INTEGRATED DISEASE MANAGEMENT ON WINTER SPORTS TURF

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THE FOLLOWING PUBLICATIONS, FIGURES, PLATES AND TABLES HAVE BEEN EXCLUDED ON INSTRUCTION FROM THE UNIVERSITY.

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To my family, particularly for my parents, Gill and Adrian, and for Graham.

Thank you for your continued encouragement, love and support.

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Abstract

The aim of this study was to formulate an integrated disease management (IDM) strategy for winter sports turf. (Winter sports turf, or coarse turf, consists primarily of perennial rye grass, *Lolium perenne*, which is used for football, rugby and hockey pitches because of its wear tolerant characteristics). IDM involves the use of a number of control strategies to suppress disease economically and efficiently. Such strategies incorporate cultural, biological, genetic, legislative and chemical control.

In order to formulate a successful disease management strategy, all the significant diseases affecting winter sports turf and the effects of different management strategies on these target pathogens needed to be identified and collated. This was achieved by a comprehensive questionnaire survey to professional football clubs (who require a high level of turf maintenance) and local authorities (moderate/low maintenance). The questionnaire sought information regarding disease, pest and weed incidence, control measures employed and general problems, e.g. drainage, wear and routine management practices. Red thread, *Laetisaria fuciformis*, and Fusarium patch, *Microdochium nivale* appeared to be the most ubiquitous diseases on winter sports turf. Some important management practices that suppress red thread can, however, encourage Fusarium patch, e.g. the application of nitrogenous fertiliser. A series of experiments and field trials have been initiated to identify a number of specific factors which manage to effectively suppress both diseases.

A field trial involving the use of species mixtures, perennial rye grass and smooth stalked meadow grass (*Poa pratensis*), illustrated that genetic diversity can help to reduce both red thread and Fusarium patch compared to turf grown in monoculture. The amount Fusarium patch and red thread cover indicated that disease severity was significantly lower in dual species stands as compared to monoculture. A mixture comprising 50% perennial rye grass and 50% smooth stalked meadow grass appeared the most effective at suppressing disease incidence. Similarly, mixtures of three perennial rye grass cultivars appeared more successful at suppressing slight outbreaks of red thread as compared to bi-blends and monoculture. In addition, individual perennial rye grass cultivars also vary in tolerance to red thread. One hundred and ten cultivars under three different nitrogen regimes were assessed to determine which were the most disease resistant. The cultivars received artificial football type wear treatment throughout the winter, to determine if red thread incidence predisposes rye grass to be less wear tolerant. The results indicate that a number of cultivars tolerant to red thread throughout the summer were also more resistant to wear. These cultivars included Quickstart, DelDwarf and Brightstar. Wear tolerance was also increased under a moderate nitrogen level (150 kg/ha/yr). Finally, a field trial investigating the effect of nitrogen rate on red thread and Fusarium patch incidence on five different constructions for football pitches was set down. Both diseases appeared to be efficiently suppressed under a moderate/high nitrogen level (N=225 kg/ha/yr). The 'pipe/slit' construction type also appeared to contain both diseases effectively, whilst sustaining a healthy, vigorous sward throughout the winter when subjected to artificial football-type wear treatment.

In addition to the field studies, an investigation to isolate potential microbial antagonists for use as biocontrol agents against Fusarium patch was undertaken; Fusarium patch was identified as the most economically important disease on winter sports turf from the original survey. A number of known antagonists and indigenous fungi and bacteria isolated from the phylloplane and rhizosphere of *Lolium perenne* were screened *in vitro* on turfgrass extract agar against Fusarium patch. This *in vitro* assay identified which species effectively suppressed disease growth. These potential antagonists were further tested *in vivo* to determine efficacy under field conditions. Fungi from the genus *Trichoderma* and bacteria from the genera *Bacillus* and *Pseudomonas* appeared the most effective antagonists against Fusarium patch in the *in vivo* study. In all cases where an antagonist was present, Fusarium patch severity was significantly lower than the untreated control, e.g. the indigenous *Bacillus* sp. reduced disease severity by 76.1%.

The results obtained from the field trials are encouraging and suggest that the use of species/cultivar mixtures, disease tolerant cultivars and a balanced fertiliser regime on a freely-draining construction type can successfully be incorporated into an IDM plan. An IDM strategy will help to effectively suppress both red thread and Fusarium patch on winter sports turf. Biological control of Fusarium patch was successful on an experimental basis, although further research is required to identify an appropriate formulation and optimum application technique for successful commercial use. The use of IDM on winter sports turf will help reduce reliance on chemical control, may delay the onset of fungicide resistance and reduce non-target impacts of fungicides. IDM will also help limit the need for potentially hazardous chemicals in recreational areas open to the public.

Chapter One:

Introduction

Introduction

The turfgrass industry is a multi-billion dollar a year business and is one of the fastest growing segments of the horticulture industry in general (Emmons, 1984). The aesthetic qualities of turf have been appreciated by numerous civilisations throughout time. Lawns were included in gardens thousands of years ago in the Middle East and Asia. Turf was used for recreational purposes in Europe for lawn bowling and cricket fields as early as the 13th Century. Golf has been popular in the U.K. since the 1400s (Emmons, 1984).

Today turfgrasses are used for a variety of purposes. The binding effect of an inter-connecting system of fibrous roots prevents soil erosion by wind and water. Along roadsides turfgrasses absorb many toxic emissions from vehicles and so have a cleansing effect upon the air. Turfgrass also has a cooling effect on the local air temperature (Turgeon, 1985). Turf plants serve a decorative purpose as lawn turf which enhance the landscape and provide recreational areas (Beard and Green, 1994). Finally several turfgrasses are used for sports turf which provides enjoyment for players and spectators. However, players, supporters and administrators can all be accused of taking the playing surface of sports turf for granted. It is often the case that only when conditions effect a closure or cancellation is consideration given to the surface. The playing surface is important to the enjoyment, quality and safety aspects of the game. This apparent lack of attention can mean false economy.

Turfgrass diseases are an important factor that significantly reduce the quality and performance of the surface. Damage ranges from slight reduction in quality to complete killing of the grass stand. Disease control relies heavily on fungicides. In the U.S., more than $50 million is spent on fungicides each year to control disease on golf courses alone, but major disease problems still persist (O'Neill, 1985a). The development and implementation of an integrated disease management (IDM) strategy represents a significant opportunity to reduce dependence on pesticides.

1.0 Integrated Pest and Disease Management (IPDM)

IPDM has been defined as a management strategy using a variety of biological, cultural and chemical measures to give stable, long term pest and disease control (Burn *et al*, 1987); IDM concerns the management of diseases alone. Such strategies also combine the use of monitoring / forecasting to increase profit margins and safeguard natural resources and the environment.

The history of control measures used in IPDM stretches back over 4,000 years. The first record of insecticide use was in 2,500 BC. In 950 BC burning crop stubble was used as a cultural control strategy and in 300 AD predatory ants were used against pests in Chinese citrus groves. In 1899 cotton, cowpeas and watermelon were bred for genetic resistance against *Fusarium* wilt. The first example of the use of legislation to control plant pests and diseases was the US Plant Quarantine Act of 1912 (Flint, 1981).

Integrated management programmes were originally developed to improve the management of insect pests in field and horticultural crops while reducing the use of pesticides (Bishop, 1990). IPDM does not eliminate pests but is based on the use of treatment only when populations reach a certain level. This threshold point is when the cost of treatment is less than the potential economic loss caused by the pest. The final goal of IPDM is not pest elimination but maintenance below these threshold levels. Integrated management is more effective, less costly and less hazardous to people and the environment (Vittum, 1986).

Pesticides will still be required if quality and competitiveness is to be maintained by producers, but biological and cultural controls can be utilised in IPDM systems both as alternatives and supplements to pesticides. The use of pesticides is increasingly being restricted in heavily populated areas, mainly due to spray drift. Concerns about pesticide use has led to the development of IPDM programmes which create a demand for effective alternatives to pesticides, making non-chemical research management possible and leading to a further reduction in pesticide use (Cox, 1991).

Reduced application rates of chemicals combined with other control strategies will achieve a high degree of reliability and efficacy. The combined use of control strategies offers control nearly equal to that of pesticide systems. Cultural practices such as rotation and the use of tolerant cultivars that are not sufficient alone can be combined with other controls, such as biocontrol agents and decreased pesticide application rates, to create a highly efficient control system.

IPDM provides a multidisciplinary and profitable approach to pest control. IPDM programmes have an outstanding track record throughout the world in the reduction of pesticide use, ensuring a safe food supply and aiding the goals of water and wildlife conservation (Jacobsen and Backman, 1993).
The basic structure of an IPDM programme involves 5 main principles, listed as follows:

1. Correct identification of the problem and its economic implications.
2. Defining the management unit e.g. inputs, organisms present.
3. Development of a management strategy to decrease inoculum and/or decrease rate of spread; this requires a thorough knowledge of disease ecology.
4. Establishing an economic threshold.
5. Developing suitable monitoring techniques.

There are numerous examples of the successful implementation of IPDM in agriculture and the turfgrass industry which are considered in the following sections.

1.1 IPDM in Agriculture

The management of cereal plant pathogens can successfully be achieved by crop rotation, comparatively low rates of nitrogen fertilisation together with the use of resistant cultivars, appropriate husbandry practices and reduced fungicide use (Yarham *et al*, 1990). In winter barley, Jordan *et al* (1989) noted that a delay in the main application of nitrogen until mid April and a single fungicide application is sufficient to substantially reduce the severity of fungal disease and improve grain yield at harvest. Similarly, effective disease control in spring barley can be achieved by the timely application and careful selection of fungicides applied in mixtures at a reduced rate which prove as effective as a full rate fungicide programme (Wale, 1990). The integrated use of fungicides, growth regulators, nitrogen and cultivars also maximise profitability and minimise production costs of winter wheat (Paulitz, 1994, Dawson *et al*, 1990).

Merida *et al* (1994) reported the occurrence of benzimidazole resistant *Helminthosporium solani*, the causal agent of silver scurf on potato; the disease could be reduced on late-maturing cultivars. The use of forecasting systems are also integral to a successful control system. The efficacy of the fungicide used against potato blight, ***Phythophora infestans***, is enhanced when applied according to a 'Blitecast' prediction based on relative humidity, temperature and rainfall. Efficacy is also increased if resistant cultivars are used (Fry, 1977).

1.2 IPDM in the Turfgrass Industry

The turfgrass industry has been the target of unfavourable publicity regarding the use of pesticides. In the U.S. 27% of the pesticides used are in densely populated areas (Brown and Cranshaw, 1989). Pesticides are relied upon as the primary means of controlling pests when the use of cultural practices could reduce the pest problem (Shearman, 1988).

IPDM encourages the use of chemicals wisely. The over dependence on chemicals substantially reduces non-target beneficial organisms causing a resurgence of unwanted pests. Potter *et al* (1989) noted that a number of organisms instrumental to the decomposition process as well as a number of predatory mites, spiders and insects were destroyed after a single pesticide application; populations remained depressed for six weeks. In addition, increases in target pests such as greenbugs and chinch bugs were noted on the treated turf. The selection pressures exerted by pesticide use are increased with each successive application encouraging greater resistance; for example, 21 out of 24 isolates of Fusarium patch, ***Microdochium nivale***, were iprodione tolerant and exhibited cross tolerance to vinclozolin and procymidione (Chastagner and Vassey, 1982). Pesticides can increase turf stress and should be limited to more selective applications e.g. spot treatments. Avoidance of chemicals if non-chemical techniques will suffice will help to preserve the efficacy of existing pesticides (Vittum, 1986).

A single pesticide application can cost several thousand dollars; every treatment avoided is money saved. The long term costs of IPDM appear to be less than preventative chemical spray routines (Grant, 1989). A number of disease problems are frequently encountered in stress situations resulting from poor management, intensive use and excessive pesticide application (Brown and Cranshaw, 1989).

IPDM utilises all appropriate control methods. The holistic approach to management decision making is information intensive e.g. use of available information (historical data, pest ecology, factors favouring development) and extensive record keeping; it is also cost effective (Leslie, 1989). Integrated management on turf functions as a stress management system rendering the turf less susceptible to disease, able to compete more successfully against weeds and tolerate higher levels of invertebrate pests without damage.

The process begins with the selection of appropriate species and cultivars, which will greatly affect turf quality (Niehaus, 1976). The grass should be suited to the climate and conditions in which it will be grown. An appropriate management programme must then be devised. This will include regular inspection of the turf; early detection of disease symptom expression can minimise severity and damage. The signs and symptoms are then evaluated and the prognosis determined. Six tactics are then available to the turfgrass manager; implementation of these in appropriate combinations will significantly improve turf quality:

1. **Cultural** - these techniques are the basic tools available to regulate turfgrass growth and reduce potential stress e.g. balanced soil pH and fertility, irrigation and increased mowing height promotes healthy, deep rooted turf able to withstand disease and pest incidence and weed competition (Vittum, 1986).
2. **Physical** - e.g. core aerating, power raking and improved drainage.
3. **Genetic** - use of adapted species and resistant cultivars.
4. **Biological** - use of natural enemies e.g. *Bacillus popillae* against Japanese beetle larvae.
5. **Regulatory** - seed certifications, quarantines and sanitation, e.g. regular cleaning of equipment and footwear.
6. **Chemical** - use of pesticides at reduced rates when the pest is at its most vulnerable stage.

A well devised management system is where the components are working together to optimise the health and vigour of the turf e.g. if nitrogen is increased the growth, density, vigour and colour will also increase. Water use levels will then rise and if they are not met stress levels may accelerate rendering the turf more susceptible to disease and pest invasion e.g. the incidence of necrotic ring spot, *Leptosphaeria korrae*, was greatly reduced by daily light irrigation following the application of organic nitrogen fertiliser (Melvin and Vargas, 1994). In addition if the turf is not mown more frequently it may thin out and become more susceptible to weed invasion. IPDM programmes require careful planning and implementation but lead to economic savings, reduced environmental hazards and better quality sports turf (Shearman, 1988). A number of successful management plans have been devised for several turfgrass diseases, pests and weeds.

1.2.1 Disease

Disease causing fungi coexist with grass and only cause damage when environmental conditions and cultural practices create opportunities for attack. A number of factors can trigger disease:

1. **Water.** Most pathogens need free water or very high relative humidity to germinate, grow and infect grass. Water applied later in the day will remain on the foliage for longer periods providing pathogens with

an opportunity for infection. If water is applied in the early morning it will dry more rapidly preventing pathogens from becoming established.

2. **Temperature.** The most effective way of minimising temperature effects on disease development is to choose species and cultivars best suited to the area.
3. **Fertilisation.** The effects of fertilisers vary with each disease
4. **Mowing.** The cut ends of leaves and shoots provide entry points for pathogens thus reducing disease resistance. Also, removal of photosynthetic tissue limits the resources available to the plant for resistance to disease attack and recovery.
5. **Aeration.** This process alleviates anaerobic conditions which promote certain disease organisms
6. **Thatch.** Thatch removal reduces the amount of nutrients available to disease organisms.

Cultural and biological practices successfully control a number of diseases. Brede (1991) noted that dollar spot on tall fescue turf is lowest at a low seedling rate. Incidence of Summer patch on Kentucky bluegrass was reduced with increased mowing heights coupled with deep infrequent irrigation and the use of sulphur coated urea. Turf quality and carbohydrate storage within the grass also increased (Davis and Dernoeden, 1991). The activity of a biocontrol agent (BCA) used against take-all, *Gaeumannomyces graminis*, was enhanced with increased fertiliser use (Lucas *et al*, 1992). The use of BCAs compatible with fungicides will aid growth enhancement e.g. the use of benomyl tolerant *Trichoderma harzianum* and benomyl against *Pythium* (Brown and Cranshaw, 1989).

Table 1 provides a summary of successful management strategies which have been employed against a number of cool season turfgrass diseases:

Table 1. Management strategies for a number of cool season turfgrass diseases (after Olkowski 1991)

Table 1 continued......

1.2.2 Pests

The use of nematodes as BCAs against insect pests is enhanced if the amount of thatch is reduced and the nematodes are also resistant to fungicides used (Brown and Cranshaw, 1989). The number of pathogenic nematodes can be reduced by increasing mowing height (Giblin-Davis *et al*, 1991). Nematodes can also be used as effective BCAs against turfgrass-infesting scarab beetles, particularly in conjunction with insecticidal treatments and regular spiking of the turf surface (Cranshaw and Zimmerman, 1989). In addition, the use of pheromone traps to predict the density of the masked chafer grub population provides an efficient sampling device to determine if control is necessary (Potter, 1993). The use of sterile insect release as a means of genetic pest control may also provide a possible alternative / supplement to insect control (e.g. the melon fruit fly was successfully controlled by this method in Japan). A number of other insect pests have also been successfully managed as summarised in Table 2:

Table 2. IPM for some common turfgrass pests (after Olkowski, 1991)

In north western Europe leatherjackets, *Tipula paludosa*, are the most common and damaging turf pest, being favoured by mild winters and cool summers (Wilkinson, 1969). The perennial nature of grass always ensures that some vegetation and root material are present. In pasture Clements and Bentley (1985) noted that the weight of the leatherjackets was greater than that of the grazing domestic livestock. Clements and Bentley suggested possible control by heavy rolling, mowing closely at critical times and the possible use of endophyte infected grasses.

1.2.3 Weeds

The presence of weeds in turf is encouraged by stress inducing practices i.e. mowing too short and / or infrequently, excess fertilisation and irrigation and soil compaction. Weeds can be successfully managed by creating a soil habitat more conducive to the growth of grass than of broadleaf weeds e.g. appropriate fertilisation, irrigation and a reduction in compaction, the primary cause of weed growth.

The use of grass species adapted to the soil, raising mowing height and adjusting mowing frequency also results in decreased weed growth (Daar, 1986); raising the mowing height can reduce weed numbers up to seven times (Olkowski, 1991). Similar management techniques which increases the vigour and density of the grass also reduce the risk of crabgrass competition (Jagshitz and Ebdon, 1985). The goal is not to eliminate weeds but rather to keep numbers low enough to prevent significant visible damage.

1.2.4 Current technology for IPDM today

As well as cultural control methods used in IPDM a number of advanced techniques for pest prediction and monitoring are now being devised as part of a management strategy in both the agricultural and turfgrass industries. More precise models for the prediction of disease development are being developed because of advancement in computer technology and weather gathering equipment. The optimum development for the majority of turfgrass diseases is favoured by combinations of particular environmental conditions. Those parameters with the greatest influence are air and soil temperature, soil moisture, leaf surface wetness and relative humidity. Mathematical models to predict disease occurrence can be developed by measuring these factors, recording them over a period of time and correlating them with disease outbreaks. These models enable more accurate applications of fungicides based on environmental conditions rather than routine application on a calendar or preventative basis. Disease prediction models e.g. *Pythium* blight and Anthracnose models results in more accurate and cost effective treatment of the two diseases with less fungicide being applied. The two models have an accuracy rate of greater than 95% in predicting disease 'outbreaks (Vargas *et al*, 1989). A successful model for predicting the occurrence of the first generation of the chinch bug has also been developed (Niemczyk *et al*, 1992). Mora-Aquilera *et al* (1993) devised a prediction model for the papaya ring spot virus in Mexico over five years resulting in effective management of the disease.

In addition to prediction models, early detection and monitoring has become more advanced. Antibody aided detection (by enzyme linked immunoabsorbant assay, ELISA) is a useful tool in confirming diagnosis and determining general pathogen population fluctuations. ELISA may also be used to monitor the effects of management actions and weather on pathogen growth and survival (Shane, 1991). Immunoassays have been devised for three fungal pathogen complexes in turfgrass - *Pythium* blight, *Rhizoctonia* brown / yellow patch and dollar spot (Miller *et al*, 1989). Necrotic ring spot, which is difficult to identify using conventional methods, can also be successfully identified using this technology (Nameth *et al*, 1990) as well as an assay based on the polymerase chain reaction (Ogorman *et al*, 1994). ELISA is sensitive, specific, reliable and user friendly ensuring accurate and timely identification of pests and diseases, a crucial aspect of successful management. Schumann *et al* (1994) has successfully integrated environment and immunoassay based forecast systems to reduce the number of fungicide applications applied to control *Rhizoctonia* blight on turfgrass.

Regular maintenance is the most important factor in maintaining high quality turf (Boskovic and Sheils, 1985). The key to successful turfgrass development is the interaction between environmental conditions, turfgrass plants and pathogens (Dernoeden, 1991). Environmental conditions are important in disease development; changing cultural practices to modify environmental conditions in favour of the turfgrass plant and against the pathogen provides the basis for a successful disease management strategy. The control measures should be implemented at the pathogens' most vulnerable stage (O'Neill, 1985a). The environment is not static and as a result cultural practices need to be continually modified to encourage vigorous growing conditions. The following section discusses a number of cultural control measures, physical and genetic, available to the turfgrass manager to control diseases and pests.

1.3 Cultural Practices on Sports Turf.

Cultural practices collectively provide a resilient framework for plant protection and serve to reduce problems that require intervention with pesticides (Jacobsen and Backman, 1993). Turfgrass culture is the science and practice of establishing and maintaining turfgrasses for specialised purposes. These practices can be divided into the following major areas: mowing, fertilisation, irrigation and cultivation. Such practices modify the microenvironment of the turfgrass plant and ensure the best possible growing conditions. The basic principles involved depend on the intensity of culture. The four major groups of turfgrass cultural systems are: greens, sports turf, lawn turf and functional turf e.g. roadsides, airfields and shooting ranges (Beard, 1973).

1.3.1 Mowing.

Mowing is the most fundamental and universal practice used in turfgrass culture. The photosynthetic capacity occurs primarily in the leaf tissue, therefore mowing strongly influences the physiological and developmental condition of the turfgrass plant. Any cutting or defoliation can be detrimental e.g. the cut tip provides an ideal site for the penetration of pathogens. An exudate associated with the cut tip containing essential elements and carbohydrates enhance the spore germination, penetration and infection rates of pathogens.

Cutting Height.

The cutting height is usually within the range of 5-100 mm. Few turfgrass species tolerate continual mowing below 5 mm or maintain adequate turfgrass uniformity and density at heights above 100 mm. Selection of cutting height depends on the condition, purpose and growth habit of the turfgrass involved. The height of cut can effect the degree of bounce, distance travelled, and roll of ball. Richards and Baker (1992) demonstrated how ball roll was decreased as the sward height increases; the maximum acceptable height for good amateur play Association football was 50 mm. The cutting height is usually a compromise between the demands of the specific game involved and the physiological principles that influence the health and vigour of the turfgrass species. Species vary greatly in tolerance to cutting height. Tolerance is a function of growth habit. Turf becomes weak and lacks vigour if the cutting height is lower than normally tolerated by a given species or cultivar; turf mown excessively close is also more prone to weed invasion. Mowing too high can cause excessive thatch accumulation. This renders the turf more prone to diseases and environmental injury. As the cutting height is lowered the following responses occur: decreased carbohydrate production and storage, decreased leaf width, root production and growth rate and rhizome growth, coupled with increased shoot growth and density and quantity of chlorophyll produced (Beard, 1973).

Mowing Frequency

The mowing frequency is determined by the shoot growth rate, environmental conditions, cutting height and the purpose of the turf. Although defoliation stimulates shoot growth and tillering, no more than 30-40 % of the leaf area should be removed at any one cutting. Turfgrass can be adversely affected if the interval between mowings is too short. If mowing frequency is increased the following responses can be observed: increased shoot density and succulence, decreased carbohydrate reserves and reduction in shoot, root and rhizome growth. Chlorophyll content also decreases (Beard, 1973).

Cutting Removal

The return of cuttings tends to reduce turfgrass quality, interfere with the roll of the ball and increase susceptibility to disease. Where cuttings are removed the fertilisation rate must be increased to replace nutrients removed in the cuttings. Cuttings also contribute a certain amount of organic matter to the soil that can result in improved soil structure. Mowing wet grass is undesirable. When the turf is dry it cuts more easily and the cuttings do not clump together and clog the mower, gives a better appearance and takes less time. Mowing wet grass also enhances the spread of disease-causing organisms (Beard, 1973).

Growth Regulation

Mowing is a costly operation in maintaining quality turf. Chemicals which inhibit or regulate turfgrass shoot growth and thus reduce the mowing frequency required have attracted considerable attention since 1945 (Beard, 1973). Partial growth retardation offers such benefits as controlled growth during wet seasons or where mowing equipment can not be used.

1.3.2 Fertilisation.

The actively growing turfgrass plant contains 75-85 % water with the remaining portion composed primarily of organic compounds. These organic compounds are composed of sixteen essential elements that are directly involved in plant nutrition and enable the plant to complete its life cycle. The sixteen essential elements are listed in Table 3.

Table 3. Essential elements utilised by turfgrass.

Micronutrients		**Micronutrients**
Obtained from CO_2 and H_2O	Obtained primarily from soil	
Carbon, C	Nitrogen N	Iron, Fe
Hydrogen, H	Phosphorus, P	Manganese, Mn
Oxygen, O	Potassium, K	Zinc, Zn
	Calcium, Ca	Copper, Cu
	Magnesium, Mg	Molybdenum, Mo
	Sulphur, S	Boron, B
		Chlorine, Cl

Nutrient Uptake

The leaves, and to a lesser degree the stems, are the major surfaces for carbon dioxide absorption. Most water and mineral nutrient absorption occurs throughout the root system. The turfgrass root system is ideally suited for nutrient uptake because it has an extensive fibrous root system with a large surface area. Nutrient ions can be absorbed into the root cells against a diffusion gradient and are accumulated within the cell. This uptake process is not reversible and is selective in nature with certain ions being absorbed and others excluded. Once absorbed the nutrients are translocated to actively growing parts of the plant.

Nutrient uptake is determined by the characteristics and condition of the root system and the surrounding soil. Uptake also depends upon energy available from root respiration. Adequate respiration rates can be maintained by ensuring an adequate oxygen supply and optimum temperatures. Poor soil aeration and waterlogged soils and extreme acidity/alkalinity severity restrict respiration and impair the uptake of essential nutrients.

Essential Nutrients

Nitrogen, N

Turfgrasses require nitrogen in the largest amount of any essential nutrient with the exception of C, H and O; turfgrasses normally contain from 3-6 % N. For this reason, N is the nutrient applied in the largest amounts in turfgrass fertilisation programmes. It is a vital constituent of chlorophyll, amino acids and proteins, nucleic acids, enzymes and vitamins. Nitrogen affects the plant in a number of ways including shoot growth and density, root growth, colour, disease proneness, heat, cold and drought hardiness, recuperative potential and the composition of the turfgrass community. The overall plant response can not continue indefinitely; at a certain point the quantity of carbohydrates available for protein synthesis becomes limiting. This causes a distinct suppression of root growth, while shoot growth continues to respond to higher N levels. Such high levels can result in the death of the root system. A decrease in cell wall thickness and an increase in cell size can also occur. Balanced N levels reduce thatch, maintain colour and shoot density and recuperative potential. The level of nitrogen can influence the severity of disease development. Certain diseases are promoted by high N levels whereas other diseases are inhibited, (Table 4)

Table 4. Effect of nitrogen levels on disease (Shurtleef *et al,* 1987).

The nitrogen source can also influence turfgrass diseases. Ammonium sulphate and ammonium chloride reduce the severity of take all patch, spring dead spot and pink snow mould. Organic nitrogen sources decrease dollar spot and necrotic ring spot and sulphur coated urea reduces summer patch (Dernoeden, 1991). Excessively low N levels can also result in the encroachment of undesirable weeds (Beard, 1973).

Phosphorus, P

Phosphorus is an essential macronutrient contained in every living cell. It is involved in a number of physiological functions within the plant including energy transformations (as adenosine triphosphate, ATP), carbohydrate transformations and it is a constituent of genetic material. The quantity of P utilised by the turfgrass plant is considerably less than the amount of N and K. Phosphorus affects the establishment, rooting, maturation and reproduction of turfgrasses. A phosphorus deficiency causes a reduction in the tillering, shoot growth and moisture content of grass shoots.

Potassium, K

Potassium is essential in plant growth and developmental processes. K functions in carbohydrate synthesis and translocation, amino acid and protein synthesis, catalysing numerous enzymic reactions including nitrate reduction, controlling transpiration by regulating stomatal guard cell turgour, controlling the uptake rate of certain nutrients and regulating the respiration rate. Potassium influences turfgrass rooting, drought, heat and cold hardiness, disease proneness and wear tolerance (Beard, 1973). Higher K levels reduce the incidence of ***Helminthosporium*** spp., brown patch, take all, ***Fusarium*** patch, red thread and dollar spot. Increased proneness to disease resulting from a K deficiency is associated with an excessive accumulation of nitrogen and carbohydrates which provides a favourable medium for pathogen activity, a thin delicate wall structure providing ideal penetration sites, and changes in the reaction and composition of cell sap which enhances pathogen activity and reduces plant vigour.

Calcium, Ca

Calcium functions as a vital constituent of cell walls, as an important component in cell division and as a neutralising factor for potentially toxic substances within the cell. Calcium deficiency results in increased susceptibility to red thread and pythium blight by reducing plant vigour (Beard, 1973).

Magnesium, Mg

Mg is a constituent of chlorophyll. It is also involved in the translocation of P and is a cofactor in many plant enzyme systems. It is essential for the maintenance of a healthy coloration and growth of turfgrasses (Beard, 1973).

Sulphur, S

The role of sulphur is primarily as a constituent of certain essential amino acids e.g. cystine, which are required for protein synthesis. It is also a constituent of certain other organic compounds in plants such as thiamine and biotin. A sulphur deficiency can result in development of powdery mildew disease because of reduced plant vigour (Beard, 1973).

Micronutrients

Micronutrients such as iron, manganese, copper, zinc, molybdenum, boron and chlorine are as important as macronutrients, but are required in much smaller amounts (Table 5).

Table 5. Function of turfgrass micronutrients.

Micro-nutrient	**Function within turfgrass plant**	**Possible mechanism in disease resistance (Graham, 1983)**
Iron	chlorophyll synthesis respiratory enzyme constituent	activates enzymes involved in lignin synthesis. Lignin provides a physical barrier against a wide range of invading organisms
Manganese	chlorophyll synthesis cofactor in plant enzyme systems	Mn^{2+} involved in several steps of lignin biosynthesis pathway
Zinc	enzyme constituent cofactor in synthesis of hormones and auxins	mechanism unclear, but reports of suppressive effects on pathogens
Copper	enzyme constituent constituent of growth promoting substances	involved in lignification
Molybdenum	cofactor in nitrate reduction enzyme system	nitrate competition
Boron	calcium utilisation	increased growth leading to increased disease tolerance
Chlorine	regulates osmotic pressure and cation balance within plant cells	mechanism unclear

Silicon, Si

The exact role of silicon in the turfgrass plant is unknown although it constitutes up to 1.4% of leaf dry matter. This amount is similar to potassium and greater than the combined levels of calcium, phosphorus, magnesium and sulphur (Lawson, 1991). All grasses including wheat and rice have high levels of silicon but it does not appear to be an essential micronutrient although it may have a role in cell wall structure (Graham, 1983). Silicon helps to maintain leaf rigidity which may increase wear tolerance and possibly aid disease and pest resistance by decreasing the penetration of pathogenic hyphae and insect mouth parts (Jarvis, 1987).

Fertiliser Practices

The primary objective in applying a fertiliser is to apply plant nutrients that are deficient in the soil in order to maintain turfgrass quality. In addition to supplying essential nutrients, fertilisers influence other soil properties including the soil reaction, nutrient availability and the soil microbial populations. An effective fertiliser programme initially involves a determination of fertility requirements. This can be achieved by observing visual symptoms, together with tissue and soil tests. Secondly, an appropriate fertiliser must be selected. Factors to consider include spreadability, water solubility, initial plant response time, efficiency and storage characteristics. Finally, rate and timing of fertiliser use must be considered which will depend on soil nutrient level, cost, environmental conditions and intensity of use. Such factors greatly influence susceptibility to disease; light, frequent applications are more desirable than heavy, infrequent applications (Beard, 1973).

1.3.3 Irrigation

Irrigation practices are needed where the quantity and seasonal distribution of precipitation is inadequate to ensure turfgrass quality. Irrigation helps to maintain adequate density and colour. The microclimate of turfgrass areas is altered considerably when irrigated. Both the soil and air temperatures adjacent to an irrigated turf are cooler than unirrigated areas. Relative humidity is also higher. Sporadic irrigation is not effective and can be detrimental to the turf in terms of reduced carbohydrate reserves, vigour and drought resistance (Beard, 1973). Considerations in developing an irrigation programme include irrigation frequency required, volume of water needed, water source and quality and method of irrigation. Frequent irrigation that allows free water to remain on the leaf for extended periods of time can result in disease problems. Early morning irrigation reduces the time that water droplets and exudates remain on the leaf. Increased irrigation also results in reduced plant vigour and quality as a result of decreased root and stem growth. The weakened turf is more subject to disease, pest and weed invasion and wear damage; the turf is less tolerant to heat, cold and drought.

Wetting Agents

Wetting agents act as surfactants. They function by reducing the surface tension between water and solids, thus enabling more rapid water penetration through thatch and soil which reduces the quantity of water required. The use of wetting agents is dependent on soil type, for example clays can absorb and inactivate wetting agents more rapidly than loam/sand based soils. Climate also determines the use of wetting agents. The need for wetting agents is decreased if there is an abundant water supply, whereas if water supply is short wetting agents increase the efficient use of water (Beard, 1973).

1.3.4 Mechanical operations

Mechanical operations used in turfgrass culture refers to methods of selectively tilling established turf without destroying any of its characteristics. The primary methods are coring, scarifying, forking and spiking. These decompaction methods are best achieved during active turfgrass growth. Such practices improve the exchange of air and water between the atmosphere and soil. This exchange involves the downward movement of oxygen and water into the soil and the upward movement of carbon dioxide and other toxic gases from the soil.

Such treatments encourage deeper, more extensive rooting and increased shoot density, and can also stimulate thatch decomposition, particularly where soil is brought to the surface where it functions as a topdressing (Adams and Gibbs, 1994). The practice of topdressing involves the distribution of a thin layer of selected or prepared soil to a turfgrass area. In addition to thatch control, topdressing is utilised for smoothing/levelling of the turfgrass surface, modification of the surface soil and winter protection of turf. Certain nutrients and micro-organisms are also provided in the topdressing that stimulate growth and improve turfgrass colour.

Thatch (a tightly intermingled layer of dead and living stems and roots that develops between the soil surface and the zone of green vegetation) provides an ideal microenvironment and medium for the development of disease-causing organisms, particularly the facultative parasites. Thatch accumulation is associated with an increased incidence of *Helminthosporium* leaf spot, *Typhula* blight, stripe smut, dollar spot and brown patch (Shurtleef *et al*, 1987). In addition to the enhancement of disease and insect activity, thatch also reduces the efficacy of pesticides. In addition to topdressing, thatch can also be managed by liming and scarification.

Mechanical techniques that amend soil for optimum root growth should be employed e.g. increasing the sand content to reduce compaction and increasing internal drainage improves root penetration. With use the soil structure begins to collapse and the balance between soil, air and moisture is disrupted. Poorer soils restrict root growth and plants are weakened as a result. Sports turf needs to be managed with constant consideration to the soil and the roots growing within it (Roberts and Grau, 1987). Schaefer and Larson (1989) reported a product which leads to an artificially increased large microbial population. The microbes act as organic soil aggregating agents and improve aggregate development and stability which helps to maintain soil structure thereby increasing plant root growth.

In addition to physical cultural practices to maintain turf vigour and reduce disease, resistant cultivar and species mixtures can be employed to increase the genetic variation and stability of the turfgrass environment.

1.4 The Use of Species and Cultivar Mixtures for Disease and Pest Control.

The buffering effect that crop mixtures have against disease losses have been known since at least 1898 (Browning and Frey, 1969). Diversity occurs in both host and pathogen populations; Leewenhoek may have been the first author to note pathogenic specialisation in rust when in 1678 he observed that some grasses were contaminated with rust whereas others were not (Browning, 1957).

In a natural ecosystem diseases and their hosts are in a state of dynamic equilibrium. Epidemics are rare despite the fact that host, parasite and favourable conditions are all present. Diversity is present in both populations; this diversity is responsible for the stability in natural ecosystems and the stability of agro-ecosystems could be increased by greater diversity. The potential instability in agricultural systems may also stem from the lack of any significant history of coevolution between plants and parasites. In natural ecosystems coevolution allows for the selection of resistance/susceptibility and avirulence/virulence loci in frequencies that enable host and parasite to coexist. In agroecosystems, evolution of the host population is frozen as it is replanted each year with no opportunity for disease to influence resistance gene frequencies (Mundt and Browning, 1985). The cultivation of mixtures within and between species help to protect crops against a number of stresses by increased diversity e.g. mixtures within wheat, barley and potatoes are widely used in the Andes, cereals and legumes in Pakistan and rice in Africa and Asia (Wolfe, 1985). In the developed world mixtures are also used in cereals, rice, soybeans, potatoes, chickpeas, oil seed rape, field peas, cotton, various tree species and turfgrasses (Wolfe, 1985). Mixtures usually yield at least as well as the mean of their components. Yield increases have been observed regularly where variety mixtures have been designed and achieved restricted disease increase; the gain can be of the order of that achieved by a single fungicide application (Wolfe, 1985). As a result of environmental variation, mixed crops provide reliable and high levels of production by buffering against differing environmental factors. Conversely, it is possible to select mixture components that differentially exploit more constant features of the environment and so decrease interspecific competition (Wolfe, 1981).

When resistant cultivars are grown on a large scale, they commonly become susceptible to specifically adapted genotypes of pathogens. To delay or prevent this, the pathogen must be presented with the greatest possible diversity of host resistance. To maximise the benefits of host diversity, host genotypes can be mixed to maximise cross inoculation between plants. A susceptible cultivar surrounded by resistant plants will tend to have less disease than if it were grown alone. If there are differences is host susceptibility, then the reaction in the mixture will tend towards that of the least effected component (Wolfe, 1981). Host mixtures restrict the spread of disease considerably (provided the components differ in their susceptibility) e.g. in mixtures of spring barley up to 80% reduction in the incidence of powdery mildew was noted compared to the mean disease levels of the components grown in pure stands (Wolfe, 1985). Similarly, incidence of *Septoria nodorum* was reduced in mixtures of wheat varieties. The spread of a pathogenic nematode has also been shown to be restricted in mixtures of soybean varieties relative to its behaviour in pure stands (Wolfe, 1985). Cultivar mixtures can be easily exploited to provide a potentially simple, cheap, effective and long lasting means of controlling important pathogens and will also insure against other unspecialised diseases that occur sporadically. The introduction of mixtures is also a strategy that can be used in conjunction with other control measures (Wolfe, 1985).

Mixture components should be phenotypically similar with respect to important agronomic characteristics e.g. height and maturity date, but as genetically diverse as possible for all other traits including disease resistance (Mundt and Browning, 1985). Wolfe and Barrett (1980) noted that barley mixtures blended to control powdery mildew also reduced the severity of stripe rust, leaf rust and *Rynchosporium* induced disease. In California a barley population has been developed that incorporates resistance to the four major barley diseases, mildew, leaf stripe, yellow rust and brown rust. Resistant components may also at least compensate for losses caused by soil borne pathogens and abiotic stresses (Mundt and Browning, 1985).

In addition to cultivar mixtures, genetic diversity can be introduced into the host population by multilines. Multilines are mixtures of near isogenic lines differing in disease resistance whereas in cultivar mixtures, individuals carry different resistance genes (Jeger *et al*, 1981). Multilines have been used successfully to control crown rust in oats (Browning and Frey, 1969). Genetic diversity helps counter the rapid emergence of new pathotypes (Jeger *et al*, 1981). The changing race populations led to 'boom and bust' cycles of popularity for pure line varieties. Several non-uniform crop varieties exhibited only partial damage, suggesting a possible solution. The buffering effects of genetic diversification were apparent (Suneson, 1960). However, if a particular mixture were to be used continuously it is unlikely to become as susceptible as the components used as pure varieties on the same scale (Wolfe, 1985).

1.4.1 Mechanisms of Disease Restriction

There are three ways in which disease is restricted in cultivar mixtures:

1. A reduction in the spatial density of susceptible plants therefore limiting the amount of susceptible tissue, and so reducing the probability of spore survival. Spore density declines exponentially along a gradient from the source and each extra reduction in plant density has an increasingly smaller effect on dispersal.
2. A barrier effect is provided by the resistant plants that fill the space between susceptible plants.
3. Resistance induced by non-pathogenic spores such that pathogenic spores that land in the same area are prevented from infecting and so are limited in their productivity.

The stage of disease restriction depends on many factors including the mixture constitution, quality and amount of inoculum and the number of pathogen generations during development of the epidemic (Wolfe, 1985).

