


A study to identify alternatives for the use of chemical amenities in turfgrass systems

A literature review & guidelines for a dynamic learning process

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R&A

GOLFALLIANTIE GREEN DEAL SPORT

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1 Preface

In the framework of the 'Green deal sport-turf 2020' (GDS) various parties share the ambition to reduce or even abandon the use of Ctgb listed chemical amenities in sports turf management (Annex 2). In practice, we see that the use of pesticides is the main measure to reduce turf pests and diseases to acceptable levels. Turfgrass management without pesticides needs new approaches to achieve the required level of sport experience and weed/pest/disease control.

From a practical point of view, the current management perspectives in golf is challenged, by a focus on a continuous access to playing facilities. The identification of factors relevant to the environmental functionality of turfgrass is compromised by keeping up to these high standards.

In that context, this literature review aims to identify the impact of common treatments (cultural, physical, and biological) on their environment to allocate alternative treatments to those species that form a threat to golf courses in north-western Europe, when chemical amenities are being banned. In consultation with the Dutch Golf Alliance (DGA) we evaluated the treatability of various target species.

Five major problem species whose management still heavily relies on the use of chemicals are reviewed in greater detail. To narrow down our scope, we decided to review treatments of combinations of measures for plagues/pest/weeds that fit in a holistic ecological approach. The outcome of this literature study contributes to the broader argumentation and problem analyses performed by the Dutch Golf Alliance and advances research possibilities within the context of the GDS.

2 Introduction

The general understanding of the interaction between turf, presence of problem species, and variability of environmental conditions seems very limited in scientific golf literature. Common practices that treat plant diseases, plagues, and weeds in turf grass, involving mostly chemical amenities, are typically placed within a short-term management structure, and remain protective for temporal control only, by removal of symptoms.

To overcome this, the introduction of structural and curative treatments without chemical amenities is needed, but can only suffice when placed in a management approach that allows to think holistically about the golf turf as an ecosystem. The review process provided insights to propose a conceptual framework, which highlights insights of population dynamics and succession in turf. To allocate scientific approaches for investigating interactions of turf species and how it impacts their contiguous environment and management, we envision a new niche of management: ‘ecology-intensive turfgrass management’.

The goal is to provide survival conditions for an ecological community in which selected turfgrass species are dominant. Without maintenance, a grass system would quickly turn into a struggle for dominance among the species present and between the current species and invaders, following the mechanisms of intra- and interspecific competition – ecologists call that ‘succession’. The mechanism of succession in a plant population is based on intraspecific competition – the competitiveness of individuals in that population for resources (biomass production) and space (density). In addition, species within the community compete among each other using various life strategies, e.g. consolidation of limiting resources (i.e. Resource Ratio Model, Law of self-thinning and Law of minimum), plant life-span strategies (i.e. K-r strategy and C-S-R strategy) and metabolism (C3 and C4).

Looking to turf in an ecological way allows for development of a dynamic learning process to support the development of a turfgrass management without the use of chemical inputs. Important part in this form of ecology is the use of population dynamics to accomplish a level of carrying capacity of a selected species. To understand the effects of common treatments on these relations, in Chapter 4 an overview is given about their impact on soil-water-plant relations. We discuss our understanding of biophysical thresholds relevant for cultural measures to be effective to inhibit target species’ growth. In Chapter 5 a scope of ecological alternatives for five major problem species is discussed. In this niche, we aim to enquire tipping points for intra- and interspecific competition and ways to control them naturally by means of predation, optimized nutrition, and external conditions. Chapter 6 provides recommendations for further research to enable possibilities for improving sward functionality within golf courses.

3 Methods

The ban on highly effective broad-spectrum chemicals has resulted in the development of alternative, reduced risk crop protection products. In time, while chemical management of turfgrass has been studied since its discovery in 1895 (Hansen 1921), a century of practice-orientated research on turfgrass, resulted in merely 53 scientific papers investigating or reporting briefly cultural management effects, with an even minor fraction for biological control (Busey 2003a). Refereed sources that do dedicate their effort to study alternative approaches for weed/pest management seem limited for sports turf or were not validated on golf turf (Bailey 2014). We used the integrated pest management (IPM) approach (figure 1) to review the applicability of treatments found for the listed problem species. An additional benefit of the use of this approach is that in practice the use of chemical amenities is placed last in priority (Bell 2011), which parallels the DGA ambition of future turfgrass management.

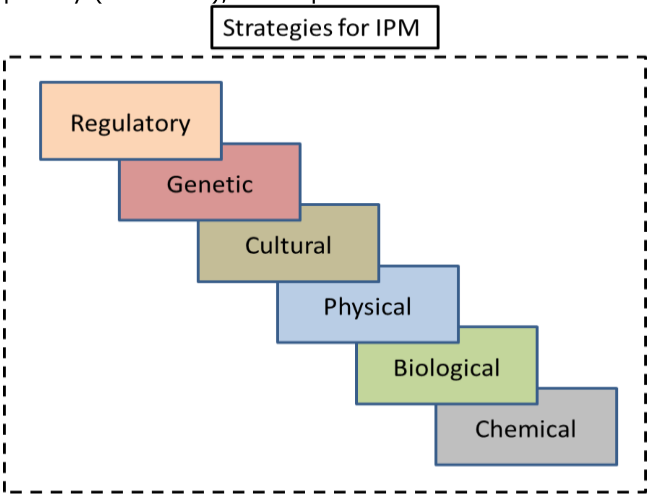

Figure 1. Schematic visualisation of prioritized strategies for integrated pest management.

Following the ranking in figure 1, six strategies were considered:

1. Regulatory: governmental restrictions on products or procedures that promote pest population growth;
2. Genetic: Turf grass varieties with resistance to bio-physical factors;
3. Cultural measures, supporting the essential conditions for sustainable plant physiology and competition, e.g. mowing, dressing, fertilizing, rolling;
4. Physical measures that prevent spreading of diseases, i.e. physical removal of weeds, cleaning of equipment;
5. Biological measures to control pest, weeds and to increase the vigour and general health of the turfgrass;
6. Chemical measures that are listed by government (e.g. by Ctgb) as harmful herbicides, fungicides, and pesticides.

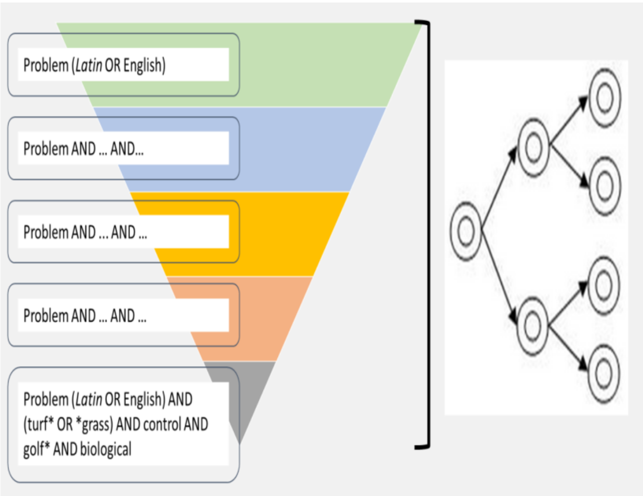

Figure 2. Schematic visualisation of literature search strategy: the triangle symbolizes the number of hits in thesauri per search entry, chain referral is applied at any level to deepen the scope of interest.

Hence, to see for alternatives, we scoped in the literature for various combinations of key words, to gather primary data specific to the study focus: problem specific treatments, without the use of chemical amenities.

