
<td>92</td>
</tr>
<tr>
<td><em>Heterodera</em> (cyst)</td>
<td>Endoparasite</td>
<td>108</td>
<td>26</td>
</tr>
<tr>
<td><em>Tylenchorhynchus</em> (stunt)</td>
<td>Ectoparasite</td>
<td>83</td>
<td>16</td>
</tr>
<tr>
<td><em>Pratylenchus</em> (lesion)</td>
<td>Endoparasite</td>
<td>77</td>
<td>35</td>
</tr>
<tr>
<td><em>Hemicycliophora</em> (sheath)</td>
<td>Ectoparasite</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td><em>Tylenchus</em></td>
<td>Ectoparasite</td>
<td>57</td>
<td>2</td>
</tr>
<tr>
<td><em>Subanguina</em> (root gall)</td>
<td>Endoparasite</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td><em>Criconemella</em> (ring)</td>
<td>Ectoparasite</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td><em>Paratrichodorus</em> (stubby root)</td>
<td>Ectoparasite</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td><em>Paratylenchus</em> (pin)</td>
<td>Ectoparasite</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td><em>Longidorus</em> (needle)</td>
<td>Ectoparasite</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td><em>Pratylenchoides</em></td>
<td>Endoparasite</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td><em>Rotylenchus</em> (spiral)</td>
<td>Ecto-endoparasite</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

*Damage thresholds will vary between sites and time of year depending on the levels of other biotic and abiotic stresses.*
are stunted and show an abnormal morphology, with small root swellings eventually developing into massive galls (Figure 5).

Management of nematodes in turfgrass
When a turf is attacked by nematodes, management options can be limited, with decisions on whether or not to take action dependent on the turf symptoms and the numbers and species of nematodes present in the root zone. Population thresholds, when significant damage is likely and control measures should be taken, have been established for some common turfgrass nematodes but are mainly based on US data and vary for different turfgrasses. Furthermore, turf usually contains mixtures of nematode species and the relative contribution of each to the turf damage is difficult to assess. Threshold levels for European turfgrass are being established (Table 1) but these are greatly modified by environmental factors and, in practice, decisions on nematode control are often made subjectively, based on experience and good guesswork.

One of the easiest ways to reduce the impact of nematode activity in turf is to reduce stress levels in the grass. This can involve techniques to increase photosynthesis, such as the use of artificial lighting in football stadiums (Figure 6) or raising the cutting heights on mowers. The use of biostimulants such as seaweed extracts and humic acid may also offer an effective means of reducing stress levels. In the case of seaweed extracts it has been suggested that this is due to the action of hormones which up-regulate levels of antioxidants in stressed grass plants (Zhang, Ervin and Schmidt, 2003). Trials in Ireland have shown that seaweed extracts can improve the recovery of turfgrass from drought stress (a key symptom of nematode damage) and enhance the appearance and structure of nematode infested turf (Fleming et al, 2006) (Figure 7).

Stress relief aside, European turf managers need effective techniques for actively reducing nematode population levels. In the USA, the most reliable control of turfgrass nematodes has been achieved using fumigant and non-fumigant nematicides. However, fumigants are difficult to apply in established turf and the production of Nemacur (fenamiphos), which has been the main nematicide used in turf since the 1970s, ceased in May 2007 following an Environmental Protection Agency review of organophosphate pesticides.

Within Europe many pesticides have also been withdrawn or are simply not available. There has been a search on both sides of the Atlantic for new products with less environmental toxicity which may help in the fight against a growing nematode problem. Consequently, there has been a plethora of new products offered to the industry for nematode management. While trials of these products have shown most to be ineffective for controlling turfgrass nematodes, a limited number may be useful.

Breakdown of many mustard (Brassica sp.) derived materials causes the release of a natural nematicide, allyl isothiocyanate and Crow (2005b) has demonstrated the value of mustard-based soil amendments in improving the colour and density of nematode-infested turf. Experiments involving...
the application of a range of granular and liquid mustard formulations to *M. minor* infested turf showed that if the infective juvenile hatch was successfully targeted, nematode levels could be significantly reduced (Figure 8).