Depending on the environment, the percentage of resistant plants in the mixture required to protect a mixed population is c. 30%. Several lines also provide adequate protection against disease, whilst a two component mixture with approximately the same percentage of resistant plants is inadequate (Mundt and Browning, 1985).

Genetic diversity can also be attained geographically and temporally. Regional deployment can be used to break the disease path by utilising different race-specific resistance genes in different geographical zones; the inoculum produced in one zone is avirulent to plants in a different zone. Deployment of different resistance genes at different times also imposes disruptive selection on the pathogen population forcing it to cycle between plants with different resistance genes (Mundt and Browning, 1985).

The flexibility and performance of mixtures extends the choice among available cultivars. There is much greater potential for assembling mixtures with resistances to a range of disease and abiotic stresses, each with many qualitative and quantitative variations. Cultivar mixtures can also be successfully integrated with fungicide use to maximise disease control.

1.4.2 Fungicides and Cultivar Mixtures.

The evolutionary dilemma created by cultivar mixtures can be mimicked with fungicide applied to seed. Treating seeds of a particular cultivar with different fungicides and mixing them prior to sowing will obtain a stand of randomised distribution of single fungicides. Such treatment can be applied separately to components of a host mixture thus increasing the heterogeneity of disease control mechanisms and problems for the pathogen. A further advantage is that a particular fungicide can be applied to a different host component in different places or years adding a further dynamic element to the confusion of the pathogen. Economic and environmental cost is kept low because of the reduced amount of fungicide required. Disease management is improved because seed treatment reduces the initial inoculum and spread of the epidemic at a stage when the host mixture itself has little effect. Varietal and chemical components thus help to protect each other against rapid evolution of the pathogen (Wolfe, 1985). The bulk of research on the effect of genetic diversity on disease has been conducted on cereals although other agricultural crops and turfgrasses have been studied.

1.4.3 The Use of Cultivar Mixtures in Agriculture.

The increased production of barley, the largest cereal crop in the U.K. was seriously constrained by a single disease, powdery mildew. The U.K. annual loss was estimated at $80m in 1980 (Wolfe and Barrett, 1980). The climate and production method is ideally suited to the biology of the pathogen. As new resistant cultivars were introduced which became popular, a large selection pressure was placed on the pathogen population for the increase of genotypes with corresponding virulence. The use of mixtures of cultivars or 'blends' reduced mildew incidence due to the retention of larger amount of green leaf area throughout the season. Mixtures provide a means of slowing epidemic development and sustaining high yields in cereals (Wolfe, 1978). Chin and Wolfe (1984) and Kølster *et al* (1989) also noted superior yield, yield stability and disease reduction when barley was grown in mixtures of cultivars relative to barley in pure stands of a single cultivar. In the U.S., Mundt *et al* (1994) reported that barley cultivar mixtures restricted leaf disease (scald and net blotch) development by 12% and disease severity was restricted by up to 32%. Browning (1957) noted the effect of mixtures of oat cultivars on stem rust losses. The yield was enhanced and disease development reduced compared to oats grown in pure stands. This trend was confirmed by Leonard (1969). Sifuentes-Barrera and Frederiksen (1994) reported that when sorghum was grown in mixtures, leaf blight, *Exserohilum turcicum*, was reduced on susceptible cultivars in the mix, resulting in increased yield.

In addition to cereals, mildew can successfully be controlled and the yield subsequently improved when swedes are grown in mixtures (Sitch and Whittington, 1983). Tarhuni and M^{c}Neilly (1990) noted that growing mixtures of spring faba bean cultivars resulted in increased productivity (between 10 and 20%) and yield stability while reducing the risk of crop failure due to sudden outbreaks of virulent pathogens.

As well as disease control, insect pest damage can also be controlled by cultivar mixtures. Weiss *et al* (1990) recorded that when potential damage caused by the wheat stem saw fly was low to moderate, cultivar mixtures were useful at suppressing the pest.

1.4.4 Choice of Grasses for Turfgrass Use and Implications for Disease Management.

There are very few research papers on the merits of species and cultivar mixtures in turfgrass literature compared to agriculture. A major part of the experimental work discussed in Chapter three refers to the beneficial effects of mixtures in terms of effective disease management on turfgrass. There are a number of turfgrass species and cultivars which have a wide adaptability to environmental conditions. Some grasses have naturally occurring resistance to diseases and pests; specific genes can also be introduced for resistance in an otherwise desirable species or cultivar. The uses of mixtures combined with the optimum seed rate can also offer successful competition with weed species. The initial choice of grass species or cultivar is based on several factors as summarised in Table 6:

Table 6. Factors determining initial choice of turfgrass species. (After Shildrick, 1980).

The use of mixtures of cultivars restores some of the adaptability which can be obtained from diversity in species and gives insurance against weakness in seasonal colour, disease tolerance and sward texture. (The final composition of turf areas all sown with the same mixture can vary greatly according to numerous factors of climate, soil and management). The choice of mixture is dependent on the use of the turf. For fine turf (5mm), *Agrostis* and *Festuca rubra* are appropriate. Heavy duty turf (20mm+) is based on *Lolium perenne* with *Poa pratensis* which provides substantial additional colour following wear treatment. For intermediate use (10-15mm), *Festuca* and *Agrostis* are used; *Poa pratensis* is added to improve durability. In low maintenance situations, *Lolium perenne* is used because of its rapid establishment. In special situations (e.g. shade, soil contamination and extreme pH), stresses of frequent defoliation and heavy wear may be more important than the particular local circumstances; it is therefore more practical to use species known to withstand these stresses than to choose naturally occurring species which may at first appear appropriate but are then unable to withstand the heavy stresses imposed on them (Shildrick, 1980). Vargas and Beard (1981) noted increased melting out and powdery mildew on smooth stalked meadow grass, *Poa pratensis*, cultivars growing in the shade. Gilbert and Dipaola (1985) reported that cultivar mixtures increase turf quality under shade conditions. Juska and Hanson (1959) noted that a mixture of *Poa pratensis* and *Festuca rubra* produced higher quality turf than either species seeded alone. It was also noted that if disease or other injury affects one species in the mixture, the resulting injury is generally not as severe as when affecting a single species.

Ebdon and Skogley (1985) stated that turfgrass mixtures of two or more species seeded together provide greater genetic diversity and improved tolerance to pests and environmental stress than do monostands. However to achieve compatibility among species it is necessary to select the appropriate percentage of each species in the mixture. Different grass species germinate and develop at different rates; *Poa pratensis* is slow whereas *Lolium perenne* is very rapid. Subsequent competition between species during and following development may result in the elimination of some species. The end product greatly depends upon the seeding rate and species composition.

As well as conventional plant breeding techniques to induce disease resistance in turfgrass, several other technologies are also being considered. These include protoplast and cell culture, interspecific protoplast fusion and recombinant DNA technology (O'Neill, 1985a).

In addition to the basic physical and more sophisticated cultural practices available, chemical control is the second major element in IPDM.

1.5 Chemical Control

1.5.1 Fungicides

The use of chemicals in disease management is extensive. They are only essential when other less expensive control measures have failed, or as supplements to other control strategies. In addition to the cost of the chemical, the cost of application and possible damage to the crop during application must be weighed against improved yield quality and quantity. Factors influencing the need for chemical use include the amount and efficacy of initial inoculum, host resistance, pathogen aggressiveness and environmental conditions. Early detection, accurate diagnosis and prompt treatment all help to increase the efficacy of fungicides (O'Neill, 1985a). The chemicals used should provide consistent and effective disease control, be non-phytotoxic, non-toxic, safe and easy to transport and easy to apply.

Fungicides available fall into three categories which are based on their degree of mobility within the plant (Table 7).

Table 7. Classification of fungicides based on degree of mobility

Chemical	**Degree of Mobility**
Protectant	not absorbed from surface layer, based on metallic compounds e.g. Cu
Eradicant	absorbed but not translocated
Systemic	absorbed and translocated

Protectants and eradicants need repeated applications and must cover the entire plant to be effective. Systemics utilise a metabolic pathway in the fungi not found in the metabolism of the plant and since they are absorbed and translocated, constant reapplication is unnecessary. However, due to increased selection pressures resistance can be a problem e.g. Ridomil (ICI), a fungicide used against downy mildew in lettuce and tobacco, was withdrawn after nine months because of pathogen resistance (personal communication - C. Bishop).

Resistance can be reduced by decreasing chemical use, thereby lowering the selection pressure. This can be aided by the use of monitoring and prediction models and identification of an economic threshold to decide if and when chemicals are to be used. Selection pressure can also be reduced by advanced spray technology so a larger amount of chemical reaches the target plant e.g. increase adhesion by making the spray electrostatic, the use of microencapsulation, dressings.

Fungicides can be applied to prevent or cure disease problems. Curative applications are more economical and environmentally sound (e.g. such applications reduce selection pressure), but only if the disease can be treated rapidly. If the disease pressure is low, protectants and eradicants can be used as they are less expensive. However, when sudden, severe or chronic disease problems occur, systemic or systemic and contact fungicides may be needed which will provide more persistent protection when disease pressure is high (Dernoeden, 1989).

1.5.2 Pesticides

There are two major groups of pesticides; inorganic and natural plant compounds. The inorganics, organo-chlorines, -phosphates and carbamates are all neurotoxins.

Organochlorines are very persistent in the environment; because of biological magnification, residues tend to build up in the food chain. The first worries in the U.K. were in the 1950s when organochlorine residues were found in milk. In addition organophosphates are very toxic to mammals. Despite apparent problems, the value of pesticides produced in the U.K. has increased 170 fold between 1949 and 1985; in 1985 the value of pesticides produced in the U.K. was £511 million (Cremlyn, 1991).

Numerous advantages are associated with pesticide use. These include:

1. Increased yield. Without chemicals large crop losses can occur in the field, storage or processing e.g. in Ghana two thirds of the cocoa crop would be lost without pesticides (Cremlyn, 1978).

2. Human health i.e. disease control via vector control e.g. malaria and yellow fever. With respect to malaria, DDT saved more lives than medicine; the chemical eradicated the disease completely in Sri Lanka, but now there is a resurgence due to chemical resistance and drug tolerance (Chapin, 1981).

3. Finance. The world wide sale of pesticides is worth over several billion dollars. The cost benefit ratio is also high e.g. 4:1 in mixed crops in the U.S. (Pimental, 1979).

4. Allows rapid intervention.

5. Easily stored.

6. Remain active over a long period of time, if stored correctly

7. Variable formulations.

1.5.3 Pesticides in the Turfgrass Industry

The use of pesticides is only cost-effective in high input situations, e.g. golf greens, cricket squares, competition football pitches. Table 8 lists a number of pesticides approved for use on sports turf.

Table 8. Pesticides approved for use on some diseases and pests of sports turf. (Ivens, 1994).

Chemicals provide powerful tools for disease and pest control ensuring rapid and significant reductions in the target organism population. However, notable drawbacks in chemical use may also occur.

1.5.4 The Disadvantages of Chemical Use

Despite the obvious benefits of chemical use, a number of disadvantages also occur.

1. **Increased cost of production.** Research and development costs and the developmental period are increasing as are the number of compounds screened e.g. in 1956, 1800 compounds were screened for activity for the development of one chemical, whereas in 1986, 24,000 compounds were tested. On average, only 1 in 10,000 of the original compounds ever becomes a commercial product (Lever, 1990).

2. **Ecological effects** e.g. death of non-target organisms, pest flare back, secondary pest outbreak and human and animal toxicity. Pesticides can affect the ecosystem at all levels; not only are the much publicised top carnivores (e.g. birds of prey) affected but also vital micro-organisms in the soil. When PCNB was added to the soil to reduce *Pythium* and *Fusarium* seedling damage, disease severity increased as the nutrient competition decreased because PCNB sensitive actinomycetes and bacteria were destroyed (Farley and Lockwood, 1969).

Whilst herbicides provide an efficient tool for the use in combination with cultural methods for suppressing weeds, they also present a hazard to the user, fish and other wildlife. Desirable plants can also be injured. Nearly all herbicides are potentially dangerous and have possible secondary effects on wildlife; toxic sublethal doses, changes in palatability of poisonous plants and contamination or death of organisms in the food chain leading to increased or decreased wildlife numbers (Gangstad, 1982). Detectable residues of the herbicide 2,4-D were found in urine of people who were bare foot and in shorts and had been exposed to recently sprayed turf (one hour after application). However, no detectable residues were found in people exposed twenty four hours after application as dislodgeable residues are reduced drastically (Harris and Solomon, 1992).

3. **Resistance** occurs where a particular pest is able to tolerate a specific pesticide dose to which it was previously susceptible. Insecticide resistance has been known about for 80 years (Metcalf, 1989). The first case of resistance recorded was in 1908 in the plant scale, *Aspidiotus perniciosus*, towards lime sulphur (Melander, 1914). Since 1958, the number of resistance cases has increased by 800%. Resistance ensures the depletion of pesticide resources and so provides a dubious long term solution to pests due widening patterns of multiple resistance. The mechanism can be behavioural (e.g. avoidance), morphological (e.g. thickness of exoskeleton) or biochemical (i.e. capable of detoxifying compounds to non-toxic metabolites). The most recent reports of fungicide resistance are of metalaxyl tolerant strains of downy mildew, *Pseudoperonospora humuli*, isolates from hops (Klein, 1994) and sterol biosynthesis inhibiting fungicide resistance in net blotch, *Pyrenphora teres*, on barley (Peever and Milgroom, 1994). Resistance can be reduced by incorporating cultural and biological methods into a control strategy to reduce reliance on chemical control and thus decrease selection pressure (Metcalf, 1989).

1.5.4.1 Side Effects of Pesticides and Fertilisers in the Turfgrass Industry

Turfgrasses are the most intensively managed plantings in the urban landscape. There is an increase in public demand for dense, uniform pest free turf which leads to increased regular chemical applications. The total annual expenditure for turfgrass maintenance in the U.S. in 1983 was $15 billion; much of this was spent on chemicals (Potter *et al*, 1989).

Pesticides and fertilisers are versatile and powerful tools but detrimental ecological effects can result from their overuse. Kendall *et al*, (1992) reported that 85 American widgeon ducks died after grazing on a fairway recently sprayed with the organophosphate, diazinon. Their use may also effect energy flow and nutrient recycling by altering primary production and/or disrupting the activity of decomposer organisms. Earthworms ('The intestines of the Earth', Aristotle), nematodes, millipedes, mites, Diptera and Collembola all play a major role as decomposers. They fragment and condition plant debris before breakdown by micro-organisms, disseminate fungi and bacteria, enrich soil with excreta and help distribute organic matter through the top soil layer. The burrowing action of earthworms also aids air and water infiltration into turfgrass - 'Natures' little ploughman' (Darwin, 1907 cited by Potter, *et al*, 1989). Potter *et al* (1990), noted a 60-99 % reduction in the earthworm population following applications of benomyl, ethoprop and carbaryl; significant effects lasted up to twenty weeks.

An imbalance in decomposition causes a build up of thatch and excess thatch causes several other problems These include: decreased water infiltration, restricted penetration of fertilisers, binding of insecticides, shallow root growth and increased vulnerability to heat and drought stress (Beard, 1973). Excess fertiliser also encourages thatch because of increased vegetative production. Nitrogen fertilisation also acidifies the soil which can inhibit the activity of micro-organisms; the repellent nature of NH_4^+ may reduce the number of soil invertebrates (Potter and Haynes, 1993). Pesticides exert many effects on non-target organisms and processes instigating a number of secondary and tertiary changes until the entire management program is improved or hindered by certain pesticides (Smiley, 1981).Turfgrass lacks the complexity of natural grassland and would be expected to be relatively susceptible to pesticide induced perturbations (Potter *et al*, 1989).

Pesticides are generally toxic to predators e.g. a single application of the organophosphate, isofenphos, reduced populations of predatory mites, spiders and insects by 60%. Populations were still depressed six weeks after application. The predation of Japanese beetle eggs and the fall army worm can be reduced by upto 74% following insecticide application (Terry *et al*, 1993). Certain pests e.g. greenbug and chinch bug, can increase on treated turf because of predator death, i.e. ants (Vavrek and Niemczyk, 1990). A further problem to arise recently is enhanced microbial degradation of pesticide residues i.e. pesticides are being used as a energy source resulting in increased amounts of chemical being applied to obtain control (Potter *et al*, 1989).

As well as environmental effects, pesticides may also have other non-target effects on turfgrass. Herbicides suppress certain diseases while increasing others by altering the virulence of pathogenic fungi, the relationship between pathogenic fungi and parasites / competitors and the level of disease resistance in grass e.g. PCDP increases the incidence of ***Fusarium*** blight and stripe smut and 2,4-D increases leaf spot (Smiley, 1981). Insecticides also affects the growth ability of the pathogen and may alter the host resistance and the balance between pathogenic fungi and other micro-organisms (Smiley, 1981).

Herbicide applications may result in reduced turfgrass quality due to increased susceptibility to environmental stress (and disease as previously reported). Turgeon *et al* (1974) noted that DCPA caused substantial injury to red fescue as well as thinning and reduced rhizome growth in Kentucky bluegrass. Herbicides, including bensulide and napropamide, have also been shown to inhibit root development thereby reducing sod tensile strength (Dickens *et al*, 1989). Thatch accumulation was noted in Kentucky bluegrass following applications of bandane. Bandane was the most consistently injurious herbicide causing a marked reduction in turfgrass quality, poor rooting and increased susceptibility to stripe smut.

Nitrogen is the largest chemical input routinely applied to turf. If not taken up rapidly, nitrogen is readily transferred to nitrate which is a very mobile anion that has great potential to move rapidly from the rootzone to groundwater (Gold *et al*, 1989). Nitrate derived from land application of fertiliser is a widespread contaminant of groundwater and accelerates eutrophication of waterways (Petrovic, 1990). Deep percolation losses also represent a loss to the growing plants and an energy waste (i.e. production energy in manufacturing the fertiliser) (Starr and Deroo, 1981).

Graminaceous species are in fact very effective at reducing run off and the sediments and nutrients carried with it. Turf stabilises the soil and fixes the nutrients held within it (Welterlen *et al*, 1989). Where fertilisation poses a threat to groundwater quality, management practices can allow for minimising nitrate leaching e.g. altering the nitrogen source; natural organic fertilisers have a very low leaching potential, reducing irrigation, the use of nitrification inhibitors and application at times of vigorous growth (Gold *et al*, 1989). Another strategy is to install irrigation wells on the down gradient side of turf e.g. golf courses, to intercept and recycle nitrate (Domangue, 1993). Practices that increase rooting will reduce nitrate loss through leaching and leaching rates are also reduced in more mature plots (Geron *et al*, 1993). Finally, recent technology has introduced a material manufactured by a reactive layer coating (RLC) process which shows promise for minimising nitrogen loss through leaching. RLC coated ureas were successful at slowing nitrogen release and have potential as slow release N. fertilisers for turf (Peacock and Dipaola, 1992).

1.5.4.2 Fungicides

In recent years there has been a significant increase in the amount of fungicide used in turfgrass culture. U.S. figures for 1989 show that more fungicides were sold for use on turfgrass than any other commodity, including food crops. The 'average' U.S. golf club spent 48% of its pesticide budget on fungicides (Couch and Smith, 1991).

There are several reports of occasions where the use of fungicides has increased the incidence and severity of disease. Smiley and Craven (1979a, b) and Smiley (1981) noted increased *Pythium* blight, *Typhula* blight, rust, red thread, brown patch and *Fusarium* patch on plots treated with fungicide. Increased *Pythium* blight was first noted by Warren *et al* (1976) following treatment with benzimidazole. Dernoeden *et al* (1985) noted that increased fungicide use resulted in reduced turfgrass quality; fungicide treated plots were predisposed to more severe red thread infection compared with the control plots. Dernoeden (1991) also noted that the use of fungicides resulted in increased summer patch and leaf spot. Other non-target effects include alteration of grass tissue dry weight and nutrient content of leaves and stolons (Couch and Smith, 1991).

Beneficial micro-organisms involved in the decomposition process are affected, allowing thatch build up e.g. thiram significantly enhanced thatch formation when compared to untreated plots (Dernoeden *et al*, 1990). Fungicides may further increase the rate of root and rhizome production contributing to thatch accumulation (Smiley *et al*, 1985).

There are numerous examples in the literature of resistance to synthetic fungicides. Couch and Smith (1991) noted resistant brown patch and *Sclerotinia* isolates. Cadmium tolerant strains of *Sclerotinia* were first reported by Cole (1968) (cited by Dernoeden *et al*, 1985). Benomyl tolerant mildew strains were noted (Goldenberg, 1973). Dernoeden (1985) also noted benomyl resistant strains of leaf spot, *Pythium* blight and superficial fairy rings in addition to thiobenzadole resistant rust. *Pythium* blight was also found to be metalaxyl resistant (Vargas, 1987). Vargas (1987) also noted benzimidazole resistant anthracnose, powdery mildew and dollar spot; tolerance occurred in the first three years of use. *Fusarium* patch resistance to iprodione was reported in 1982; the disease was also cross tolerant to vinclozolin and procymidione (Chastagner and Vassey, 1982); additionally, Pennucci *et al* (1990) reported dicarboximide resistant strains of Fusarium patch in New Zealand.

Sanders *et al* (1985) demonstrated how reduced rate fungicide mixtures can delay fungicide resistance, whilst effectively controlling turfgrass diseases. Other compounds of natural origin may help to reduce synthetic fungicide reliance and delay resistance. Aoyama and Dol (1992) reported the antifungal activities of fern wood extractives against pathogenic turfgrass fungi including *Fusarium* and *Rhizoctonia*.

In addition to use of chemicals, biological control is also available as a possible control mechanism in IPDM and this is considered in the following section.

1.6 Biological Control

Biological control (biocontrol) is defined as the use of natural antagonists to maintain pest populations below economically damaging levels (DeBach, 1964).

In the past, approaches to biocontrol has been rather haphazard e.g. use of mongooses to control rats in Jamaica resulting instead in decimation of domestic chicken populations. However a number of early successes did occur:

a) The use of predatory ants, *Oecophylla*, to control insect pests in Chinese citrus groves in 1200 AD (Samways, 1981). The first major successful biocontrol programme was also in citrus groves in California in the 1880's. The trachinid fly and vedalia beetle were used to maintain cotton cushiony scale populations. This successful programme is still in use today.

b) In Australia (in the 1920s) the prickly pear cactus which had become an invasive weed was controlled successfully with a moth, *Cactoblastis cactorum* (Samways, 1981).

There are numerous advantages of biocontrol over chemical control. These include the cost benefit ratio. Biocontrol has been reported to be ten times cheaper than chemical control, largely due to increased chemical development costs; $20-40m is now associated with the development of a synthetic chemical pesticide (Jacobsen and Backman, 1993). The chances of finding new active molecules decreases yearly, and registration costs have significantly increased (Lenteren and Woets, 1988). Biocontrol is safer, less harmful to wildlife and results in less environmental pollution.

Disadvantages of biocontrol include lack of commercial involvement, unreliability and a relatively slow acting mode of action. However the Californian cotton cushiony scale control programme is still proving effective after 110 years. If biocontrol is to succeed commercially it must be consistently safe, reliable and cost effective (Renwick and Powell, 1990). The agent must exhibit a repeatable level of performance, survive under field conditions and be non-pathogenic to the crop with minimum chance of genetic mutation (Scher and Castagno, 1986).

Few biocontrol agents (BCAs) have reached the market place because of difficulties in effective commercial formulations and maintaining consistent benefits. In the U.S. only six BCAs are registered for use (Jacobsen and Backman, 1993):

1. Binab-T, a *Trichoderma* based product for protection of pruning wounds.
2. Gallatroll-A, *Agrobacterium radiobacter* for the control of crown gall.
3. Dagger-G, based on *Pseudomonas fluorescens* for the control of cotton seedling diseases.
4. F-Stop, a *Trichoderma* product for the control of damping off of peas, beans and corn.
5. GL-21, *Gliocladium virens* used against *Pythium* spp. and root rot of ornamentals.
6. Quantum 4000 HB, *Bacillus subtilis*, is used to inoculate peanut, bean and corn seed against *Rhizoctonia* root rot.

Such a small number is not surprising since research orientated toward product development has been pursued for a relatively short period (15-20 years). In comparison, modern synthetic fungicides have been under development since the 1930s. The estimated funding for biocontrol development is a small fraction of that expended for the development of synthetic chemical pesticides (Jacobsen and Backman, 1993). Despite an apparent lack of commercial interest a wealth of research has been undertaken to investigate the fundamental factors governing efficacy, mode of action and safety of released organisms (Lynch, 1988). Previous reliance on chemical control has resulted in non-degradable residues in the environment, pesticide resistance and elevation of minor pests to a major status e.g. insecticidal control of the cotton bollworm led to severe outbreaks of white fly in Sudan. There are several examples of successful biocontrol programmes particularly in protected cultivation, horticulture, forestry and the turfgrass industry.

1.6.1 Protected Cultivation

Greenhouses provide the ideal environment for successful biocontrol as conditions can be modified to suit the BCA and host plant. The use of chemicals in greenhouses is limited because of toxic residues and phytotoxicity to plants.

Three major pests of greenhouse crops are successfully controlled biologically. Chilean mites are used to control red spider mites; parasitic wasps control leaf miners and parasitoid moths and *Verticillium* fungi control white fly. *Bacillus thuringiensis* effectively parasitises the tomato moth and *Verticillium* is also used against aphids. The result is cheap reliable and permanent pest control (Lenteren and Woets, 1988).

A number of important phytopathogenic diseases are also successfully controlled biologically. The major BCAs are fungi of the genus *Trichoderma*. *Trichoderma* spp. are very important as they have multifuntional mechanisms for controlling disease that will be discussed in detail below. *Trichoderma harzianum* successfully controls brown rot, *Rhizoctonia solani*, in lettuce (Whipps and Lumsden, 1991). *Trichoderma*, *Gliocladium* and non-pathogenic *Fusaria* isolated from *Fusarium* suppressive soils effectively suppress *Fusarium* wilt of carnations (Lynch and Ebben, 1986). Benomyl resistant strains of saprophytic *Fusarium* and benomyl also control *Fusarium* wilt of carnations effectively. *Fusarium* basal rot of *Narcissus* is also successfully controlled by a *Trichoderma* spp, *T. viride* integrated with a *Streptomyces* sp., *Minimedusa polyspora* and a thiobendazole fungicide (Beale and Pitt, 1990). A commercial formulation of *T. harzianum*, *Gliocladium virens*, *Streptomyces* and *Pseudomonas fluorescens* is used effectively against damping off, *Pythium*, diseases of seedlings (Whipps and Lumsden, 1991).

The bacteria *Enterobacter cloacae* successfully controls *Pythium* rot on cucumber seedlings, particularly if the seeds are pregerminated (Hadar *et al*, 1983). *Pythium* rot of tomato is controlled by an antibiotic-producing species of *Penicillin*. Finally Blakeman and Fokkema (1992) discovered an *Ampelomycete* spp. which successfully controls mildew on cucumbers; a further benefit is an increase in yield as red spider mite predators are sensitive to mildew fungicides but the *Ampelomyces* fungi are resistant.

Examples of integration of biocontrol successfully with fungicides include the control of cucumber grey mould, *Botrytis cinerea*, (up to 96%) by the alternation of *Trichoderma harzianum* and a dicarboximide fungicide, resulting in a reduction in the use of chemical sprays (Elad *et al*, 1993). Kay and Stewart (1994a, b) reported four fungal biocontrol agents which are insensitive to a number of fungicides used to control onion white rot, *Sclerotium cepivorum*; in this case, biocontrol agents could help to reduce fungicide sprays.

1.6.2 Horticulture

Codling moths are a serious pest in orchards. These insects can successfully be controlled by the introduction of granuloviruses. The virus can be genetically improved by the addition of the scorpion genome which codes for venom production resulting in a fast acting neurotoxin (Tickell, 1995).

Several horticultural diseases are also controlled by BCAs. A major commercial application of biocontrol is the use of an avirulent strain of *Agrobacteriumradiobacter*, the causal agent of crown gall in fruit trees. The pathogen induces unregulated cell division but can be completely controlled by the agrocin (antibiotic) producing non-pathogenic strain (Lynch and Ebben, 1986). The use of a non-pathogenic mutant of the detrimental strain is more likely to succeed as competition exists for the same substrates. Whipps (1986) demonstrated the phenomenon of 'cross protection' in cucumbers with an avirulent strain of *Colletotrichum lagenarium.* An avirulent strain of *Phytophthora parasitica* has successfully been used against damping off in a bedding plant, *Catharanthus roseus*; this may prove of value as metalaxyl resistant strains of the pathogen have been isolated (Holmes and Benson, 1994).

A commercial preparation of *Trichoderma*, Binab T, is used to control apple leathery rot, *Phytophthora cactorum* (Gear, 1986). *Trichoderma* spp. are also used to control *Botrytis cinerea* in strawberries (Lynch, 1988), silver leaf disease (*Chondrostereum purpureum*), pruning wounds of fruit trees (Whipps, 1986) and dry rot of grapes and apples (Blakeman and Fokkema, 1982). Apple scab, *Venturia inaequalis*, can be effectively controlled by a urea spray which stimulates the growth of antagonistic *Pseudomonas* spp. Saprophytic *Pseudomonas* spp. and bacteriocin producing *Erwinia* spp. provide control as effective as fungicides against fire blight (Blakeman and Fokkema, 1982). Royse and Reis (1978) reported successful control of perennial peach canker, *Cytospora cincta*, by three fungi isolated from peach twigs.

A yeast, *Sporbolomyces roseus*, completely eradicated blue mould (*Penicillium expansum*) and grey mould (*Botrytis cinerea*) on apples in storage. The yeast shows promise for commercial development because it is ubiquitous in nature and occurs naturally on fruits i.e. a natural antagonist (Janisiewicz *et al*, 1994). Another yeast, *Sporothrix flocculosa*, used under strict commercial conditions to control rose powdery mildew exerted control comparable to that of a fungicide (Belanger and Labbe, 1994). McLaren *et al* (1994) reported that an application of *Talaromyces flavus* and *Conoithyrium minitans* at seeding decreased the incidence of *Sclerotinia* wilt in sunflowers and increased yield.

1.6.3 Forestry

The gypsy moth (*Lymantria dispar*), a major pest species in forestry is now controlled effectively by *Bacillus thuringiensis* (Wainhouse, 1987). Today the largest European biocontrol programme is in Poland where a bioinsecticide extracted from *B. thuringiensis* saved 150, 000 hectares of pine forest from caterpillars of the nun moth, *Lymantria monacha* (Coghlan, 1994). A number of commercially important diseases are also controlled biologically. *Heterobasidion* rot of pine is controlled by formulation of *Peniophora gigantea* (Lynch and Ebben, 1986). Dutch elm disease, *Ceratocystis ulmi*, and rot, *Lentinus lepideus*, of utility poles are controlled very effectively by a commercial formulation of *T. viride*, nutrients and metabolites (Gear, 1986).

1.6.4 Agriculture

The commercial use of biological control in agriculture is limited as management of the environment is more restricted. An environment with a degree of control is better suited to biocontrol as micro-organisms are more sensitive than chemicals to the physical environment (Lynch and Ebben, 1986). However a number of successful biocontrol programmes exist whilst several *in vivo* trial results appear encouraging and may provide possible future antagonists.

Two agricultural pests are currently controlled biologically; in France the cabbage moth is controlled by a virus whilst a parasitic moth is used to control the cassava mealy bug in Central Africa (Samways, 1981). *Trichoderma* and the closely related antagonist *Gliocladium* exhibit antagonism against a number of common agricultural disease organisms. These include *Sclerotinia* which infects several host plants (Lynch and Ebben, 1986). *Sclerotium rolfsii* is a serious disease of peanuts and warm season turfgrass; *T. harzianum* significantly reduces disease and increases yield (Backman and Rodriguez-Kabana, 1975). Canullo *et al* (1992) noted that *S. rolfsii* was reduced by the application of three urea derived compounds which reduce the viability of pathogenic spores whilst increasing antagonistic populations of *Trichoderma* spp.

Commercial control of cereal diseases is difficult in practice, although a number of possible antagonists have been identified. *Microdochium nivale*, (formerly *Fusarium nivale*), is a cereal stem base and ear disease and a virulent turfgrass pathogen. Blakeman and Fokkema (1982) successfully controlled the disease on cereals using *Alternaria* spp. and *Cladosporium* spp. *Chaetomium cochoides* and *C. globosum* are as effective as mercury seed dressings against the disease (Tveit and Wood, 1965). Gramicidin S, isolated from *Bacillus brevis*, was found to be sporicidal to *M. nivale* (Murray *et al*, 1986), whilst the commercial formulation of *Streptomyces* ('Mycostop') effectively controls the strain causing seedling blight. The severity of take all, *Gaeumannomyces graminis var tritici*, a common and important cereal root disease, appears to be reduced if the seeds are drilled with *Pseudomonas* spp. (Lynch and Ebben, 1986). Control by *Pseudomonas* is positively correlated with the degree of root colonisation (Bull 1991). Capper and Campbell (1986) noted that addition of ammonium nitrate optimised the rhizosphere pH for maximum root colonisation by *Pseudomonas*; the optimum pH range is between 6.0 and 6.6 (Ownley *et al*, 1992). *Pseudomonas* antibiotic (phanazine carboxylic acid) production is also increased in the presence of iron. Clarkson and Lucas (1993) recorded that *Pseudomonas* plus a commercial strain of *Streptomyces* was also effective at controlling eyespot stem base diseases.

A number of antagonists of sugar beet diseases have also been identified. *Nocardia* and *Pseudomonas* spp. plus physiological priming of the seed successfully controls *Pythium ultimum* (Lynch, 1988). Whipps (1986) reported a *Laetisaria* spp. which effectively controls *Rhizoctonia*. *Trichoderma viride* is used to control an unidentified stem rot of sugar cane (Blakeman and Fokkema, 1982). *Trichoderma viride* can also be used to control *Rhizoctonia solani* on field beans resulting in a doubling of yield (Lynch, 1988). *T. viride* exhibits activity against *R. solani* on radish and *Pythium* on peas (Whipps, 1986). *Fusarium* root rot of peas and *Fusarium* wilt of radishes can reduced by the addition of chitin to the soil which increases populations of soil actinomycetes (Mitchell and Alexander 1961, 1962). *Pseudomonas* spp. exhibit antagonism against a bacterial disease, *Erwinia* soft rot, of potatoes (Lynch, 1988). A fungal disease of this crop, *Rhizoctonia solani*, can also be managed by using resistant cultivars, reduced fungicide applications and a *Verticillium* sp. as a BCA (Chand and Logan, 1984). Beagle-Ristaino and Papavizas (1985) also noted a marked decrease in *Rhizoctonia* severity (50-55%) after seed was treated with the fungal antagonists *Trichoderma viride* and *Gliocladium virens*. Schisler and Slininger (1994) has identified eighteen bacterial strains which constantly suppress dry rot, *Gibberella pulicaris*, on potatoes including members of the genera *Pseudomonas* and *Enterobacter*.

1.6.5 Weed Control

The use of microbial herbicides is less common than biological pest and disease control; at present, thirty weed species are controlled biologically. These are in environments where the use of chemicals would be too expensive, e.g. control of *Senecio jacobea* (ragwort) by the Cinnabar moth on range lands, or too dangerous, e.g. control of water fern, *Salvinia* sp. by the Brazilian weevil in waterways. Other examples of microbial herbicides include the use of the fungus *Phytophthora* to control milkweed vine in citrus groves (Samways, 1981).

1.6.6 Biological Control in Turfgrass

The turfgrass environment is suited to biological control as a degree of control over conditions influencing the success of the BCA, and the grass itself can be maintained. A number of successful disease, pest and weed control programmes have been devised for the turfgrass manager and are outlined as follows:

1.6.6.1 Diseases

The three methods of disease control are:

1. Disease resistant species and cultivars e.g. perennial rye grass, *Lolium perenne*, is resistant to necrotic ring spot.
2. Application of biologically active composts. These composts contain fungi and bacteria which increase the availability of nutrients, produce substances which stimulate plant growth, reduce disease, protect plant surfaces and induce the plants natural defence mechanism. For example, *Pythium* root rot on creeping bent grass, *Agrostis stolonifera*, and necrotic ring spot, *Leptosphaeria korrae*, on Kentucky bluegrass, *Poa pratensis*, are successfully controlled by application of suppressive composts (Burpee, 1991).
3. Application of biologically active pesticides e.g. suppression of grey snow mould, *Typhula incarta*, with the non-pathogenic fungi, *T. phacorrhiza* and *T. ishikariensis var ishikariensis* (Burpee *et al*, 1987). Lawton and Burpee (1990) noted that increasing the application rate of *T. phacorrhiza* reduces the intensity of grey snow mould, the time required for the turf grass to recover from injury and the number of *T. incarta* spores in the thatch.

The use of suppressive soils (composts) to manage diseases is practical both economically and technologically as the soils can be readily combined and applied with top dressings. Dollar spot, *Sclerotinia homoeocarpa*, is significantly reduced when soil enhanced with the bacteria, *Enterobactercloacae*, is applied. The bacteria is as effective as a fungicide and suppression is still evident two months after application (Nelson and Craft, 1991a, b). The use of suppressive soils in disease control in general is discussed below.

Take all, (*Gaeumannomyces graminis var graminis*), an important fungal pathogen of turfgrass, can also be controlled biologically. Wong and Siviour (1979) controlled the disease completely by the use of an avirulent strain of *G. graminis var graminis* and three *Phialophora* spp. Baldwin *et al* (1991) reported disease suppression by a bacteria species, *Pseudomonas*. Sarniguet and Lucas (1992) noted that the ratio of *Pseudomonas* species to rhizosphere bacteria differed across the take-all patch. The ratio was highest in the centre of the patch which had been recolonised by the same grass species indicating microbial activity. Yuen *et al* (1994) demonstrated that an antagonistic species of *Rhizoctonia* and *Gliocladium virens* consistently inhibited *R. solani* in laboratory bioassays. When applied in the field, the antagonists persisted for one month and reduced disease to less than 20%.

Table 9 (taken from Nelson, 1992) indicates common turfgrass diseases for which successful biological control has been demonstrated, together with the controlling organisms.

1.6.6.2 Pests

Villani *et al* (1988) noted that organic phosphates and carbamates became less effective when constant reapplications were made to control turfgrass pests. Klein (1989) suggested that insect resistance, microbial degradation of chemicals, and thatch preventing movement of chemicals to target organisms were all possible factors which may reduce the efficacy of pesticides. Possible alternatives against common turfgrass insect pests include the use of the bacteria, *Bacillus popillae*. The activity of this antagonist has been known for 50 years and causes milky diseases in white grubs e.g. Japanese beetle, *Popilla japonica*, a common and very serious warm season turf pest causing $234, 000, 000 annual damage in Eastern US (Redmond and Potter, 1990). The bacteria produces spores which accumulate in the haemolymph giving it a milky appearance, hence the common name. Another *Bacillus* species, *B. thuringiensis*, has been used successfully against lepidopteran pests of forests and ornamentals. The bacteria, *Serratia*, has been used in New Zealand successfully against turf grubs (Klein, 1989), particularly in combination with traps baited with insect attractants.

Shetlar (1989) described the possible use of entomogenous nematodes for the control of turf grass insects. Insect parasitic nematodes have been studied since the 1920's, but interest declined with the discovery of synthetic organic pesticides. However interest in biocontrol has been resumed and a number of serious pests can be successfully controlled by nematodes. Two species, *Neoplectaria glaseri* and *Heterorhabditis heliothidis*, successfully control white grubs, sod web worms, army worms, mole crickets, bill bugs and crane flies; 100% control of Japanese beetle larvae has been achieved by *H. bacteriophora*. No non-target effects on beneficial organisms were observed (Klein and Georgis, 1992). The efficacy of nematodes as BCAs is increased when the turf is irrigated prior to and following treatment (Downing, 1994).

1.6.6.3 Weeds

Reliance on herbicides for weed control in turfgrasses is common (Raikes *et al* 1994a, b). However non-target plants are also affected by broad spectrum herbicides as few species-specific chemicals exist. Annual meadow grass, *Poa annua*, is a very important weed in turfgrass as selective herbicides are only available in the U.K. for perennial rye grass turf and red fescue seed crops. However a naturally occurring bacteria, *Xanthomonas* sp., was found which effectively suppresses and kills annual meadow grass without affecting other grass species (Roberts, 1989). Riddle and Burpee (1987) demonstrated that repeated applications of a moderately virulent indigenous fungus significantly reduced the population of dandelions in a turfgrass sward; there were no visible effects on the turfgrass during the study.