Based on the entries obtained with some of the criteria, a non-probability (non-random) sampling method, called ‘snow sampling’ or ‘chain-referral sampling’ was applied (see Figure 2).

This method provides a quick insight into primary data sources, referring to another potential primary data source to be used in the search. In general, snowball sampling is used when characteristics to be possessed by samples are rare and difficult to find. This research method is especially efficient for studies with a short duration of time.

4 How common treatments work

Every single management strategy for turfgrass is ideally based on the competition element that favours grass types over visitors to survive and dominate (Dobbs and Potter 2014). However, golf-related literature on turfgrass management mainly results insights about how to advance playability indicators, whilst the impact on the sward functionality of those measures taken are not commonly discussed or even neglected. In our view, advancing the understanding the implications of frequently used practices is one step further to achieving a sustainable playing surface.

4.1 Main conclusions

Using the insights of the literature study on the biotic and abiotic stresses that make survival for problem species possible, we analysed the role of various practices on this survival rate. Per practice four criteria were used to identify the expected effect on the problem species, respectively 1. shoot competition for sunlight (shading effect), 2. ability to survive long inundation or wetted surfaces, 3. ability to grow on nutrient enriched soils, and 4. ability to withstand soil compaction. Results of this exploration are shown in table 1.

Table 1. Expected effects of treatment on problem species' survival rate; subsequently divided in: 1. positive effect (decreases survival rate effect) (+), 2. negative effect (improves survival rate) (-), and 3. unknown effect (0).

Effect of treatment	Mowing	Irrigation	Fertilizing	Rolling	Aeration	Topdressing
Plantago major (Weeda 2003)	-	-	-	-	+	-
Veronica filiformis (Weeda 2003)	-	-	-	0	-	-
Veronica arvensis (Weeda 2003)	-	+	-	+	+	+
Taraxacum officinalis (Weeda 2003)	+	+	-	0	-	-
Bellis perennis (Weeda 2003)	-	-	-	0	+	-
Trofolium repens (Weeda 2003)	-	-	-	-	-	-
Sagina procumbens (Weeda 2003)	-	-	+	-	-	-
Sclerotinia homoeocarpa (Smiley et al. 2005)	+	-	+	0	+	+
Microdochium nivale (Smiley et al. 2005, Pennstate University 2016)	+	-	-	0	+	+
Gaeumannomyces graminis (Smiley et al. 2005, Cornell University 2016)	+	-	-	0	+	+
Laetisaria fuciformis (Smiley et al. 2005, Cornell University 2016)	+	-	+	0	+	+
Colletotrichum graminicola (Smiley et al. 2005, Kansas State University 2016)	-	-	-	+	+	+
Lepiota spp. (Fidanza et al. 2005, Smiley et al. 2005, Fidanza et al. 2016)	-	+	+	+	+	+
Tipula padulosa (Mann 2004)	+	+	-	+	+	+
Phylopertha horticola (Mann 2004)	+	+	-	+	+	+
Nematodes	0	0	0	0	0	0

4.2 Mowing

Grasses grow by cell division and thus the oldest part of a leaf is its tip and the youngest its base. The practice of mowing removes the tip part of the leaf, which contains chlorophyll molecules that kick start photosynthesis. As a result, shoot density increases, at the expense of root density as mowing height decreases. To compensate for the reduction in reduced leaf area experienced under low mowing heights, plant leaf chlorophyll content increases (Bell 2011). The turfgrass stand's ability to tolerate biotic and abiotic stresses will ultimately be affected by this limited root system, with a weaker grass plant as the final outcome. The problem is worsened by inert sand-based media as on many golf greens, which have limited amounts of soil organic matter and poor water holding capacity.

4.3 Irrigation

Water is a major growth-limiting factor of all turf grasses. Regardless of water quality, the question of frequent, light irrigation versus infrequent, deep irrigation is still unanswered, with theories suggesting that infrequent, heavy irrigation, helps to increase root mass and plant stress resistance (Romero and Dukes 2016). The ability of a turfgrass plant to take up applied water, is ultimately affected by the length and density of its root system, with extensively rooted grass plants having greater access to a larger rootzone volume. There is a fine line between applying enough water to satisfy the plant's needs and over-watering the rootzone. Over-watering leads to a reduction in root growth because the roots are basically sitting in a highly-saturated soil on a regular basis. On the other hand, irrigation to field capacity, where irrigation is applied before any signs of wilt are visible, is a highly effective method of irrigation, but should be avoided, as it may cause excessive water use (Aamlid et al. 2016).

4.4 Fertilizing

Correct nutrition is essential for the plant to maintain high quality and to carry out physiological processes (Barton and Colmer 2006). Nitrogen, phosphorus, and potassium are the main macronutrients turfgrass requires for growth and function.
Nitrogen is the mineral required in greatest quantities by the turfgrass plant. Nitrogen is required for tissue growth and wear tolerance. However, the concept that it is better to apply more than less - as applies to N application - may not be beneficial (Snyder and Cisar 2000). It is well known that excessive nitrogen concentrations can create succulent tissue, reduce carbohydrate reserves, resulting increased shoot growth, reduce rooting and reduce wear tolerance of the turfgrass sward. Thus, excessive N applications weaken the turfgrass sward, making it more susceptible to disease and reducing stress tolerance.
Phosphorus is important to turfgrass because it enables energy transfer within the plant, which is required for growth. Phosphorus is of importance at the turfgrass establishment stage, since it promotes root development (Hamel and Heckman 2006). Potassium is vitally important for photosynthesis, and regulates water uptake in the plant system. It is also of great consequence in increasing wear tolerance and plant resistance to environmental stresses (Liu et al. 1995).
When growth is slowed for reasons of nutrient availability, this results in a grass that has the capacity to take up any excess when growing conditions are temporarily impaired. However, when aiming for strong growth to repair damage quickly, a more urgent issue is to reduce the nutrient supply with a change to bad weather. If this is not done, there is a risk of the nutrient excess created leaching out during heavy rainfall (Bierman et al. 2010). Growth is controlled to the level that best suits the conditions at that time. Precision fertilising involves application of nutrients required for the intended growth. Excessive fertilisation affects not only the grass plant, but also the microorganisms in the soil that help in the uptake of nutrients and water (Bailey et al. 2013).

4.5 Aeration and Rolling

Aeration is the naturally occurring process of air exchange between the soil and its surrounding atmosphere. Practically speaking, aeration — also called aerification — is the process of mechanically removing small plugs of thatch and soil from a turf area to improve soil aeration.

Coring is principally used to improve soil porosity, bulk density and infiltration rate (Nektarios et al. 2007). This type of cultivation basically breaks up the rootzone, which makes it easier for the turfgrass root system to penetrate the underlying soil, helping to create a more expansive root mass, hence increasing the plant's stress tolerance levels. It also allows for enhanced soil-water uptake, solid fertilizer uptake (Candogan et al. 2015) and reduces puddling. In terms of growth, it improves turfgrass rooting and improves heat- and drought-stress tolerance. By incorporating air in the soil matrix, risk of soils to become compacted is avoided. Intensively used greens are exposed to stress from traffic injury. Walking, playing and mowing are forms of traffic that compact soil. Aeration of heavily compacted soils helps to improve the depth and extent of turfgrass rooting, allowing better water uptake, enhancing fertilizer use and speeding up thatch breakdown.

Rolling was originally practised to smooth minor disruptions in the turf surface. As an establishment aid, rolling is conceived irreplaceable (Nikolai et al. 2001, Giordano et al. 2012). Besides its smoothing effect, rolling helps the soil settle and ensures critical seed- (or stolon-) to-soil contact.