Work in South Africa and the USA has also demonstrated that 2-furfuraldehyde, a pentose sugar derivative, acts as a contact nematicide and can be effective in reducing populations of plant parasitic nematodes (Haydock *et al.*, 2006). These and other biologically-derived materials may soon provide an environmentally acceptable contribution to nematode management in sports turfgrasses.

**Are nematodes a growing problem?**

The perceived growth in nematode activity within the European turfgrass industry raises an important question. Has there actually been an increase in nematode damage or are we simply now aware of a problem that has always existed but which has been overlooked in the past? Without detailed historical data this is difficult to answer, but most turf managers would support the view that the damage currently faced by the industry is a new phenomenon. If this is the case, why are we seeing nematode problems now?

Certainly one contributing factor is the greater use of sand-based constructions in football fields and golf courses. The attraction of modern sand-based football pitches can be appreciated by anyone who remembers the muddy pitches which typified soccer matches during the 1960s. Similarly, compared to traditional soil-based golf greens, sand constructions provide excellent drainage, suffer much less from compaction and can maintain fast smooth putting surfaces, even when levels of play are high. Most soil-based golf courses also now apply large amounts of sand to tees, fairways and greens as part of their normal maintenance programme.

Unfortunately, many of the nematodes that attack turfgrasses prefer light soils and the tolerance of grasses to nematode damage normally decreases as the sand content increases. This is due to the lower water-holding capacity and higher rate of nutrient leaching in sandy soils (Crow *et al.*, 2005a).

There is now a growing acceptance that a major driver behind the current level of damage in the turfgrass industry is soil temperature and suspicion is falling on climate change as the underlying cause. Hotter summers and milder winters have become the norm in the British Isles, with winter frosts significantly reduced in many areas (Hulme *et al.*, 2002).

Higher soil temperatures favour nematode reproduction and activity, and nematode damage is usually less common in regions that experience significant periods of low temperature.

High soil temperatures also make nematode damage worse by reducing plant tolerance to the pests. For example, the transpiration requirements of turf will rise with temperature, but nematode-damaged root systems cannot supply enough water to meet these increased demands. As the industry witnessed during 2006, nematode symptoms are most noticeable during periods of high temperature.

The hypothesis that changes in the occurrence and abundance of plant parasitic nematodes are a response to climate change is supported by the rapid appearance of *M. minor* throughout north-west Europe. In addition to the British Isles, this new species has now been detected in the Netherlands, Belgium and Portugal – and its geographic range is likely to be much wider. The species has a broad host range, feeding on most monocotyledonous and dicotyledonous crops, and it has already been found in pastures and in potato fields (Lammers *et al.*, 2006).

During 2007, new outbreaks of *M. minor* in potato have shown both ware and seed crops to be vulnerable, with tuber weight reductions of 70% recorded in affected plants (C Fleming, unpublished data). The effects of *Meloidogyne* on crop quality can be even more significant, with only a 5% tuber infection rate resulting in an unmarketable crop due to the presence of blemishes and discolouration in the tubers (European Plant Protection Organisation – EPPO *Meloidogyne chitwoodi* datasheet). It therefore seems unlikely that nematologists and plant pathologists could have overlooked such a polyphagous and damaging species unless its abundance has increased significantly only in the very recent past.

*M. minor* represents a serious threat to European agriculture with potential crop losses of many hundreds of millions of eu-
ros per year. Perhaps more significantly, this worm may be providing an early indication of wider changes occurring in nematode communities throughout the British Isles and Europe. Should the current trend in soil temperatures continue, it seems likely we will witness greater levels of nematode damage in the agricultural and horticultural sectors, both from existing nematode pests and from new species extending their range and occurrence.

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References
EPPO EPPO Meloidogyne chitwoodi datasheet. Online publication: www.eppo.org/QUARANTINE/nematodes/Meloidogyne_chitwoodi/MELGCH_ ds.pdf

Further reading
Plant and insect parasitic nematodes: http://nematode.unl.edu
Plant parasitic nematodes and their hosts: www.ipm.ucdavis.edu/NEMABASE
Plant parasitic nematodes: www.cals.ncsu.edu/pgg/dan_webpage/Nematodes/nema.htm

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