1.6.7 The Use of Suppressive Soils in Disease Control

A number of soils appear to have the ability to suppress disease naturally. The physical, chemical and biological interactions in soil are so complex and varied it is difficult to determine specific affects responsible for disease control. Huber and Watson (1970) categorised three possible mechanisms of disease suppression in soil:

1 . Increased biological buffering of the soil, suggesting that pathogen suppression is of microbial origin and is more influenced by management practices than actual soil type, e.g. the buffering capacity of older soil is greater than that of recently cultivated soil. Shipton *et al* (1973) noted that severe take all, *Gaeumannomyces graminis var tritici*, occurred in fields recently converted from a virgin state but not in wheat fields with a long history. Antagonism can be conferred to virgin soil by the addition of 'old' soil at a rate as little as 1% W/W.

2 . Decreased pathogen number during anaerobic decomposition of organic matter. Adequate disease control can be maintained if propagule numbers are below a certain level; total pathogen elimination is not necessary for adequate disease control.

3 . Direct effect on nitrification which influences the form of N. predominating in the soil. The specific form of N. available to the plant and soil microflora in turn influences specific microbial associations and host physiology e.g. in general increased N. results in increased spore germination and hence more disease. Meyer and Shew (1991) reported that the mechanism of suppression of black root rot, *Thielaviopsis basicola*, of burley tobacco was of abiotic origin and dependent on the inter-relationships among soil pH, base saturation and exchangeable aluminium.

Although the exact mechanism of disease suppression in soils remains complex and difficult to determine exactly, a number of successful examples of disease control by suppressive soils exist in both agriculture and the turfgrass industry.

Agriculture

Khalifa (1965) successfully controlled pea wilt, *Fusarium oxysporum f.sp. pisi*, by the addition of chitin to the soil. Chitin greatly increases the number of rhizosphere actinomycetes and bacteria which inhibit *Fusarium* spore germination resulting in a reduction in the pathogen population. Scher and Baker (1980) isolated a bacteria species, *Pseudomonas*, which was very effective at inducing suppressiveness. Introduction of the bacteria to other soils confers *Fusarium* suppressiveness. The same bacteria in combination with a *Bacillus* sp. isolated from compost extract was also found to be suppressive to potato blight, *Phytophthora infestans* (Kessel *et al*, 1992). Chisnall-Hampton and Coombes (1991) was also able to totally eradicate potato wart, *Synchytrium endobioticum*, by the addition of crab shell meal.

Kay and Stewart (1994a) reported that when bran and sand amended with *Trichoderma harzianum* and *Chaetomium globosum* were added to soil, there was a reduction in onion white spot equivalent to that of fungicide use. Similarly, when *Gliocladium virens* was applied in a bran formulation to carrots, *Sclerotium rolfsii* was reduced consistently over three years. The control was equivalent or better than that of a fungicide; an increased yield also resulted (Ristaino *et al*, 1994). Voland and Epstein (1994) noted that damping off of radish caused by *Rhizoctonia solani* was least severe in seedlings planted in soil amended with straw and urea.

Turfgrass

Several turfgrass diseases including *Rhizoctonia solani*, brown patch (Nelson and Craft, 1990b), *Laetisaria fuciformis*, red thread and *Sclerotinia homoeocarpa*, dollar spot (Nelson and Craft, 1990a) are successfully controlled by compost-amended top dressings. When applied as preventative treatments at monthly intervals control is consistent and as effective as conventional fungicides (Nelson and Craft, 1991a, b, 1992).

In addition to amended top dressings the role of endophytic fungi is becoming increasingly important in turfgrass pest and disease control.

1.6.8 Endophytic Fungi in Turfgrass Pest and Disease Control

Endophytes were first discovered in New Zealand in the 1940's (Anon., 1987). Siegal *et al* (1989) defined an endophyte as a fungus contained within a plant spending all, or the majority, of its life cycle within the host. Approximately thirty species of endophytes have been recorded (Clay, 1988a). Endophytes (Family *Clavicipitacea*, Ascomycetes) and grasses are mutually symbiotic. The endophytes receive protection from the plants plus enhanced survival and dissemination via the seed (Seigal *et al*, 1989). The fungi produce physiologically active alkaloids in the host tissues which makes the grass toxic to mammals and increases resistance to insect herbivory.

The endophyte, *Acremonium*, reduces feeding and oviposition of flour beetles, sod web worms and stem weevils on perennial rye grass whilst aphids and army worms avoid the grass (Clay, 1988b). Funk *et al* (1985) also noted that *Acremonium*-infected perennial rye grass exhibited enhanced resistance to bill bugs and weed invasion. Further insect species affected by endophyte toxins include the Russian wheat aphid (Kindler *et al*, 1991), American cockroaches, nematodes and Japanese beetle larvae (Siegal *et al*, 1989), cutworms and chinch bugs (Anon, 1988); the latter four species being common warm season turfgrass pests. Murphy *et al* (1993) noted that endophyte-infected tall fescue was resistant to white grub (Scarabaeidae) damage.

Antifungal compounds are also produced by *Acremonium*, providing possible disease resistance. Siegal *et al* (1989) noted that *Acremonium*-infected perennial rye grass exhibited improved growth, increased dry matter, total leaf area, tiller production and the number and growth of roots. Seed set, germination and seedling growth was also improved.

Many commercial cultivars of lawn seed are infected with endophytes (Clay, 1988b). Such chemical defences can be incorporated into most turfgrass cultivars using standard breeding techniques (Funk *et al*, 1985) and so provide a possible non-pesticide control strategy for use in an urban environment. Siegal *et al* (1989) also suggested the use of genetically modified (i.e. improved) endophytes for pest and disease control in turfgrass.

1.6.9 Mechanisms of Disease Control

The efficacy of biocontrol is increased if the BCA is adapted to the environment in which it will be working i.e. growth and competitive ability with indigenous microflora and fauna will be greater (Whipps, 1986), e.g. the use of naturally occurring *Pseudomonas* bacteria produce siderophores to compete for ferric iron, a limited nutrient required by plant pathogens (Jacobsen and Backman, 1993). Therefore the use of naturally occurring antagonists will promote more efficient biocontrol (Blakeman and Fokkema, 1982). Although competition for space and nutrients is an important control mechanism, there are a number of others control which are not necessarily mutually exclusive. Knowledge of the exact mode of action enables optimum timing of antagonist inoculation and application of the antagonist in an appropriate form and quantity.

Lynch (1988) classified biocontrol methods as follows:

1. Competition for active sites/ nutrients/ space
2. Antibiosis
3. Parasitism
4. Cross protection
5. Growth stimulation

Antibiosis (antibiotic production)

Antibiotics are metabolites of microbial origin e.g. lytic agents, enzymes, volatile compounds or other toxic substances. Antibiotics are organic compounds with low molecular weights (Fravel, 1988). Production is greatly affected by the environment e.g. water availability. In 1979 there were 3,000 known antibiotics; 50-100 new compounds are discovered each year (Fravel, 1988). Antibiosis usually acts in conjunction with competition and/or parasitism. When environmental conditions are unfavourable for a BCA, antibiotics can be used directly on crops. Examples of antibiosis include the production of agrocin from *Agrobacteriumradiobacter*, the BCA used to control crown gall in fruit trees. Phenazine is produced by *Pseudomonas fluorescens*, a bacterial agent used against take all on cereals and *Pythium* on cotton. The volatile antibiotic ammonia is produced from the BCA, *Enterobacter cloacae*, and used against seedling diseases. Volatile alkyl pyrones are produced from *Trichoderma harzianum* which inhibit *Rhizoctonia solani*, the causal agent of damping off in several plants (Fravel, 1988).

Parasitism / Predation

Parasitism involves penetration of the tissue or hyphal interactions e.g. hyphal coiling causing physical restriction or penetration (Blakeman and Fokkema, 1982), e.g. when the delicate hyphae of *Trichoderma* penetrate the large hyphae of *Pythium* and *Rhizoctonia* with ease.*T. koningii* effectively parasitises *Sclerotinia* spp. by hyphal coiling (Papavizas, 1985).

Cross Protection

Induced resistance in a host plant can be achieved by inoculation with an avirulent strain of the pathogen, e.g. control of crown gall in fruit trees by a non-pathogenic, antibiotic producing strain of *Agrobacterium radiobacter* (Lynch and Ebben, 1986).

Growth Stimulation

BCA interaction with the host plant may result in induced protective responses in host tissue presumably by altering the plant metabolism (Blakeman and Fokkema, 1982).

The most successful antagonists exhibit more than one mode of action. *Trichoderma* spp. are very successful BCAs because of the multifunctional control mechanisms they exhibit. In 1985 alone over 120 scientific publications and technical articles appeared with regard to many aspects of the biology of *Trichoderma* (Gear, 1986).

1.6.10 *Trichoderma* and *Gliocladium*

Mode of Action

Trichoderma spp. can control plant pathogens in several ways. These include competition for nutrients, space and oxygen; the species grows rapidly which also makes it a good competitor. *Trichoderma* spp. also produce antibiotics and other toxic metabolites e.g. chitinase and other lytic enzymes (Blakeman and Fokkema, 1982). The first demonstration of metabolite production was made by Weindling (1937) who extracted two toxins using chloroform. The culture filtrates of *T. ligrorum* were found to be toxic to *Rhizoctonia solani*. Non-volatile antibiotics include the sesquiterpene, trichodermin, produced by *T. polysporum*, peptide compounds including alamethicine and unsaturated monobasic acids e.g. dermadine (Dennis 1971a). The anti-fungal compound, viridin is produced by *Gliocladium virens*. *G. virens* also produces a closely related compound, viridiol which is phytotoxic to weeds; viridiol is used as a herbicide against pig weed, *Amaranthus*, in cotton seedlings (Howell and Stipanovic, 1984). A number of volatile antibiotics are also produced giving a characteristic coconut smell, particularly by *T. viride*. The first compounds discovered were carbon dioxide and ammonia. Other volatiles include hydrogen cyanide, ethylene and acetylaldehyde (Dennis, 1971b). *Trichoderma* spp. are also parasitic to pathogens; interactions include hyphal coiling, penetration and disorganisation of pathogen cell contents (Blakeman and Fokkema, 1982).

Growth and Ecology

Trichoderma spp. are saprophytic soil fungi. They can metabolise a wide range of compounds and abound in wet, basic habitats (Papavizas, 1985). Numerous species are photosensitive and sporulate readily on many natural and artificial substrates in a concentric pattern of alternating rings in response to diurnal alteration of light and darkness with conidia being produced in the light period (Papavizas, 1985).

Trichoderma and *Gliocladium* are distributed worldwide and occur in nearly all soils and natural habitats. Populations are decreased in long periods of dry conditions. *T. viride* and *T. polysporum* are restricted to low temperatures, *T. harzianum* is favoured by warm temperatures while the optimum temperature range for *T. hamatum* and *T. koningii* is more diverse. The ability of *Trichoderma* to degrade various substrates, metabolic versatility and resistance to microbial inhibitors ensures that the antagonist can survive in many ecological niches (Papavizas, 1985).

1.6.11 Production and Delivery Systems

The use of fermentation technology could be adapted for the mass-production of *Trichoderma* for biocontrol. Solid media have also been tested. Additional substrates include bark pellets, wheat bran plus peat, barley grain, composted hardwood bark and pellet formulations. Pellets of *T. harzianum* inserted into trees in Belgium effectively control Dutch elm disease (Gear, 1986). A bran/peat preparation of *T. harzianum* applied to the soil or rooting mixture effectively suppressed damping off, (*Pythium* spp.), by 85% in peas, cucumbers, peppers, tomatoes and *Gypsophilia* (Sivan *et al*, 1984) . A *Trichoderma* sp. was formulated in chain saw oil for application to tree wounds (Papavizas, 1985). An untested delivery system involves the incorporation of *Trichoderma* or *Gliocladium* spores with diluted liquid pesticides applied through sprinkler irrigation (Papavizas, 1985).

Several seeds can be directly treated with *Trichoderma* or *Gliocladium*, e.g. peas and radishes have been treated with *T. harzianum* to prevent damping off (Harman *et al*, 1980). Field studies conducted by Ruppell *et al* (1983) demonstrated increased yields of snap bean, corn, pea, soybean and squash when seeds were treated with *T. harzianum* to control *Pythium* sp. Recent technology has enabled encapsulation of spores with a nutrient carrier (Papavizas, 1985).

Several successful control programmes using *Trichoderma* have been reported for soil pathogens, one example being the use of *T. viride* against *Phytophthora*, the causal agent of root and heart rot of pineapple (Papavizas, 1985). Biocontrol on the phylloplane is more difficult as leaf surface temperature and moisture vary more than in the rhizosphere. In addition the use of chemical sprays can destroy the balance between saprophytes and pathogens on the leaf surface e.g. the use of 'tonic' copper caused coffee berry disease, *Colletotrichum* spp., which was previously insignificant (Acland, 1975). Benomyl was also found to reduce saprophyte numbers ten fold on rye leaves. The saprophytic activity of *Trichoderma* decreases the amount of available nutrients which may stimulate necrotrophic pathogens (Blakeman and Fokkema, 1982). Despite the variability of conditions on the phylloplane *Trichoderma* still appears effective against a number of diseases such as *Botrytis cinerea* on strawberries and apples and the inoculation of tree wounds after pruning to prevent infections (Blakeman and Fokkema, 1982).

1.6.12 *Trichoderma* and Integrated Disease Management (IDM)

The efficacy of disease control can be increased if a number of elements are involved in a management plan i.e. biocontrol agents should not be the exclusive option (Lynch and Ebben, 1986).

The induction of fungicide tolerance of *Trichoderma* using prolonged exposure to increasing concentrations of fungicides provides a useful tool in IDM systems (Abd-el-Moity *et al*, 1982) e.g. Benomyl resistant strains of *T. viride* and chlorothalonil resistant strains of *T. harzianum* (Blakeman and Fokkema, 1982). *T. harzianum* plus low levels of PCNB provides excellent control of damping off of beans, tomatoes and eggplant seedlings (Hadar *et al*, 1979). *T. harzianum* in conjunction with soil sterilisation effectively controls *Sclerotium rolfsii* and *Rhizoctonia solani* in greenhouses (Papavizas, 1985).

To conclude, there is a long history of attempted biocontrol of plant diseases. Most early studies involved the use of disease suppressive soils. Since the initial attempt by Hartley (1921) (cited by Campbell, 1989) to control damping off of pine seedlings by inoculation with antagonistic fungi there have been many attempts to control disease by inoculation (Lynch, 1988). There are several bacterial and fungal preparations now available to control plant disease. Fifteen companies produce BCAs with an estimated annual turnover of £10m (1990 figure). However, BCAs still make up less than 1% of the control agents used in plant protection (Wood and Way, 1989). There is scope to expand BCA use, particularly in horticulture or where an element of control over the environment exists (Lynch and Ebben, 1986).

1.7 Aims and Objectives

The objective of this study is to formulate an integrated disease management (IDM) strategy for winter sports turf. Such a strategy will help to economically and efficiently reduce disease levels, decrease reliance on chemical control and maintain turf vigour. Control measures include a number of cultural practices including species and cultivar mixtures, fertiliser use and the possible use of biological control agents.

To identify the major diseases on winter sports turf and determine the effect of management practices on symptom expression, a comprehensive survey of professional football clubs and local authorities was carried out (Chapter 2). The survey results identified the primary management practices which influence disease. On the basis of these findings, a range of field trials were initiated in order to identify key cultural practices which could be exploited to effectively maintain disease (Chapter 3). In addition to cultural control, biological control can form a vital component of a IDM strategy. *Microdochium nivale*, Fusarium patch, was identified as being the most economically damaging pathogen on intensively maintained winter sports turf in the U.K. (Chapter 2). A number of fungi and bacteria from genera with known antagonistic properties as well as indigenous micro-organisms were tested *in vitro* and *in vivo* for activity against *M. nivale*, to facilitate the identification of possible biocontrol agents (Chapter 4). After assimilation of the results obtained from the field studies and the biological control investigations, an IDM strategy for winter sports turf was formulated (Chapter 5). Finally, Chapter six discusses the economic cost and recent advances in IPDM, suggests a number of possible recommendations for future studies and provides a general discussion and conclusion for this project.

Chapter Two:

Survey of the Major Diseases, Pests, and Weeds on Winter Sports Turf

2.0 Diseases, pests and weeds on winter sports turf - the extent of the problem.

The presence of disease on sports turf is well documented (Baldwin, 1990), however very little is known about the extent of the problem under different management regimes. In addition, information regarding control measures employed on winter sports turf is scarce. Winter sports turf, or coarse turf, is the type used on football, rugby and hockey pitches, comprising mainly of perennial rye grass (*Lolium perenne*) as opposed to the finer turf that is used on golf and bowling greens which include bent (*Agrostis*) and fescue (*Festuca*) species

In order to formulate an integrated disease management (IDM) strategy for this particular type of sports turf specific target diseases had to be identified. In addition, the particular effects of management practices on disease incidence and severity needed to be collated. To enable this, both professional football clubs (PFCs) and local authorities (LAs) were sent a postal questionnaire (appendices I and II and appendix III respectively) concerning not only diseases but also a number of pest and weed problems. General management practices were also surveyed. PFCs and LAs were surveyed separately because they correspond to two different levels of turf management intensity on winter sports turf. PFCs are subject to relatively high levels of management i.e. increased chemical and fertiliser input combined with intense cultural practices, for example frequent, low mowing and increased spiking and Verti-Draining. LA pitches receive lower chemical and fertiliser inputs and moderate cultural maintenance practices. However, the principles of disease management can be applied successfully to both management intensities.

2.1 Major diseases, pests and weeds of winter sports turf. I. Results of a questionnaire survey of professional football clubs

Summary

The 130 professional football clubs in the UK were sent a postal questionnaire, which sought information on the following: [i] the incidence, severity, distribution, time of year and control measures for the major diseases (including red thread, fusarium patch, rust and seedling diseases), pests and weeds affecting both the competition pitch and the training ground; [ii] pesticide use and legislation; [iii] general problems including drainage, wear, fertiliser nutrition and other maintenance factors. Following the return of the postal questionnaire, an additional questionnaire was completed by telephone, visit or post. This concerned general maintenance and cultural factors, including: underground heating, usage, construction, drainage, soil type, grasses used and mowing, fertiliser, spiking and irrigation regimes. The results showed that fusarium patch (*Microdochium nivale*) and red thread (*Laetisaria fuciformis*)were the most abundant diseases on the competition pitch and the training ground; earthworms (*Lumbricus* and other spp.) and leatherjackets (*Tipula paludosa*)were the most common pests, whilst white clover (*Trifolium repens*), plantain (*Plantago major*) and annual meadow-grass (*Poa annua*) were the most prolific weeds.

Introduction

At present the disease, pest and weed problems of sports turf are well documented (Baldwin 1990), but the scale, patterns of occurrence and control measures used are less well known. The objective of the work described in this chapter was to undertake a questionnaire survey of professional football clubs in order to evaluate pest, disease and weed incidence in winter sports turf under different management regimes. The results identify principal problems encountered based on levels of maintenance, use and cultural factors. The survey outcome provides a useful tool to identify specific problem areas and to target subsequent research. Field trials and laboratory experiments have now been devised to reduce disease, based on various cultural and maintenance strategies (Chapters 3 - 4).

The objective is to formulate an integrated pest and disease management (IPDM) strategy for winter sports turf. Such a strategy will involve the use of cultural, biological and chemical factors to manage pests and diseases resulting in effective and economic suppression with minimum effect on non-target organisms, people and the environment (Baldwin and Drinkell, 1992). In common with increasing concern for the environment, coupled with greater public interest in 'green' issues, IPDM focuses on non-pesticide control methods. Such management programmes have been devised for a number of agricultural situations and to a lesser extent, sports turf in the USA. To date this concept is virtually unknown to groundsmen and greenkeepers in the UK.

Materials and Methods

A postal questionnaire (Appendix I) was sent to the 130 professional football clubs in the UK relating to pest incidence and severity, control methods, pesticide use and legislation and general problems affecting the competition pitch (CP) and the training ground (TG). Following the return of the postal questionnaire, an administered questionnaire (Appendix II) concerning general management practices was completed using information derived by telephone or personal interview or by correspondence.

Results obtained from the survey have been standardised and expressed in terms of % of total number of questionnaires returned.

Where appropriate, statistical analysis of the results obtained has been completed using chi square (χ^2) at the significance level $p < 0.05$. The null hypothesis states that there was no significant association between the incidence of a pest and a certain management factor, e.g. presence or absence of spiking or nitrogen level. All statistical tests concerned the CPs only as the quantity of TG data was insufficient.

Results

The response rate to the postal questionnaire was excellent with 92 (70.8%) of the 130 clubs returning the initial form (Appendix I). Of the 23 clubs that had training grounds, the majority were in the premier division. The overall response rate was greatly influenced by division, being highest in the premier and the first divisions.

The survey contained detailed information concerning the incidence of weeds, pests and diseases.

Table 10 presents a summary of the percentage of clubs affected by the problems listed. Tables 11 - 17 contain more detailed information on the severity, distribution, seasonality and control measures of each pest on both the CP and the TG pitches.

TABLE 10, % of responding clubs affected by disease, pests and weeds (n = 92)

Problem	CP	TG
Disease		
Red thread	57	74
Fusarium patch	57	45
Leaf spot	16	12
Seedling	12	27
Rust	11	12
Other	7	0
Pests		
Earthworm casting	76	73
Leatherjackets	23	9
Mammals	7	4
Chafers	4	0
Fever fly	1	0
Other	0	0
Weeds		
Clover	82	54
Plantain	72	86
Annual meadow-grass	51	54
Other	20	0
Speedwell	12	23
Algae	5	4
Moss	4	14
Lichens	4	4

Red thread (*Laetisaria fuciformis*) and fusarium patch (*Microdochium nivale*) were the most common diseases on the CPs and TGs. In addition, over one quarter of TGs were also affected by seedling diseases. Earthworm casting was the major pest problem on both CPs and TGs; leatherjackets were also problematic on CPs (23% affected). Clover, plantain and annual meadow-grass were the most ubiquitous weeds on CPs and TGs.

Diseases

[1] Red thread (Laetisaria fuciformis)

This disease was the most commonly reported, although severe attacks were more frequent on TGs. It generally occurred in isolated patches in the summer and autumn. Both chemical and cultural (nitrogen application) methods were used to control this disease on the CP and TG (Table 11).

TABLE 11, Reported % occurrence and control of red thread

	CP	TG
Incidence:		
never	43	46
occasionally	49	37
often	8	17
Severity:		
slight	56	42
moderate	40	34
severe	4	24
Distribution:		
isolated patches	63	50
large areas	16	25
grouped patches	21	25
Season:		
spring	5	25
summer	72	50
autumn	21	25
winter	2	0
Chemical control:		
yes	42	50
no	58	50
Cultural control:		
yes	56	33
no	44	67

[2] Fusarium patch disease (Microdochium nivale)

This disease was the second most abundant after red thread. The data trends were similar for the CP and TG. Generally, a slight/moderate outbreak occurred occasionally in isolated patches in the summer and autumn. Chemical and cultural control were used (Table 12).

TABLE 12, Reported % occurrence and control of fusarium patch disease

	CP	TG
Incidence:		
never	43	56
occasionally	51	44
often	6	0
Severity:		
slight	69	80
moderate	20	20
severe	11	0
Distribution:		
isolated patches	77	70
large areas	12	20
grouped patches	11	10
Season:		
spring	12	10
summer	31	40
autumn	52	50
winter	5	0
Chemical control:		
yes	79	70
no	21	30
Cultural control:		
yes	39	30
no	61	70

[3] Leaf spot (Drechslera spp.)

Slight and occasional outbreaks occurred on the CP and TG, although 40% of outbreaks could be severe on the CP and large areas could be affected. In general, it was distributed in isolated patches and 75% of outbreaks occurred in summer. A combination of control factors were used to manage the disease, although no chemicals were used on the TGs and only 15% of CPs received any cultural control (e.g. resistant cultivars).

[4] Seedling diseases

These diseases were more prevalent on TGs. The attacks tended to be slight to moderate, although severe attacks did occur on the CPs. The diseases generally occurred in the spring and summer in isolated patches. Both types of control measures were used, although again the emphasis was on chemical control, which was used by 56% of clubs compared with 11% who used cultural control (e.g. well prepared seedbed, good drainage and an appropriate fertiliser regime).

[5] Rust (Puccinia spp.)

Puccinia spp. seldom occurred on winter sports turf (only 11% of CPs affected) although it could be distributed in large areas when attacks were severe. The disease occurred in the warmer summer and autumn months. Only 13% of clubs used chemical control on the CP. Possible cultural control included selection of resistant species and cultivars, adequate nitrogen and regular mowing.

[6] Other diseases

These included fairy rings (*Marasmius oreades*) and mildew(*Erysiphe graminis)*; TGs were not affected and the incidence on the CPs was rare. Attacks tended to be slight and isolated, occurring in the summer and autumn. Both control measures were used by the majority of clubs, 80% used chemical and 60% used cultural methods.

Pests

[1] Earthworm casting

Earthworm casting was the most common pest problem, although there was variation in severity, distribution and season. Both types of control measures were used, although cultural control was the most favoured (Table 13)

TABLE 13, Reported % occurrence and control of earthworm casting

	CP	TG
Incidence:		
never	24	27
occasionally	44	38
often	32	35
Severity:		
slight	35	32
moderate	34	38
severe	31	30
Distribution:		
isolated patches	32	19
large areas	50	53
grouped patches	18	28

Season:		
spring	23	25
summer	5	6
autumn	68	69
winter	4	0
Chemical control:		
yes	46	31
no	54	69
Cultural control:		
yes	41	50
no	59	50

[2] Leatherjackets (Tipula paludosa)

These pests were the second most abundant after earthworm casting. Both the CP and TGs were affected, although the incidence was most common on the former. Attacks were slight to moderate with varied distribution, occurring all year apart from the winter. Chemical control was used on both CPs and TGs, but only cultural control was used on the CPs.

[3] Mammals

Common mammal pests included dogs, foxes and rabbits. Only 5% of clubs were affected, however, attacks could be moderate and could occur all year. Only cultural control methods were used.

[4] Chafers (Phyllopertha horticola)

These pests were only a minor problem on the pitches. Attacks were slight and isolated, occurring in the spring and summer. One-third of clubs sprayed against chafers on the CPs.

[5] Fever fly (Dilophus febritis)

These were very minor pests, 1% of clubs were affected. Attacks could be severe and large areas were affected. Chemical control was used to control the pest.

[6] Other pests

No other pests were reported.

Weeds

[1] White clover (Trifolium repens)

This weed appeared to be the most ubiquitous on the CP (82% of clubs affected). Variation occurred in severity, although half the occurrences were considered to be moderate to severe. Clover was reported at all times of year except winter and was distributed in isolated patches. Both control methods were used, chemical control being the most favoured, used by 84% of clubs (Table 14).

TABLE 14, Reported % occurrence and control of clover

	CP	TG
Incidence:		
never	18	46
occasionally	58	41
often	24	13

Severity:		
slight	54	59
moderate	33	25
severe	13	16
Distribution:		
isolated patches	26	33
large areas	62	58
grouped patches	12	9
Season:		
spring	26	0
summer	62	58
autumn	12	9
winter	0	0
Chemical control:		
yes	84	83
no	16	50
Cultural control:		
yes	18	8
no	82	92

[2] Plantain (Plantago major)

This weed was very common (72% of CPs and 86% of TGs were affected). Infestation could be slight/moderate and occurred in isolated or grouped patches. As with most weeds, summer was the usual season. Both control measures were used (Table 15).

TABLE 15, Reported % occurrence and control of plantain

	CP	TG
Incidence:		
never	28	14
occasionally	58	65
often	14	21
Severity:		
slight	60	21
moderate	32	64
severe	8	15
Distribution:		
isolated patches	66	16
large areas	21	37
grouped patches	13	47
Season:		
spring	28	37
summer	64	53
autumn	8	10
winter	0	0
Chemical control:		
yes	72	79
no	28	21
Cultural control:		
yes	34	16
no	66	84

[3] Annual meadow-grass (Poa annua)

Half of the TGs and CPs were affected. Infestation could be slight to moderate and again occurred all year. There was equal distribution between isolated patches and large areas. Cultural techniques were the most popular control measures (Table 16).

TABLE 16, Reported % occurrence and control of annual meadow-grass

	CP	TG
Incidence:		
never	49	46
occasionally	36	46
often	15	8
Severity:		
slight	47	41
moderate	32	51
severe	21	8
Distribution:		
isolated patches	40	33
large areas	45	42
grouped patches	15	25
Season:		
spring	45	50
summer	40	42
autumn	7	0
winter	8	8
Chemical control:		
yes	13	8
no	87	92
Cultural control:		
yes	45	17
no	55	83

[4] Other weeds

Problems with other weeds, including dandelions (*Taraxacum officinale*) and daisies (*Bellis perennis*), were only noted on the CPs. The severity and distribution were diverse. The weeds occurred most frequently in the summer. One-quarter of clubs used cultural control and three-quarters used chemical sprays (Table 17).

TABLE 17, Reported % occurrence and control of other weeds

	CP	TG
Incidence:		
never	80	100
occasionally	14	0
often	6	0
Severity:		
slight	33	–
moderate	47	–
severe	20	–
Distribution:		
isolated patches	49	–
large areas	9	–
grouped patches	42	–
Season:		
spring	33	–
summer	67	–
autumn	0	–
winter	0	–
Chemical control:		
yes	73	–
no	27	–
Cultural control:		
yes	27	–
no	73	–

[5] Speedwell (Veronica spp.)

This is a fairly minor weed, although a quarter of TGs were affected. Severity varied and the majority of the incidences were isolated and occurred in the summer. Chemical control was used by 80% of clubs but no cultural control was employed.

[6] Algae

Only 5% of clubs were affected. Occurrence was slight and occurred in isolated patches in the autumn and winter. Only cultural control was used.

[7] Moss

A minor problem on winter turf. TGs appeared to be more affected. Occurrence was only slight and isolated and occurred all year except winter. Only cultural control was used on the CP and chemical sprays were used on a third of TGs.

[8] Lichen

This was a minor problem with only 4% of clubs affected. Occurrence was slight and isolated and occurred all year round. Cultural control was used on the CPs.

Geographical area

The geographical location of each responding club could have influenced the incidence of pests and diseases, the north of the country tends to be cooler, whilst the west is generally wetter. The % of CPs and TGs in each region is illustrated in Table 18.

TABLE 18, Geographical distribution (% of total) of survey respondents

Area	CP	TG
South-west	13	9
South-east	24	22
Midlands	13	26
North-west	15	26
North-east	11	13
Southern Scotland	3	–
Central Scotland	15	4
Northern Scotland	6	–

There appeared to be a significant association between the incidence of annual meadow-grass and the east/west division of the country:

$\chi^2 = 8.64$, df = 3, p = 0.034

When infestation was only 'slight', over twice as many incidences (48%) occurred in the east. However, when infestation was more severe the trend was reversed, twice as many instances (42%) occurred in the western region of the country.

Pesticide use and legislation

Tables 19-23 illustrate the % of clubs with staff trained in the application, storage and disposal of chemicals.

TABLE 19, Type of training gained (38% of groundsmen hold the NPTC Certificate of Competence for applying pesticides)

Type of training	%
Specific	38
General	27
Other	4
None	31

TABLE 20, % of respondents reporting different storage of chemicals

Locked cupboard	56
Portastore/Chemsafe	15
Purpose built building	4
Other	25

TABLE 21, % of respondents reporting different quantities of chemicals stored (kg or l)

0– 5	57
6–10	19
11–20	15
21–50	9

TABLE 22, % of respondents reporting different methods of disposal of pesticides, concentrate and empty containers

	Pesticide concentrate	Dilute pesticide	Empty containers
Licensed removal	15	12	19
Return to manufacture	7	7	3
Dustbin/skip sink	4	4	22
Burial	1	1	1
Burning	3	3	20
Other	70	37	35

TABLE 23, % of respondents reporting different application methods

Tractor mounted sprayer	49
Knapsack sprayer	32
Walkover	1
Other	18

A substantial proportion (approximately 40%) of clubs used outside contractors who provided, sprayed and disposed of unwanted pesticides. This is indicated in the 'Other' category in Tables 20 and 22. This also explained why 31% of club staff (Table 19) had no recognised training in pesticide use.

A number of clubs used knapsack sprayers for spot treatments as well as a tractor mounted sprayer for larger chemical applications.

General problems

The final section of the postal questionnaire consisted of a list of twenty common problems. The groundsmen were asked to select five of the most significant and rank them in order of importance (Table 24).

TABLE 24, % of respondent clubs affected by the 5 most common problems on the CPs and TGs

Problem	1st		2nd		3rd		4th		5th	
	CP	TG	CP	TG	CP	TG	CP	TG	CP	TG
Drainage	25	57	12	14	10	5	7	-	10	-
Wear	37	33	23	33	17	-	10	19	4	6
Compaction	16	-	15	19	26	29	13	19	4	11
Irrigation	1	10	10	10	10	10	13	19	7	6
Weeds	6	-	7	5	7	14	3	14	10	17

Drainage, wear, compaction, irrigation and weeds appeared to be the five most ubiquitous problems. Other minor problems also included renovation, thatch, nutrition, insect pests, diseases, drought and vandalism.

General management

The following results are from the second half of the survey:

Underground heating

Twenty-eight percent of clubs had undersoil heating on the CPs. No TGs had heating systems in operation. There was a significant association between the presence of under-ground heating and the incidence of red thread and fusarium patch disease.

Red thread $\chi^2 = 5.31$, df = 1, p = 0.021

Fusarium patch $\chi^2 = 5.32$, df = 1, p = 0.021

For both diseases 28% of clubs with under-ground heating were affected, whereas over twice as many clubs (72%) without a heating system suffered from these diseases.

Pitch usage

The number of hours the pitch was used is illustrated in Table 25.

TABLE 25, Amount of pitch usage reported by respondents (%)

Hours of use per week	CP	TG
1- 5	76	8
6–10	24	54
11–20	–	23
21–25	–	15

A significant association occurred between pitch usage and the incidence of fusarium patch disease:

$\chi^2 = 4.15$, df = 1, p = 0.042

Fusarium patch disease was more abundant on pitches used less frequently (64% on pitches used 2-3 hours per week), compared with more frequently used turf (36% on pitches used 4-10 hours per week).

Construction type

The types of construction could have influenced the outbreak of pests. Half of the CPs and three-quarters of the TGs were of a soil construction, only 1 CP had the 'Cell-system'. These results are shown in Table 26.

TABLE 26, Summary of construction types of CPs and TGs reported by respondents (%)

Construction type	CP	TG
Soil	50	77
Soil/sand mix	24	15
Sand carpet	24	8
Cellsystem	2	–

A significant association appears to exist between construction type and the incidence of earthworms and plantain:

earthworm casting $\chi^2 = 7.55$, df = 2, p = 0.02

On soil constructions 46% of clubs reported earthworm casting as compared with only 28% and 26% in sand and sand/soil mixtures respectively:

plantain $\chi^2 = 10.27$, df = 2, p = 0.006

Again, the occurrence of plantains was approximately twice as great on soil (46%) compared with sand (28%) and sand/soil mix (26%).

Reinforcement

None of the TGs were reinforced. Eighteen percent of the CPs were: 16% with Fibresand and 2% with Netlon Advanced Turf.

Age

Forty-four percent of the CPs were less than 6 years old although 25% were over 50 years old (Table 27).

TABLE 27, Summary of the ages of CPs and TGs reported by respondents (%)

Age (years)	CP	TG
1– 5	44	40
6–10	9	20
11–25	16	20
26–50	6	20
50+	25	–

Drainage system

Eighty-one percent of CPs had some kind of drainage system, including pipe (84%) and slit (6%). Forty-six percent of TGs had a system, 83% of which had pipe drainage.

Soil type

Approximately half of the CPs were of a medium (loam) soil type and very few (8%) were of a heavy clay. Conversely, nearly half of the TGs were on heavy soils. These results are shown in Table 28.

TABLE 28, Soil type on CPs and TGs reported by respondents (%)

Soil type	CP	TG
Light (sand)	40	23
Medium (loam)	52	31
Heavy (clay)	8	46

The incidence of red thread appears to be significantly associated with soil type:

$\chi^2 = 6.99$, df = 2, p = 0.03

There were 25% more cases of red thread on light soils than on medium/heavy soils.

pH

There were insufficient data to run any statistical tests. However, the vast majority of CPs (94%) reportedly had a neutral pH (6-8). Only 2% were acid (1-5) and 4% basic (9-14). Seventy-five percent of the TGs were neutral, whilst 17% were acid and 8% basic.

Frequency of waterlogging

Two-thirds of the CPs never or rarely waterlogged, whereas 85% of TGs were prone to waterlogging occasionally/often as shown in Table 29

TABLE 29, Frequency of waterlogging reported by respondents (%)

Waterlogging	CP	TG
Never	24	–
Rarely	38	15
Occasionally	29	31
Often	9	54

The number of games lost per season due to frost and waterlogging also varied between CPs and TGs. There appeared little difference in the number of competition games lost through frost and waterlogging. More games appeared to be lost in total by frost on the TGs as shown in Table 30.

TABLE 30, Games lost per season as a result of waterlogging and frost (% reported by respondents)

No. games lost	Waterlogging CP	Waterlogging TG	Frost CP	Frost TG
0	52	46	48	31
1–3	45	16	50	46
4–6	3	38	2	23

Grass mixtures sown or currently present in the sward

As expected, *Lolium perenne* (perennial ryegrass) was the most common grass used. Nearly half of all CPs (Table 31) and over half the TGs (Table 32) were 100% *L. perenne*. *Festuca* (fescues) were also popular in seed mixtures on the CPs and TGs. *Poa pratensis* (smooth-stalked meadow-grass) was more commonly found in the mixtures used on the CPs.

TABLE 31, Grass mixtures sown or present on the CPs (% reported by respondents)

% used	Lp	Pp	Ag	Fr	Pa
0	–	78	85	61	83
1–5	–	6	11	6	2
6–10	–	4	2	15	2
11–50	15	12	2	18	12
51–99	37	–	–	–	1
100	48	–	–	–	–

Lp = *Lolium perenne*, Pp = *P. pratensis*, Ag = *Agrostis* spp., Fr = *Festuca rubra*, Pa = *Poa annua*.

Common cultivars used included:

L. perenne – 'Mondial', 'Majestic', 'Troubadour', 'Lisabelle', 'Master', 'Surprise', 'Elka', 'Score', 'Lilotta', 'Lisuna', 'Meteor' and 'Barclay'.

Poa pratensis – 'Ampellia', 'Conni', 'Cynthia' and 'Broadway'.

F. rubra – 'Boreal', 'Ceres', 'Sunset', 'Commodore', 'Victor', 'Moncorde' and 'Bingo'

TABLE 32, Grass mixtures sown or present on the TGs (% reported by respondents)

% used	Lp	Pp	Ag	Fr	Pa
0	–	92	92	54	92
1–5	–	–	8	8	–
6–10	–	–	–	16	–
11–50	15	8	–	22	8
51–99	31	–	–	–	–
100	54	–	–	–	–

Lp = *Lolium perenne*, Pp = *P. pratensis*, Ag = *Agrostis* spp., Fr = *Festuca rubra*, Pa = *Poa annua*.

Common cultivars used included:

L. perenne – 'Troubadour', 'Master', 'Surprise', 'Score' and 'Barclay'.

P. pratensis – 'Broadway'.

A. castellana – 'Highland'.

F. rubra – 'Boreal', 'Ceres', 'Sunset', 'Commodore', 'Victor', 'Moncorde' and 'Bingo'.

There were insufficient data to run any statistical tests for *P. pratensis*, *Agrostis* spp. and other grasses. However, significant associations were found between the amount of *L. perenne* and the incidence of earthworm casting and plantain:

earthworm casting $\chi^2 = 3.89$, df = 1, p = 0.049

38% of clubs with 30-85% *L. perenne* suffered from earthworm casting, compared with 62% of clubs with 90-100% *L. perenne*.

plantain $\chi^2 = 7.42$, df = 1, p = 0.006

again only 38% of clubs with up to 85% *L. perenne* had problems with plantain, whereas 62% of clubs with 90-100% *L. perenne* were affected.

A significant negative association also occurred between the incidence of red thread disease and the presence of *F. rubra*:

$\chi^2 = 4.74$, df = 1, p = 0.029

34% of clubs were affected when *Festuca* spp. were present in the grass mix, compared with 66% of clubs where *Festuca* spp. were absent.

Mowing regime (summer)

The majority of CPs (84%) and TGs (92%) were mown 2-3 times per week. Seven percent of CPs were mown 4 or more times per week. The remaining pitches were mown weekly. Eighty-eight percent of clubs removed cuttings from the CPs, as shown in Table 33.

TABLE 33, Fate of cuttings reported (% of respondents)

Cuttings	CP	TG
Returned	5	54
Removed	88	40
Both	7	6

Table 34 shows the prevalence of different cutting heights on CPs and TGs. Most pitches were cut at a height of between 1–2" (25-50 mm).