4.6 Topdressing

Sand topdressing, adding sands to the topsoil, improves the rootzone drainage and reduces soil compaction. In turn, warren turf may recover quicker after occasional thinning. Sand helps cushion leaf tips and crowns and reduces algae (Kowalewski et al. 2010). The amount of sand applied depends on the time of year and growth rate of the turfgrass. Sand topdressing functions as an isolator for the soil in cooler parts of the season, to prevent the soil from thatch build up due dormancy.

5 Ecological alternatives for 5 cases

5.1 Main conclusions

Most the reviewed studies showed that adapted cultivars and species of turfgrass that are genetically resistant to biotic and environmental stresses have the fewest weed/ pest problems. Adapted turfgrass species can sometimes be effectively managed in the absence of herbicides, especially if they are well established. In summary, table 2 presents successful applications found in the reviewed cases. It should be stressed that the applicability of the reviewed alternative options to control weeds, fungi, and pests in turfgrass systems still require validation for a wider range of environmental conditions and management practices.

Table 2. Overview of identified ecological alternatives, which in literature are proven to be efficient in turfgrass systems

Problem species	Successful ecological alternatives
Dollar spot (*Sclerotinia homoeocarpa*)	fertilization with nitrogen; (Nelson and Craft 1991, Hodges et al. 1994, Williams et al. 1996) rolling; (Giordano et al. 2012)
Snow mold *(Microdochium nivale)*	Compost; (Block 1997, Boulter et al. 2000) nitrogen in urea; (Mattox 2015) arbuscular mycorrhizal fungi; (Gange and Case 2003) fertilization with potassium; (Dempsey et al. 2012)
Leatherjackets *(Tipula spp.)*	entomopathogenic nematodes; (Koppenhöfer and Fuzy 2003, Oestergaard et al. 2006, Tasehereau et al. 2009) black pepper; (Scott et al. 2005)
White clover *(Trifolium repens* L.*)*	nitrogen fertilization; (Larsen et al. 2004, Reicher 2007, Bailey et al. 2013)
Dandelion *(Taraxacum spp.)*	*Sclerotinia minor*; (Abu-Dieyeh and Watson 2006, 2007b) *P. macrostoma*; (Zhou et al. 2004) corn gluten meal (Quarles 2010)

5.2 Dollar spot (Sclerotinia homoeocarpa)

Dollar spot is a fungal disease, caused by *Sclerotinia homoeocarpa*, and affects the quality (see figure 3) and performance of turfgrasses from May to October throughout much of the northern United States, Canada, and Europe (Smiley et al. 2005). Conventional control of this disease relies on input of chemical compounds. However, resistance in *S. homoeocarpa* to fungicide like benzimidazole (Burpee 1997), dicarboximide (Jo et al. 2006) and demethylation inhibitor (DMI)(Burpee 1997, Jo et al. 2008) are reported repeatedly.

Lightweight rolling has been shown to have positive effects on dollar spot incidence when implemented on putting greens multiple times per week (Nikolai et al. 2001). Giordano et al. (2012) confirmed these results in a multi-year experiment. Moreover, a cumulative effect of disease suppression was shown. Rolling two times per day showed a significant reduction in the incidence of the disease. Furthermore, rolling after mowing resulted in fewer infection centres. Giordano et al. (2012) also mentioned a positive effect of percentage of volumetric water in the root zones, which may be related to a higher proportion of bacterial in the soil. Additionally, Beard (2002) proposed that routine rolling can produce a more prostrate turf canopy and limit the gradual elevation of plant crowns at the thatch–soil surface during the growing season which could have an effect on preventing conditions for de development of the disease.

Figure 3. Turf affected by Sclerotinia homoeocarpa, resulting in turfgrass degradation, with visible dried-out, bare spots.

To improve the efficiency of the application and the duration of the control which is affected for several factors, weather variables have been studied to predict probability of dollar spot development on creeping bentgrass putting greens and fairways at sites in Oklahoma and Wisconsin (Smith and Kerns 2010). Results show that temperatures between 57°F and 85°F, with 5-day average relative humidity values of 70% or above were considered sufficient for dollar spot development. Breaking up this pattern could mitigate the problem.

As part of the management the severity of the disease can be reduced by providing turf with adequate nitrogen fertility, displacing leaf wetness, and the planting of less susceptible cultivars (Williams et al. 1996). Research has been done to improve nitrogen fertilization base on remote sensing technologies. Bell et al. (2004) using a spectrometer measured the energy reflected from the turfgrass and then calculated the normalized difference vegetation index (NDVI) as well as the green normalized difference vegetation index (GNDVI).

Both indices were effective for estimating nitrogen status as most commonly evaluation such as the shoot growth rate (SGR). López-Bellido et al. (2011) studied how to develop predictive models of the seasonal needs of nitrogen fertilizers to optimize the green quality, based on measurements obtained with remote sensors (using FieldScout CM1000 and a digital camera) for A. stolonifera in golf green under Mediterranean conditions and based on the sufficiency index. These remote sensing approaches have also been useful to study plant stress in creeping bentgrass helping in the detection of water stress to improve the irrigation schedule 6 to 48 hours before visual observation, without influence of nitrogen fertility (Johnsen et al. 2009). These technologies will help in the development of management strategies based on accurate monitoring of the grass condition.

Regarding the biological management strategies for controlling dollar spot Walsh et al. (1999) mentioned that these have been less effective than fungicides. Walsh et al. (1999) grouped biological control into two approaches. One is the application of nutrients and organic amendments to stimulate naturally occurring populations of microorganisms in the phyllosphere. The other approach is the more typical use of inundation applications to turf of specific bacteria and fungi known to suppress disease.
The literature is insufficient to conclude on the mechanisms of action of organic amendments (Walsh et al. 1999, Boulter et al. 2000). Researchers have shown that suppression of dollar spot was mainly due to microbial effects of the compost which appeared to directly interfere with pathogen growth and competition (Nelson and Craft 1991, 1992, Nelson et al. 1994, Block 1997). Moreover, sterile amendments could stimulate naturally occurring microbial populations causing disease suppression (LIU 1995, Walsh et al. 1999). While others authors mention that the suppression of the disease could be due to a more vigorous plants (Landschoot and McNitt 1997, Walsh et al. 1999).

Although several bacterial and fungal species (*Fusarium heterosporum*, *Acremonium spp*., *Rhizoctonia spp*., *Enterobacter cloacae*, *Pseudomonas fluorescens*, *P. lindbergii* and others) have been highly suppressive to dollar spot, nitrogen application is still considered an implicating factor in control (Nelson and Craft 1991, Hodges et al. 1994). Another suggested role of enteric bacteria in dollar spot suppression is the metabolic provision of nitrogen nutrition to turf (Nelson and Craft 1991). Here more methodical and consistent research is needed to clarify and to implement the biocontrol in turfgrass management reducing the fungicide use in a more integrated management approach.

5.3 Snow mold (*Microdochium nivale*)

Currently pink snow mould management, as well as other turfgrass winter diseases, depends on chemical fungicide application (Smith et al. 1989, Aamlid et al. 2015). However, fungicides increase disease management costs and the environmental impact of a golf course (Boulter et al. 2002). Aamlid et al. (2015) mentioned that a realistic approach is to minimize the use of pesticides within the concept of integrated pest management.