TABLE 34, Cutting heights on CPs and TGs

Height of cut	CP	TG
Less than 1"	9	15
1-2"	83	77
2.1-3"	8	8

Fertiliser regime

Table 35 shows proportions of N, P_2O_5 and K_2O present in the range of proprietary fertilisers used by the responding clubs. The data indicate the % of respondents using different proportions of the major nutrients in each category. For example, a club using a 15:10:10 N:P_2O_5:K_2O fertiliser in the autumn would contribute once to the '12+' category and twice to the '7-12' category used on CPs in the autumn, winter and spring.

TABLE 35, % of clubs that used different fertiliser regimes on the CPs

units of fertiliser	N	P_2O_5	K_2O
Autumn			
0	6	22	7
1–6	56	24	19
7–12	29	46	59
12+	9	8	15
Winter			
0	28	32	28
1–6	53	13	3
7–12	13	51	60
12+	6	4	9
Spring			
0	0	11	2
1–6	9	39	37
7–12	49	46	55
12+	42	4	6

Table 36 shows the number of applications on the CPs.

TABLE 36, % of fertiliser applications applied to the CPs

No. of applications	Autumn	Winter	Spring
0	6	29	–
1	72	57	28
2	20	14	44
3	–	–	22
4	–	–	2
5	2	–	4

In the autumn 1-6 % of N and 7-12 % of P_2O_5 and K_2O appeared to be the most common proportions of fertiliser used, although considerable variation existed. Approximately 6% of clubs used no N or K_2O in the autumn and 22% used no P_2O_5. The amount of P_2O_5 used in the autumn was positively associated with the incidence of fusarium patch disease:

$\chi^2 = 5.97$, df = 1, p = 0.015

78% of clubs who used P_2O_5 in the autumn suffered from fusarium patch disease, compared with 22% who did not.

Three-quarters of clubs applied fertiliser once in the autumn (Table 36). No significant association appeared to occur between the number of autumn applications of fertiliser and the incidence of pests.

Similar results for the NPK rates applied in the winter were obtained, although nearly one-third of clubs applied no fertiliser in the winter (Table 35). Over half applied fertiliser once in the winter (Table 36).

The presence of N, P and K and the number of applications in the winter were all associated with the incidence of clover.

Nitrogen $\chi^2 = 4.35$, df = 1, p = 0.037

Twice as many clubs (68%) who used N in winter were affected by clover in the summer. A similar pattern occurred for phosphate and potassium.

Phosphate $\chi^2 = 6.04$, df = 1, p = 0.014
Potassium $\chi^2 = 4.35$, df = 1, p = 0.037
No. of applications $\chi^2 = 4.35$, df = 1, p = 0.037

The amount of phosphate applied in the winter was also significantly associated with the incidence of annual meadow-grass.

$\chi^2 = 5.07$, df = 1, p = 0.024

64% of clubs were affected who use P compared with 34% who did not.

The ratios of N:P:K used in the spring altered as compared with those used in autumn and winter (Table 35) and the number of applications (Table 36) increased. Nearly half the clubs used 12 + % of N and 7-12 % of P_2O_5 and K_2O. All clubs applied some fertiliser in the spring. The ratios of N, P and K appeared to have no significant associations with the incidence of pests. However, the number of spring applications and the incidence of clover and plantain were significantly associated.

Clover $\chi^2 = 5.36$, df = 1, p = 0.021

70% of clubs who applied fertiliser 2-5 times in the spring were affected by clover, whereas only 30% of clubs were affected who applied fertiliser once. A similar trend was noted for plantain.

Plantain $\chi^2 = 3.91$, df = 1, p = 0.048

Tables 37 and 38 illustrate fertiliser regimes for training grounds.

TABLE 37, Fertiliser regime for the TGs (% of respondents)

Units of fertiliser	N	P_2O_5	K_2O
Autumn			
0	10	30	10
1–6	40	20	10
7–12	50	20	70
12+	–	–	10
Winter			
0	33	56	33
1–6	56	–	11
7–12	11	44	56
12+	–	–	–
Spring			
0	10	40	30
1-6	-	-	-
7–12	50	60	70
12 +	40	–	–

TABLE 38, No. of applications of fertiliser applied to the TGs (% of respondents)

No. of applications	Autumn	Winter	Spring
0	9	30	–
1	73	70	64
2	18	–	36

More N and K appear to be used (Table 37) but less P in the autumn compared with competition pitches. The winter regimes are similar, although the number of applications are less (Table 38). In the spring all the training grounds receive some fertiliser (Table 38) and the proportion of N is increased (Table 37).

Top dressing

The number of tonnes of top dressing applied per pitch is shown in Table 39. Amounts between 51 and 100 tonnes appear to be the most common for the CPs and TGs.

TABLE 39, No. of tonnes of top dressing applied per pitch (% of respondents)

Top dressing (tonnes per pitch)	CP	TG
0	4	15
1–50	33	23
51–100	56	46
101–200	7	16

Spiking

Table 40 shows the frequency of spiking. Seventy-two percent of competition pitches were spiked 1-2 times per week and half the TGs were spiked weekly.

TABLE 40, % of respondents reporting different frequencies of spiking

Weekly	48	54
2 x week	24	8
3 x week	2	8
Monthly	21	30
Every 2 months	5	–

Verti-Draining

The majority of CPs (71%) and TGs (69%) were Verti-Drained once or twice per season (Table 41).

TABLE 41, % of respondents reporting different frequencies of Verti-Draining

Every 3 seasons	7	16
Every 2 seasons	5	–
Seasonally	36	46
2 x season	35	23
Other	5	–
Never	12	15

Irrigation regime

Ninety-two percent of CPs were irrigated, 42% of which were irrigated manually and 58% automatically. Sixty-nine percent of TGs were irrigated (67% manual and 33% automatic). Surprisingly 43% CPs and 62%

of TGs reportedly suffered from drought. A significant association between the incidence of earth-worm casting and the extent of drought was observed:

$\chi^2 = 3.98$, df = 1, p = 0.046

Less earthworm casting occurred in drought affected turf. The use of wetting agents was rare, 5% of CPs and 8% of TGs.

Thatch

The incidence of thatch was more common on the training ground (23%), whereas only 14% of competition pitches were affected. Thatch was managed by scarification and removal.

Marking out

White paint (e.g. Indeline) was the most popular method of marking out (Table 42).

TABLE 42, % of respondents reporting different methods of marking out

Method	CP	TG
Caustic lime	10	-
White paint	81	100
Snow Cal	7	-
Other	2	-

Repairs/renovations

All areas of worn turf were reseeded, no one returfed targeted areas. Thirty-six percent of competition pitches had problems with turf easily ripping out during play.

Shading

Forty-eight percent of CPs had problems due to shading by high stands.

Discussion

Up to 3 matches (approximately 10 hours) per week were played on the CPs and the TGs were used over twice as much. This intensity of play, coupled with vigorous maintenance programmes, means that the soil will be subjected to considerable compactive force. It follows then that the major problems are drainage, wear and compaction. However, the entire system is under stress and as a result, at times succumbs to diseases and pests and suffers competition from weeds.

As in any questionnaire survey of this nature, it was possible the sample was biased, premier and first division clubs having more resources for chemical and cultural control, whereas in the lower divisions finance may be more limited. In addition, it should be remembered that correlation between variables does not necessarily indicate causality (Snedecor & Cochran 1967). However, a number of significant trends to appear in the data in terms of effect of cultural practices and the incidence of major pests.

Construction type

Earthworm casting and plantain were more prevalent on 'soil only' pitches, as opposed to a sand construction or a sand/soil mix. Earthworm casting is generally encouraged by moist conditions which are found in the less free-draining soil constructions. Consequently, as the degree of drought increased, the incidence of earthworm casting decreased as one would expect.

Soil type

Soil types affected the incidence of red thread which was more prevalent on the light sandy soils. These soils are free-draining with lower nutrient content and retention. Low fertility conditions are known to favour red thread (Baldwin 1990).

Grass mixtures sown or present

The grass species used also affected the incidence of red thread. The disease was reduced when fescues were present in the mix. This is surprising as red fescue (*Festuca rubra*) is one of the principal host turfgrasses of the disease. However, in a mixed stand susceptibility to disease may be decreased because of an increase in stress tolerance, compared with a monoculture.

When the proportion of perennial ryegrass increased in the grass mix (90-100%) the incidence of earthworm casting and plantain also increased.

Fertiliser regime

The fertiliser regime was significantly associated with the incidence of diseases and weeds. Increased use of fertiliser in the autumn increased the incidence of fusarium patch, a fact reiterated constantly in literature.

The use of nitrogen, phosphate and potassium in winter all increased the incidence of clover in the summer, a rather surprising trend as clover is naturally a good competitor in a low fertility environment, due to nitrogen-fixing bacteria located in nodules on the roots. The incidence of annual meadow-grass is also increased following winter applications of fertiliser.

Increased applications in the spring also continue to encourage clover as well as increasing the incidence of plantain.

Area

Finally, geographical area appeared to significantly affect the severity of *P. annua*. The majority of 'slight' incidences occurred in the east, whilst in the western regions infestations were more severe. It is probable that more moist, climatic conditions could favour seed germination of *P. annua* and aid its growth and establishment.

After collation of the survey results, several field trials have been laid down to investigate the effect of a number of factors on the incidence of disease in more detail and to formulate any possible control guidelines. Trials include:

[1] The effect of fertiliser application rate and pitch construction on red thread and fusarium patch disease.
[2] The effect of cultivar mixtures of perennial ryegrass and soil type on red thread disease.
[3] The effect of grass species mixtures on red thread and fusarium patch disease.

Microscreening for biological control agents against fusarium patch disease, followed by *in vivo* testing and possible field trials, is also being undertaken as a consequence of the survey results. Such integrated strategies seem more critical considering 50-80% of clubs spray routinely against such diseases.

IPDM would reduce routine sprays thereby saving money and the inconvenience of bulky spraying equipment. Intense chemical use may also cause problems such as extermination of natural enemies, promotion of minor pests to a more significant status and may promote pesticide resistance within organisms. IPDM strategy involves adherence to sound cultural practices which reduce the incidence of diseases, pests and weeds. These include overseeding with resistant cultivars, monitoring soil nutrient and pH status, adjusting mowing heights and fertiliser regimes accordingly and controlling thatch. Table 43 (following page) summarises a number of factors which inhibit and promote the two most commonly reported diseases on winter sports turf, red thread and fusarium patch disease.

TABLE 43, Factors influencing outbreaks of red thread and fusarium patch disease

Disease	**Promoted by**	**Inhibited by**
Red thread	Low nitrogen Susceptible cultivars Thatch Increased surface moisture	High nitrogen Resistant cultivars Thatch removal Adequate drainage
Fusarium patch	Alkaline conditions, e.g. lime Excessive nitrogen Poorly drained turf Thatch Shade Longer grass in winter	Balanced soil pH Balanced soil fertility Adequate drainage, decreased surface humidity Thatch removal, boxing off clippings Increased light intensity Decreased height of cut

A balanced use of cultural controls which may serve to suppress the incidence and intensity of these diseases would form a potential basis for an IPDM strategy for fungal pathogens of winter sports turf.

The following section (2.2) documents the results obtained from the survey of local authorities.

2.2 Major diseases, pests and weeds of winter sports turf. II. A questionnaire survey of local authorities

Summary

The 563 local authorities (LA) of the UK were sent a postal questionnaire which sought information on the incidence of the following on full-size football pitches: [i] disease, pest and weed problems; [ii] pesticide application and legislation; [iii] general information regarding management including usage, construction, drainage, soil type, renovation and mowing, spiking and fertiliser regimes; [iv] general problems including wear, compaction and drainage. The design of the survey was revised substantially and greatly simplified to account for the fact that the local authorities are responsible for varying numbers of winter sports pitches. The survey concerned full size non-education (public use) football pitches. The results showed that fusarium patch (*Microdochium nivale*) and red thread disease (*Laetisaria fuciformis*) were the most ubiquitous diseases and earthworm casting and leatherjackets (*Tipula paludosa*) were the major pest problems. In addition, the majority of local authority (82%) pitches were affected by the incidence of dogs. Plantain (*Plantago major*), clover (*Trifolium repens*), dandelion (*Taraxacum officinale*) and annual meadow-grass (*Poa annua*) were the most common weeds.

Introduction

In the previous section (2.1), the findings of a questionnaire survey on diseases, pests and weed problems of professional football club pitches were described. The objective of the work described here was to conduct a parallel survey on local authority (LA) sports grounds. The survey enabled collation of disease, pest and weed incidence so the most common could be identified and subsequent research targeted accordingly. Although LA pitches receive lower management inputs than professional grounds, principles of integrated pest and disease management (IPDM) can still apply. IPDM involves the co-ordinated use of biological, cultural and chemical methods to maintain pests at an economic level, with the least possible hazard to people, property and the environment (Leslie 1989).

Such long-term strategies prove cost-effective and are site specific. For example in the case of LAs, selection of an appropriate grass cultivar for the use pattern of the site would be a beneficial initial management decision.

Materials and Methods

A questionnaire (Appendix III) was sent to the 563 local authorities in the UK concerning pest, disease and weed incidence and control methods employed on full size, non-education (public use) football pitches. The final sections of the survey related to pesticide use and legislation, routine management and general problems affecting pitches.

Results obtained from the survey have been standardised and expressed in terms of a % of total number of LA football pitches in the UK, represented by surveys returned.

Where appropriate, statistical analysis of the results obtained have been completed using chi-square (χ^2) at the significance level $p < 0.05$. The null hypotheses states that there is no significant association between the incidence of a pest and a certain management factor, e.g. presence or absence of spiking or soil type.

Any significant results or indicative trends were recorded in the appropriate sections in the results.

Results

The response rate to the questionnaire was good. Of the 563 surveys posted 251 (45%) were returned.

Diseases, pests and weeds

Table 44 illustrates the percentage of pitches affected by different types of diseases, pests and weed problems and the percentage of LAs who use chemical and cultural control.

TABLE 44, Disease, pest and weed incidence and control measures reported by respondents (n = 251)

Problem	% incidence	% chemical control	% cultural control
Disease			
Red thread	20	30	41
Fusarium patch	18	46	29
Rust	6	20	33
Other	4	25	14
Leaf spot	3	0	0
Seedling	2	25	25
Pests			
Dogs	82	0	44*
Earthworm casting	53	32	21
Other mammals	34	32	37
Leatherjackets	28	33	9
Chafers	6	22	0
Other	3	25	0
Fever fly	1	0	0
Weeds			
Plantain	84	82	8
Dandelion	77	79	8
Clover	77	72	6
Annual meadow-grass	61	29	22
Knotweed	41	77	9
Speedwell	36	79	5
Other	20	88	9

*local bylaws

Red thread (*Laetisaria fuciformis*) and fusarium patch (*Microdochium nivale*) were the most common diseases. In the rather broad 'pest' category dogs (presumably problems with fouling of public areas) and earthworms were cited as the main problems. Of the insect pests only leatherjackets (*Tipula paludosa*) were of significant occurrence. Weed problems were extremely common, plantains (*Plantago major*), clover (*Trifolium repens*) and dandelions (*Taraxacum officinale*) being reported by c. 80% of respondents. In over one third of the cases of pests and diseases chemical control was used. For weed control three-quarters of

LAs sprayed herbicides routinely. There was less emphasis on cultural control, with fewer than 10% of LAs using such measures.

Pesticide application and legislation

Eighteen percent of LAs used outside contractors for the application of pesticides. However, 95% of LA staff who did spray pesticides had received specific training. All pesticides kept by local authorities were stored safely in either a Portastor/Chemsafe or a purpose-built building.

The actual quantity of pesticide stored (Table 45) could be high. Fifteen percent of LAs stored over 100 kg or l.

TABLE 45, Quantity of pesticides stored by LAs (as % of respondents in each category)

Quantity kg or l	%
0–5	10
6–10	13
11–20	22
21–50	24
51-100	16
101–250	8
250+	7

Table 46 indicates how LAs disposed of unused concentrate, dilute pesticides and empty containers. The majority of LAs (95%) utilised the services of a waste disposal company or returned unused chemicals to the manufacturer.

TABLE 46, Disposal of pesticides and empty containers reported by respondents (%)

Disposal	Unused concentrate	Diluted pesticide	Empty containers
Water disposal company	71	60	57
Return to manufacturer	24	13	19
Dustbin/skip/ sink	–	2	4
Burial	2	4	14
Burning	–	1	5
Other	3	20	1

Area

Of the surveys returned, the majority came from the south-east (32%) and the north-west (22%) (Table 47).

TABLE 47, Geographical distribution (% of total) of survey respondents

Area	%
South-west	14
South-east	32
Midlands	14
North-west (including N. Ireland)	22
North-east	9
Scotland	9

General problems

Table 48 provides a summary of the results obtained when the LAs were asked to select five of the most important problems affecting their pitches, from a list of twenty. The list included factors such as drainage, wear, thatch, irrigation, pests and nutrition balance. The five problems were then ranked in order of importance.

TABLE 48, Five most important and common problems among respondents

Rank	Problem	%
1st	Drainage	44
	Wear	31
	Soil compaction	12
2nd	Wear	35
	Drainage	24
	Soil compaction	13
3rd	Earthworm casting	20
	Soil compaction	19
	Renovation	14
4th	Renovation	17
	Soil compaction	14
	Weeds	13
5th	Dogs	20
	Renovation	16
	Weeds	13

Drainage, wear and compaction were the major problems. However, earthworm casting, renovation, weeds and dogs were also of significance, with up to 20% of pitches affected in some cases.

General information/routine management

Usage

Sixty-nine percent of pitches were used three or more hours per week (Table 49).

TABLE 49, % of respondents reporting different amounts of use of LA pitches (hours per week)

Number of hours	%
1.5	26
3	45
9	18
Other	6
Not known	5

The usage of the pitch and the incidence of fusarium patch disease appear significantly associated:

$\chi^2 = 5.86$, df = 1, p = 0.015

Seventy percent of incidences occurred on pitches used up to 3 hours per week, compared with only 30% of fusarium patch incidences on pitches used more frequently (over 3 hours per week).

Construction

The majority of pitches were soil construction (67%) (Table 50), 54% of all LA pitches were constructed within the last 10 years.

TABLE 50, % of respondents reporting different types of pitch construction

Soil	67
Sand/soil	20
Sand	5
Other	3
Not known	5

Drainage

Of the pitches which had a drainage system (54%), 35% had pipe drainage and 19% had slit drainage.

Soil type

Eighty per cent of pitches had a medium to heavy soil type (clay loam), 20% were sandy. As a direct consequence 70% of pitches were prone to waterlogging occasionally to often. Thirty percent of pitches never waterlogged. There appeared to be a significant association between the incidence of waterlogging and fusarium patch disease. Sixty-eight percent of fusarium cases occurred on pitches which waterlogged occasionally to often:

$\chi^2 = 9.81$, df = 2, $p = 0.007$

Mowing regime

Table 51 shows the mowing regime employed on pitches in the summer and autumn. Ninety-four percent of pitches were mown at least fortnightly in the summer. In the autumn the pattern was very similar.

TABLE 51, % of respondents using different mowing regimes in summer vs. autumn

Mowing regime	Summer (%)	Autumn (%)
2 x week	5	2
Weekly	39	33
Fortnightly	50	56
Monthly	1	4
Never	2	1
Other	2	3
Not known	1	1

Differences occurred in the height of cut in the summer and autumn (Table 52). In the summer a quarter of the pitches were maintained at a height of less than 1", whereas nearly half that number were maintained at such a height in the autumn.

TABLE 52, % of respondents using different heights of cut (inches) in summer vs. autumn

Height (inches)	Summer (%)	Autumn (%)
Less than 1	26	14
1–2	61	63
2.1–3	9	19
3+	1	1
Not known	3	3

Fertiliser regime

Only 11% of pitches received no fertiliser (Table 53), the majority applied was compound fertiliser (Table 54).

TABLE 53, % of respondents reporting different frequencies of fertiliser application

None	11
Once per year	39
Twice per year	47
Other	3
Not known	0

TABLE 54, % of respondents using different types of fertiliser

Compound	92
Nitrogen only	4
Other	3
Not known	1

There appeared to be a significant association between the frequency of fertiliser application and the incidence of red thread disease. Seven percent of red thread cases occurred when no fertiliser was applied, compared with 23% when fertiliser was applied once and 71% red thread incidence when fertiliser was applied twice:

$\chi^2 = 8.3$, df = 2, p = 0.016

In the absence of fertiliser there was only a 7% occurrence of fusarium patch disease, compared with 93% incidence when fertiliser was applied. Similarly, 79% of the incidences of clover occurred when fertiliser was used.

Spiking

Table 55 shows the % spiking regime in the playing and close season.

TABLE 55, % of respondents using different spiking regimes

Spiking regime	Playing season	Close season
2 x week	0	1
Weekly	14	3
Fortnightly	25	7
Monthly	46	20
Never	13	41
Other	1	27
Not known	1	1

Pitches were spiked more frequently in the playing season, only 13% were not spiked at all, compared with 41% in the close season. The incidence of red thread disease appeared to increase when pitches were spiked less.

Monthly	45%
Fortnightly	31%
Weekly	24%

Fifty-nine percent of earthworm casting incidence occurred when pitches were spiked monthly, compared with only 11% incidence when pitches were spiked every week. A similar trend was noted for fusarium patch disease, leatherjackets and all weed species, i.e. increased spiking was associated with a lower incidence of pests.

Verti-Draining

Over half the pitches received no Verti-Draining (Table 56). Only 14% of pitches were Verti-Drained seasonally.

TABLE 56, % of respondents using different Verti-Draining regimes

Every 3 seasons	10
Every 2 seasons	11
Every season	14
Twice per season	1
Never	53
Other	9
Not known	2

There appears to be a significant association between the incidence of leatherjackets and the frequency of Verti-Draining:

$\chi^2 = 6.70$, $df = 2$, $p = 0.035$

As the number of Verti-Drain operations increased, the incidence of leatherjackets decreased:

Regime	% incidence
1-2 per season	21%
Every 2/3 seasons	41%
Never	38%

Irrigation

Few pitches were irrigated, only 13% in the close season and 10% in the playing season.

Marking out

Eighteen percent of pitches were still marked out with caustic lime, now illegal (Table 57), although the majority used white paint or Snowcal.

TABLE 57, % of respondents using different methods of marking out

Method	%
Caustic lime	18
Pesticide	5
White paint	42
None	3
Other*	30
Not known	2

*Mainly Snowcal

Renovation

Virtually all pitches received some kind of renovation practice repairs. The majority of pitches (89%) were renovated in April/May each year (Table 58). The timing of these repairs is crucial to ensure the pitches are ready for the start of the playing season.

TABLE 58, % of respondents carrying out renovation in different months

March	2
April	31
May	58
June	8
July	1

Discussion

A number of LAs store over 250 l or kgs of pesticides that are used regularly on the 8,000-9,000 football pitches in the UK. It would appear that a sizeable amount of chemicals are utilised by LAs to control diseases, pests and weeds on land open to public access. Despite public concern about the hazards involved, a number of other problems arise from chemical use. These include the inconvenience of bulky spraying equipment, expense, extermination of natural enemies, the possible promotion of minor pests to a more important status and finally, due to such intense selection pressure chemical resistance in organisms may occur.

These pitches are also subject to further stress due to an increase in the sell-off of land used as school playing fields (Ward 1983).

As with all surveys, the results can be biased and a totally representative sample is hard to ensure. For example, some LAs have increased funding for sport and amenity areas, take more responsibility for turf management or have higher standards of maintenance. One must also remember that correlation present between variables does not necessarily indicate cause and effect. However, a number of significant trends do appear in the data which have also been noted on the survey of professional Football League clubs.

Several management factors appear to influence the most important disease, pest and weed problems suggesting there is tremendous scope for the development and implementation of integrated pest and disease management (IPDM) on LA land. These factors can be exploited as part of an IPDM strategy and so decrease the extensive emphasis on chemical control.

[1] Red thread disease

Twenty percent of pitches are affected by this disease. The results suggest that red thread is reduced by spiking whose practice may help to reduce thatch which in turn provides moisture and nutrients for pathogenic fungal growth. Spiking, combined with the use of resistant cultivars and sufficient nitrogen to stimulate plant growth and vigour, will help maintain red thread at an acceptable level.

[2] Fusarium patch disease

The results suggest that fusarium patch disease increases with increased fertiliser use and water-logging, coupled with decreased spiking and Verti-Draining. The disease is also encouraged by an alkaline pH (Baldwin 1990). Half of the outbreaks are controlled chemically. An alternative strategy might be to reduce surface moisture by regular slitting and aeration and decreasing the amount of nitrogen applied or change the nitrogen source, e.g. ammonium sulphate can reduce fusarium patch damage. The control of thatch, boxing of clippings and the use of acidifying fertilisers to reduce soil pH, coupled with the judicious use of fungicide, will also help control this disease.

[3] Earthworm casting

One-third of LAs control earthworm casting chemically. The results also suggest that earthworm casting may be reduced by spiking. Although the casts are unsightly, the worms themselves greatly improve soil structure and nutrient availability, so is control of earthworms on winter sports turf really necessary?

[4] Leatherjackets

This pest occurs on 28% of pitches, 33% of cases are treated chemically. Little is known about cultural turf conditions which favour outbreaks of leatherjackets, although the data suggest numbers can be reduced by Verti-Draining. An effective pesticide may be applied when the larvae are found feeding near the surface.

[5] Weeds

Seventy to eighty percent of pitches (approximately 6 500) receive herbicides on a regular basis. The results suggest spiking may reduce weed invasion. In general, weed incidence can be reduced if a healthy, vigorous sward is maintained by sound management, e.g. well-drained soil, balanced soil fertility and pH, together with an increased mowing height. Persistent weed problems may be controlled by spot treatments with an effective herbicide

In general, adhering to sound cultural practices is paramount in reducing disease, pest and weed severity. As the turfgrass environment is not static, management decisions must be continually modified to encourage vigorous growing conditions, i.e. monitor nutrient and pH status of the soil, adjust mowing height, overseed with disease resistant cultivars, manipulate nitrogen sources and control thatch. These practices, coupled with prudent chemical use, will provide effective and long-term control of diseases, pests and weeds below economically damaging levels, in short IPDM. The problems encountered on LA pitches are very similar to those on professional football club (PFC) pitches. These include the diseases red thread and fusarium patch, earthworm casting, leatherjackets and a number of weed species, e.g. clover, plantain and annual meadow-grass. Although IPDM is relevant on PFC pitches, such a strategy would have far greater impact on LAs in view of the large number of pitches involved.

The following chapter discusses a number of cultural control mechanisms investigated that may be of possible use to both PFCs and LAs in reducing the severity of red thread and Fusarium patch.

Chapter Three:

Cultural Disease Control

3.0 Cultural Control of Turfgrass Pathogens.

Cultural factors play a crucial role in the development of disease symptoms on turfgrass. Cultural management practices provide the basic tools for the turfgrass manager in reducing disease incidence and severity.

From the results of the survey regarding diseases and current management practices on football pitches in the U.K. (Chapter 2) red thread (*Laetisaria fuciformis*) and Fusarium patch (*Microdochium nivale*) were identified as being the two most common diseases on winter sports turf. The following table highlights the extent of the problem.

Table 59. The occurrence of *L. fuciformis* and *M. nivale* on football pitches in the U.K.

Type of pitch	% pitches affected by *L. fuciformis*	% pitches affected by *M. nivale*
PFC* competition pitch	57	57
PFC training ground	74	45
Local authority	20	18

* PFC - professional football club.

A series of experiments and field trials have been set out to determine the effects of the major cultural factors identified from the survey on the incidence and severity of *L. fuciformis* and *M. nivale*. The results obtained will assist the formulation of an integrated disease management strategy resulting in the possible suppression of both pathogen species.

The initial choice of turfgrass species and cultivars is fundamental in terms of disease management. Certain grass species are more susceptible to disease than others e.g. *Lolium perenne* and *Festuca rubra* are the principal hosts of *L. fuciformis* in the U.K. whereas *Agrostis* spp. are more susceptible to *M. nivale*. In addition, turfgrass cultivars are available which are more tolerant to disease, e.g. *L. perenne* cultivars Wendy and Prester are more tolerant to *L. fuciformis* than cultivars Juwel and Entrar (Turfgrass Seed 1994, The Sports Turf Research Institute).

In addition to the variation in susceptibility between individual species/cultivars, disease suppression can also be obtained through the use of **mixtures** of species/cultivars. The buffering effects of mixtures against disease loss has been known for nearly one hundred years. Mixtures of turfgrass species and cultivars mimics the diversity and stability of natural ecosystems where disease epidemics are rare (Mundt and Browning, 1985).

An experiment was conducted to determine the effect of monostands and mixtures of turfgrass species on the incidence and severity of both *L. fuciformis* and *M. nivale* (Section 3.1).

One of the most common general problems on winter sports turf is wear. The survey regarding disease and general management (Chapter 2) revealed that approximately 60% of professional football clubs indicated that wear is the most significant problem on both the competition pitch and training ground. Similarly, 66% of local authorities consider wear a major problem on winter sports pitches. Section 3.2 in this chapter examines how *L. fuciformis* outbreaks in the summer may predispose different *L. perenne* cultivars to be less wear tolerant during the playing season. In addition the cultivars received different rates of nitrogen to determine the interaction between disease, wear and nitrogen rate.

A field trial was also set out to examine the effects of *L. perenne* cultivars, with varying tolerance to *L. fuciformis*, when grown in mono, dual and triple swards. The trial was replicated on a different soil type to determine the significance of this factor on disease incidence (Section 3.3).

In addition to species and cultivar choice, pitch construction and nitrogen application rate were also investigated to determine the effect on disease. The construction of the pitch e.g. 'pipe drains only' or 'sand profile', greatly influences the availability of water both to the turfgrass plant and the pathogen. As well as the availability of moisture, construction also determines nutrient availability; i.e. fertiliser applied on a freely draining construction will pass rapidly through the rootzone and leach out of the system. The availability of water and nutrients are possibly the two most important factors that influence the vigour and quality of turfgrass and whether pathogenic fungi present in the turf, thatch and soil will express deleterious symptoms. A field trial was set out to determine the effect of six nitrogen levels on the incidence and severity of *L. fuciformis* and *M. nivale* on five different pitch constructions for football (Section 3.4).

3.1 The Effect of Dual-species Mixtures and Monocultures on Disease.

Introduction

Winter games pitches e.g. football, rugby and hockey are subject to intense wear at a time when the grass is not growing and the recuperative potential is low. *L. perenne* is usually the major component of winter sports turf. *L. perenne* has one of the fastest establishment rates of all the cool season turf grasses; it also has a coarse leaf texture, moderately high shoot density, and good wear tolerance. The species has a rapid germination and seedling growth rate which are beneficial because the close season, when renovation practices occur, is relatively short (approximately three months).

The addition of another species is recommended as a polystand is more resistant to changes in environmental conditions. If one species succumbs to environmental stress or disease, the entire sward will not be destroyed as the surviving species will spread and eventually fill in the bare patches.

Poa pratensis is also used in winter sports turf because of its attractive appearance, strong rhizomatous spreading habit, medium leaf texture, good tolerance of most environmental and soil conditions and the large selection of improved cultivars available (Emmons, 1984).

Red thread (*Laetisaria fuciformis*) is a foliar pathogen and Fusarium patch (*Microdochium nivale*) infects the stem base. Both diseases can infect *Poa pratensis* and *Lolium perenne*. The diseases can be spread rapidly under appropriate conditions, (for example high levels of moisture), resulting in a reduction in the quality of the playing surface. The use of species mixtures not only buffers against unfavourable environmental conditions, such as increased levels of surface moisture, but can also effectively suppress disease spread in several ways. A mixture of turfgrass plants restricts the spatial density of susceptible plants thereby reducing the amount of susceptible tissue and decreasing the probability of spore survival. Resistant plants also provide an effective barrier between susceptible plants.

The aim of the experiment is to determine which mixtures of *L. perenne* and *P. pratensis* suppress both *L. fuciformis* and *M. nivale*, the most common diseases on winter sports turf. An initial pilot study was carried out to determine any differences in disease levels on monoculture and mixtures before a full-scale field trial was set out.

Materials and Methods.

PILOT STUDY

Lolium perenne cv. Mondial and *Poa pratensis* cv. Cynthia were sown in 25 cm x 40 cm seed trays in four randomised blocks in the following ratios:-

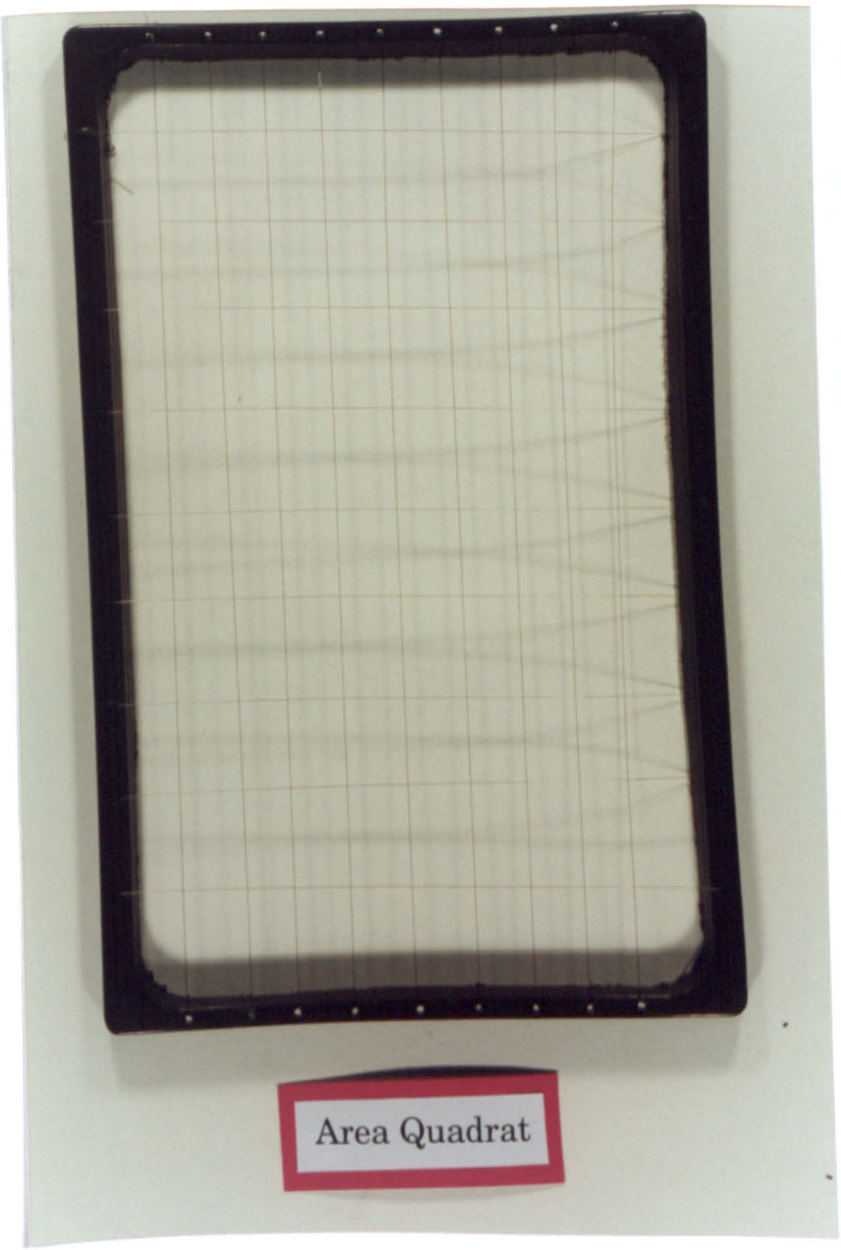
L. perenne : *P. pratensis* **1**. 0:100, **2**. 10:90, **3**. 20:80, **4**. 30:70, **5**. 40:60, **6**. 60:40, **7**. 80:20, **8**. 100:0
The seed was sown at 35 g/m^2 in June, 1993. *P. pratensis* cv. Cynthia was pre-treated with nitrogen to improve germination rate, to enable more successful competition with *L. perenne* cv. Mondial which germinates more rapidly. The soil used was a freely draining all purpose loam based compost. All the trays were treated with 12:6:6 N:P_2O_5:K_2O @ 35 g/m^2 applied in the spring and autumn. The sward was maintained at 25 mm and the cuttings were removed. The trial was watered as required.

The trial was inoculated with *Laetisaria fuciformis* three months after sowing (September, 1993). Mycelial fragments of *L. fuciformis* were obtained in liquid culture from potato dextrose broth (shaken at 80 rpm) inoculated with *Laetisaria* sclerotia. Prior to inoculation, the sclerotia were washed in warm running water, surface sterilised for 30 seconds in 10% sodium hypochlorite, rinsed twice in sterile distilled water and blotted on sterile filter paper. The mycelia was extracted after two weeks, surface dried and macerated, two grams were added to each tray in 50 mls of distilled water.

Three months after inoculation with *L. fuciformis*, the trial was inoculated with *Microdochium nivale* spores. *M. nivale* was isolated from leaves of *Lolium perenne* by washing the material under warm running water, surface sterilising in 10% sodium hypochlorite for 30 seconds and rinsing in sterile distilled water. The material was then plated onto tap water agar (15 g of agar per litre of tap water), a nutrient-free medium to induce maximum sporulation. After three weeks incubation (10° C, 12 hour photoperiod), the spores were extracted from the surface of the plate. To extract the spores the plates were flooded with a small volume of distilled water and a few drops of 0.01% Tween 80. After vigorous shaking, the spore suspension was filtered through two layers of muslin to remove any mycelial debris. The spore concentration in the suspension was then adjusted to 10^7 spores per ml using a haemocytometer. Fifty millilitres of the spore suspension was added to each tray.

The incidence of disease was assessed using an area quadrat to determine % area affected by disease (Plate 1). Assessments took place eight weeks after inoculation.

Plate 1. Quadrat to determine percent area affected by disease in the pilot study.

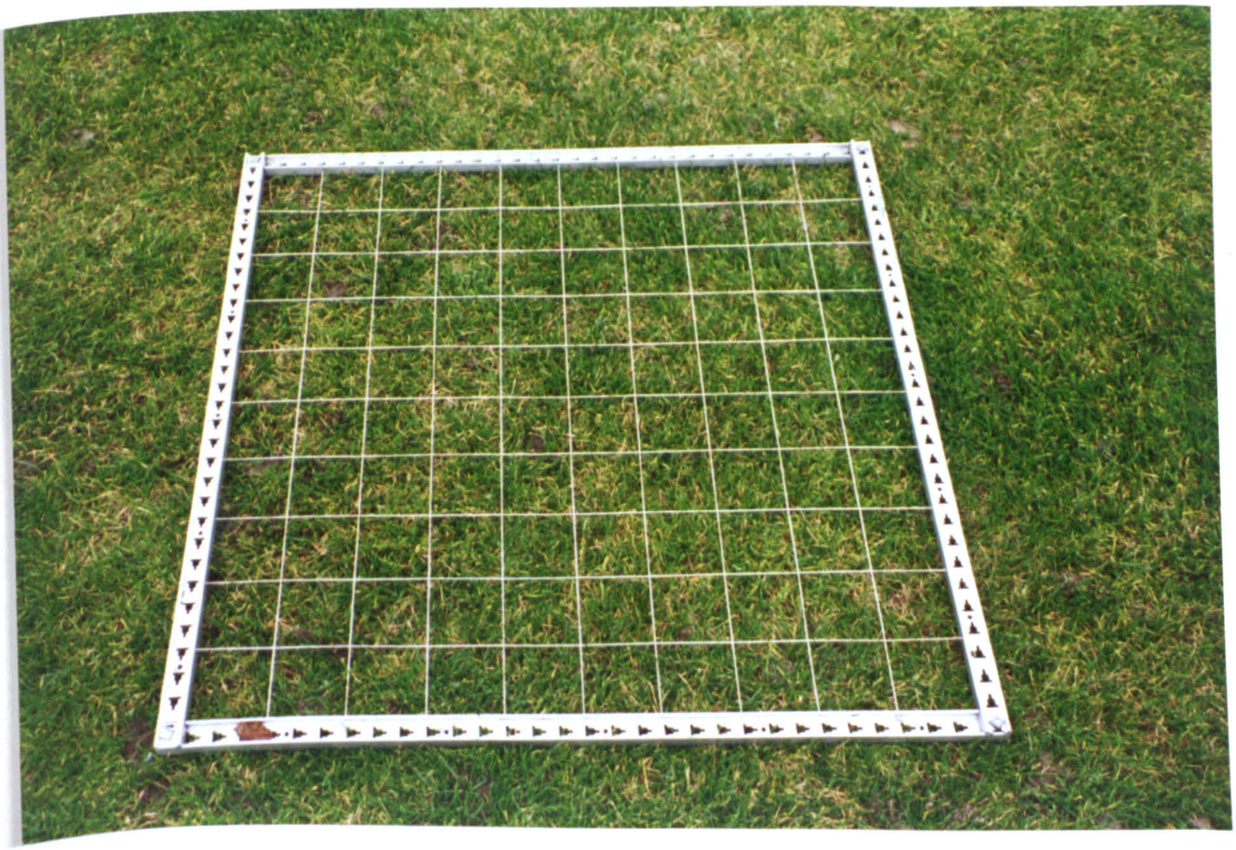


FIELD TRIAL

Lolium perenne and *Poa pratensis* were sown in 1m x 2 m plots at the experimental grounds at the Sports Turf Research Institute (NGR SE095391), according to the original experimental design utilised in the pilot study. The trial was sown in August, 1994 with 35 g m^{-2} of 11:6:9 N:P:K seed bed fertiliser. The sward was maintained at 25 mm and cuttings were removed. Dried blood was applied in October, 1994 at 12.5 g m^{-2} to encourage *M. nivale* in the winter.

Disease cover was determined using a 0.75 m^2 quadrat (Plate 2). *M. nivale* was assessed every month from December, 1994 to March, 1995; *L. fuciformis* cover was assessed from June-August, 1995.

Plate 2. Quadrat (0.75 m^{2}) to determine percent area affected by disease in field study.



The data was analysed for normality and analysis of variance tests were used to determine any significant differences, $p = 0.05$, between experimental treatments in the pilot study and field trial. Following analysis of variance, a second order polynomial was fitted to the resulting means.

Results.

PILOT STUDY

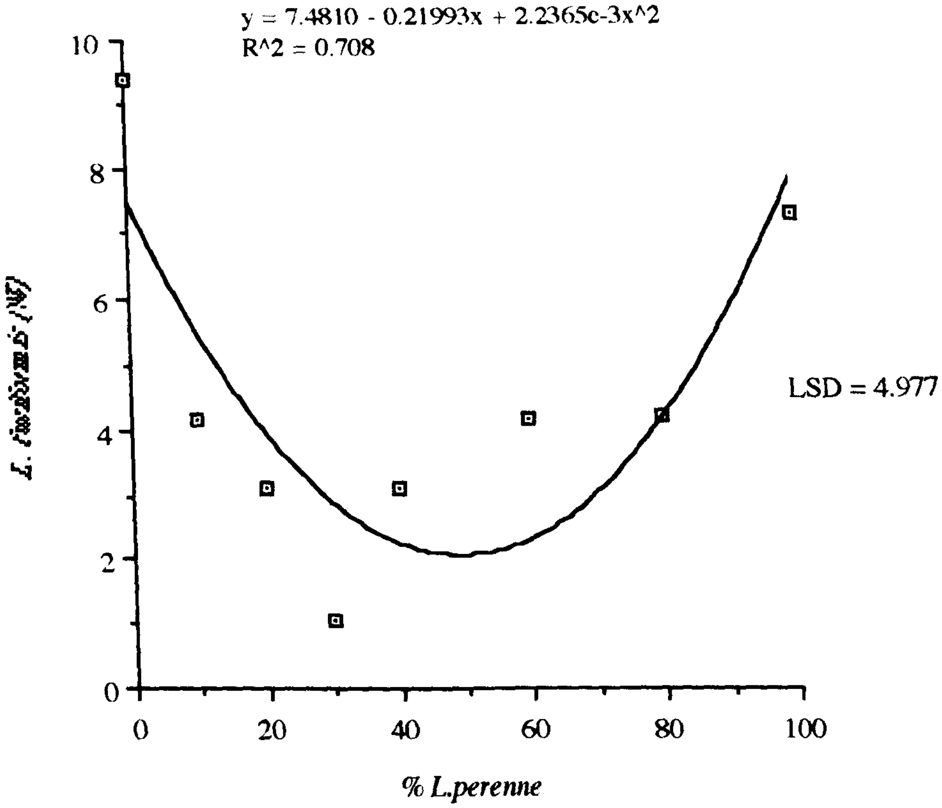
Red thread, *Laetisaria fuciformis*

Results from the *L. perenne*: *P. pratensis* swards are given in Table 60 and Figure 1. Disease incidence was greatest in monostand of *L. perenne*, with a notable reduction in mixtures with between 60-80% *P. pratensis* added.

Table 60. Response of *L. fuciformis* to mono and dual culture swards.

L. perenne:P. pratensis	**Mean % disease cover**	**Standard deviation**
0:100	9.40	6.24
10:90	4.18	3.39
20:80	3.12	3.98
30:70	1.05	2.10
40:60	3.12	3.98
60:40	4.15	4.79
80:20	4.20	0.00
100:0	7.28	2.05

Fig. 1. Effect of species mixtures on Laetisaria fuciformis, (pilot study)



The data was tested for normality and analysis of variance were carried out. The following results were obtained:

Treatment: $F_7 = 2.38$, $p = 0.059$, ns

Block: $F_3 = 2.93$, $p = 0.057$, ns

No significant differences were obtained for treatment and block effects on the incidence of *L. fuciformis*.

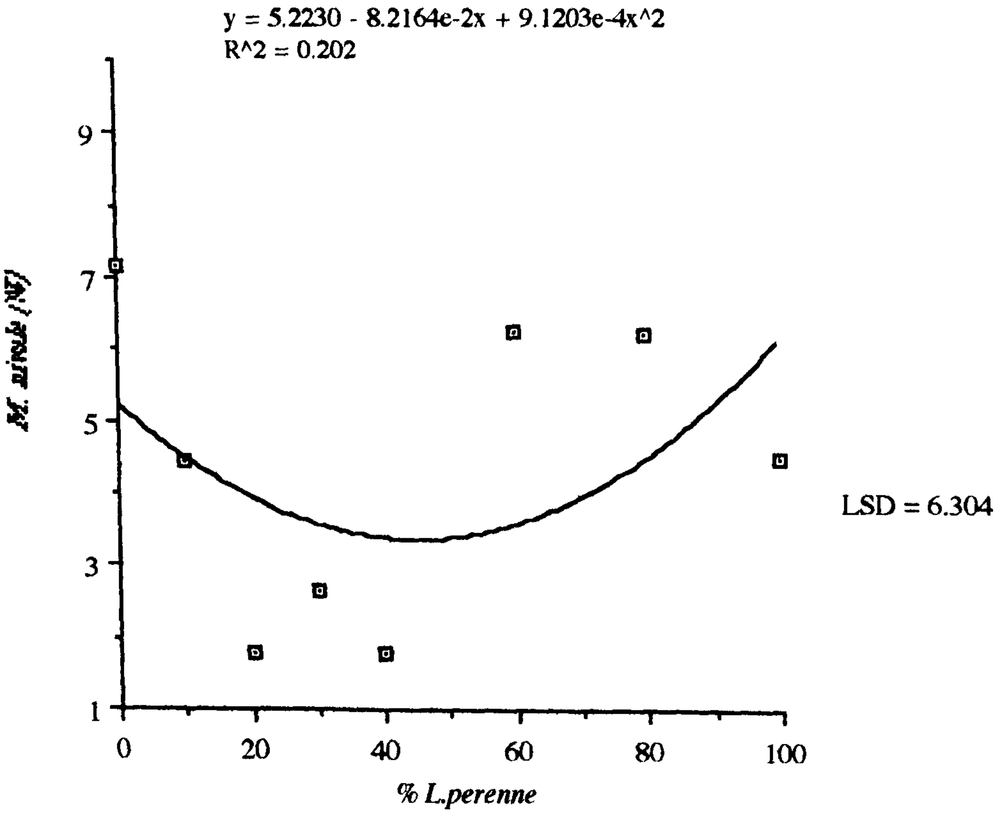
Fusarium patch, *Microdochium nivale*

Results from the *L. perenne* : *P. pratensis* swards are given in Table 61 and Figure 2. Disease incidence was greatest in the monostand of *P. pratensis*, with a notable reduction in mixtures with between 10-40% *L. perenne* added.

Table 61. Response of *M. nivale* to mono and dual culture swards.

L. perenne:P. pratensis	Mean % disease cover	Standard deviation
0:100	7.15	6.52
10:90	4.45	3.39
20:80	1.80	2.08
30:70	2.67	3.40
40:60	1.80	2.08
60:40	6.25	5.34
80:20	6.22	8.41
100:0	4.48	1.75

Fig. 2. Effect of species mixtures on Microdochium nivale, (pilot study)



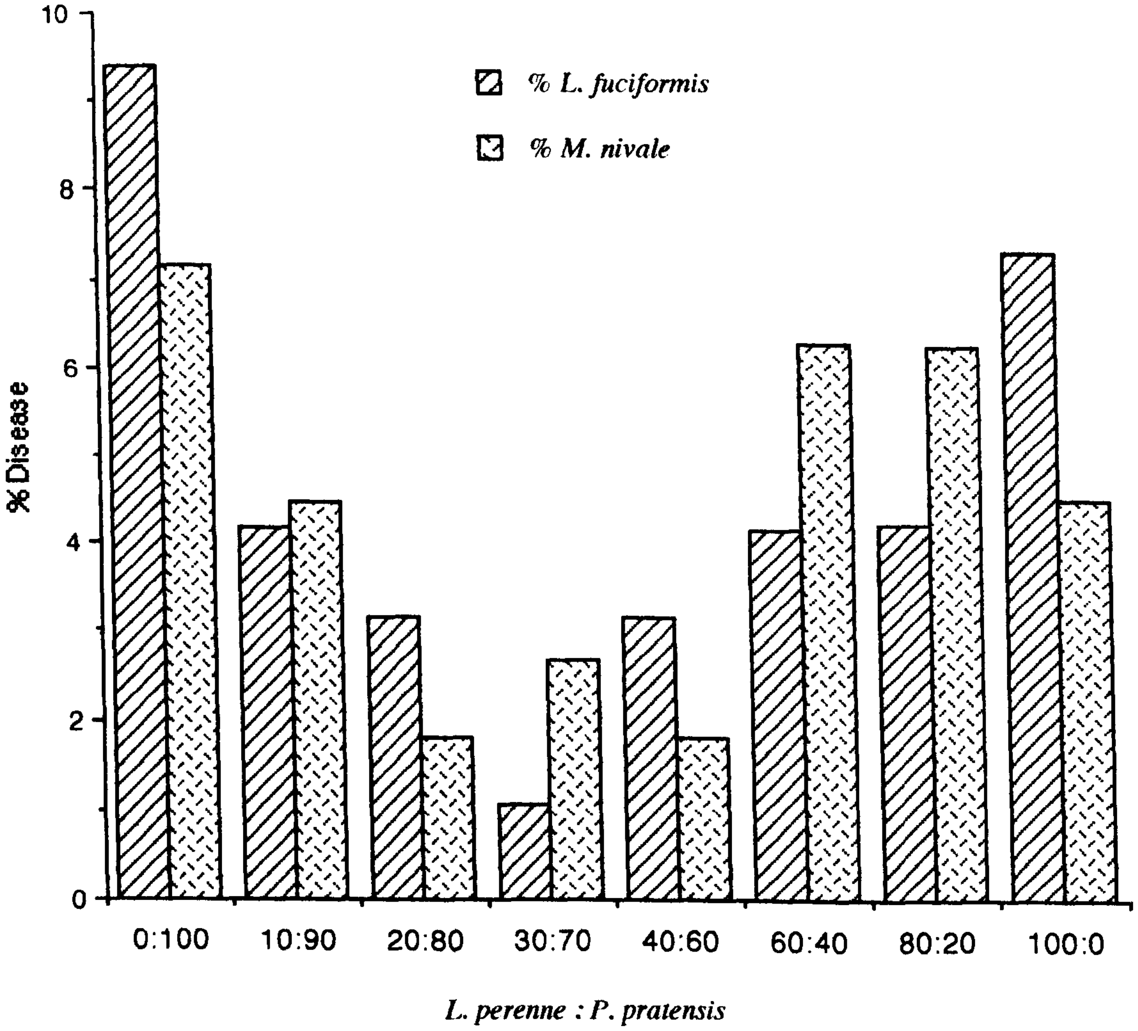
No significant differences were obtained for treatment and block effects on the incidence of *M. nivale*:

Treatment: $F_7 = 0.96$, $p = 0.486$, ns

Block: $F_3 = 2.61$, $p = 0.078$, ns

Figure 3 compares the response of monostands and dual species mixtures to *L. fuciformis* and *M. nivale*. Both diseases follow a similar trend where the incidence was reduced when both species were present in the mix.

Fig. 3 The response of dual species mixtures to L. fuciformis and M. nivale



FIELD TRIAL

Despite no significant treatment differences in the pilot study, a reduction in disease cover was apparent on the bistands compared to monoculture; a trial was set down (at the experimental ground, the Sports Turf Research Institute) to determine if bistands were more effective at reducing disease severity under the appropriate field conditions.

The results obtained from the disease assessments on the field trial (Table 62) illustrate that species mixtures significantly reduce *M. nivale* when compared to monoculture. The result was noted throughout the winter from the first assessment in December, 1994 to the final assessment in March, 1995.

Table 62. Response of *M. nivale* to mono and dual culture swards, December, 1994 to March, 1995.

Ratio	**Dec., 94**		**Jan., 95**		**Feb., 95**		**Mar., 95**	
*L. p:P. p**	% DC#	S DΔ	% DC#	S DΔ	% DC#	S DΔ	% DC#	S DΔ
0:100	22.25	4.03	15.50	1.29	10.00	0.71	6.50	0.71
10:90	14.00	4.34	14.50	3.32	9.25	4.84	3.50	0.58
20:80	9.00	3.11	6.88	1.89	6.38	1.49	3.63	0.48
30:70	5.75	2.50	4.63	0.75	4.38	1.44	1.38	1.11
40:60	4.50	4.92	4.86	2.10	2.88	0.75	1.63	1.49
60:40	8.50	3.34	7.38	2.84	2.88	1.11	2.13	1.32
80:20	13.50	5.69	8.63	2.63	6.75	0.96	2.13	2.02
100:0	12.88	2.02	10.75	3.12	9.75	1.44	5.38	0.85

* *Lolium perenne : Poa pratensis* # Disease cover Δ Standard deviation

Figures 4 - 8 illustrate the trend throughout the winter that *M. nivale* incidence was reduced on dual species mixtures compared to monoculture. The overall level of disease decreased from December, 1994 to March, 1995

Fig. 4. Effect of Species Mixtures on Microdochium nivale. Dec. 1994

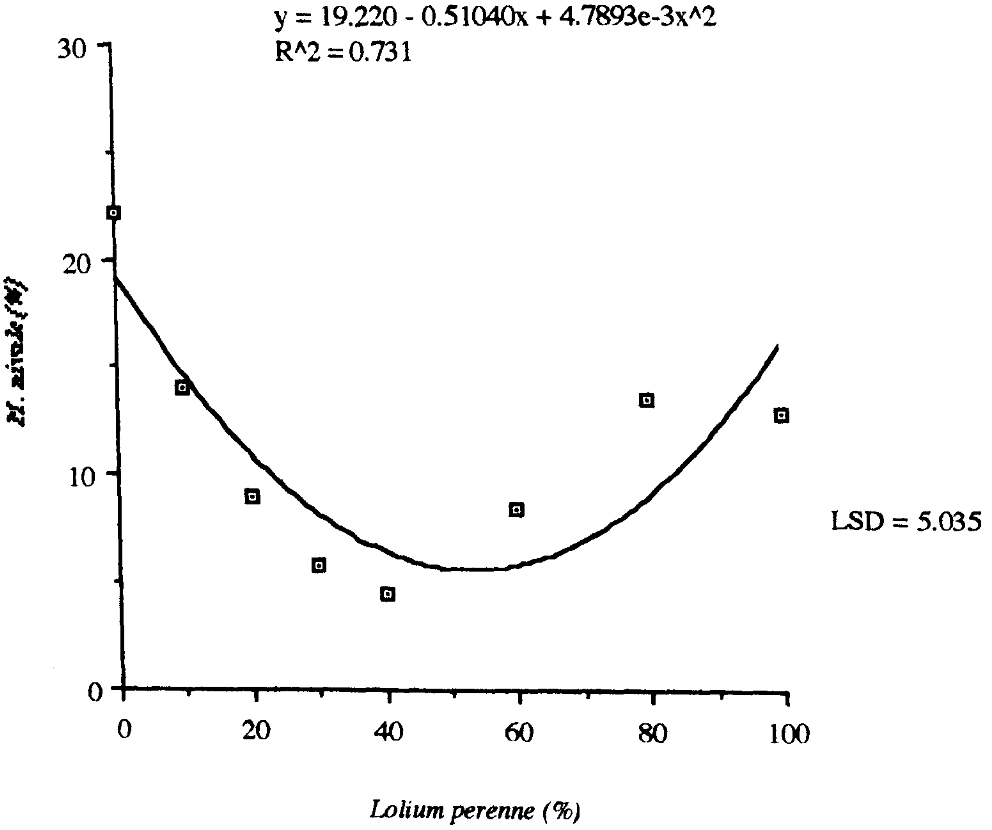
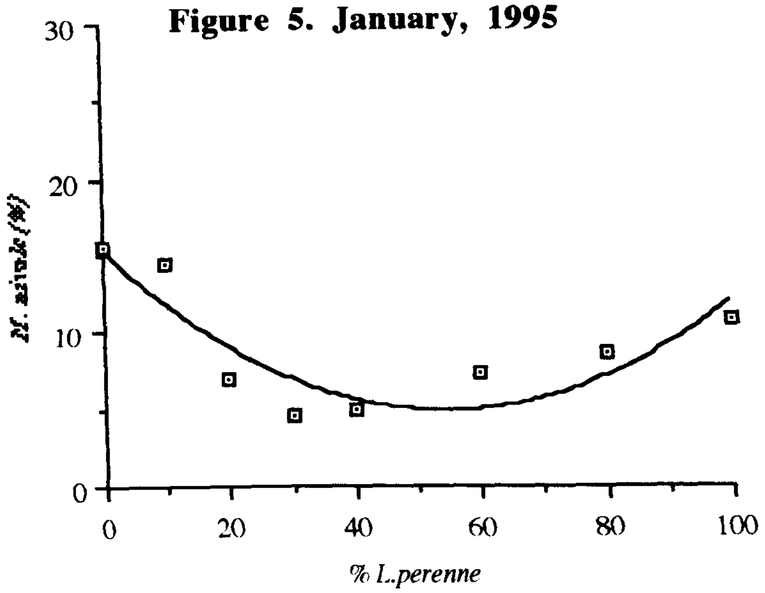


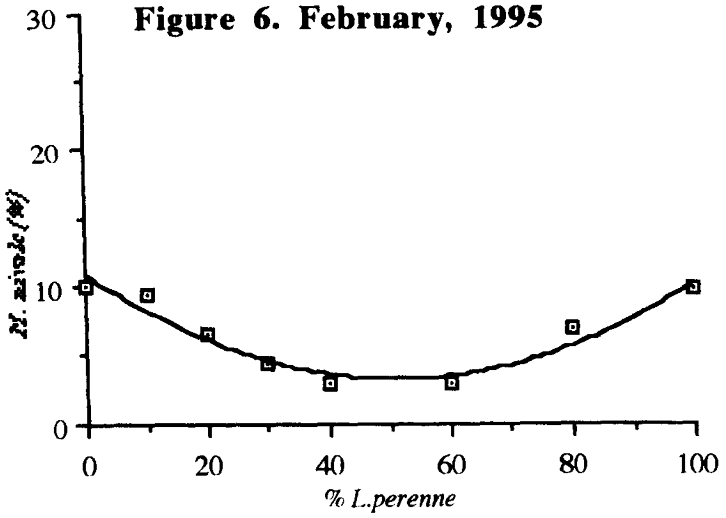
Figure 5. January, 1995



y = 15.262 - 0.37952x + 3.4814e-3x^2
R^2 = 0.766

LSD = 2.028

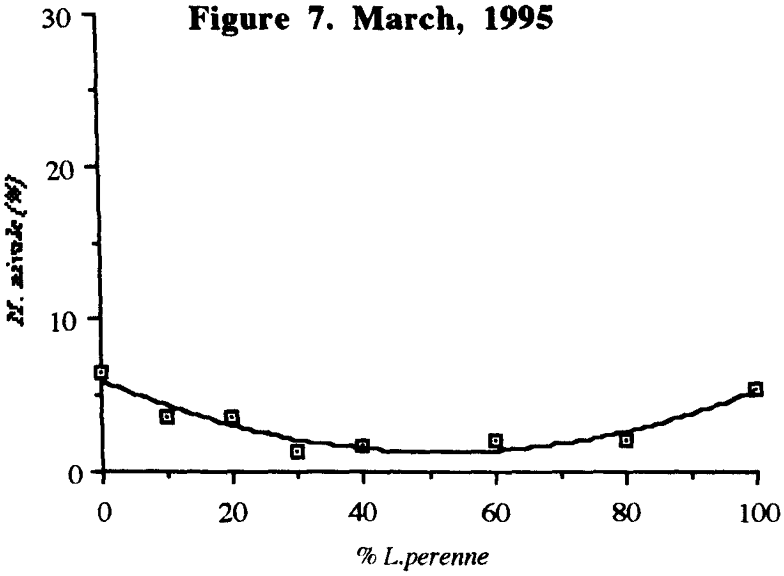
Figure 6. February, 1995



y = 10.781 - 0.29566x + 2.8935e-3x^2
R^2 = 0.930

LSD = 3.092

Figure 7. March, 1995



y = 5.9887 - 0.18230x + 1.7544e-3x^2
R^2 = 0.888

LSD = 1.470

On all assessment dates there were significant differences in the ***M. nivale*** severity between experimental treatments. A significant block effect was also noted in December, January and March (Table. 63).

Table 63. Statistical analysis of % ***M. nivale*** on mono- and bistands.

Assessment Date	Analysis
December, 1994	Treatment: F_7 = 10.96, p = 0.0001 Block: F_3 = 3.47, p = 0.034,
January, 1995	Treatment: F_7 = 11.84, p = 0.0001 Block: F_3 = 5.59, p = 0.006
February, 1995	Treatment: F_7 = 8.48, p = 0.0001 Block: F_3 = 0.46, p = 0.710, ns
March, 1995	Treatment: F_7 = 13.71, p = 0.0001 Block: F_3 = 4.06, p = 0.020

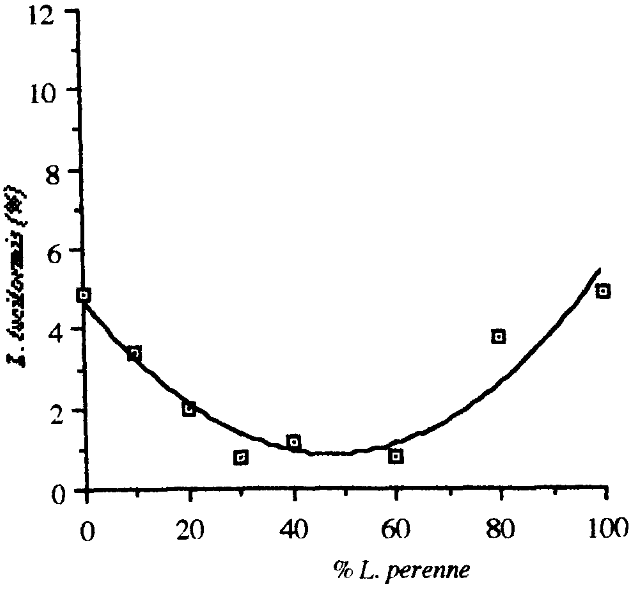
Red thread assessments were carried out on the field trial from June to August, 1995. Table 64 and Figures 8-10 illustrate the results obtained.

Table 64. Percent red thread cover on monocultures and multispecies mixtures of *Lolium perenne* and *Poa pratensis*.

Ratio	**June, 1995**		**July, 1995**		**Aug., 1995**	
*L. p:P. p**	**% DC#**	**S DΔ**	**% DC#**	**S DΔ**	**% DC#**	**S DΔ**
0:100	4.88	1.12	10.88	2.46	4.38	1.65
10:90	3.38	0.85	11.63	2.98	4.13	1.32
20:80	2.00	1.58	6.13	1.38	2.88	1.25
30:70	0.75	0.87	6.13	4.21	2.63	1.38
40:60	1.13	1.44	3.00	1.08	1.25	0.96
60:40	0.75	0.96	1.63	1.94	1.50	1.78
80:20	3.75	1.66	7.63	0.75	4.75	2.06
100:0	4.88	1.49	9.50	1.87	8.00	3.39

* *Lolium perenne : Poa pratensis* # Disease cover Δ Standard deviation

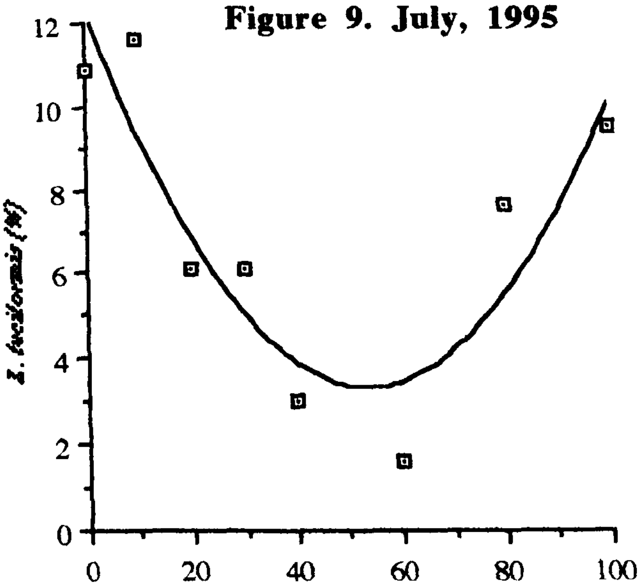
Fig. 8. Effect of species mixtures on Laetisaria fuciformis. June 1995



y = 4.6610 - 0.15984x + 1.6773e-3x^2
R^2 = 0.895

LSD = 1.725

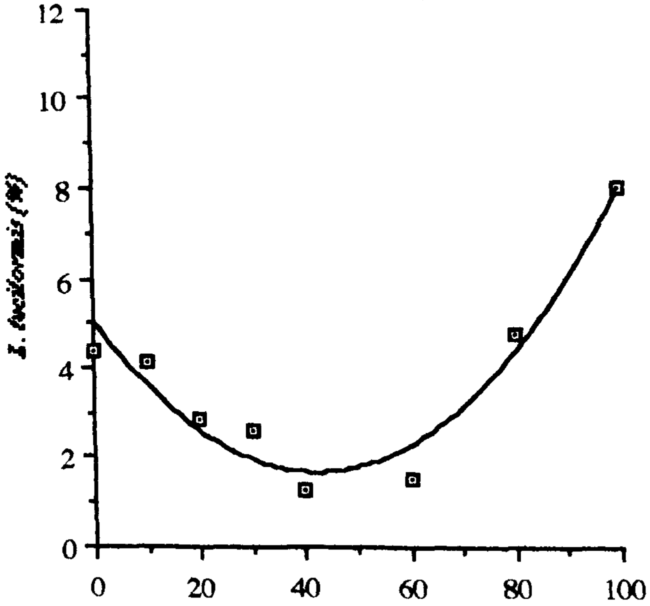
Figure 9. July, 1995



y = 12.318 - 0.33613x + 3.1421e-3x^2
R^2 = 0.796

LSD = 3.352

Figure 10. August, 1995



y = 5.0266 - 0.15875x + 1.8819e-3x^2
R^2 = 0.935

LSD = 2.025

On all assessment dates there were significant differences in the *L. fuciformis* severity between experimental treatments, but no significant block effects (Table 65).

Table 65. Statistical analysis of % *L. fuciformis* on mono- and bistands.

Assessment Date	Analysis
June, 1995	Treatment: $F_7 = 8.97$, $p = 0.0001$ Block: $F_3 = 2.58$, $p = 0.081$, ns
July, 1995	Treatment: $F_7 = 9.84$, $p = 0.0001$ Block: $F_3 = 1.42$, $p = 0.266$, ns
August, 1995	Treatment: $F_7 = 9.99$, $p = 0.0001$ Block: $F_3 = 2.37$, $p = 0.092$, ns

Red thread incidence was significantly lower when two species were present, on all assessment dates (Figs. 8-10, Table 65), particularly on a 50:50 ratio of perennial rye grass to smooth stalked meadow grass.

Discussion

Lolium perenne is the major host of *Laetisaria fuciformis* in the U.K. *Poa pratensis* is less susceptible although it can also be affected. The results from the pilot study however, suggest that disease was greatest on 100% *P. pratensis* although the difference in red thread severity on 100% *L. perenne* and 100% *P. pratensis* was very slight (Fig. 1). Both *L. perenne* and *P. pratensis* are moderately susceptible to *Microdochium nivale*. *Agrostis* spp. (the bentgrasses) used in fine turf e.g. golf and bowling greens, are the principal hosts of *M. nivale* in the U.K. In the pilot study *M. nivale* was most severe on 100% *L. perenne* (Fig. 2). The disease was lowest when 60 - 80% *P. pratensis* was present. However, when the majority of the blend was *L. perenne* (60 - 100%), *M. nivale* appeared to increase. Trays sown with a higher proportion of *L. perenne* may tend towards monoculture because of the competitive nature of the species and increased establishment rate compared to *P. pratensis*. The mixture which effectively suppresses both diseases (Fig. 3) to below 5% cover was when 60 - 90% *P. pratensis* was present. The blend with a greater proportion of *L. perenne* is favoured for use on winter sports turf because of its excellent wear tolerant properties.

Although no significant differences were obtained, the trends suggest that the mixtures of turfgrass species appear more effective at reducing disease than monoculture. The addition of *P. pratensis* to the mixture underpins the theory that genetic diversity effectively suppresses disease in turfgrass (Beard, 1973).

The results obtained from the field trial, however, are more encouraging. On all assessment dates for both diseases, symptom expression was significantly reduced on the bi-species swards. Disease levels were lowest on a 50:50 *Lolium perenne*:*Poa pratensis* mix. This trend was consistent throughout the assessment period, from the initial Fusarium patch assessment in December, 1994 until the final red thread assessment in August, 1995.

The use of species mixtures as a control strategy can be readily employed as many pitches are either resown or oversown annually. Frequent alterations in the turfgrass mixture will provide a more diverse host population which can significantly dilute the effect of disease. Turf mixtures broaden the genetic base of the host, thus enabling disease resistance and tolerance to environmental extremes. Mixtures of *L. perenne* and *P. pratensis* will provide turf with rapid establishment and hard wearing characteristics obtained from *L. perenne* and the long term high quality of *P. pratensis*.

Selection of a multi-species provides an inexpensive, simple and effective means of disease management. The mix chosen, however, must also be culturally and environmentally adapted for the area in which it is utilised. The use of species mixtures to manage disease would help reduce reliance on costly fungicides and its associated problems, e.g. reduction in natural antagonists and other beneficial non-target organisms (particularly micro-organisms and invertebrates involved in nutrient recycling) and selection of resistant strains within the pathogen population. The introduction of mixtures is also a strategy that can be used in conjunction with other control measures, making species mixtures an ideal component for an IDM strategy. Investment in a mixture of good quality grasses which wear well and result in a healthy vigorous sward will help reduce disease incidence, enable the turf to compete more successfully with weeds and tolerate higher levels of invertebrate pests without damage.

The following section assesses the merits of individual cultivars of perennial rye grass in terms of disease and wear tolerance under three different nitrogen regimes.

3.2 The Effect of Red Thread Incidence on Wear Tolerance of Monostands of Perennial Rye Grass Cultivars Under Three Levels of Nitrogen.

Introduction

The results from the questionnaire survey of the professional football clubs and the local authorities reported in chapter two revealed that red thread is the most ubiquitous fungal pathogen on winter sports turf in the UK. Over half (57%) of the competition pitches, 74% of training grounds and 20% of local authority pitches are frequently effected by the disease. In addition, wear was also one of the most significant common problems reported. As the football playing season becomes longer, commencing in August and concluding in May, the influence of summer diseases will have an increasingly important effect on turfgrass quality and durability throughout the season. The aim of this trial was to determine which *L. perenne* cultivars are the most tolerant to *L. fuciformis* under three nitrogen regimes and to determine whether disease tolerance throughout the summer predisposes turf to be more tolerant of wear during the playing season.

Materials and Methods

A field trial was sown at the experimental ground at the Sports Turf Research Institute on 29th April, 1994, by hand sowing seed of *Lolium perenne* at 25 g m^{-2} into a free draining sandy loam, with a pH of 5.5. The soil had previously received a seedbed fertiliser of 62.5 g m^{-2} 12:3:9 $N:P_2O_5:K_2O$ (75 kg ha^{-1} N.). The high nitrogen (225 kg ha^{-1} N.) treatment received an additional identical dressing on the 21st June and the high and medium nitrogen (150 kg ha^{-1} N.) treatments received a further dressing on the 25th August. The experiment contained one hundred and ten *Lolium perenne* cultivars in 1m x 1m plots randomly arranged in six blocks, (Plate 3), two under each of the three nitrogen levels. Mowing height was gradually reduced from 50 mm on 8th June to 30 mm on 4th July. The trial was mown twice weekly until 18th July and then maintained at 30 mm. Irrigation was applied when necessary.

Plate 3. Winter wear on *Lolium perenne* cultivars, the Sports Turf Research Institute, October, 1994.

Red thread incidence was assessed visually by a 0.75 m^2 quadrat as previously described in section 3.1 (Plate 2) on 5th October, 1994.

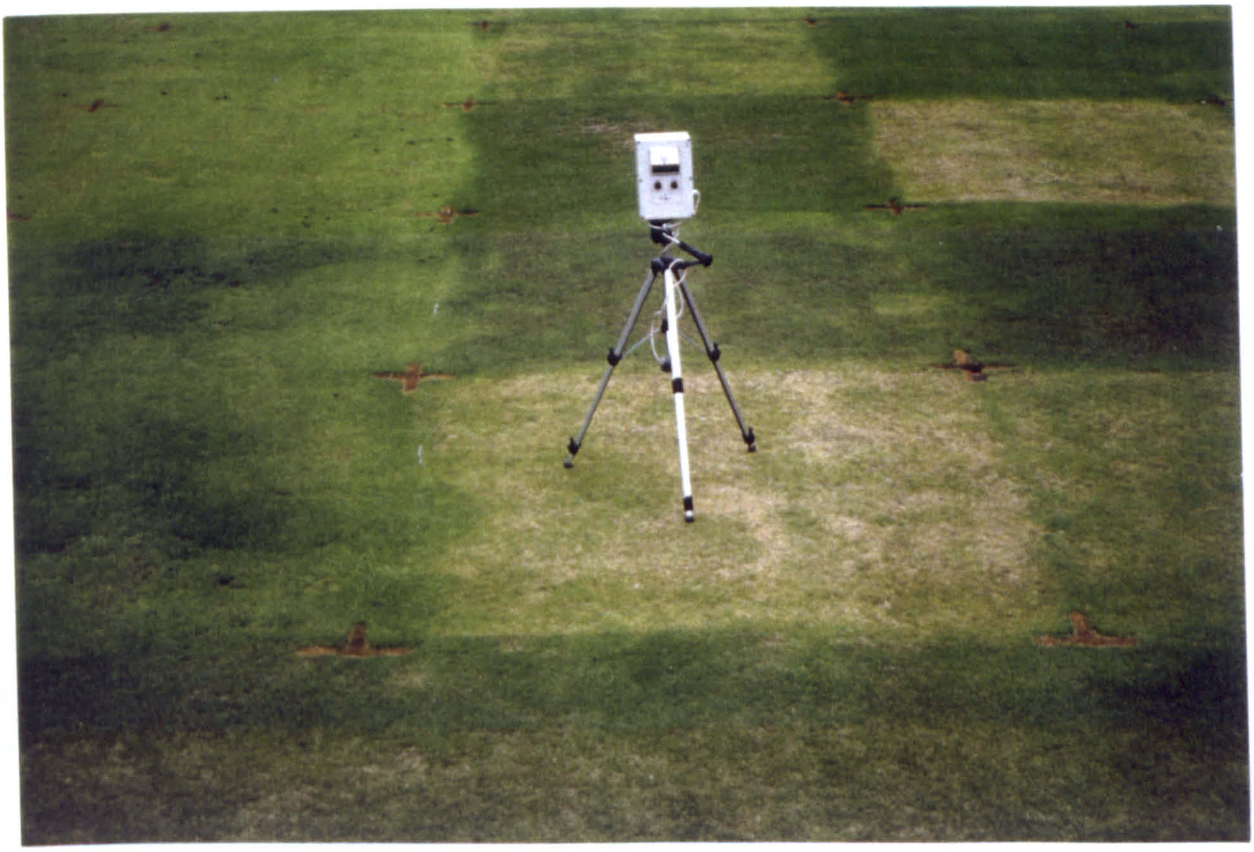
The trial received artificial football type wear treatment (see Plate 4), commencing on 11th October, 1994. Each plot received four passes per week with the wear machine until 31st March, 1995.

Plate 4. The artificial football type wear machine.

Ground cover was assessed by a reflectance ratio (RR) meter (see Plate 5). The RR meter measures near infra-red (peak at 750 nm) to red (peak at 650 nm) radiation. Grass absorbs red light but reflects infra-red whilst bareground reflects both. The amount of ground cover is directly related to the ratio of red light recorded. A black surface is used to zero the scale prior to assessments. A reading of eighty approximates to one hundred percent ground cover. The sensor was positioned 0.55 m above ground level on a tripod and assessments were made every month from November, 1994 - March, 1995.

This study was part of the Sports Turf Research Institute ongoing cultivar evaluation programme. This comprises a mixture of established and novel cultivars together with a range of selected breeder's lines.

Plate 5. The reflectance ratio meter in use at Wimbledon Lawn Tennis Club.

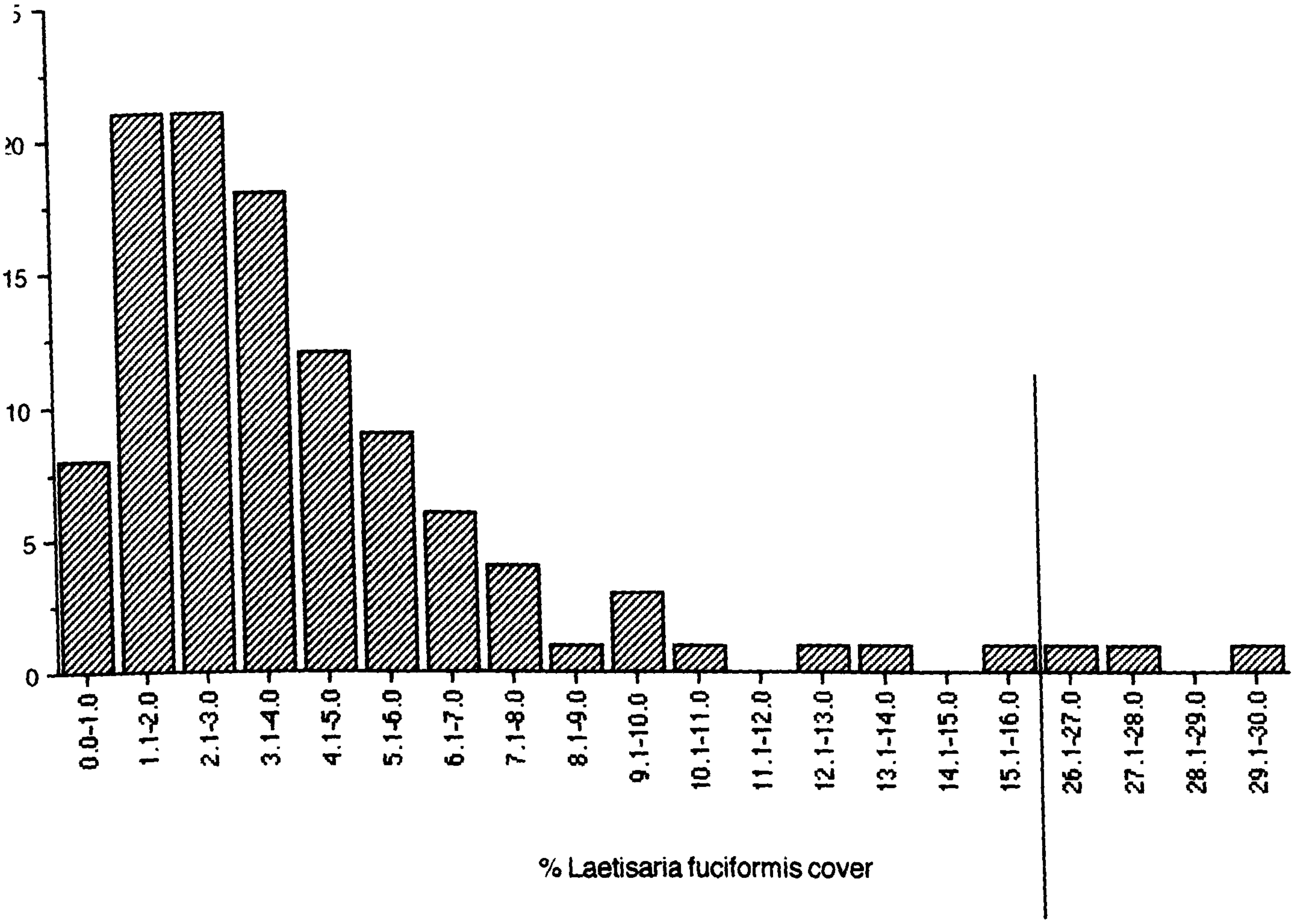


Analysis of variance was used to determine any significant differences between treatments ($p = 0.05$). Pearsons test was also used to determine correlation between cultivar disease and wear tolerance.