The fungus *Microdochium nivale* is believed to be spread on infected seed from infected plants or debris through mycelia, conidia and ascospores (Tronsmo et al. 2001). Prończuk and Messyasz (1991) reported that inoculation of *Lolium perenne* with mycelia promote severe disease, being more useful for screening of plants for resistance. On the other hand, conidia did not show any symptoms because spore inoculum requires longer incubation time than mycelia. Prończuk and Messyasz (1991) showed that recombination and migration are likely playing important roles in the diversity of the pathogen as well as in its population biology.

Figure 4. The fungus Microdochium nivale is often seen in cool season turfgrass species.

Aamlid et al. (2015) mentioned that none of the cool-season turfgrasses used on golf courses are resistant to microdochium patch (see figure 3), but annual bluegrass (*Poa annua*) and bentgrasses (*Agrostis sp*.) are usually considered more susceptible than red fescue (*Festuca rubra*) and Kentucky bluegrass (*Poa pratensis;* in Gregos et al. (2011) and Kvalbein & Aamlid (2012).
Combinations of cultural practices with chemical control are the main approaches for control of *Microdochium nivale*. Chang (2011) mentioned Pink snow mould severity can be reduced by several cultural practices such as moisture control, maintenance of turf vigour, and fertility control (Smith et al. 1989, Chang 2011). Maintenance of low soil pH is important to control the disease or reduce its severity (Smiley et al. 2005). Other cultural practices recommended are a regular mow turf until dormancy; maintaining balanced fertility as well as the reduction of thatch.
Bonos et al. (2006) mentioned another strategy based on the need for new cultivars with improved tolerance to disease using both conventional and molecular breeding to conserve our natural resources and to provide a cleaner environment by reducing pesticide use. Therefore, resistance or tolerance is an alternative for the disease management (Chang 2011), that has not been methodically exploited for snow mould. Bonos et al. (2006) pointed out that one decade ago there were few or hardly any reports on breeding or selection for resistance studies.

In the last decade importance has been given to the determination of the extent of genetic variability for snow mould resistance within host species and the identification of resistant genotypes, which are necessary steps towards the development of improved cultivars (Bertrand et al. 2009). Chang (2011) evaluated the susceptibility of commercial bentgrass cultivars and breeding lines to pink snow mould, and compared the virulence of selected isolates as well as their sensitivity fungicide. For these Chang (2011) developed inoculation methods in a growth chamber for *M. nivale* showing the potential application as an easy approach for evaluating resistance in bentgrass cultivars/lines to pink snow mould.

Bertrand et al. (2009) studied resistance of bluegrass to snow mould developing by using a screening procedure to assess resistance in control conditions which are reproducible and sensitive to discriminate levels of resistance. Based on this method and using bulked segregant analysis, it was possible to detect polymorphic markers that could be used as markers for snow mould resistance in annual bluegrass.

Another study by Bertrand et al. (2011) demonstrated that several cold-induced metabolic changes are affected by snow mould infection in annual bluegrass. Concentrations of cryo-protective sugars such as sucrose and HDP fructans decreased, whereas amino acids like glutamine and arginine accumulated following infection with snow mould. This highlighted the importance of HDP fructans as an indicator and target trait of resistance to snow mould and tolerance to freezing in annual bluegrass.

An alternative approach in management of the disease is the biocontrol for which literature is limited. The approaches follow two main strategies (Walsh et al. 1999); the first one is application of nutrients and organic amendments to stimulate naturally occurring populations of microorganisms. The second strategy is applications to turf of specific bacteria and fungi known to suppress the disease. Regarding the first strategy Boulter et al. (2002) showed the use of composts incorporated into normal golf course maintenance by replacing sphagnum peat or other organic materials used in topdressing mixtures. The capacity of composts to suppress disease in turfgrass has been reported. Block (1997) reported an 80–

90% reduction in disease, obtained with a late spring application of a compost of yard trimmings. Compost has been suggested as a beneficial material in which a high proportion of organic matter may offset sand content and increase or restore soil microbial populations (Abad et al. 1994, Boulter et al. 2002). A compost of yard trimmings did not suppress snow mould but did increase the turf's rate of recovery from disease during the spring (Block 1997).

For the biocontrol strategy of microorganism application to suppress disease, Gange and Case (2003) reported the potential of arbuscular mycorrhizal (AM) fungi. These may have potential for been used in a biocontrol programme against microdochium patch in fine turf. This is based on a negative correlation found between AM fungal abundance and disease incidence, while addition of AM fungi to a putting green produced some evidence that this resulted in a reduction in pathogen attack. Moreover, findings of potential biocontrol of the pathogen in other related crops could be extrapolated to turfgrass. Levenfors et al. (2008) have shown the potential of using *Pseudomonas brassicacearum* against seed-borne *Microdochium/Fusarium spp*. in field-grown winter wheat using climate chamber experiments.

Regarding the fertilization, Dempsey et al. (2012) showed that sequential applications of potassium phosphite (KH_2PO_3) did not reduce *M. nivale* to an acceptable level, but significantly reduced the incidence and severity of the disease and this application significantly improved the turfgrass quality when compared with the untreated plots. Furthermore, the addition of potassium phosphite to iprodione can significantly enhance suppression of *M. nivale*.

Mattox (2015) showed evidence that rolling could reduce microdochium patch intensity on annual bluegrass putting greens, however, only in the absence of other fungicide alternative disease control techniques such as Civitas One, Sulphur DF or PK Plus treatments. Preliminary trials showed rolling was able to reduce microdochium patch by as much as 75% on an annual bluegrass putting green (Mattox et al., 2014). Moreover, rolling in combination with biological control products (BW136N or Rhapsody) was shown to reduce microdochium patch disease. Despite that chemical control remains better in controlling the disease, the result from Mattox (2015) could provide alternatives in a context of restricted chemical use.

Regarding nitrogen, Mattox (2015) showed that a low rate of nitrogen (4.88 kg N ha^{-1}) applied every two weeks in the form of urea on annual bluegrass putting greens during the winter period did not increase microdochium patch incidence. This is useful to assist annual bluegrass wear tolerance and recuperation from golfer traffic during the winter months on putting greens. Moreover, experiments of Mattox (2015) evidenced that increase in rates of iron sulphate caused a decreases in microdochium patch incidence on an annual bluegrass putting green, and the combination of high iron sulphate rates with low nitrogen was shown to decrease microdochium patch incidence to levels acceptable for golf course putting greens, while providing nitrogen for turfgrass recuperation. However, turfgrass quality ratings were not deemed acceptable due to a loss of turfgrass density and/or unacceptable turfgrass color. It is unclear what the mode of action of iron sulphate is and therefore further studies will be necessary to determine whether iron sulphate suppresses microdochium patch due to iron, sulfate, a pH effect or some other factor.

5.4 Leatherjackets & chafer grubs

The European crane fly (ECF) (*Tipula paludosa Meigen*) is the major pest on turfgrass in temperate climates in North West Europe and has been accidentally introduced to North America. The larvae of *T. paludosa* (leatherjackets) cause damage mainly through feeding aboveground on the leaves (Tasehereau et al. 2009). Oviposition occurs during late August and first instars hatch from September until mid-October in cool season areas (see figure 5). Older instars (L2–L4) occur in the upper soil and thatch (see fig. 5). Major damage occurs in spring, resulting in bare patches, which are then invaded by weeds (see fig. 8). Secondary damage is caused by birds, like crows, which destroy the grass by preying on the larvae (Mann 2004).