Results

The trial was examined regularly for active patches of *L. fuciformis* from July, 1993. The first active patches were noted in October and the percent cover on each plot was assessed. There were small differences in overall susceptibility to *L. fuciformis*. The majority of cultivars (78 out of 110) exhibited less than 5 % disease cover, whilst only seven cultivars had greater than 10 % disease cover. This is illustrated Figure 11.

Fig. 11. Disease cover (%) on Lolium perenne cultivars, October, 1994



Despite the small differences overall, there were significant cultivar and nitrogen rate effects on red thread incidence:

Cultivar: $F_{109} = 8.70$, $p = < 0.001$, LSD = 7.920
Nitrogen rate: $F_2 = 30.89$, $p = 0.031$, LSD = 7.900
Cultivar * N. rate : $F_{218} = 1.25$, $p = 0.035$, LSD = 4.572

The correlation between *L. fuciformis* incidence on the 110 cultivars in October and the subsequent wear tolerance from November, 1994 to March, 1995 was low. However, Table 66 illustrates that out of the ten most disease tolerant cultivars, a number also appeared to tolerate wear throughout the winter. Note that Quickstart and DelDwarf were in the top five most disease tolerant cultivars in October and in the ten most wear tolerant cultivars in the following March. Table 66 ranks the cultivars according to the ten most disease tolerant (% cover) and wear tolerant (RR reading) throughout the winter.

Table 66. Ten most disease and wear tolerant cultivars and the correlation between disease tolerance in October, 1994 and the subsequent wear tolerance throughout the winter of all 110 cultivars. Each individual cultivar that appears to be disease tolerant and wear tolerant is assigned a specific depth of shading.

Rank out of 110 cultivars	**Disease** Tolerance * 10.94	**Wear** Tolerance ◊ 11.94	**Wear** Tolerance 12.94	**Wear** Tolerance 1.95	**Wear** Tolerance 2.95	**Wear** Tolerance 3.95
1st	Brightstar 0.333	Quickstart 73.67	Brightstar 71.94	Gen90 65.17	DelDwarf 55.43	SGP132 6.83
2nd	Quickstart 0.333	Brightstar 73.46	Gen90 71.89	Prizem 64.97	Gen90 54.72	VV1183 45.50
3rd	LR6321 0.667	Gen 90 72.25	Quickstart 71.28	DelDwarf 64.74	Prizem 54.62	BarER176A 45.33
4th	Barrage 0.833	LR6315 72.17	SR4200 70.67	BA11773 63.87	VV1183 54.50	Pro2385 45.11
5th	DelDwarf 0.833	Amadeus 72.17	Prizem 70.67	Brightstar 63.47	Advent 54.45	DelDwarf 44.72
6th	Gen 90 0.833	Decapo 72.00	LR6315 70.44	SGP132 63.00	BarER176A 54.23	Master 44.56
7th	Prester 1.00	Numan 71.79	Amadeus 70.39	Quickstart 62.80	BA11773 54.12	Quickstart 44.39
8th	Hermes 1.00	Advent 71.67	DelDwarf 70.22	SR4200 62.63	Barrage 54.02	LLpG211 44.22
9th	Troubadour 1.67	SR4200 71.62	Advent 69.89	Advent 62.57	Pro2385 53.98	ZLp8872 44.22
10th	Pavo 1.67	Fancy 71.54	BA11773 69.83	ZLp8872 62.20	SGP132 53.98	MomLp3035 44.11
Correlation Pearsons, r	1.00	0.341	0.363	0.358	0.347	0.242

* Disease tolerance: % *Laetisaria fuciformis* cover

◊ Wear tolerance: Reflectance ratios

The effect of nitrogen on the incidence and severity of red thread is well documented (Baldwin, 1990). As nitrogen application rate increases the severity of red thread is reduced. Nitrogen rate exhibited a significant effect on red thread incidence as noted above. Table 67 confirms this effect of nitrogen rate on the overall level of red thread incidence on the ten most disease-tolerant cultivars.

Table 67. The effect of nitrogen level on red thread incidence on the ten most disease tolerant cultivars.

Nitrogen level	**Mean % cover *L. fuciformis* (SD)**
Low (75 kg ha^{-1})	1.450 (0.369)
Medium (150 kg ha^{-1})	0.700 (0.789)
High (225 kg ha^{-1})	0.300 (0.483)

As the total nitrogen applied to the plots increases, the incidence and severity of *L. fuciformis* was reduced.

Individual cultivars may perform differently under varying nitrogen regimes. Table 68 examines in more detail which specific perennial rye grass cultivars were more appropriate in terms of disease and wear tolerance under three nitrogen levels.

Table 68. Ten most *L. fuciformis*-tolerant cultivars under low, medium and high nitrogen levels [values in brackets are RR readings] based on the initial red thread assessments in October, 1994.

Disease tolerance rank	Low N. (75 kg ha^{-1})	Medium N. (150 kg ha^{-1})	High N. (225 kg ha^{-1})
1st	MomLp 3035 [41.33]	SGP132 [51.0]	Master [47.00]
2nd	Lisabelle [34.83]	DelDwarf [48.00]	Quickstart [45.17]
3rd	SR4200 [37.67]	Gen90 [47.67]	LLpG211 [44.33]
4th	Quickstart [41.50]	Quickstart [46.50]	RGAGP32 [43.67]
5th	Gator [40.83]	BarER176A [46.5]	Hermes [43.17]
6th	LR6321 [39.17]	Barlow [45.83]	Renoir [42.83]
7th	Brightstar [38.83]	Barlinda [45.83]	SR4200 [42.50]
8th	DP87428 [36.50]	TS2FF92 [45.50]	Essence [41.00]
9th	DP87437 [35.83]	Brightstar [44.33]	WWE232 [40.83]
10th	Gen90 [40.67]	Navajo [44.33]	SR4300 [40.83]

Under low N., the first two cultivars, MomLp3035 and Lisabelle exhibited no *L. fuciformis* symptoms. Under medium N. levels 21 out of 110 cultivars were free from *L. fuciformis*; the ten with the greatest ground cover in March were selected for the table, similarly 31 cultivars under high N. levels were free from disease and again the ten cultivars exhibiting the greatest wear tolerance throughout the winter were selected.

Throughout the winter there was a significant cultivar effect in relation to wear tolerance but the nitrogen level appeared to be insignificant at $p = 0.05$, note the cultivar effect is also significant at 99.9%:

November 1994.
Cultivar: $F_{109} = 5.66$, $p = < 0.001$, LSD = 4.103
Nitrogen rate: $F_{2} = 7.54$, $p = 0.117$, ns, LSD = 5.529
Cultivar * N. rate : $F_{218} = 1.09$, $p = 0.234$, ns, LSD = 2.369

December, 1994.
Cultivar: $F_{109} = 9.00$, $p = < 0.001$, LSD = 3.692
Nitrogen rate: $F_{2} = 14.37$, $p = 0.065$, ns, LSD = 4.276
Cultivar * N. rate : $F_{218} = 1.08$, $p = 0.274$, ns, LSD = 2.131

January, 1995.
Cultivar: $F_{109} = 12.01$, $p = < 0.001$, LSD = 4.903
Nitrogen rate: $F_{2} = 9.66$, $p = 0.094$, ns, LSD = 5.658
Cultivar * N. rate : $F_{218} = 1.34$, $p = 0.009$, LSD = 2.831

February, 1995.
Cultivar: $F_{109} = 8.63$, $p = < 0.001$, LSD = 5.459
Nitrogen rate: $F_{2} = 8.98$, $p = 0.100$, ns, LSD = 6.087
Cultivar * N. rate : $F_{218} = 1.34$, $p = 0.009$, LSD = 3.152

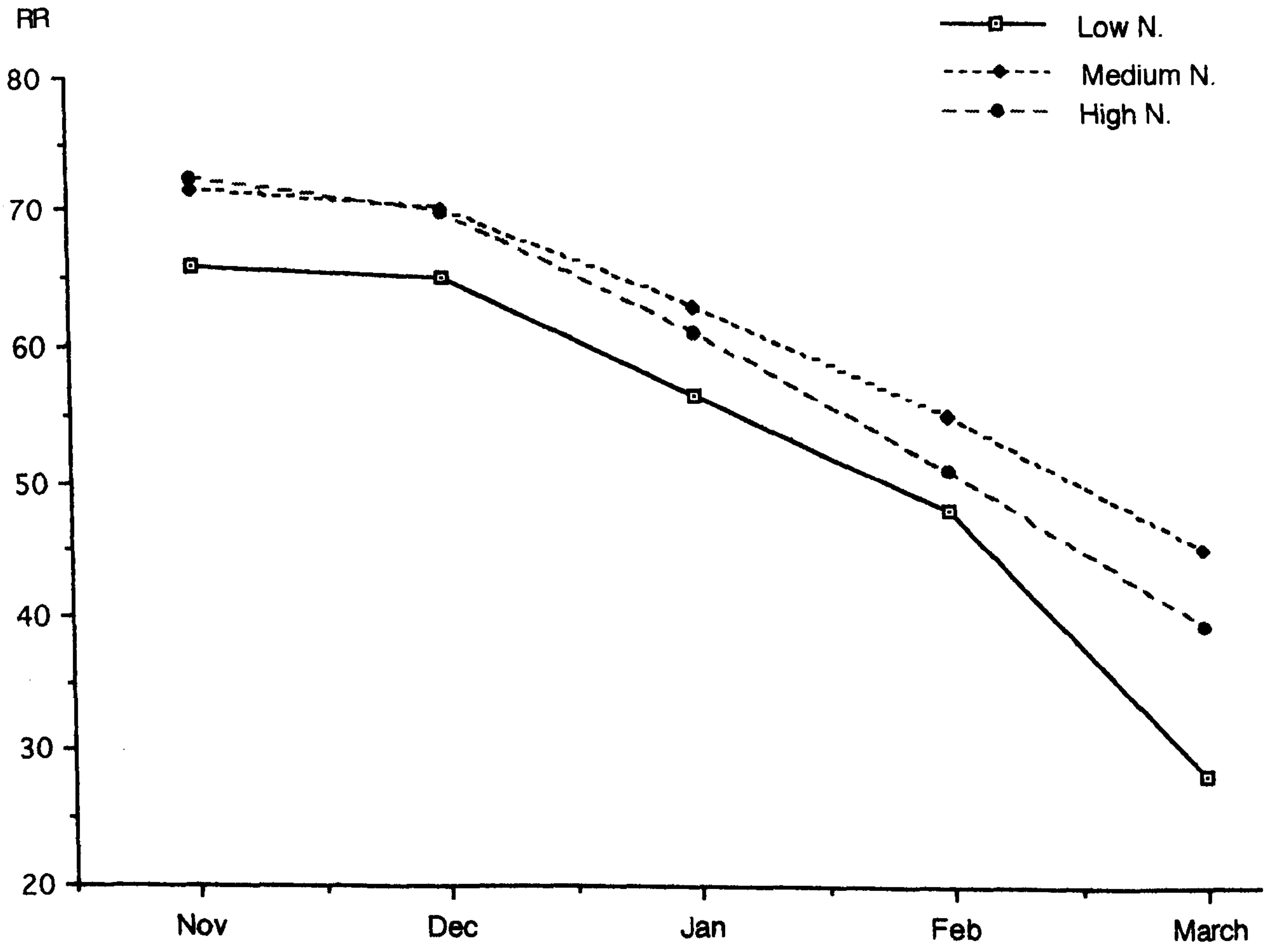
March, 1995.
Cultivar: $F_{109} = 4.59$, $p = < 0.001$, LSD = 7.611
Nitrogen rate: $F_{2} = 4.45$, $p = 0.183$, LSD = 8.476
Cultivar * N. rate : $F_{218} = 1.08$, $p = 0.273$, ns, LSD = 4.394

As the winter progresses, ground cover gradually decreased (Table 69 and Figure 12). Despite no significant differences between fertility levels, the ten most disease tolerant *L. perenne* cultivars appeared to be more resistant to wear treatment under a medium level of nitrogen, Table 69.

Table 69. The effect of nitrogen level on wear tolerance. Mean (SD) reflectance ratio from November, 1994 to March, 1995 of the ten most disease-tolerant cultivars.

Nitrogen level	**Nov. 1994**	**Dec. 1994**	**Jan. 1995**	**Feb. 1995**	**March 1995**
Low **(75 kg ha^{-1}N.)**	65.949 (3.409)	64.952 (3.624)	56.490 (4.876)	48.005 (4.123)	38.284 (4.101)
Medium **(150 kg ha^{-1}N.)**	71.673 (2.439)	70.083 (2.715)	62.910 (3.963)	55.010 (3.109)	45.067 (2.531)
High **(225 kg ha^{-1}N.)**	72.492 (2.371)	69.953 (3.349)	60.950 (5.090)	51.010 (5.228)	39.367 (4.722)

Fig. 12. The effect of N. level on wear tolerance in rye grass cultivars



Discussion

The results obtained underpin the importance of selecting the appropriate cultivar for a particular site, use and management regime. There appear to be significant differences in cultivar resistance to both wear and disease thus providing the turfgrass manager with a number of possible cultivar choices. For example, if a site requires moderate to low maintenance and the level of nitrogen supplied is low, the turfgrass sward may be particularly susceptible to red thread (*L. fuciformis*) and rust (*Puccinia* spp.) diseases. The outbreak of such diseases will reduce the playing quality of the pitch and reduce the aesthetic quality of the sward. In this case selection of a disease tolerant cultivar may be more appropriate. However, it is important to note the most disease resistant cultivar is not practical if it does not have good agronomic qualities. In addition to cultural adaptation, the cultivar selected should also be environmentally suitable to ensure a more healthy, vigorous turfgrass sward.

The choice of cultivar should be altered frequently to prevent pathogen adaptation and new or previously unimportant diseases becoming significant. Before the perennial rye grass cultivar 'Manhattan' was introduced in the USA, red thread was not considered an important problem. The cultivar is no longer recommended because of susceptibility to this disease. The smooth stalked meadow grass (*Poa pratensis*) cultivar 'Merion' was also widely grown in the US because of its excellent resistance to melting out (*Drechslera poae*). However, after a number of years, stripe smut (*Ustilago striiformis*) was promoted from a minor to a major disease and necrotic ring spot (*Leptosphaeria korrae*) and summer patch (*Magnaporthe poae*) which were previously unheard of, also became major diseases (Vargas, 1994). These examples illustrate the importance of the use of present day knowledge in any cultivar evaluations.

The major component of winter sports turf is *Lolium perenne*. In previous years the major emphasis has been on improving mowing quality and little attention has been given to disease resistance. A high level of improved 'mowability' exists, perhaps attention can now be turned toward developing cultivars with improved disease resistance. However, perennial rye grass does have one advantage over most grasses in that many contain endophytes. These mutually symbiotic fungi living within the plant provide protection from foliar feeding insects by toxin production. Antifungal compounds are also produced by some endophytic species. Siegal *et al* (1989) also noted that endophyte-infected perennial rye grass exhibited improved growth, increased dry matter, total leaf area, tiller production and the number and growth of roots. Seed set, germination and seedling growth was also improved. The use of cultivars with such physiological and morphological advantages may render the turfgrass sward less susceptible to disease attack.

Overall the results obtained are encouraging. Despite a low to moderate correlation between disease and wear tolerance of the one hundred and ten cultivars tested, it would appear the a number of superior cultivars in terms of disease tolerance also appear more resilient to wear. Selection of such cultivars may assist in the alleviation of a major disease, red thread, and help reduce wear on winter sports turf.

The use of several superior cultivars in an appropriate blend as opposed to growing only one cultivar, will further increase the diversity and stability of the turfgrass sward. The benefits of cultivar mixtures are discussed in the following section (3.3).

3.3 Effects of Mixtures of Cultivars of Perennial Rye Grass on Red Thread Incidence on Two Different Soil Types.

Introduction

Good sward establishment is the first and major critical step in a successful turfgrass management plan. If the site is prepared and planted correctly, the result will be a permanent stand of grass that exhibits satisfactory quality. Although greatest uniformity in the turf can be achieved by planting one cultivar, there are serious drawbacks to monostands in terms of environmental stress and disease tolerance. If a polystand is established, the permanence of the turf is guaranteed as it is unlikely that all the species or cultivars used will succumb to the same environmental stress or disease.

A number of factors influence the choice of grass mix. *Lolium perenne* is the major component of winter sports turf. *L. perenne* has been cultivated in the U.K. for over three hundred years, mainly for agricultural purposes. By the mid 1970s cultivars began being selected for amenity uses; the number of amenity cultivars has increased from three in 1977 to in excess of fifty today provided by twelve turfgrass breeding companies in the UK (Newell, 1994). *L. perenne* has the most rapid germination rate and the highest resistance to wear of all the cool-season turfgrasses as a result of coarse leaf structure and moderate shoot density which makes it an ideal species for use on winter sports pitches. As well as morphological characteristics, the choice of blend is also dependant on the use of the turf e.g. intensive use where texture, eveness and speed are important as well as ease of cut and a good appearance. It is recommended that if only one species is used, at least three cultivars should be grown (Emmons, 1984).

Cultivar mixtures restore some of the adaptability which can be obtained from diversity in species and gives insurance against weakness in seasonal colour, disease tolerance and sward texture (Shildrick, 1980). The use of mixtures combined with the optimum seed rate can also offer successful competition with broad-leaved weed species.

The efficacy of cultivar polystands to reduce disease is maximised if there is a difference in host susceptibility; the reaction in the mixture will tend towards that of the least affected component present (Wolfe *et al*, 1981). The choice of cultivars used in the blend should be altered at times. When resistant cultivars are grown on a large scale, they commonly become susceptible to specifically adapted genotypes of the pathogen e.g. smooth stalked meadow grass, *Poa pratensis*, cv. Merion was a popular cultivar choice for many years but today is susceptible to several diseases (Vargas, 1994). Pathogen adaptation can be delayed or prevented by maximising host resistance by mixing host genotypes in blends; a susceptible cultivar surrounded by resistant plants will tend to have less disease than if it were grown alone (Wolfe *et al*, 1981).

The aim of the trial was to determine the effect of the number of *L. perenne* cultivars present in the sward on *L. fuciformis* incidence and to assess any differences in disease incidence on two different soil types, sandy and silty loam.

Materials and Methods

FIELD TRIAL

Four cultivars of *L. perenne* were evaluated: Cartel (C), Entrar (E), Juwel (J) and Prester (P). They were sown in mono, dual and triple swards in four randomised blocks at a rate of 35 g/m^2 in 1 x 2 m plots on July 24th 1992. The four cultivars chosen have different resistance levels to *L. fuciformis* (Anon, 1991). The resistance of the cultivars was:- P > C > E > J. The trial received 12:6:6 N:P_2O_5:K_2O @ 35 g/m^2 in the spring and autumn, was mown at 25 mm and the clippings were removed. Irrigation was applied when necessary.

Plate 6. *Lolium perenne* cultivars in mono- bi- and triple stands, Sports Turf Research Institute, June, 1993.

The trial on sandy loam was at the Sports Turf Research Institute (STRI), Bingley. The trial was assessed for active patches of *L. fuciformis* which occurred in May - July 1993. In the second season assessments were performed every month from June, 1994 until October, 1994. Assessments were carried out using a 0.75 m^2 area quadrat (Section 3.1, Plate 2) to determine the % area affected by disease; two readings per plot were taken and a mean value determined. The trial on silty loam was at Johnson Seeds, Boston, Lincolnshire (NGR TF33457548). The trial was assessed for active patches of *L. fuciformis* every month from January to March in 1994 in the first season and September to November, 1994 in the second season using the method described above. Both trials were sown simultaneously and received identical management regimes.

Analysis of variance was used to determine any significant differences between treatments ($p = 0.05$).

SOIL ANALYSIS

Soil samples from both sites were analysed by the STRI chemistry laboratory. Nutrient content (total N., P_2O_5 and K_2O) and pH were determined. For full method details see Appendix IV.

Results.

DISEASE ASSESSMENTS

The results obtained from the first *L. fuciformis* assessments on a sandy loam (Bingley) are listed Table 70 and illustrated in Figures 13-15.

Table 70. *L. fuciformis* cover (%) on mono, dual and triple swards of *L. perenne* cultivars on a sandy loam.

CVS*	**May, 93**		**June, 93**		**July, 93**	
	% DCΔ	**SD‡**	**% DC**	**SD**	**% DC**	**SD**
P, Prester	0.50	0.41	5.75	5.95	6.63	1.65
C, Cartel	6.38	2.72	7.88	2.14	8.37	3.04
E, Entrar	7.88	2.46	9.25	4.29	9.87	2.59
J, Juwel	2.13	1.60	6.38	4.39	6.38	1.80
PC	2.13	1.55	6.25	1.50	9.37	3.42
PE	4.50	2.38	7.00	2.97	8.00	2.20
PJ	2.25	1.32	2.88	1.88	3.63	3.09
CE	3.87	2.50	5.12	3.57	7.88	3.25
CJ	6.63	6.91	7.88	3.71	7.88	2.75
EJ	2.75	1.32	9.37	3.66	9.25	2.53
PCE	5.75	6.20	4.25	2.63	4.38	2.66
CEJ	2.88	1.93	5.00	1.83	6.63	3.75
EJP	1.38	1.03	4.13	2.02	6.00	0.82
JPC	3.50	3.03	4.62	2.87	4.63	1.80

* **CVS** = cultivars sown. Δ **% DC** = mean % disease cover of 4 replicates. ‡ **SD** = Standard deviation.

Figure 13. The Response of Cultivars on a Sandy Loam, May, 1993

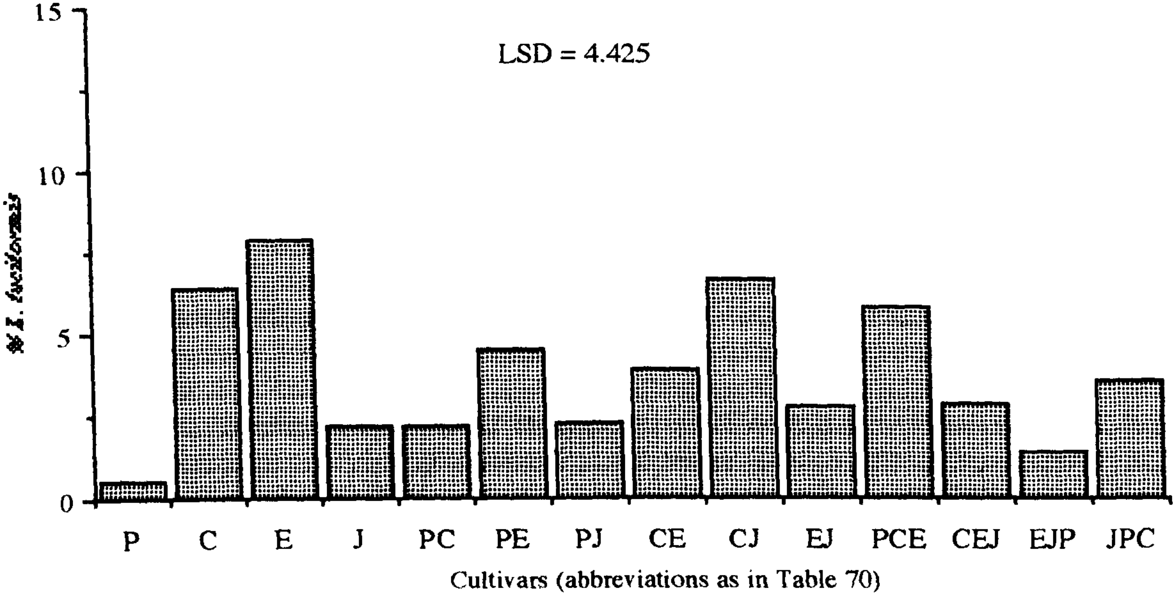


Figure 14. June, 1993

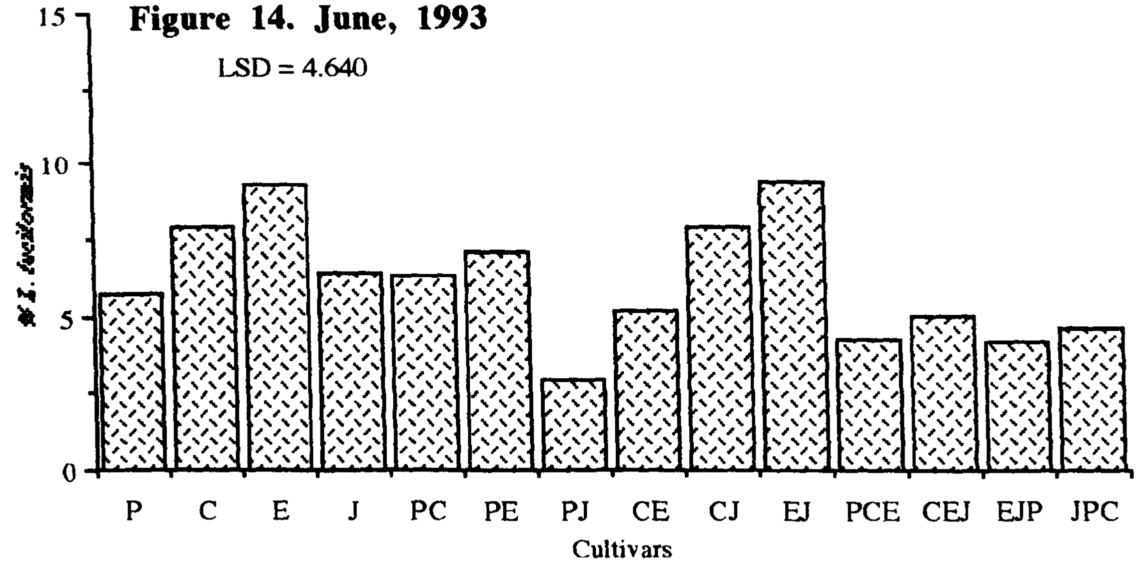
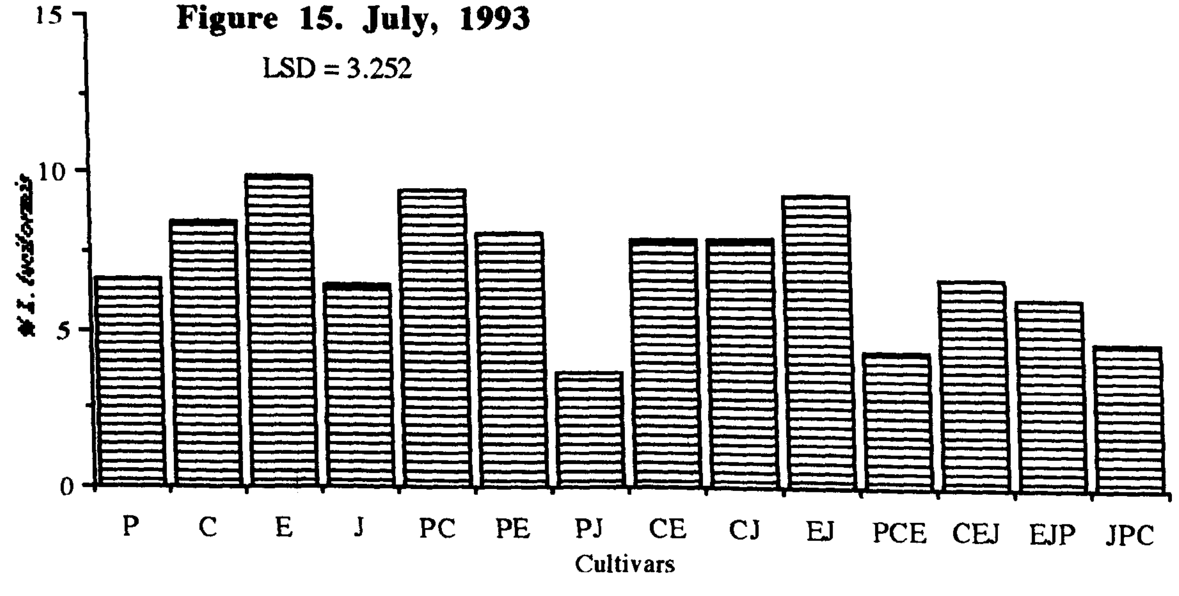


Figure 15. July, 1993



The data were analysed for normality and found to follow a normal distribution. Analysis of variance tests were used to identify any significant differences ($p = 0.05$). The following results were obtained,

Table 71. Statistical analysis of % disease cover on mono, dual and triple swards on a sandy loam.

Assessment Date	Analysis
May, 1993	Treatment: $F_{13} = 2.00$, $p = 0.047$ Block: $F_3 = 1.01$, $p = 0.397$, ns
June, 1993	Treatment: $F_{13} = 1.46$, $p = 0.175$, ns Block: $F_3 = 1.71$, $p = 0.182$, ns
July, 1993	Treatment: $F_{13} = 2.19$, $p = 0.005$ Block: $F_3 = 5.88$, $p = 0.002$

Increasing the number of cultivars on a sandy loam appeared to significantly (95% confidence level) reduce the incidence of *L. fuciformis*. Although the general level of disease increased over time, the trend of reduced disease on bi- and triple varietal swards compared to monoculture was consistent (Figures 13-15). A significant block effect was noted in July, 1993.

Prester and Juwel consistently exhibited the lowest disease incidence in monoculture. Entrar showed the poorest response over the first assessment period.

The results obtained from the second *L. fuciformis* assessments on a sandy loam (Bingley) are listed in Table 72 and illustrated in Figures 16-20

Table 72. *L. fuciformis* cover (%) on mono, dual and triple swards of *L. perenne* cultivars on a sandy loam.

CVS	June, 94		July, 94		Aug., 94		Sept., 94		Oct., 94	
	% DC	SD	% DC	SD	% DC	SD	% DC	SD	% DC	SD
P	6.87	6.12	8.37	7.49	8.12	3.50	7.37	3.15	6.63	2.48
C	13.88	6.49	18.88	10.65	14.00	4.32	12.75	9.60	12.37	1.23
E	10.75	2.72	17.13	9.04	14.88	1.78	12.25	6.24	13.62	1.14
J	12.00	6.75	18.13	7.92	8.00	3.94	9.13	6.17	6.87	1.55
PC	8.75	3.23	11.63	5.92	13.12	3.61	8.87	3.33	9.00	1.88
PE	12.75	1.85	14.75	1.94	13.12	5.39	12.50	9.42	11.12	2.15
PJ	9.5	5.08	14.00	6.42	8.12	3.59	8.75	4.97	9.37	3.10
CE	12.37	5.23	14.50	6.39	13.62	6.05	12.50	6.22	14.13	4.78
CJ	7.25	2.33	14.25	3.86	11.63	4.11	7.62	3.94	6.87	1.91
EJ	10.38	3.92	15.88	5.72	12.37	4.44	9.62	3.09	7.62	1.16
PCE	10.75	4.37	12.62	4.53	15.75	4.25	10.38	4.64	13.00	0.35
CEJ	11.38	3.42	13.88	3.82	10.25	4.17	7.25	3.71	8.50	2.52
EJP	11.50	2.92	14.87	3.12	11.38	3.01	10.25	2.72	10.12	1.30
JPC	10.88	2.59	16.75	4.92	11.25	2.25	6.25	1.85	7.50	0.82

Figure 16. The response of cultivars on a sandy loam. June, 1994

LSD = 6.226

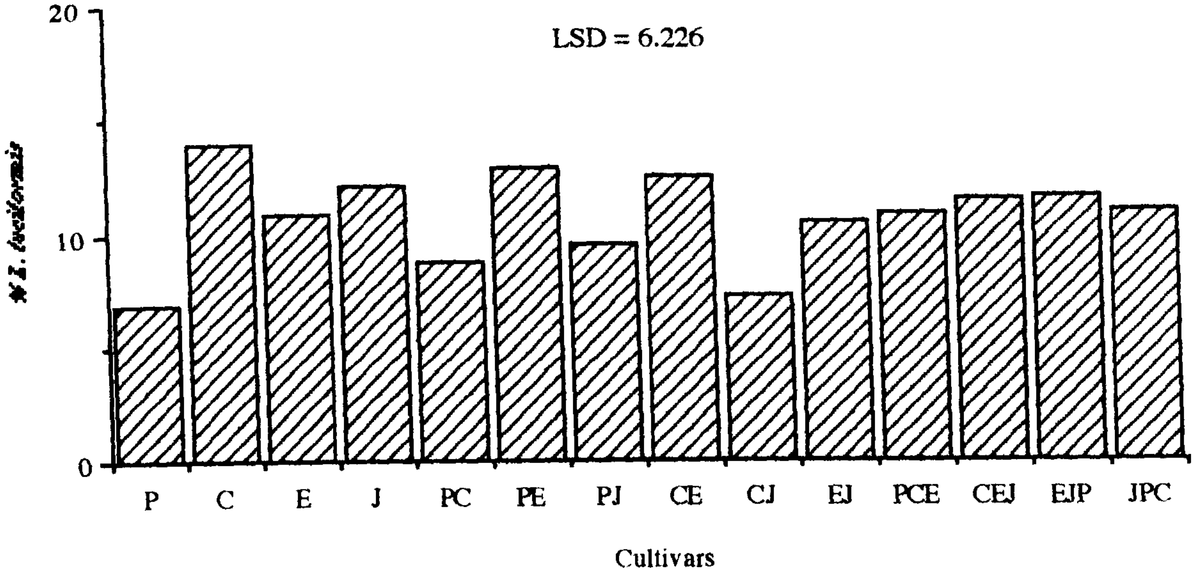


Figure 17. July, 1994

LSD = 7.485

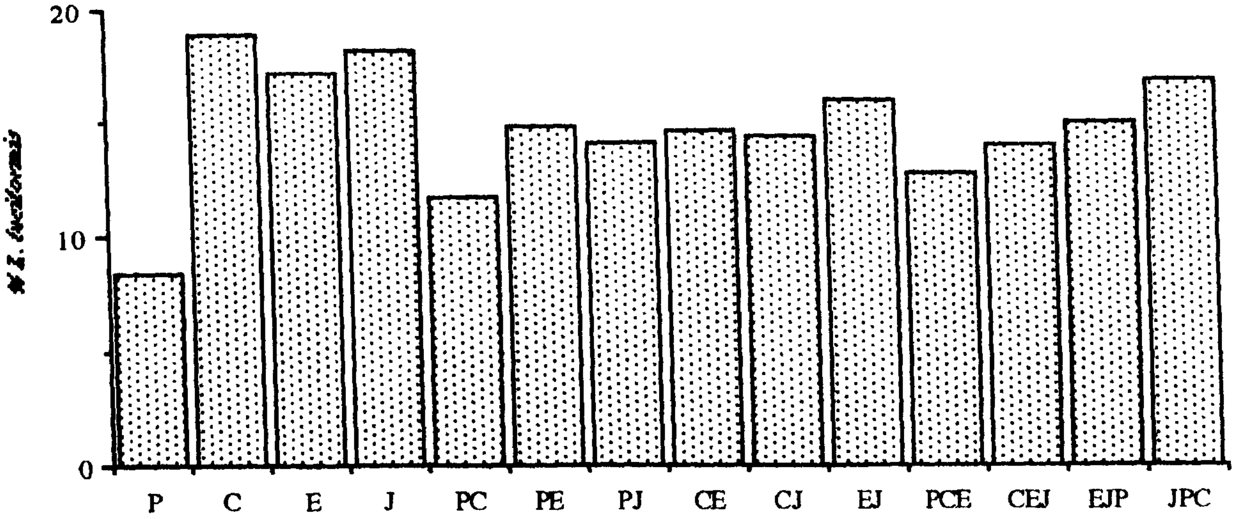


Figure 18. August, 1994

LSD = 4.362

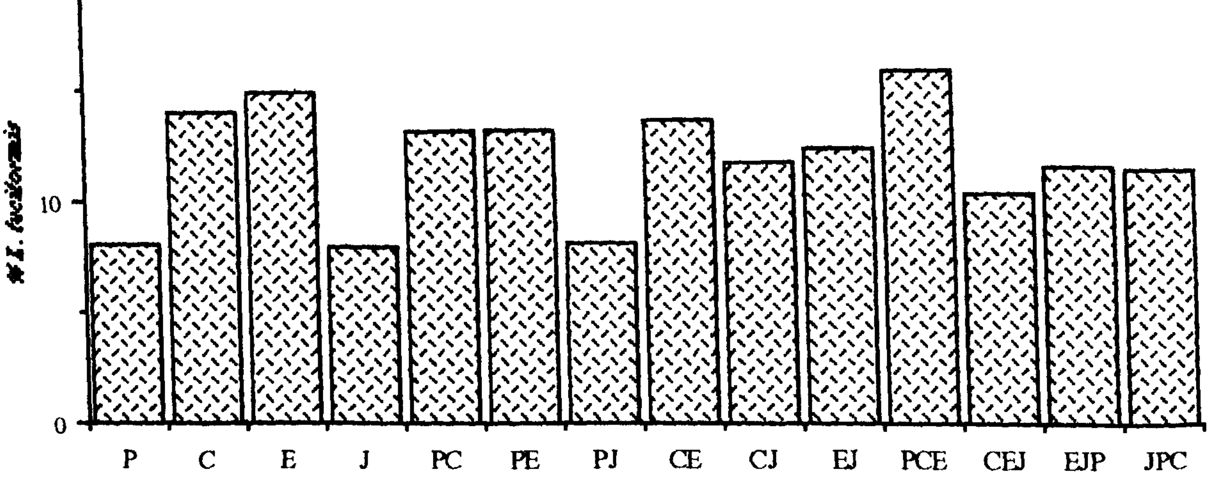


Figure 19. September, 1994

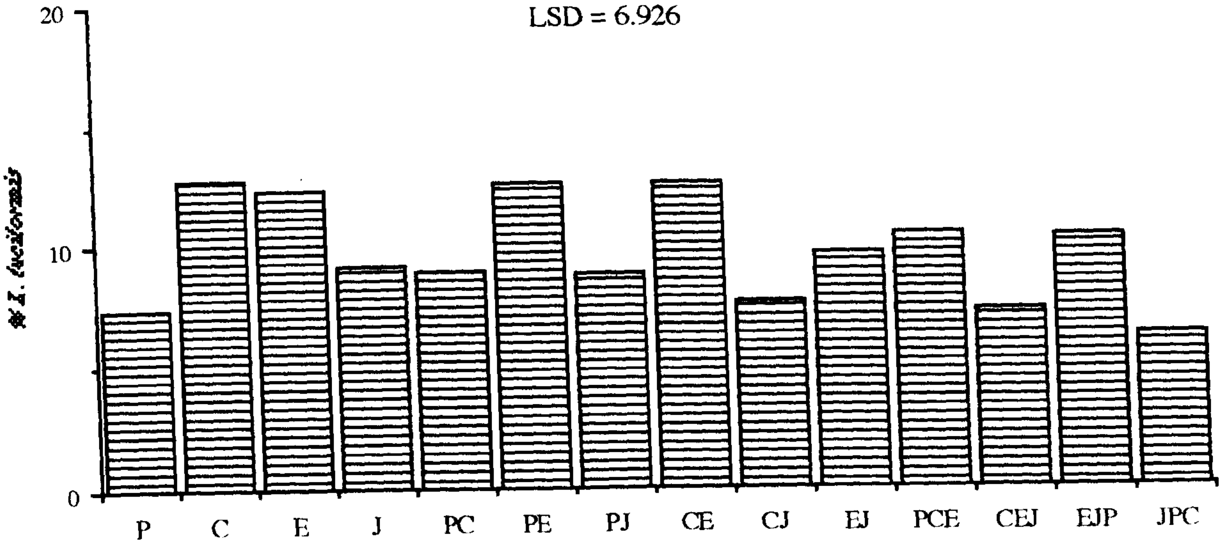
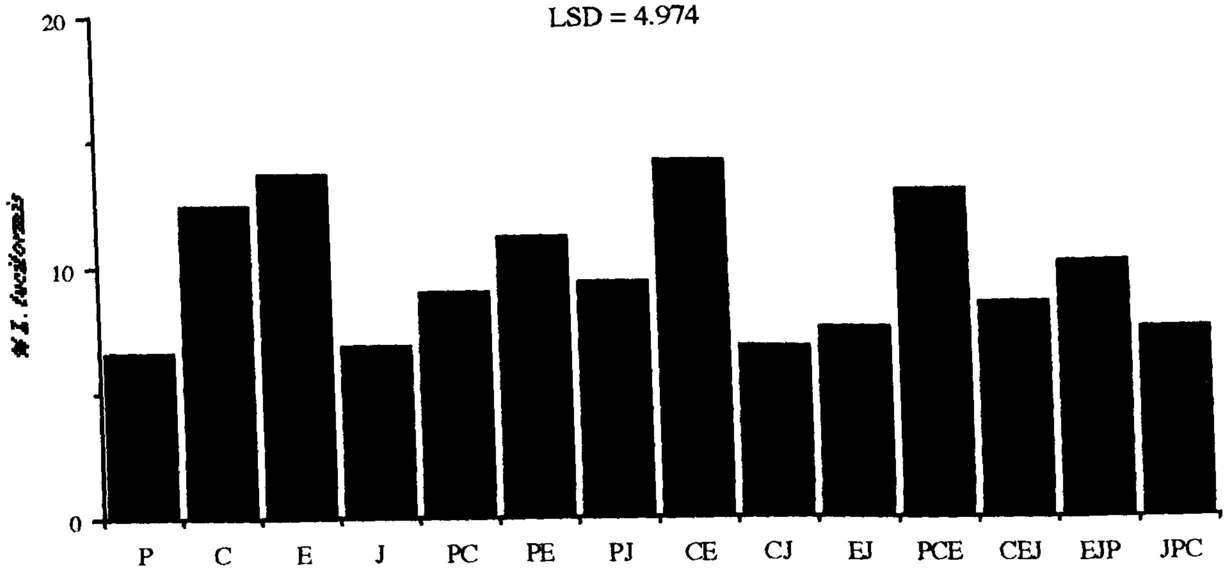

LSD = 6.926

Figure 20. October, 1994


LSD = 4.974

The data were analysed for normality and found to follow a normal distribution. Analysis of variance tests were used to identify any significant differences ($p = 0.05$). The following results were obtained,

Table 73. Statistical analysis of % disease cover on mono, dual and triple swards on a sandy loam (2nd assessments).