The white grub, *Hoplia philanthus* Füessly (*Coleoptera: Scarabaeidae*), adults emerge from the soil in the first week of June, feed on the foliage of various plants, and eventually oviposit in the soil (Ansari et al. 2008). Most grubs reach the second-instar by mid-September and may continue feeding until November of the first year (see fig. 7). Larvae move downwards into the soil for overwintering before the soil surface freezes in cool season areas. It takes three years before larvae initiate pupation, eventually in May.
Major damage occurs in spring, resulting in bare patches, which are then invaded by weeds (see fig. 9).

Figure 5. Indicated life stages for Tipula padulosa and Scarabaeidae spp. are similar; courtesy by (Cornell University 2016).

Figure 6. Larvae stage (L4) of Tipula padulosa Meigen

Figure 7. Larvae stage (L4) of Hoplia philanthus

Figure 8. Damage by leatherjackets to golf turf

Figure 9. Damage by white grub larvae in golf turf

Oestergaard et al. (2006) conducted laboratory and field trials to assess the control potential of entomopathogenic nematodes (EPN) (*Steinernema carpocapsae* and *S. feltiae*) and *Bacillus thuringiensis* subsp. israelensis (Bti) against *T. paludosa* and to investigate whether synergistic effects can be exploited by simultaneous application of nematodes and Bti. Their results indicate that the early instars of the insect are most susceptible to nematodes and Bti. In the field the neonates prevail when temperatures tend to drop below 10 °C. Their results indicated that application of Bti and nematodes will only be successful and economically feasible during the early instars and that the success of *S. carpocapsae* is dependent on temperatures >12 °C.

A survey on Quebec's golf courses in 2003 and 2004 by Tasehereau et al. (2009) showed that larval abundance of ECF was positively related to silt, clay, Ca, Cu, K, and Mg, and negatively related to sand and uncompressed thatch thickness. Field trials of Ansari et al. (2006) demonstrated that grub mortality was more than 95% when nematodes (*Heterorhabditis megidis* or *Steinernema glaseri*) were applied 4 weeks after the application of the fungus *Metarhizium anisopliae*.
Koppenhöfer and Fuzy (2003) tested the efficacy of the new entomopathogenic nematode species, *Steinernema scarabaei*, amongst others nematodes against the European chafer, *Rhizotrogus majalis*, in the laboratory and field conditions. They found that the European chafer larvae were highly susceptible to *S. scarabaei* in contrast to other nematode treatments. Overall, Koppenhöfer and Fuzy (2003) conclude that *S. scarabaei* shows exceptional potential for the biological control of white grubs.
Scott et al. (2005) performed greenhouse and field trials to test the efficacy of a botanical formulation based on black pepper, *Piper nigrum L.* (*Piperaceae*), seed extracts to European chafer larvae, *Rhizotrogus majalis*. Successful treatment in the field was accomplished with the application of a 2% *P. nigrum* formulation to turfgrass infested with *R. majalis* second and third instars. The 2% pepper extract activity was comparable with the conventional insecticide diazinon in the first field trial. However, the 4% pepper extracts significantly affected the earthworm populations in treated plots compared with diazinon in the second field trail. The results confirmed the expectation that under field conditions the residual activity of the *Piper nigrum* extract was less than conventional insecticides (up to 3 days), thereby reducing the environmental risk associated with pesticide use.

5.5 White clover (*Trifolium repens* L.)

Cultural practices in turfgrass management promoting vigorous, dense turf are the most important and least recognized means of preventing weed establishment and encroachment (McCarty and Murphy 1994). These practices involve the adjustment of fertilizer level, the use of mechanical methods such as spring-tine harrowing or vertical cutting, over-seeding with turfgrass seed, or application of top-dressing material. Literature on the effects of such management practices on the growth of and competition between grass and weeds is very scarce (Larsen et al. 2004). Weed control in turfgrass has primarily been based on the use of herbicides. However environmental concerns pushing towards a limited use of herbicides make it necessary to explore non-pesticides control.

Since clover is a legume that is very competitive under low nitrogen conditions, increasing the annual nitrogen fertilization is advised as good method for long-term control. Regarding control of white clover, Elford et al. (2008) studied the effect of perennial ryegrass over seeding rates and timings on weed suppression and species composition in an established Kentucky bluegrass stand.

Figure 10. White clover (Trifolium repens L.*) stands up on dense sward*

Over the short term, high-rate and frequent over seeding with perennial ryegrass appears to provide competition against perennial weeds when weed cover is high with normal growing conditions; this practice should be considered an important part of a weed management program for municipal turfgrass managers. Decreased in perennial weed cover, specifically white clover in an irrigated trial and dandelion in a non-irrigated trial was highlighted.

A key issue in non-pesticide weed control is to minimize the development of ecological niches where weeds may establish in the turf, this is possible by using management that encourages grass growth and a dense turf with a high competitive ability against weeds (Watschke and Engel 1994). Vertical mowing, aerification, and topdressing give to the grass a competitive advantage against weeds (Stier et al. 2013).

Larsen and Fischer (2005) evaluated the effect of various cultural practices on the extent of cover with grass or weeds, and bare ground on golf course fairways. Vertical cutting combined with over-seeding resulted in more grass and less weed in some cases but the effect differed among golf courses and among fertilizer levels. Thus, the effect of different cultural practices may interact with a range of factors including treatment frequency, timing of the treatment, fertilizer level as well as various factors differing among golf courses (Larsen and Fischer 2005).

On the other hand, Abu-Dieyeh and Watson (2007b) mentioned that the use of bioherbicide has had limited commercial or practical success because of problems with mass production, formulation and commercialization, and persistence under harsh environmental conditions (Kennedy and Kremer 1996, Hallett 2005). Biocontrol is successful when the biotic components and the environment interact in such a manner that weed control or suppression occurs (Kennedy and Kremer 1996). Application timing is a key factor in bio-herbicide performance, not only because of the need to match the proper meteorological conditions for microbial growth but also the need to match the weakest eco-physiological time of the target plant species. Proper timing is determined by interacting factors such as pathogen, host, and environment. Therefore, research is needed to understand those factors and their interactions.

Abu-Dieyeh and Watson (2007b) investigated the effect of an *Sclerotinia minor* (IMI 344141), barley-based formulation, on the population dynamics of dandelion and the consequences on associated broadleaf species with respect to seasonal timing and in comparison, with a standard chemical herbicide treatment. Results showed that *S. minor* was effective in suppressing dandelions as well as populations of white clover, broadleaf plantain, birdsfoot trefoil, and common ragweed. The suppression effect was similarly with both the *S. minor* or the herbicide treatments. Moreover, Abu-Dieyeh and Watson (2009) found that when turfgrass plots treated with the bio-herbicide were covered with burlap fabric for 3 days, broadleaf weed control was greatly enhanced.

Abu-Dieyeh and Watson (2009) also mentioned *S. minor* is asporogenic, and the bio-herbicide active ingredient does not spread beyond the treated areas. The eruptive mycelium of the *S. minor* bio-herbicide does not persist in the absence of a susceptible host and quickly decays within 10 days when it is applied to turfgrass (Watson 2007). Turf field trials have confirmed the efficacy of *S. minor* in controlling dandelion and reducing broadleaf weed ground cover (Abu-Dieyeh and Watson 2005, 2007a, b, 2007d).

Quarles (2010) has compiled several alternative and organic herbicides in turfgrass. Corn gluten meal (CGM) is mentioned to control clover. This is a waste product from the processing to produce corn syrup. Corn gluten meal is 60% protein and approximately 10% nitrogen (N) by weight and it is used as a selective herbicide (Christians 1991). The high nitrogen content and herbicidal properties of corn gluten meal make it a near ideal "weed and feed" product that can be applied to mature turfgrass as a top dressing and fertilizer. Over time, it acts as a pre-emergence herbicide that suppresses growth of annual weeds such as crabgrass, *Digitaria* spp., clover, *Trifolium* spp., and dandelion, *Taraxacum officinale*. Reductions of about 90% were seen over a 4-year period (Christians 1991, Bingaman and Christians 1995, Quarles 1999).