Assessment Date	Analysis
June, 1994	Treatment: $F_{13} = 0.84$, $p = 0.620$, ns Block: $F_3 = 1.06$, $p = 0.378$, ns
July, 1994	Treatment: $F_{13} = 1.08$, $p = 0.406$, ns Block: $F_3 = 7.15$, $p = 0.001$
August, 1994	Treatment: $F_{13} = 2.69$, $p = 0.008$ Block: $F_3 = 11.47$, $p = 0.0001$
September, 1994	Treatment: $F_{13} = 0.81$, $p = 0.646$, ns Block: $F_3 = 4.65$, $p = 0.007$
October, 1994	Treatment: $F_{13} = 2.34$, $p = 0.021$ Block: $F_3 = 8.77$, $p = 0.0001$

In the second season *L. fuciformis* appeared slightly later in the year. Following the initial outbreak in June, disease levels rapidly increased in July and then decreased throughout the remaining summer and autumn months (Figures 16-20); significant differences were noted in treatments on the sandy loam in August and October and a significant block effect was noted from July to October.

Table 74 and Figures 21-23 show the results obtained from the first disease assessments carried out on a silty loam.

Table 74. *L. fuciformis* cover (%) on mono, dual and triple swards of *L. perenne* cultivars on a silty loam

CVS	**Jan., 94**		**Feb., 94**		**March, 94**	
	% DC	**SD**	**% DC**	**SD**	**% DC**	**SD**
P	2.75	2.78	1.87	3.12	6.87	3.64
C	4.63	1.80	5.75	2.36	10.50	2.65
E	4.62	2.39	5.37	3.09	11.50	3.19
J	3.00	1.08	7.13	1.38	7.50	6.34
PC	3.12	2.53	7.62	3.64	9.50	4.95
PE	1.25	1.04	4.75	4.70	10.25	2.87
PJ	3.13	1.03	6.50	3.03	11.12	4.09
CE	2.12	2.17	5.25	1.19	5.00	4.02
CJ	2.75	2.06	8.62	4.96	11.00	2.27
EJ	2.00	1.23	7.25	2.25	10.50	1.08
PCE	2.00	0.71	7.00	2.86	7.00	3.39
CEJ	2.63	0.85	9.00	3.24	6.63	1.18
EJP	2.88	1.03	7.13	1.97	11.75	5.85
JPC	2.50	1.08	8.62	2.78	12.25	0.65

Figure 21. Response of Cultivars on a Silty Loam, Jan, 1994

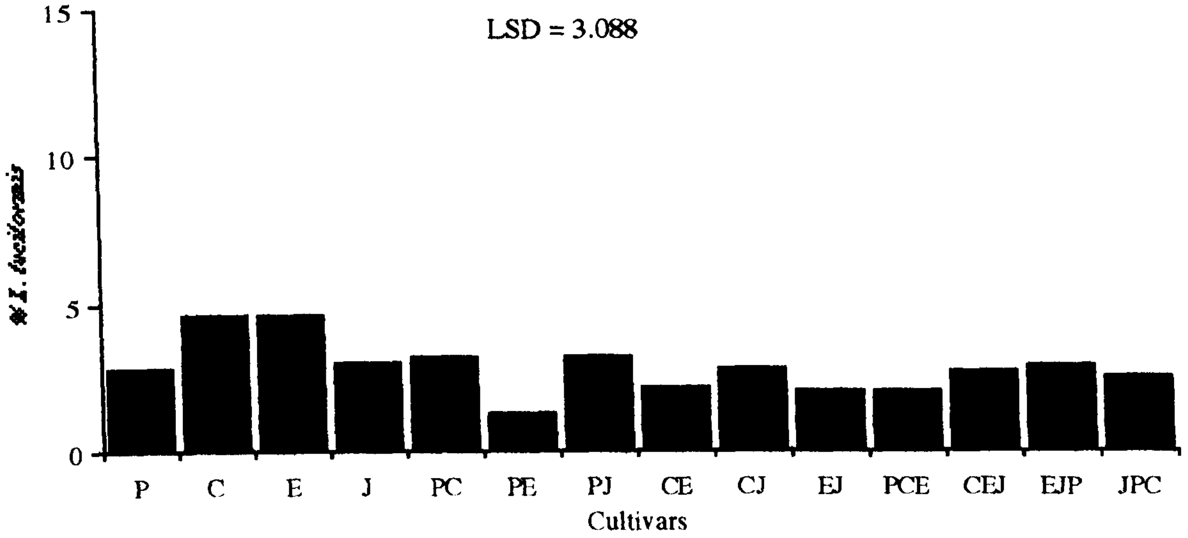


Figure 22. February, 1994

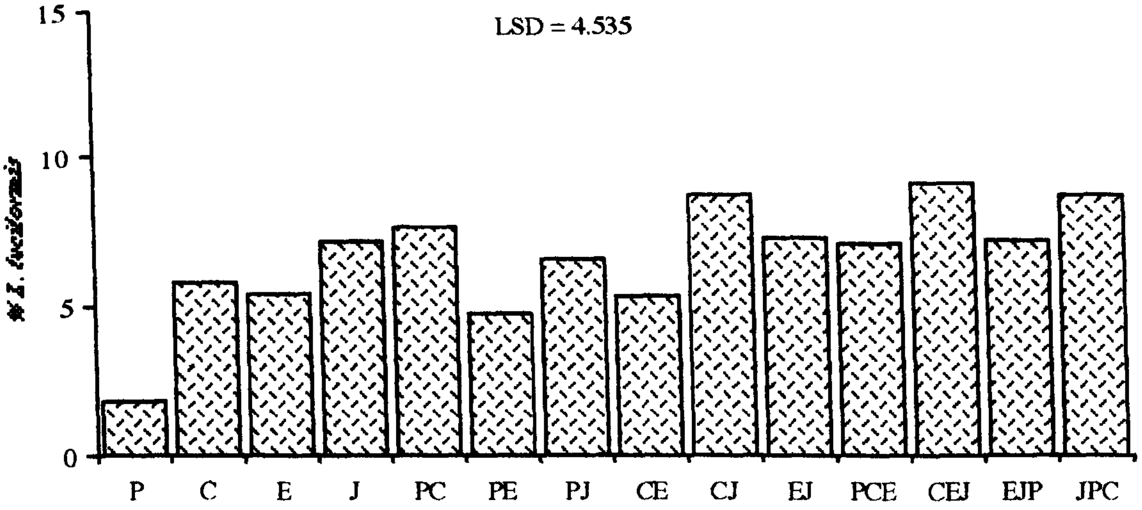
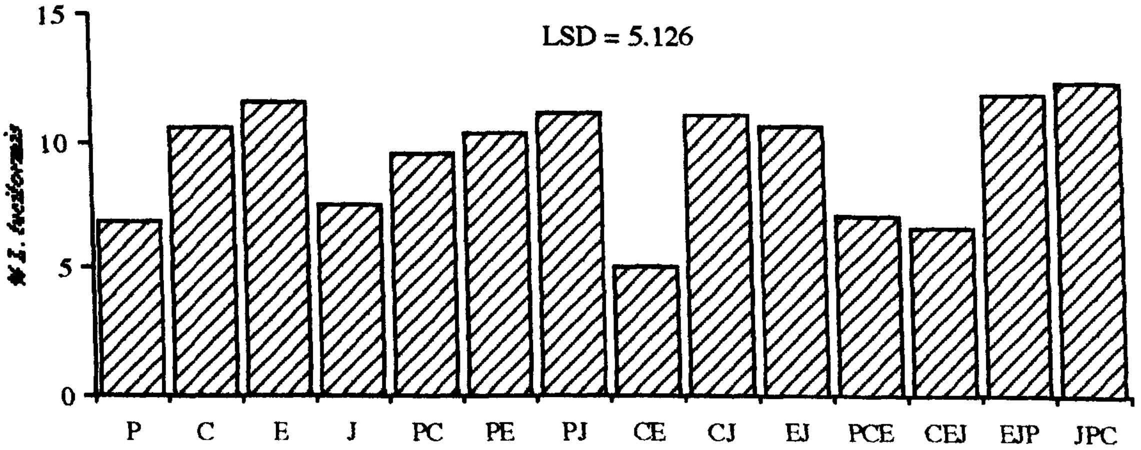


Figure 23. March, 1994



The data were analysed for significant differences ($p = 0.05$). The following results were obtained,

Table 75. Statistical analysis of % disease cover on mono, dual and triple swards on a silty loam.

Assessment Date	Analysis
January, 1994	Treatment: $F_{13} = 1.13$, $p = 0.367$, ns Block: $F_3 = 0.22$, $p = 0.882$, ns
February, 1994	Treatment: $F_{13} = 1.41$, $p = 0.200$, ns Block: $F_3 = 0.20$, $p = 0.898$, ns
March, 1994	Treatment: $F_{13} = 1.67$, $p = 0.108$, ns Block: $F_3 = 1.80$, $p = 0.163$, ns

No significant cultivar or block differences were noted for the silty loam soil type.

Disease on the silty loam appeared several months later than on the sandy loam. Figures 21-23 illustrate that disease generally increased over time. The trend noted on the sandy loam where increasing the number of cultivars in the mix reduced disease incidence was noted initially on this soil type (Figure 21) but disappeared with time (Figures 22-23) although on occasions where disease severity was reduced or remained constant two or three cultivars were present (CE, PCE, CEJ); Entrar and Cartel being present in all cases.

Entrar appeared the most susceptible cultivar in monoculture, whilst Prester is the most resistant; this trend is consistent with that noted on the sandy loam. The performance of each cultivar in monoculture on both soil types was similar, Prester and Juwel exhibited greater tolerance to *L. fuciformis* whilst Entrar and Cartel were more susceptible.

The second red thread assessments on the silty loam were carried out between September, 1994 and November, 1994. These results are illustrated in Tables 76-77 and Figures 24-26.

Table 76. *L. fuciformis* cover (%) on mono, dual and triple swards of *L. perenne* cultivars on a silty loam (September to November, 1994).

CVS	**Sept., 94**		**Oct., 94**		**Nov, 94**	
	% DC	**SD**	**% DC**	**SD**	**% DC**	**SD**
P	30.00	3.92	11.12	3.97	5.00	2.12
C	31.38	9.29	11.87	3.71	4.50	0.41
E	21.38	1.93	13.00	5.89	6.25	3.71
J	24.37	3.90	12.37	2.29	6.75	2.90
PC	27.62	9.36	10.38	2.29	7.00	5.21
PE	25.13	4.17	7.37	3.35	4.13	2.36
PJ	24.75	2.84	11.12	4.03	4.50	1.92
CE	29.37	4.78	12.37	2.95	6.63	3.50
CJ	23.75	2.22	9.00	5.03	5.25	1.85
EJ	26.75	5.62	14.00	1.41	8.12	3.97
PCE	25.38	6.97	10.50	1.08	2.75	1.32
CEJ	24.87	6.91	13.00	2.16	6.63	3.12
EJP	28.25	5.52	10.38	3.07	5.00	1.92
JPC	23.87	4.55	11.13	1.84	7.25	2.18

Figure 24. The response of cultivars on a silty loam, September, 1994

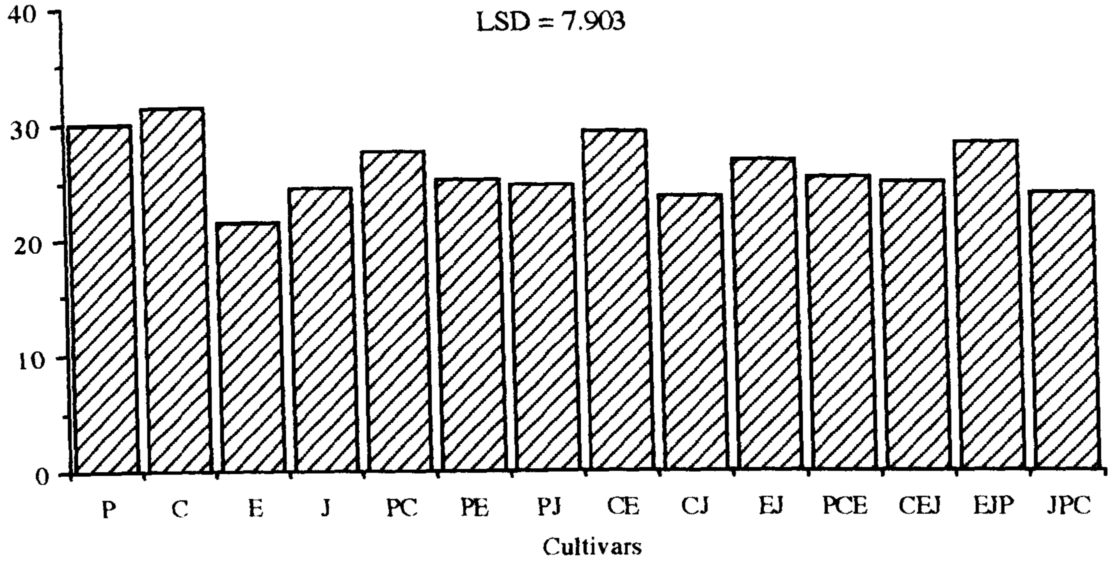


Figure 25. October, 1994

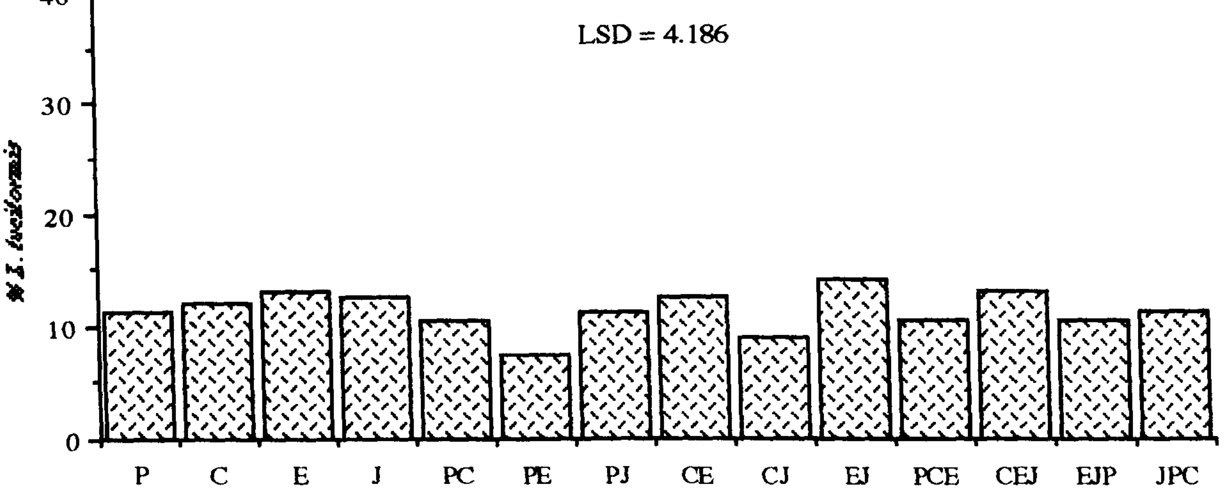
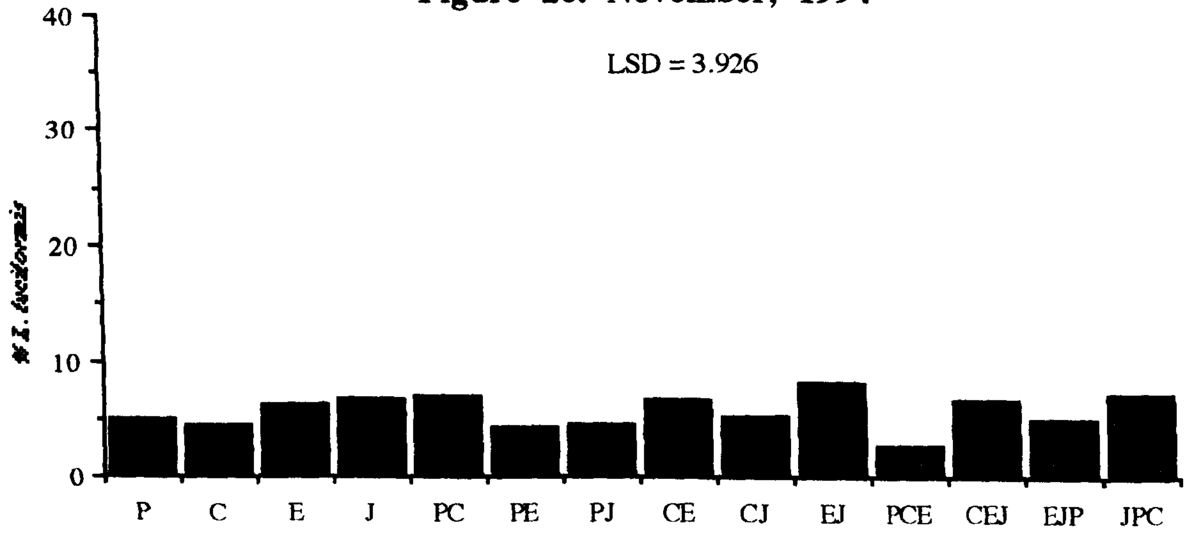


Figure 26. November, 1994



The data were analysed for significant differences, $p = 0.05$. The following results were obtained,

Table 77. Statistical analysis of % disease cover on mono, dual and triple swards on a silty loam.

Assessment Date	Analysis
September, 1994	Treatment: $F_{13} = 1.02$, $p = 0.449$, ns Block: $F_3 = 1.44$, $p = 0.247$, ns
October, 1994	Treatment: $F_{13} = 1.40$, $p = 0.205$, ns Block: $F_3 = 5.30$, $p = 0.004$
November, 1994	Treatment: $F_{13} = 1.16$, $p = 0.345$, ns Block: $F_3 = 2.20$, $p = 0.103$, ns

The results obtained from the second disease assessments on the silty loam were similar to the first - no significant differences in cultivar treatments although there was a significant block effect in October. *L. fuciformis* appeared later in the year on the silty loam (autumn / winter). The initial outbreak was very severe (approximately 30% cover) followed by a rapid decline in disease severity whereas in the first season, severity gradually increased from January to March.

Prester consistently exhibited the best response in monoculture over both seasons. When disease was very severe (Figure 24), *L. fuciformis* levels were almost consistent on all plots (approximately between 25-30% cover) but as disease levels decreased slightly, although statistically insignificant, treatment differences appeared. In Figure 26 disease decreases slightly as the number of cultivars present in the sward increase, except in blends where the cultivars sown have a similar tolerance to *L. fuciformis*, e.g. in the treatment PC disease cover is 7%, whilst PE = 4.13%. Prester and Cartel have a similar tolerance to *L. fuciformis* whilst Entrar is more susceptible. The lowest disease incidence was where three cultivars are present, PCE = 2.75% cover.

SOIL TYPE

Soil samples were obtained from Bingley (sandy loam) and Boston (silty loam) and a complete soil analysis was carried out. Table 78 illustrates the results.

Table 78. Soil analysis results from both soil types.

Soil Type	**pH**	**P_2O_5 mg/l**	**K_2O mg/l**	**Total N. %**
Sandy Loam (Bingley)	4.5 *low*	44 *medium*	41 *low*	0.145 *moderate*
Silty loam (Boston)	6.6 *satisfactory*	>165 *very high*	121 *satisfactory*	0.21 *high*

The analysis of soil samples from both sites revealed that the silty loam was higher in nutrient content. Despite the differences in nutrient availability, the effect of soil type on disease incidence is difficult to ascertain. Outbreaks of red thread occurred at different times on the two trial sites, e.g. in the first season disease was noted from May to July on the sandy loam, whilst red thread was not apparent on the silty loam until the following January when conditions were cooler and wetter (Appendix V). Therefore, any differences in disease severity may be because of differing soil nutrient availability or the differing climatic conditions at the both trial sites when disease outbreaks were prevalent.

Discussion

The results obtained from the trial on the sandy loam in the first season were encouraging; clearly by increasing the number of cultivars in the mix, *Laetisaria fuciformis* can be successfully managed. The use of such a strategy could be easily integrated into an overall disease management plan as the majority of winter sports pitches are oversown annually and pitches that are maintained more intensively e.g. Premier League competition football pitches are completely resown every year. Frequent changes of cultivars of equivalent playing quality will help to confuse the pathogen by altering the host genotype thereby delaying or preventing pathogen adaptation.

The appearance of *L. fuciformis* on the silty loam was several months after the disease was first noted on the sandy loam. The delay in symptom expression may be due to the more fertile nature of the silty soil and the neutral pH (6.6) better suited to leaf and root growth. Once established the disease levels were also slightly lower on the silty loam as expected because the disease is discouraged by high levels of soil fertility (Baldwin, 1990). However, in September, 1994, disease levels were significantly higher on the silty loam; rainfall was also significantly higher (Appendix V). Symptom expression is also increased under moist, humid conditions provided by such an increase in rainfall.

The response of the dual and triple cultivar swards on the silty loam was less marked. Initially disease appeared to be lower on mixed swards but over the following two months this trend disappeared and no significant differences in treatments were noted. This may be because *L. fuciformis* is not only encouraged by lower soil fertility as found in sandy loams but also adequate moisture and higher temperatures. Silty loams are less freely draining and therefore moisture is more readily available; the trial on the silty loam at Boston is further south and air temperatures are generally higher (Appendix V). The combination of increased moisture and warmer temperatures may predispose the trial to increased disease and the genetic diversity provided by cultivar mixtures alone may be inadequate under these conditions. In such cases if only one species is present at least three cultivars should be grown. For example, Mundt *et al* (1995) noted that a four-way mixture of winter wheat provided better control against yellow rust (*Puccinia striiformis*) and eyespot (*Pseudocercosporella herpotrichoides*) and provided greater yield stability than a two component mixture. The use of different species may be more appropriate on a site where several factors that encourage *L. fuciformis* are present as illustrated in the previous section, 3.2. It is worth noting however, that when *L.*

fuciformis is contained or reduced on the silty loam at least two cultivars were present. Disease reduction was evident on treatments CE, PCE and CEJ; in all cases the two cultivars exhibiting the lowest resistance to *L. fuciformis* in monoculture, Entrar and Cartel, were present in the mix. This underpins the general observation that cultivar mixtures are more efficient when a wide range of tolerance is present. Such a simple strategy involving the use of multi-cultivar blends could be readily employed as part of an IDM plan.

By the second year any significant cultivar effects had disappeared on both soil types. Simply mixing any cultivars will not necessarily improve the quality, longevity and disease tolerance of a turfgrass sward. A blend of two improperly selected cultivars may produce a less desirable sward than a single superior cultivar. The blend selected should be site-specific, for example level of maintenance or shaded turf i.e. develop the blend for a particular environment and cultural regime. It is also possible that over the two and half year assessment period, susceptible cultivars within the bi- and triple swards may have been eliminated so genetic diversity is reduced. Ideally, all the cultivars should be environmentally and culturally adapted to a specific area.

In addition to alteration in the blend components over time, the fungal pathogen itself can genetically adapt rapidly and may overcome turfgrass tolerance thereby adding a further dynamic dimension for the turfgrass manager to consider. Mundt *et al* (1995) noted that a virulent race of yellow rust could infect a resistant winter wheat cultivar after only two years of use. Significant commercial losses were being reported after another two years.

Despite no significant differences in treatments in the second year, it is worth noting that when the overall disease severity was lower, the bi- and triple swards exhibit a better response than monoculture (e.g. Figure 21, January, 1994, silty loam). This suggests that the use of cultivar mixtures to control disease would be more effective if combined with other cultural and chemical methods. For example the evolutionary dilemma created by cultivar mixtures can also be enhanced by using fungicide treated seed. Treating seeds of a particular cultivar and mixing them prior to sowing will result in a stand of randomly distributed single fungicides. Such treatments can be applied separately to components of a host mixture thus increasing the heterogeneity of disease control mechanisms and problems for the pathogen. A further advantage is that a particular fungicide can be applied to a different host component in different years adding a further dynamic element to the confusion of the pathogen. Economic and environmental costs are kept low because of the reduced amount of fungicide required. Disease management is improved because seed treatment reduces the initial inoculum and spread of the epidemic at a stage when the host mixture itself may have little effect. Varietal and chemical components thus help to protect each other against rapid evolution of the pathogen.

In addition to the cultivar and soil type effects previously discussed, a number of *L. fuciformis* assessments revealed a significant block effect on both soil types but particularly on the sandy loam (Bingley). This could possibly be accounted for by limitations in the experimental design. Ideally the blocks should follow a 'square design' in order to minimise any external environmental gradient e.g. sunlight / shading, soil nutrient differences or soil moisture levels. The blocks in this experiment were rectangular in nature, running from one side of the trial to the other where any external gradient could influence the results.

In conclusion, the use of cultivar mixtures to reduce disease on winter sports turf appears promising provided at least three cultivars are used all of which are environmentally and culturally adapted for a specific site. The best grasses for winter sports turf will perform badly on under-fertilised and poorly-drained pitches. The choice of cultivars grown should be altered at least every two years to prevent cultivars becoming susceptible to specifically adapted genotypes of the pathogen. The major advantage of cultivar mixtures is the provision of a genetically diverse background which can provide protection against more than one disease e.g. a four-way mixture of winter wheat reduces both yellow rust and eyespot disease levels (Mundt *et al*, 1995) as well as providing a plant community with greater environmental stress resistance and longevity. Finally, cultivar mixtures can be easily integrated into an overall disease management plan involving other beneficial cultural and chemical control measures to maintain turfgrass diseases effectively.

In addition to species and cultivar mixtures, fertiliser regime and drainage also play an important role in turfgrass disease symptom expression and the possible manipulation of these factors may help to reduce disease and maintain turf quality. The following section, 3.4, attempts to identify the optimum nitrogen rate and construction type to reduce both red thread and fusarium patch on winter sports turf.

3.4 The Effect of Six Nitrogen Levels on Disease Incidence on Five Different Constructions for Football.

Introduction

Red thread (*Laetisaria fuciformis*) and Fusarium patch (*Microdochium nivale*) are the most ubiquitous and economically important diseases on winter sports turf. Both professional football clubs and local authorities regularly apply fungicides to control *L. fuciformis* and *M. nivale* (Raikes *et al*, 1994a, b). Reliance on chemical control is costly, inconvenient and may cause the death of a number of beneficial organisms, e.g. microbial and invertebrate decomposers and natural antagonists/predators. The extensive use of chemicals also increases selection pressure on fungal pathogens, leading to fungicide resistance.

Cultural practices in conjunction with reduced chemical input may help to decrease both diseases whilst protecting the viability of valuable chemical resources. However, some major cultural practices that suppress *L. fuciformis* encourage disease expression in *M. nivale*. A 'balanced' programme combining the effects of a number of cultural practices on both diseases may provide the greatest possible benefit to turfgrass managers.

One of the most significant factors influencing the incidence of both diseases is nitrogen level. Increased nitrogen effectively suppresses *L. fuciformis* although it may render turfgrass more susceptible to *M. nivale*. An excessive increase in nitrogen application not only encourages *M. nivale*, but also increases expense, possible nitrate leaching and is a waste of energy.

The availability of nitrogen, and indeed water, is ultimately governed by pitch construction. Construction types range from undrained pitches to more elaborate (and expensive) freely draining sand profile constructions. The provision of adequate drainage is essential; poor drainage will affect the playing quality of the pitch leading to waterlogging, poor sward development and potential loss of fixtures. *L. fuciformis* and *M. nivale* are both encouraged by increased surface moisture, therefore a well drained pitch not only increases turf vigour and prolongs the longevity of the playing surface, but may also help to reduce pathogen symptom expression.

The aim of the field trial was to identify a particular nitrogen rate and pitch construction type which effectively suppresses both diseases whilst maintaining adequate draining properties and turf vigour.

Materials and Methods

The trial was constructed on the experimental ground at the Sports Turf Research Institute during 1986 (Baker and Canaway, 1990). The trial area was levelled and the five construction treatments were replicated in two blocks. The five construction treatments were:

1. **Pipe drained.** Top soil was spread over the subsoil formation to a depth of 250 mm. 60 mm perforated plastic drain pipe was introduced at a depth of 600 mm and the drain trench backfilled with gravel to 200 mm

from ground level and blinded with 50 mm of coarse sand. Topsoil was placed over the backfill to provide 150 mm firmed depth.

2. **Slit drained.** Top soil and pipe drainage installed as above. After sward establishment, 50 mm wide slit trenches were excavated at 600 mm centres. These were filled with 125 mm of 6 mm Lytag drainage aggregate topped with 100 mm coarse sand.

3. **Slit drained, sand top.** Initial construction was as the pipe drained treatment except that the top soil depth was 225 mm. This was covered with 25 mm firmed depth of medium-fine sand before sowing. Slit drains were added to the same specification of the slit drained treatment.

4. **Sand carpet.** Top soil was spread to a depth of 150 mm. The pipe drainage was installed as above except that the drain trench was only 500 mm deep. The trench was backfilled to 50 mm from the topsoil surface prior to blinding with 50 mm coarse sand. Slit drenches of 50 mm width, 200 mm depth were introduced at 1.5 m centres. These were backfilled with 100 mm of gravel and 50 mm blinding sand. A 100 mm firmed depth of medium-fine sand was then spread over the topsoil surface.

5. **Sand profile.** 150 mm of subsoil was excavated from the initial subsoil formation level to give the required depth. The pipe drain was installed at a depth of 250 mm and backfilled with gravel. A 100 mm depth of gravel was then spread over the subsoil formation surface and blinded with 50 mm coarse sand. The rootzone layer of medium-fine sand was then spread to give a 250 mm firmed depth.

Each construction treatment was 13 m by 6 m and isolated from adjacent areas by a polythene membrane. The trial area was sown with perennial rye grass, ***Lolium perenne***, 'Elka' at 22 g m^2. Annual cycles of wear and renovation were carried out until June, 1993 when the present trial was set out.

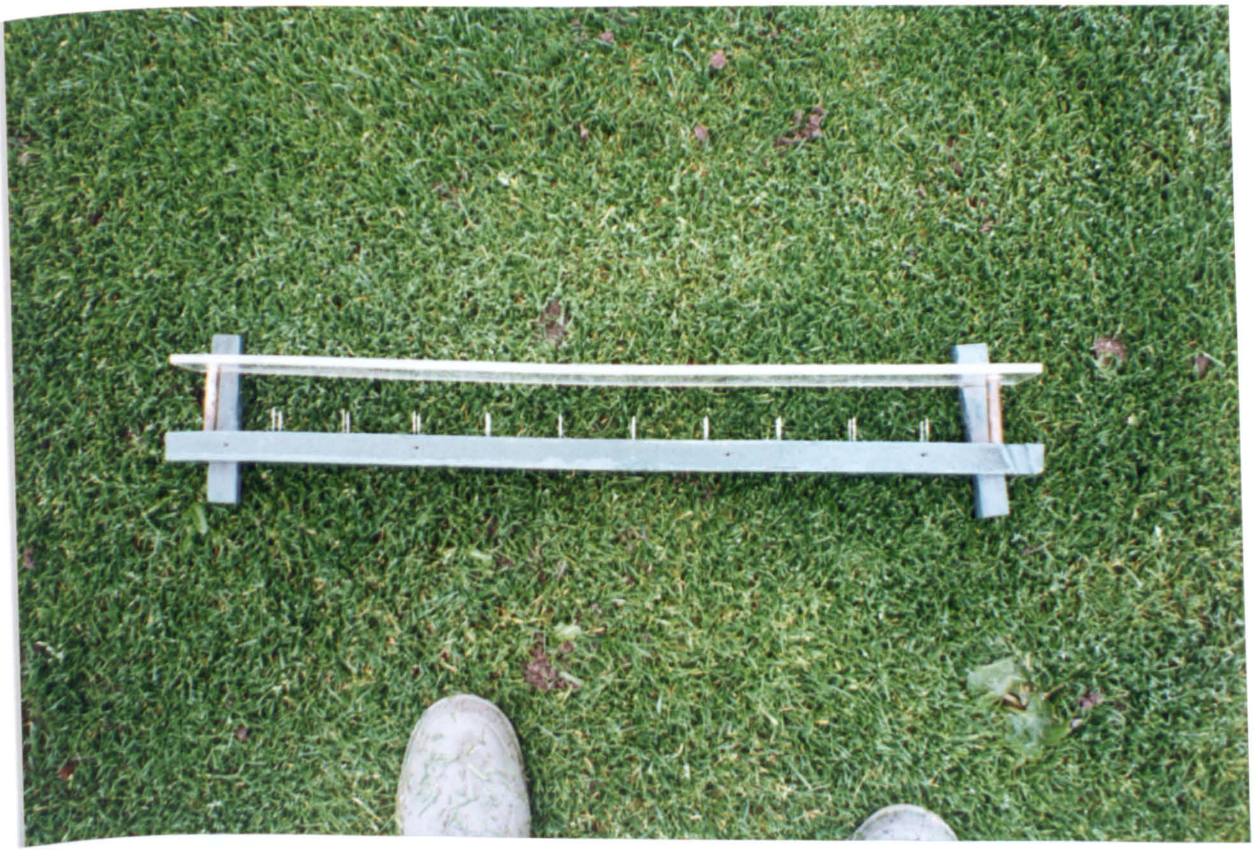
Six rates of nitrogen were applied as sub-plots on the main construction treatments. The nitrogen treatments (ammonium nitrate, 35% N.) were 0, 25, 100, 225, 400 and 625 kg/ha per annum. Potassium (potassium chloride, 60% K_2O) and phosphate (superphosphate: mono-calcium phosphate and calcium phosphate, 19% P_2O_5) were also applied in the ratio of (N): 1 : 3. Nitrogen and potassium were applied in 8 applications in solution and phosphate as super-phosphate in two dressings at applications 1 and 5. Applications were carried out every four weeks from June to November, 1993 (note: only six dressings were applied in 1993) and March to October, 1994.

The trial was maintained at 25 mm and the cuttings were removed. Sand dressings were applied in July/August (4 kg m^{-2}). In addition 2 kg m^{-2} was applied to all plots in November. The trial was watered as required.

The trial received artificial football type wear treatment (Plate 4, section 3.2) from 18th October, 1994 to 21st March, 1995 inclusive. Each plot received 68 passes in total throughout the wear treatment period.

Prior to the commencement of wear treatments in October, 1994, a survey of the botanical composition of each plot was carried out using a point quadrat (Plate 7). Ten pairs of pins were used in the frame, each pair separated by 5 cms. The frame was placed systematically in a 'V' shape 10 times on each plot so that the whole 2 x 2m area (avoiding the edges) was sampled and 100 points were obtained in each case. Sightings were taken down the tips of the pairs of pins onto the vegetation. Living species, bare ground and dead grass were scored. A final botanical composition survey was also carried out on each plot following the completion of wear treatment on 22nd March, 1995.

Plate 7. Point quadrat frame for the estimation of cover in close mown turf (Laycock and Canaway, 1980).



The trial was assessed for disease by an area quadrat (0.75m^2, Plate 2, section 3.1). Four quadrat readings were taken from each sub-plot (3 m x 2.5 m) and a mean value determined. *L. fuciformis* assessments were conducted in the summer and autumn after half and all the nitrogen had been applied. In the first season *M. nivale* was assessed after the initial outbreak in January and then for the next two months until symptoms were no longer visible (in late March). In the second season (during wear treatments), *M. nivale* was assessed in December, 1994 and January, 1995.

The data were analysed as a randomised block with sub-plots, using analysis of variance tests (p = 0.05).

Results

Red thread, *Laetisaria fuciformis*

The trial was assessed for *L. fuciformis* twice; after half and after the full amount of nitrogen had been applied.

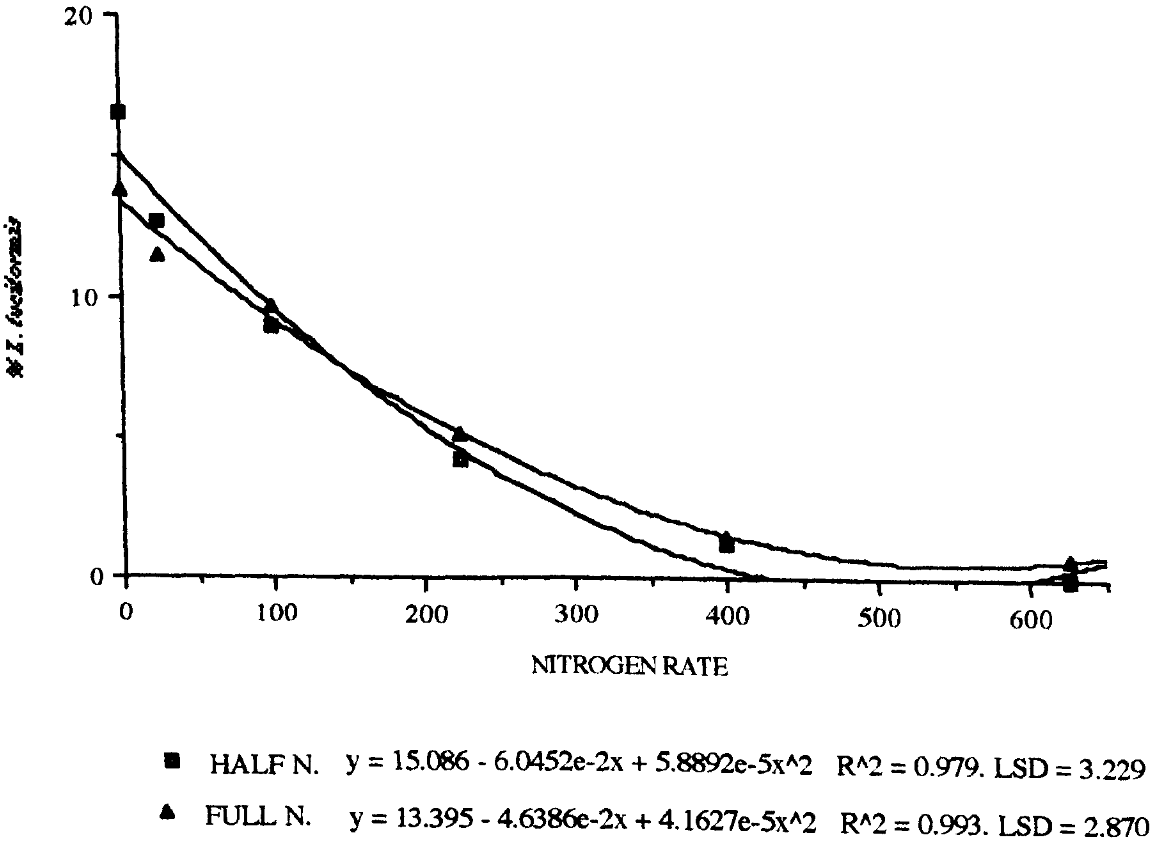
1993 Assessments

Table 79 and Figure 27 illustrate the effect of nitrogen on the incidence of *L. fuciformis* after half rate and full rate N., 1993.