5.6 Dandelion (*Taraxacum spp*.)

Common dandelion, *Taraxacum officinale,* is the most abundant and frequent weed within turfgrass in temperate climates. The weediness of *T. officinale* is mainly the result of its high seed production, dispersal and germination potential. *T. officinale* is a strong colonizing and competitive plant. In cool climate areas, it overwinters in the soil as seeds or perennial roots that re-sprout in the following spring (see fig. 11 and 12). May and September are peak months of a nearly year-round emergence of dandelion (Weeda 2003). Reported methods for cultural management of weeds in turfgrass involved combinations of the use of mowing, fertilization, irrigation, cultivation, seeding, and turfgrass selection to affect weed populations (Bell 2011). Consensus occurs in the literature on the efficacy of some of those cultural practices, but they differ in durability in warm- and cool-season turfgrasses.

Numerous studies investigated the efficacy of various chemical treatment combinations. By now, commercially acceptable control of weeds is currently provided by the use of combined and repeated applications of phenoxy herbicides (see amongst others (Zhou et al. 2004, Calhoun et al. 2005, Abu-Dieyeh and Watson 2006)), which provide sufficient control (i.e., >95%) of dandelion (*Taraxacum officinale*) and white clover (*Trifolium repens* L.) in cool-season turfgrasses in North America and Europe. Without proper cultural management, the weed control provided by herbicides will be at best, temporary.

Figure 11. Taraxacum officinale in flowering stage; forms leaf rosette on the surface.

Figure 12. Dandelion after flowering stage.

Integrated approaches on turfgrass management are increasingly focusing on the vital role of plant competition, i.e. by restricting the frequency of vegetation gaps to a minimum and encouraging the growth of grasses that produce a dense turf (Watschke and Engel 1994). The existence of weeds in turfgrass is largely a matter of the competitive ability of the grasses. The key issue of non-pesticide weed control is, therefore, to minimize the development of ecological niches necessary for weed encroachment in the turf (Bell 2011).

Turfgrass management recommendations to professional lawn care contractors often include mowing at the tallest recommended height and providing adequate nitrogen fertility to maximize turfgrass vigour. These recommendations are based on the premise that a vigorous turf will be better suited to compete with diseases, weeds and insects and will be better able to recover from physical damage (Calhoun et al. 2005). Weeds are usually a symptom of a weakened turf. A successful long-term weed control strategy should suppress established plants, exert negative effects on seed production and prevent seedling establishment (Bell 2011).

With increasing legislation banning herbicides, non-chemical means of control are needed to replace phenoxy herbicides (Zhou et al. 2004). In this search for alternatives, long-time trials by Calhoun et al. (2005) showed first insights on successful repression of dandelion with reduced use of pesticides. They conclude that any combination of nitrogen fertilization and herbicide treatment has resulted in a 91-95%reduction in dandelion infestation, regardless of mowing height, over the six-year trial period.
The most prevalent broadleaf weed species on the football pitches were dandelion (*Taraxacum officinale* Weber) followed by daisy (*Bellis perennis* L.), white clover (*Trifolium repens* L.), and broadleaf plantain (*Plantago major* L.). These species were found on most football pitches, while speedwell species (*Veronica* spp), geranium species (*Geranium* spp.), buttercup species (*Ranunculus* spp.), chickweed species (*Cerastium* ssp.) and yarrow (*Achillea millefolium* L.) were found on certain pitches (Larsen et al. 2004).

Besides these combinations of cultural and chemical management of weeds in turfgrasses, literature on weed control slowly shifts towards more integrated forms, recognizing the need for use of biological control organisms, such as entomopathogenic nematodes, -fungi and bacteria.

In various field studies the efficacy of the fungus *Sclerotinia minor* in controlling dandelion and reducing broadleaf weed ground cover has been studied (Abu-Dieyeh and Watson 2006, 2007b). In particular, its effectiveness on dandelion seeds and seedling establishment without negative effects on turfgrass was explored. Abu-Dieyeh and Watson (2007a) looked into the potential of *Sclerotinia minor* to cause dandelion seed mortality and reduce seedling emergence without impact on turfgrass species. They performed several greenhouse and field experiments which demonstrated that *S. minor* reduces seed numbers, seedlings and establishment of *T. officinale* and, when combined with grass overseeding, the grass sward flourishes and weed emergence and colonization are significantly reduced. Other work of the same authors, describing a 3-year field study, looking into the effect of *Sclerotinia minor*, and a common herbicide, Killex, on amongst others dandelion seedbank survival, showed that *S. minor* treatments significantly reduced the dandelion seed bank, and this effect was not significantly different from the Killex herbicide treatment (Abu-Dieyeh and Watson 2007b). They found no effects for rate, frequency, and seasonal timing of application on the dandelion seed-bank size, but terminating the application would gradually replenish the seed bank.

Zhou et al. (2004) demonstrated that *P. macrostoma* did not persist in soil longer than one year and appeared to have limited. The results suggested that *P. macrostoma* could be used for biological weed control safely with minimal environmental impact due to its ubiquitous nature, limited mobility, and weak persistence over seasons. This bio-herbicide showed retained efficacy on dandelion in conjunction with typical fertility practices and the combination of the bio-herbicide with nitrogen fertilizers improved bio-herbicide efficacy, especially in low nitrogen soils (Bailey et al. 2013).

6 Recommendations for further research

To allocate useful solutions whilst applying the current standards in the golf sport (turf quality and demand for pristine playing conditions), a shift in planning and management should take place. Studies underline the importance of evaluation of turfgrass management without pesticides. To do so, turf grass population dynamics should be included in new research, other than for the local conditions they refer to. Various authors stress that it is important to understand the mechanisms for cultural management of weeds and turfgrass diseases. The current paradigm about the choices of herbicide and/or cultural practices as part of an integrated management system should be optimized for turfgrass management.

To achieve a wide range of solutions, following steps should be taken:

1. Identify pitfalls in your turfgrass management plan, when leaving out chemical amenities
2. Optimize problem control using IPM strategy 2, 3 and 4 in sequential order
3. If not sufficient: introduce new measure in any strategy but 6 (see explanation of Fig. 1):
    a. Analyse what ecological/biophysical mechanisms are to be targeted
    b. Assess the sensitivity of those mechanisms to environmental factors
    c. Identify constraints for turf growth at the selected target location
    d. Validate efficacy of the measure in the long term
4. Learning phase:
    a. Evaluate the durability of the tested measures within the current IPM plan
    b. Combine information from step 3 and 4a into a generic IPM rule
    c. Mainstream experiences and knowledge gathered in step 3 to identify specific research gaps/questions regarding turf system science
5. Redefine step 1.

For the cases reviewed (weeds, diseases, or pests), we showed specific examples of technologies developed as an alternative to chemical measures. We acknowledge the importance of the integration of these approaches in achieving management schemes that are designed for the long term. The practices reviewed in chapter 4 are fundamental in golf courses management because they directly affect the playability and the cosmetic aspect of the field. In addition, these practices affect physical factors (e.g. moisture in the soil, soil drainage capacity, soil air capacity) and biological factors (e.g. growth stages of the grass and weeds species (like vegetative stage, elongation stage, reproductive stage). Overall, these affect the interaction between grass and other species (weeds, diseases, and pests). However, the documented knowledge about the effect of these practices in the management of the problems they are used for, is limited (frequency of the practices, combination of different practices etc.).

In a way forward, we advise to define validation criteria for no-regret measures, i.e. for biological or cultural technical measures, that suffice in soil and plant protection when applying ecological mechanisms. Validation of (no-regret) measures will provide the information needed to define a new set of rules to allocate ingredients for the development of an integrated system approach for turfgrass management. In this context, the efficacy of alternative measures including the use of entomopathogenic organisms, nematodes, bacteria, and biological abstracts should be tested and embedded into an integrated management plan to overcome unfavourable course conditions that promote the use of pesticides. Milestones in such sustainable turfgrass management approach should be envisioned to ensure an integrated long term planning, based on a decision-making scheme that embeds input of advanced monitoring.

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Annex 1. Databases used for literature review

Table 3. Description of databases used for this review

	USGA TGIF	CAB	Scopus	WUR library	Google scholar
	Materials indexed in the USGA Turf Grass Information File include: turfgrass literature from peer reviewed publications, technical reports and conference proceedings, trade, and professional publications, local professional newsletters, and popular magazines as well as monographs, theses and dissertations, fact sheets and brochures, software, and web documents.	CAB Abstracts is the most comprehensive database for bibliographic information on agriculture and applied life sciences worldwide. Over 9,000 scientific journals and other serial works in many different languages are scanned and updated monthly. Each record contains an English translation of the title, keywords from the CAB-thesaurus and an extensive abstract.	Scopus is a large, multidisciplinary bibliography of over 14000 journal titles from 4,000 publishers providing access to over 25 million abstracts going back to 1966 and 5 years of reference back years.	The Wageningen UR Library Catalogue contains the titles of the books and journals held by participating libraries, with subjects relevant for research and education purposes of Wageningen UR. The catalogue is updated daily.	Google Scholar provides a simple way to broadly search for scholarly literature. From one place, you can search across many disciplines and sources: articles, theses, books, abstracts, and court opinions, from academic publishers, professional societies, online repositories, universities and other web sites.
Access by/through	DTRF	WUR	WUR	WUR	Google Inc.

Annex 2. Overview of listed Ctgb chemicals used in The Netherlands

Table 4. Overview of chemical amenities currently used in The Netherlands

Ctgb reg.No.	Product name (NL)	Chemicial agent	Target	Label reference
14261	Interface	256,4gr/l Iprodion, 16gr/l Trifloxistrobin	Fusarium, Dollar Spot en Rooddraad	http://www.environmentalscience.bayer.nl
13818	Chipco Green	255gr/l Iprodion	Sneeuwschimmel, Rooddraad, Dollar Spot, Anthracnose, Bladvlekkenziekte en Roest.	http://www.environmentalscience.bayer.nl
12746	Caramba	60 gr/l Metconazool	Fusarium, Bladvlekkenziekte, Kroonroest	http://www.fytostat.nl
12630	Signum	26,7% Boscalid, 6,7 % Pyraclostrobin	Fusarium, Dollar spot, Anthrachnose	http://www.agro.basf.nl/agroportal/nl/media/migrated/nl/productenboekje_app/etiketteksten_1/Signum.pdf
12553	Heritage	500gr/kg Azoxystrobin	Fusarium	http://www.everris.com
12585	Primstar	100gr/l Fluroxypyr , 2,5gr/l Florasulam, 144 gr/l fluroxypyr-meptyl	Eenjarige breedbladige onkruiden	http://msdssearch.dow.com
14852	Dicophar SL	70 gr/l 2,4D, 70 gr/l MCPA, 42 gr/l mecoprop-P, 20gr/l dicamba	Breedbladige onkruiden	http://www.ctb.agro.nl/ctb_files/150703_14852.PDF
14706	Starane TOP	333 gr/l fluroxypyr-meptyl	Breedbladige onkruiden	http://msdssearch.dow.com
12175	Primus	50gr/l Florasulam (4,9%)	Breedbladige onkruiden	http://www.nefyto.nl
6034	Basagran	480gr/l Bentazon	Sterk op eenjarige onkruiden	http://www.nefyto.nl
14497	Floranid Turf + Herbicide	3,3 gr/kg 2,4D, 1,6 gr/kg dicamba	Breedbladige onkruiden	http://www.ctb.agro.nl/ctb_files/151016_14913.PDF
10945	Agrichem Glyfosaat 2	360 gr/l glyfosaat	Doodspuiten sportvelden	http://www.fytostat.nl
13321	Merit Turf	150gr Imidacloprid/ha	Engerlingen, emelten	http://www.environmentalscience.bayer.nl
12706	Primo Maxx	trinexapac-ethyl 121G/L,	Algemeen (growth regulator)	http://www.ctb.agro.nl/ctb_files/140815_12706.PDF

Annex 3. Original descriptions for selected problem species

<u>Weeds</u> (Watschke and Engel 1994, Charudattan and Dinoor 2000, Busey 2003b, Weeda 2003, Abu-Dieyeh and Watson 2007b, Bailey 2014, Harding and Raizada 2015)

Plantago major / large plantain

Germination takes place under wetted and compacted conditions. seedlings grow well on compacted soils. both juvenile and mature stages can survive under heavy wear. The roots take limited space. They are sensitive to competition for room of neighbouring species´ roots. Seeds are easily dispersed as their gluey shell sticks to cattle fur or peasants' shoes. Seeds are not being digested by mammals and birds, and can easily be transported by wind. Perennial plant that flowers in May and spring. Tolerate wearing and grazers, as stem growth only occurs close to ground. P. major performs well at natural rich or enriched soils, when no other species compete for cover. Present in open, well-wetted ploughed or compacted soils. Gluey seeds when wetted may transported by peasants and animals.

Plantago lanceolate / goosegrass

capsule. Cross fertilization is mayor mechanism of dispersion. Produces massive amounts of pollen, which are to be carried by the wind. Seeds germinate in spring season, sometimes after resting for several years buried under. Perennial plant that flowers as early as spring (West-Europe) to the end of autumn. P. lanceolate performs well at natural rich or enriched soils, when no other species compete for cover. Avoids silted, humificated or compacted soils. Present in high vegetation stands. Two types: short spikelet plantain and long spikelet plantain. Short spikelet plantain is found at degraded, weared or grazed low-height vegetation cover in dry dune landscapes. Long spikelet plantain is found on nutrient rich, wetted, non-compacted, unspoiled soils. Long spikelet plantain survives the lifetime of short spikelet plantain by succession. Compaction by wear decreases causes seed production to hold, resulting decreased density.

Veronica filiformis / speedwell

In West-Europe climate conditions do not allow speedwell to reproduce by seed development, but do allow vegetative regeneration by production of root stolons, that may sprout on root nodes. Perennial plant that flowers in spring season (West-Europe) and inhabits mainly near surface zones. V. filiformis prefers moderate wetted, nutrient rich soils. Cannot outperform plants with higher canopy. Verti-cutting and mowing may increase vegetative reproduction. Leaving litter after mowing is a source of dispersion. Dispersion after runoff is common problem.

Veronica arvensis / speedwell

Capsules slowly release their seeds when dispersed on the surface. Germination can take place over night, but suffocates under high canopies. Perennial plant that flowers in spring season (West-Europe) and inhabits mainly near surface zones. V. arvensis prefers nutrient rich, bare spots, that catch sunlight, sitting on dry mineral soils (loam and sandy clay). Avoids heavy clay and peaty substrates. Suffocates after topdressing.

Taraxacum officinalis/ dandelion

Settles at bare spots. Capsules germinate at high temperatures in pre-summer, shortly after being dispersed. Germination can take place over night, but suffocates under high canopies. High nitrogen concentrations and sunlight improve germination conditions. Perennial plant that flowers in spring season (West-Europe) and can survive half shade positions throughout the year. Sun light is requirement for growth potential. Prefers degraded forest soils, sandy clay, and soils in transition zones. Despite sexual reproduction generated by capsule production, cutting of rhizosphere will allow plants to offspring from released cuttings.

Bellis perennis / enlish daisy

Perennial plant that needs redundant incoming light and frequently grazing/cutting to grow well. Prefers wetted, but not inundated, nutrient rich or enriched, humified soils, sitting on various substrates. Grows well at compacted soils. Likes wetted, but not inundated, nutrient rich or enriched, humified soils.

Trifolium repens / white clover

Settles at bare spots. Perennial plant that flowers througt the year, and can withstand temperal inundation. In need of lots of sun light, avoids stands with higher plant canopy. Prefers compacted and nutrient rich or enriched soils. Fixates nitrogen in soil by root nodes. Lives in close symbiosis with Lolium perenne. Cutting of rhizosphere will allow plants to offspring from released cuttings.

Sagina procumbens /lying pearlwort

vegetative regeneration by production of root stolons, that may sprout and flower on the root nodes. Perennial plant that flowers in summer (West-Europe). vegetative regeneration by production of root stolons, that may sprout and flower on the root nodes. Can survive in shallow soils on rock substrate. Prefers slightly wetted, sandy or clay soils. S. procumbens is an indicator plant for soil compaction.

Diseases/Pests (Nelson et al. 1994, Block 1997, Walsh et al. 1999, Gange and Case 2003, Mann and Newell 2005, Smiley et al. 2005, Ansari et al. 2008, Aamlid et al. 2015)

Sclerotinia homeocarpa / dollar spot

Ubiquitous in golf course settings and appears within a year of seeding. It is not a soil-borne pathogen. The limited spread of this pathogen within a season, indicating that equipment does not contribute to spread of inoculum. Other mention that mycelium equipment and even shoes could spread mycelium. Dollar spot favours high humidity and moderate temperatures (15C to 26C). Excess moisture, water stress, fog, or thatch accumulation contribute to disease development. The following conditions promote the development of the disease. High frequency in irrigation schedules. Prolonged muggy summer weather. Nitrogen deficiency is also related with the dollar spot development.

Microdochium nivale /snow molt

The fungus survives warm dry weather as dormant fungal mycelium or as dormant spores in soil and thatch. Spores germinate in cool, wet conditions, producing hyphae that infect grass leaves. Disease associated with snow cover, appearing when snow melts. Microdochium patch comes from spores that germinate in cool temperatures (4C to 16C), wet conditions, producing hyphae that infect grass leaves (from October to April). Excessive nitrogen applications in mid-fall will help to the development of the symptoms Excessive nitrogen applications, over growth of leaves, no regular mow, high unclipped grass that tends to fall over. Straw mulches and piles of leaves provide a favourable environment for pink snow mold. If pink snow mold develops in the cold, wet weather in early fall, the fungus may continue its activity through the winter and into spring. Damage to the turf is then likely to be quite severe and long-lasting.

Gaeumannomyces graminis / take-all

The fungus overwinters as mycelium in the thatch layer or on tissues of perennial grass species. The fungus spreads by mycelium growing from plant to plant, invading the roots and crown of susceptible hosts. Symptoms begin to show up as the weather becomes warmer and drier even though moist, cool conditions favor infection and growth of the causal fungus. Only bentgrasses are susceptible, so it is seen most commonly on golf course greens and fairways, where it can cause serious turf losses. Newly seeded sites tend to be most susceptible to this fungus, especially where bentgrass is being established on soil with a high pH. The problem has been known to occur on where turfgrass is planted on recently cleared forest sites, soils with a high sand content, or soil that has been recently fumigated. In these situations, the beneficial microorganisms that compete with or antagonize Gaeumannomyces are present in low populations. It may also occur where a site has been recently or heavily limed.

Laetisaria fuciformis / red threat disease

The fungi overwinter as a dried gelatinous mycelium covering on infected dead leaves or in clipping debris from previously infected plants. It spread by transport of mycelium or infected leaves to new areas. occurs as a Pathogen within the turf grass seed and ultimately the mature grasses. Red thread and pink patch diseases develop more readily when air temperatures are 18C to 24C, with prolonged periods of rainy or humid weather. At times, the disease occurs in warmer, drier weather. Low nitrogen levels promote the develop of symptoms. On sandy soils this may be the result of persistent rain diluting or just moving the nitrogen away from the roots. On heavier soils, it may be the result of waterlogging causing a depression in grass growth vigour.

Colletotrichium graminicola / antrachnose

Overwinters as mycelium or conidia associated with previously infected plant tissue. It is also possible survive as darkly pigmented aggregates of hyphal cells (stromata) that are formed on stolons and at the base of tillers. Exposure of the stromata to sunlight and moderate temperatures of 15 to 25ºC (59 to 77ºF) can induce formation of conidia. The conidia may serve as initial inoculum for basal rot anthracnose in the spring or early summer. The disease develops during the warm and humid summer weather and occasionally in spring condition. The disease can outbreak in putting green, tee, or fairway. Anthracnose most often develops when cool-season turf is experiencing heat or drought stress. It is considered a weak pathogen, requiring substantial injury to the turfgrass plant for invasion. The presence of anthracnose often signifies significant injury to turf from environmental, chemical, or other pathological causes.

Agrocybe pediades, Marasmius oreades and Lepiota spp./ fairy rings

The fungus survives as a white mass of mycelia in the soil or thatch layer, or can be spread by spores dispersed by the mushrooms produced by the rings. Sandy soils, newly constructed greens, dense thatch layer and excessive organic matter accumulation. Addition of composts or other organic material that have not been fully decomposed, extremes in soil moisture, nutrient deficiency, especially nitrogen.

Tipula paludosa / leatherjackets

The European crane fly (ECF) (Tipula paludosa Meigen) is the major pest on turfgrass in temperate climates in North West Europe and has been accidentally introduced to North America. The larvae of T. paludosa (leatherjackets) cause damage mainly through feeding aboveground on the leaves. Oviposition occurs during late August and first instars hatch from September until mid-October in cool season areas. Older instars (L2–L4) occur in the upper soil and thatch. Major damage occurs in spring, resulting in bare patches, which are then invaded by weeds. Secondary damage is caused by birds, like crows, which destroy the grass by preying on the larvae.

Phylopertha horticola and others / chafer crubs

Larvae move downwards into the soil for overwintering before the soil surface freezes in cool season areas. In the second year, most economic damage is caused after the larvae have moulted from the second- to the third-instar in June. In late October and early November of the second year, third-instar larvae migrate deeper into soil. In late March of the third-year overwintering larvae become active and move towards the soil surface for a brief feeding period and initiate pupation in May. The white grub, Hoplia philanthus Füessly (Coleoptera: Scarabaeidae), adults emerge from the soil in the first week of June, feed on the foliage of various plants, and eventually oviposit in the soil (Ansari et al. 2008). Most grubs reach the second-instar by mid-September and may continue feeding until November of the first year.

Nematodes

Plant parasitic nematodes are microscopic roundworms that feed exclusively on plant tissues. Most species parasitize plant roots and several different species may coexist in turf. Nematodes have a wide host range, and vary in their environmental requirements and in the symptoms, they cause.