Table 79. *L. fuciformis* cover (%) after half and full N., 1993

Nitrogen rate kg ha^{-1} year^{-1}	% *L. fuciformis* after half N.		% *L. fuciformis* after full N.	
	mean % disease	standard deviation	mean % disease	standard deviation
0	16.50	5.82	13.82	6.12
25	12.65	4.39	11.48	4.67
100	8.90	4.38	9.63	2.83
225	4.15	3.07	5.03	1.42
400	1.23	0.94	1.40	1.10
625	0.00	0.00	0.70	0.86

Figure 27. Incidence of L. fuciformis after half and full N.



■ HALF N. y = 15.086 - 6.0452e-2x + 5.8892e-5x^2 R^2 = 0.979. LSD = 3.229

▲ FULL N. y = 13.395 - 4.6386e-2x + 4.1627e-5x^2 R^2 = 0.993. LSD = 2.870

Analysis of the data indicates that nitrogen rate exhibited a significant effect on the incidence of *L. fuciformis*, Table 80. Significant variation also existed between each block.

Table 80. Significance of nitrogen rate on *L. fuciformis* incidence, 1993.

	After half N.	After full N.
Nitrogen rate	$F_5 = 33.38$, $p = 0.0001$	$F_5 = 29.04$, $p = 0.0001$
Block	$F_1 = 4.60$, $p = 0.037$	$F_1 = 10.56$, $p = 0.002$

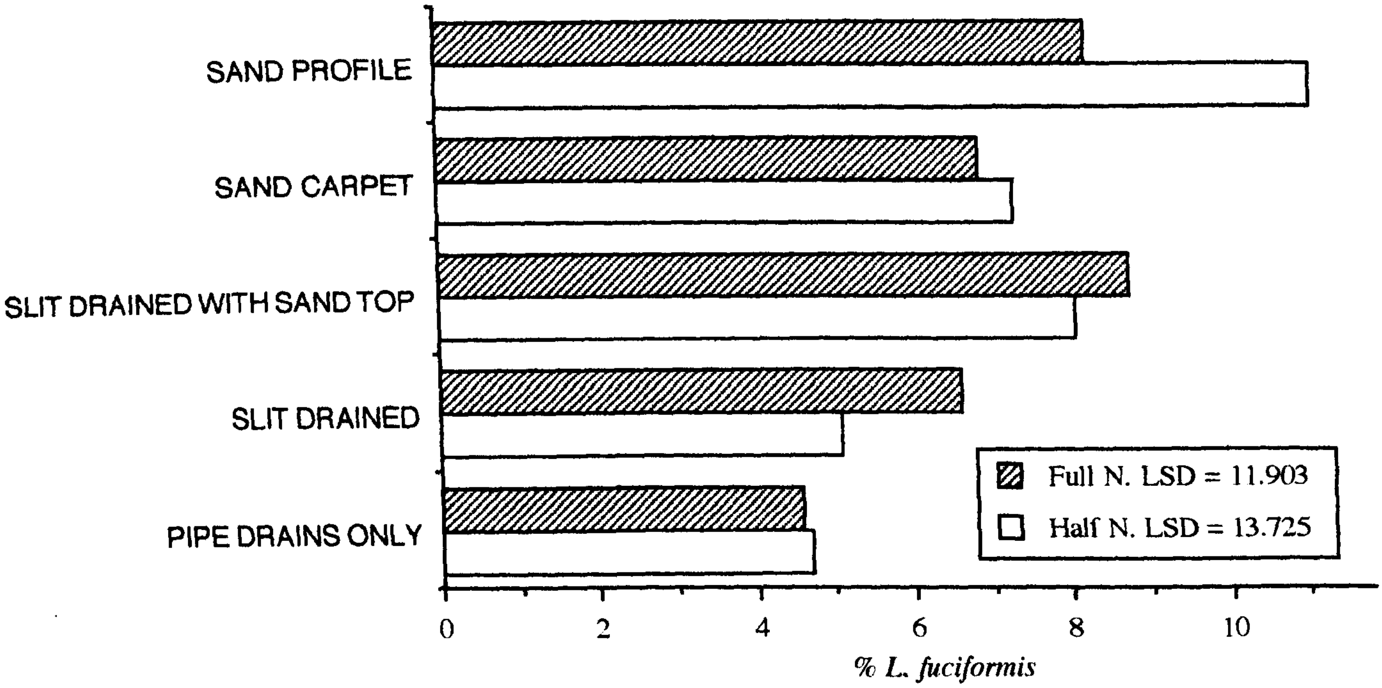
As the nitrogen rate increased, *L. fuciformis* incidence decreased. The trend in *L. fuciformis* incidence was identical after half and after full N. There was little change in *L. fuciformis* severity with time (Figure 27), however at nil and 25 kg ha^{-1} severity was slightly reduced over time.

Table 81 and Figure 28 illustrate the effect of construction type on *L. fuciformis* after half and full nitrogen levels have been applied, 1993.

Table 81. *L. fuciformis* cover (%) on different constructions after half and full N., 1993.

Construction type	% *L. fuciformis* after half N.		% *L. fuciformis* after full N.	
	mean % disease	standard deviation	mean % disease	standard deviation
Pipe drains only	4.69	5.22	4.60	3.28
Slit drained	5.08	4.68	6.63	4.94
Slit drained with sand top	8.06	6.67	8.73	7.57
Sand carpet	7.29	6.31	6.87	5.22
Sand profile	11.06	10.09	8.25	7.82

Figure 28. Laetisaria fuciformis cover after half and full N. on different constructions, 1993



Analysis of the data (Table 82) indicates that construction type did not exhibit a significant effect on the incidence of *L. fuciformis*. In addition, there were no significant block effects.

Table 82. Significance of construction type on *L. fuciformis* incidence, 1993.

	After half N.	After full N.
Construction type	$F_4 = 1.70$, $p = 0.164$	$F_4 = 0.89$, $p = 0.475$
Block	$F_1 = 1.27$, $p = 0.265$	$F_1 = 3.07$, $p = 0.086$

Despite no significant differences in construction type, Figure 28 illustrates that *L. fuciformis* incidence was highest on the freely draining constructions, e.g. the sand profile and sand carpet. The incidence of disease was over twice as much on these constructions compared to less freely draining construction types i.e. 'pipe drains only'. There was little variation in the level of disease over time, although there is a marked reduction in *L. fuciformis* severity on the sand profile.

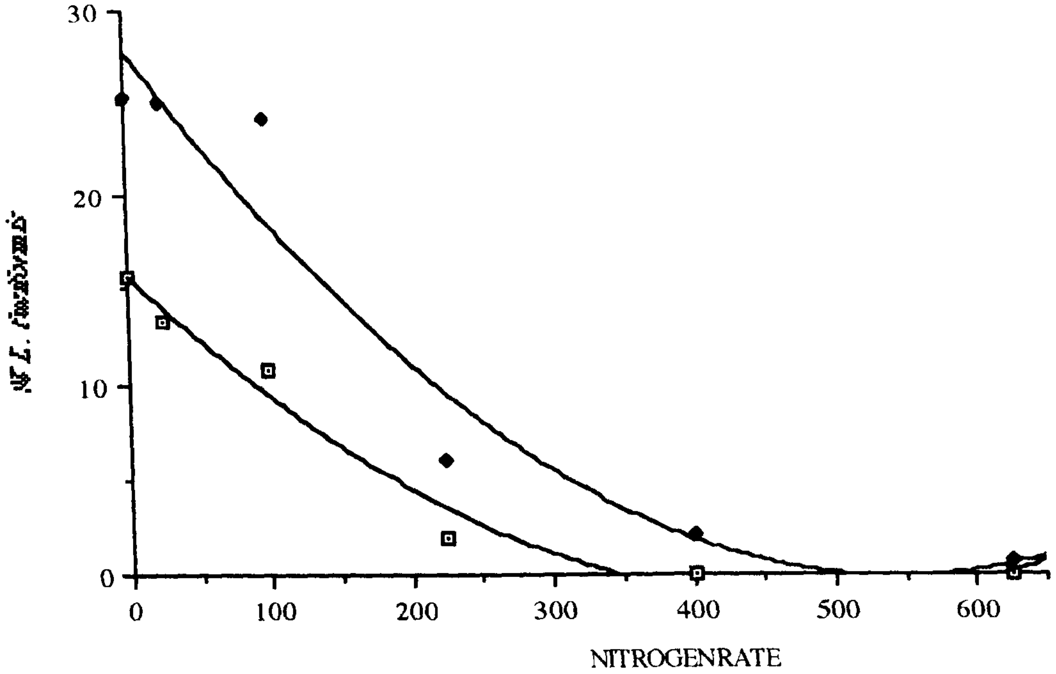
1994 Assessments

Table 83 and Figure 29 illustrate the effect of nitrogen on the incidence of *L. fuciformis* after half rate and full rate N., 1994.

Table 83. *L. fuciformis* cover (%) after half and full N., 1994

Nitrogen rate	% *L. fuciformis* after half N.		% *L. fuciformis* after full N.	
kg ha^{-1} year^{-1}	mean % disease	standard deviation	mean % disease	standard deviation
0	15.75	9.92	25.40	12.11
25	13.32	8.33	25.08	6.84
100	10.73	6.66	24.13	10.99
225	1.98	2.08	6.08	4.78
400	0.00	0.00	2.05	1.58
625	0.00	0.00	0.80	1.32

Figure 29. Incidence of L. fuciformis, 1994



▣ HALF N. $y = 15.650 - 7.0354e\text{-}2x + 7.2942e\text{-}5x^2$ $R^2 = 0.979$. LSD = 5.318

◆ FULL N. $y = 27.801 - 0.10258x + 9.4422e\text{-}5x^2$ $R^2 = 0.933$. LSD = 6.831

Analysis of the data indicates that nitrogen rate exhibited a significant effect on the incidence of *L. fuciformis*. Table 84 shows the significant effect after half and full N., 1994. There were no significant block effects.

Table 84. Significance of nitrogen rate on *L. fuciformis* incidence, 1994.

	After half N.	After full N.
Nitrogen rate	$F_5 = 14.56$, $p = 0.0001$	$F_5 = 25.52$, $p = 0.0001$
Block	$F_1 = 2.51$, $p = 0.119$	$F_1 = 0.04$, $p = 0.836$

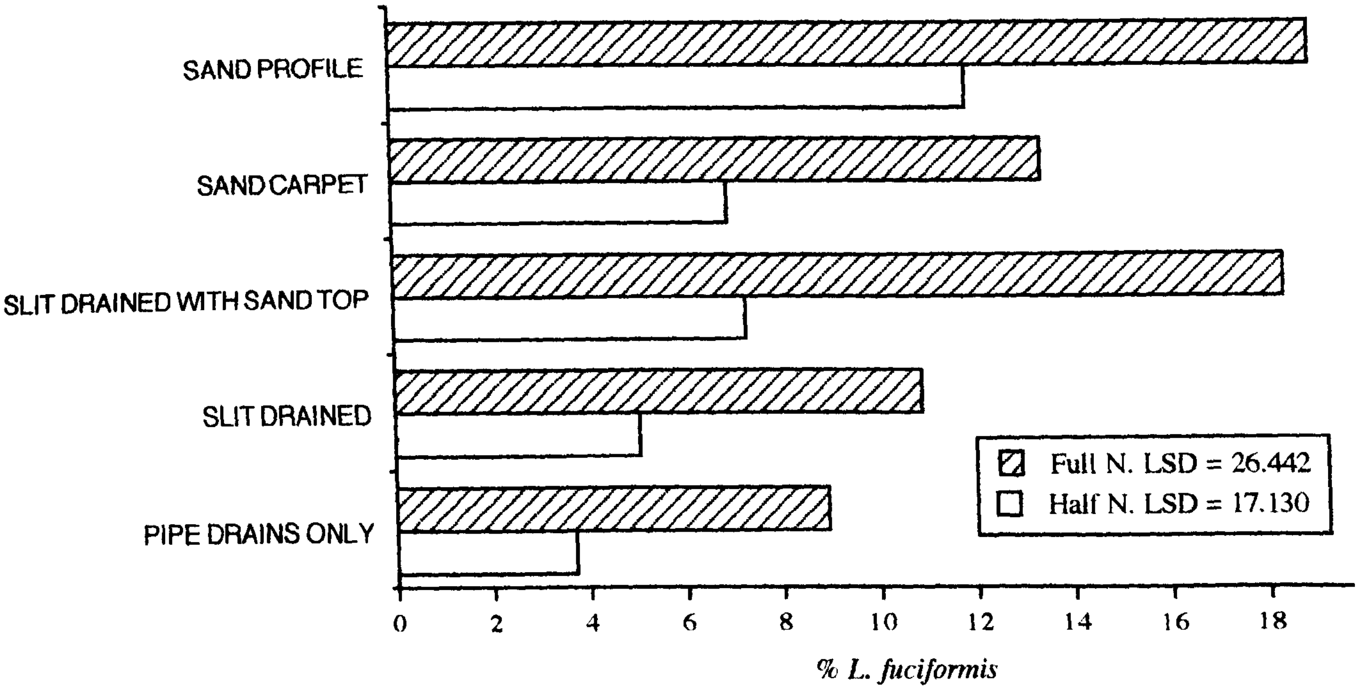
As the nitrogen rate increased, *L. fuciformis* incidence decreased. This trend in was identical after half and after full N. and from season to season. After the final nitrogen application, disease levels appeared to increase (Figure 29).

Table 85 and Figure 30 illustrate the effect of construction type on *L. fuciformis* after half and full nitrogen levels had been applied in 1994.

Table 85. *L. fuciformis* cover (%) on different constructions after half and full N., 1994

Construction type	% *L. fuciformis* after half N.		% *L. fuciformis* after full N.	
	mean % disease	standard deviation	mean % disease	standard deviation
Pipe drains only	3.71	4.64	8.94	9.94
Slit drained	5.08	5.24	10.87	10.60
Slit drained with sand top	7.27	6.54	18.33	16.23
Sand carpet	6.96	9.75	13.42	10.74
Sand profile	11.87	13.36	18.94	16.67

Figure 30. Laetisaria fuciformis cover after half and full N. on different constructions, 1994



Analysis of the data (Table 86) indicates that construction type did not exhibit a significant effect on the incidence of *L. fuciformis*. In addition there were no significant block effects. Similar results were obtained in the previous season, 1993.

Table 86. Significance of construction type on *L. fuciformis* incidence, 1994.

	After half N.	After full N.
Construction type	$F_4 = 1.58$, $p = 0.194$	$F_4 = 1.47$, $p = 0.223$
Block	$F_1 = 1.21$, $p = 0.276$	$F_1 = 0.01$, $p = 0.905$

Despite no significant differences in construction type, Figure 30 illustrates that *L. fuciformis* incidence was highest on the freely draining constructions, for example the sand profile. This trend was also noted in 1993. The incidence of disease was over twice as much on these constructions compared to less freely draining construction types, e.g. 'pipe drains only'. Disease was more severe after the final application of nitrogen.

Fusarium patch, *Microdochium nivale*

1994 Assessments

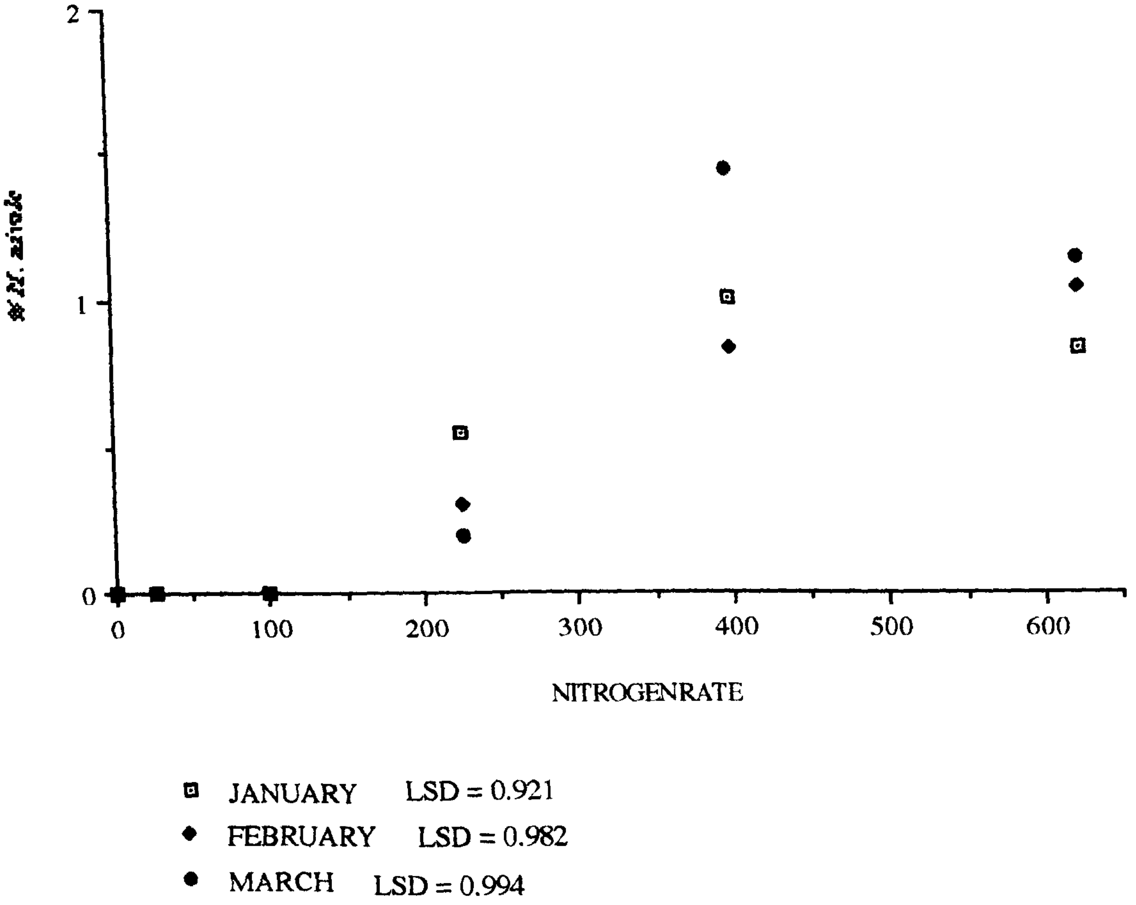
M. nivale was first noted on the trial in January, 1994 after full nitrogen application in the previous growing season. The initial outbreak was assessed; further assessments took place four (February) and eight (March) weeks after the initial observation of visual symptoms. Table 87 and Figure 31 illustrate the effect of nitrogen on the incidence of *M. nivale*.

Table 87. Effect of nitrogen rate on *M. nivale* cover (%) recorded in January, February and March.

Nitrogen rate kg ha^{-1} $year^{-1}$	January, 1994		February, 1994		March, 1994	
	mean % DC*	SD‡	mean % DC	SD	mean % DC	SD
0	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00
225	0.55	0.97	0.30	0.48	0.20	0.44
400	1.00	1.86	0.83	1.96	1.43	2.18
625	0.825	1.34	1.03	1.76	1.13	1.58

*DC = Disease cover. ‡ SD = Standard deviation.

Figure 31. Incidence of M. nivale, 1994



Analysis of the data indicates that nitrogen rate exhibited a significant effect on the incidence of *M. nivale* in March. There appeared to be no significant block effects (Table 88).

Table 88. Significance of nitrogen rate on *M. nivale* incidence in March.

	January, 1994	February, 1994	March, 1994
Nitrogen rate	$F_5 = 1.69, p = 0.10$	$F_5 = 1.76, p = 0.14$	$F_5 = 3.38, p = 0.01$
Block	$F_1 = 0.00, p = 0.98$	$F_1 = 1.13, p = 0.29$	$F_1 = 1.50, p = 0.227$

The effect of nitrogen rate appeared to have a significant effect on disease incidence at the final assessment . Although $p > 0.05$ at the first and second assessments, all the results follow a similar trend - as nitrogen rate increased, the incidence of *M. nivale* increased. No visual symptoms occurred on 0, 25, and 100 kg/ha N. At N. = 225 kg/ha, disease was very slight, less than 5% cover, and decreased with respect to time (Figure 31). Disease was present at N = 400 and 625 kg/ha and appeared to increase with time.

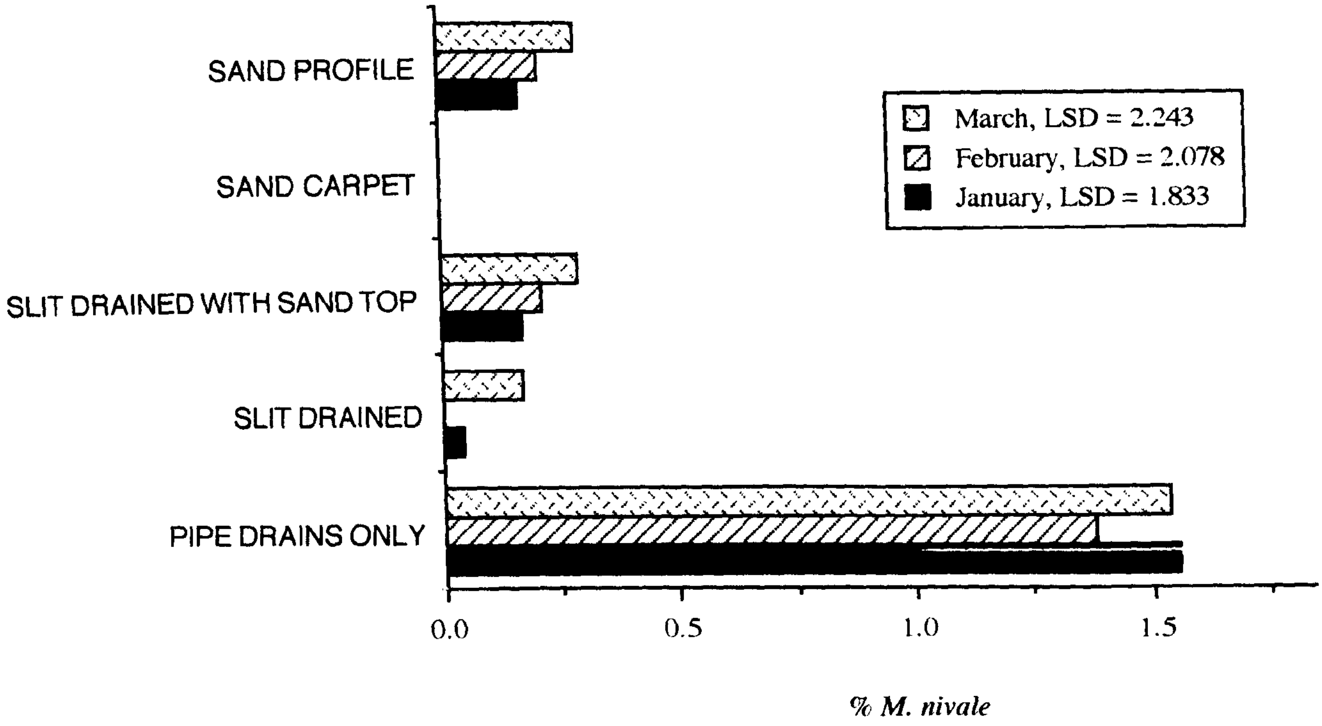
Table 89 and Figure 32 illustrate the effect of construction type on *M. nivale* in Jan., Feb. and March.

Table 89. *M. nivale* cover (%) on different constructions in January, February and March, 1994.

Construction type	January 1994		February 1994		March 1994	
	Mean % DC*	SD‡	Mean % DC	SD	Mean % DC	SD
Pipe drains only	1.56	1.94	1.38	2.20	1.54	2.33
Slit drained	0.04	0.14	0.00	0.00	0.17	0.58
Slit drained with sand top	0.17	0.44	0.21	0.53	0.29	0.57
Sand carpet	0.00	0.00	0.00	0.00	0.00	0.00
Sand profile	0.17	0.33	0.21	0.50	0.29	0.46

* DC = Disease Cover, ‡ SD = Standard Deviation

Figure 32. Microdochium nivale cover on Different Constructions, 1994



Analysis of the data (Table 90) indicates that construction type exhibited a significant effect on the incidence of *M. nivale*. There appeared to be no significant block effects.

Table 90. Significance of construction type on *M. nivale* incidence at the initial outbreak (January) and the following four (February) and eight weeks (March).

	January, 1994	February, 1994	March, 1994
Construction type	$F_4 = 6.28$, $p = 0.0001$	$F_4 = 3.74$, $p = 0.009$	$F_4 = 3.66$, $p = 0.010$
Block	$F_1 = 0.00$, $p = 0.972$	$F_1 = 1.26$, $p = 0.27$	$F_1 = 1.47$, $p = 0.231$

For the first, second and third assessments a similar trend in disease incidence occurred (Figure 32). As drainage capacity increases, *M. nivale* was reduced. There was little difference in disease on freely draining constructions, where disease incidence was very low (less than 0.3%), although a slight increase occurred with time. Disease was most prevalent on 'pipe drains only' where the incidence remains constant throughout the assessment period.

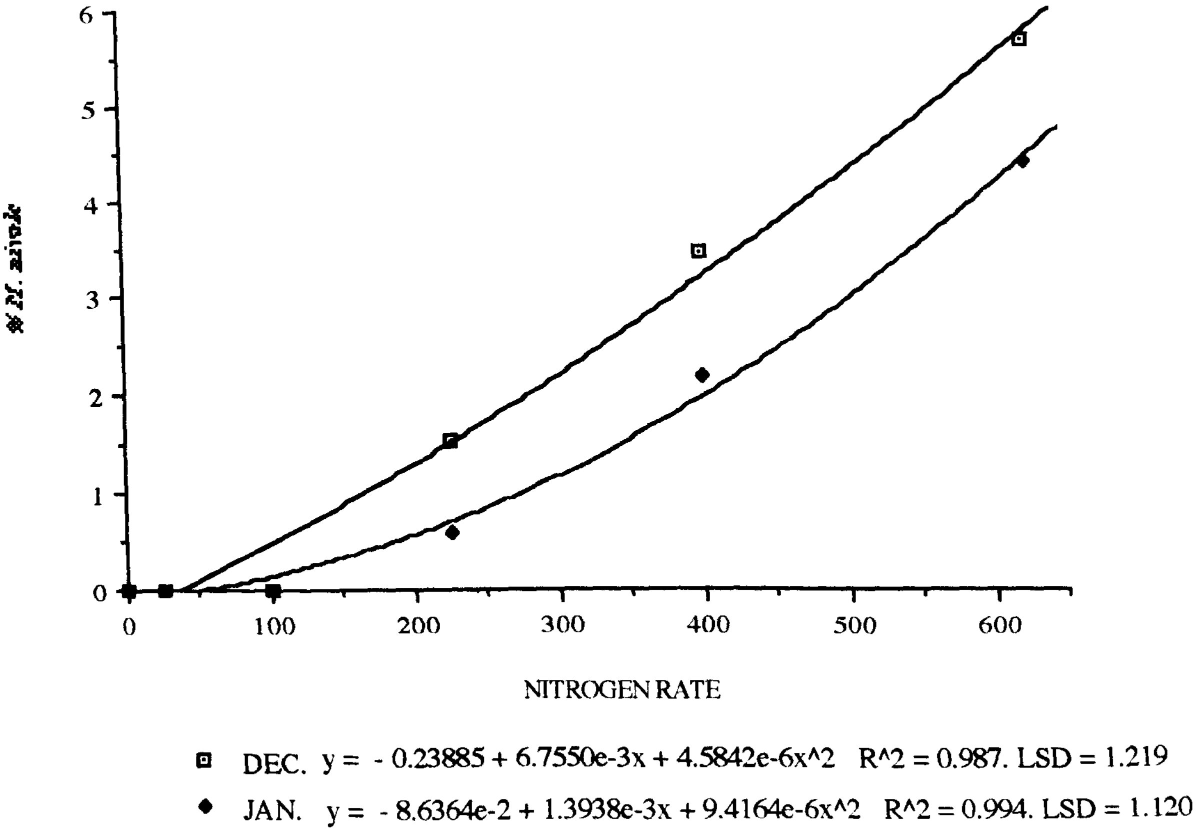
<u>1994/1995 Assessments</u>

M. nivale was first noted on the trial in December, 1994. The disease was assessed for a further month until January, 1995. Table 91 and Figure 33 illustrate the effect of nitrogen on the incidence of *M. nivale*.

Table 91. Effect of nitrogen rate on *M. nivale* cover (%) recorded in December 1994 and January, 1995.

Nitrogen rate kg ha^{-1} $year^{-1}$	December, 1994		January, 1995	
	mean % disease cover	Standard deviation	mean % disease cover	Standard deviation
0	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00
225	1.53	1.23	0.58	0.29
400	3.45	2.07	2.18	1.25
625	5.68	2.26	4.40	2.60

Figure 33. Incidence of M. nivale, Dec. 94 - Jan. 95.



Analysis of the data indicates that nitrogen rate exhibited a significant effect on the incidence of *M. nivale*. Table 92 shows the significant effect on disease incidence. There appeared to be no significant block effects.

Table 92. Significance of nitrogen rate on *M. nivale* incidence at the initial outbreak (December 1994) and the following month.

	December, 1994	January, 1995
Nitrogen rate	F_5 = 29.85, p = 0.0001	F_5 = 20.42, p = 0.0001
Block	F_1 = 0.23, p = 0.64	F_1= 0.00, p = 0.959

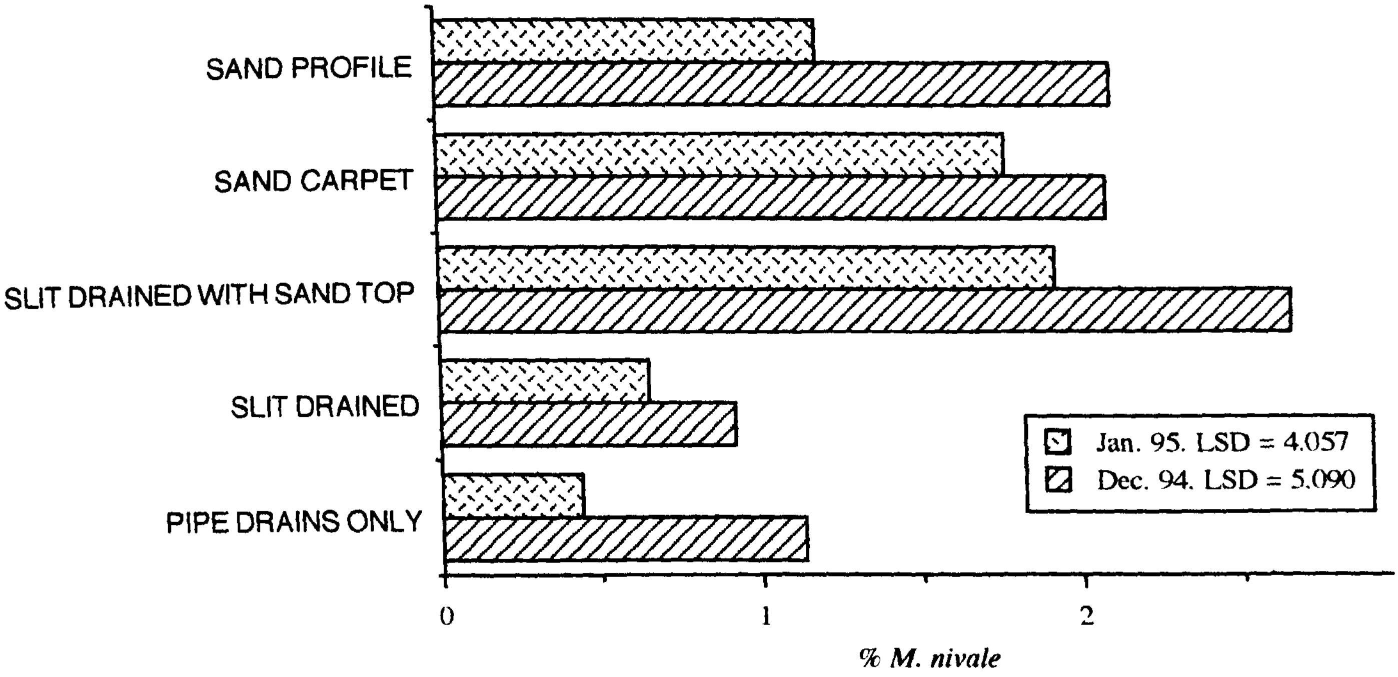
The results follow a similar trend as those from the previous year; as nitrogen rate increased, the incidence of *M. nivale* also increased. No visual symptoms occurred on 0, 25, and 100 kg/ha N. At N. = 225 kg/ha disease was very slight, less than 2 % cover, and decreased with respect to time (Figure 33). Disease was present at N = 400 and 625 kg/ha and appeared to decrease with time.

Table 93 and Figure 34 illustrate the effect of construction type on *M. nivale* in December, 1994 - January, 1995.

Table 93. *M. nivale* cover (%) on different constructions.

Construction type	December, 1994		January, 1995	
	Mean % Disease cover	Standard deviation	Mean % Disease cover	Standard deviation
Pipe drains only	1.13	1.52	0.44	0.70
Slit drained	0.92	1.40	0.65	1.16
Slit drained with sand top	2.65	3.59	1.92	2.79
Sand carpet	2.08	2.76	1.77	2.66
Sand profile	2.10	2.63	1.19	1.85

Figure 34. Microdochium nivale cover on different constructions, 1994/1995



Analysis of the data (Table 94) indicates that construction type did not appear to have a significant effect on the incidence of *M. nivale* in December, 1994 and January, 1995. There appeared to be no significant block effects.

Table 94. Significance of construction type on *M. nivale* incidence at the initial outbreak (December) and the following January.

	December, 1994	January, 1995
Construction type	$F_4 = 0.99$, $p = 0.422$	$F_4 = 1.27$, $p = 0.29$
Block	$F_1 = 0.06$, $p = 0.800$	$F_1 = 0.00$, $p = 0.98$

The following figures, 35-36, illustrate the effect of nitrogen rate on botanical composition.

Figure 35. Botanical composition before wear treatment, October, 1994

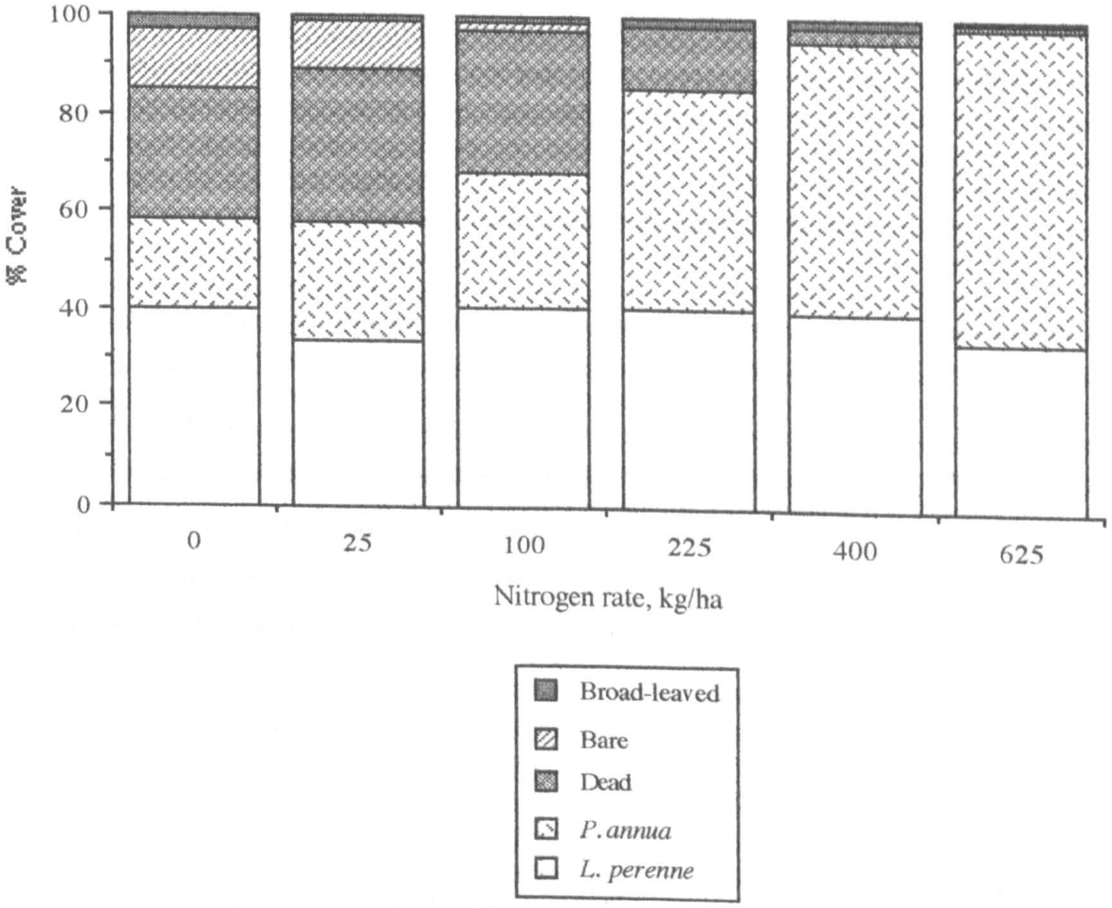


Figure 36. Botanical composition after wear treatment, March, 1995

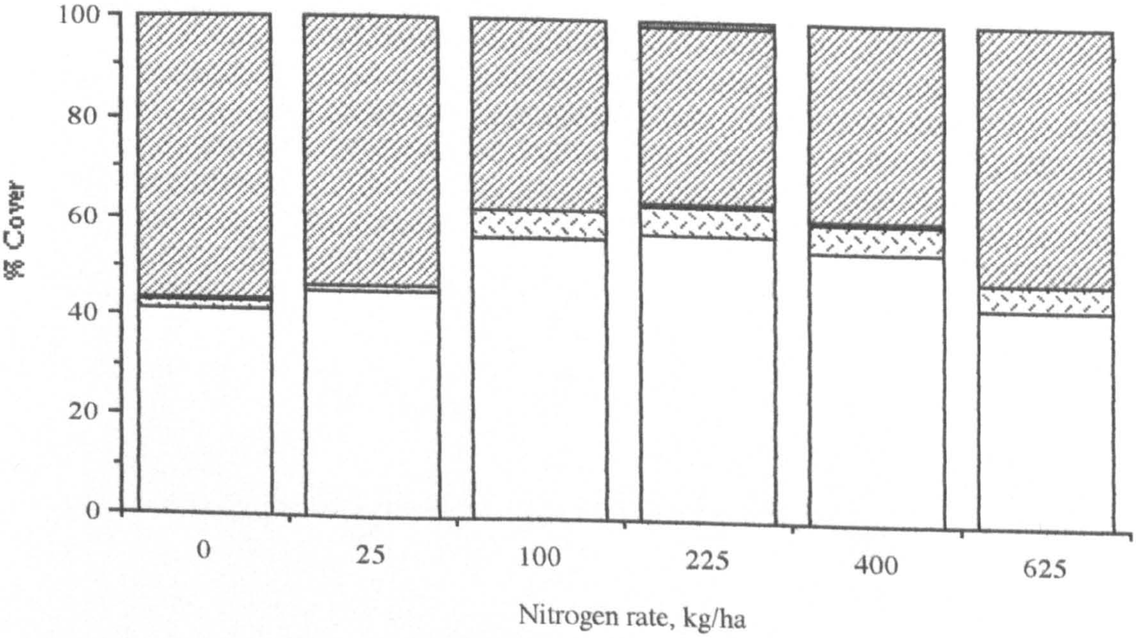


Figure 35 (Botanical composition before wear treatment) illustrates that as nitrogen rate increased, the proportion of annual meadow grass, *Poa annua*, in the sward increased, whilst the amount of bare patches and dead plants were reduced. Perennial rye grass, *Lolium perenne*, cover was highest at moderate nitrogen levels, N = 100 - 225 kg/ha. Figure 36 illustrates how botanical composition alters with respect to nitrogen rate after wear treatment. Overall, *P. annua* was reduced whilst the proportion of *L. perenne* was increased, particularly when moderate levels of nitrogen were applied (N = 100 - 225 kg/ha). At high and low nitrogen levels, the proportion of bare ground was greatest but was reduced under moderate nitrogen levels.

Figure 37 illustrates the effect of construction type on botanical composition in October before wear treatment commenced. The effect of construction type on botanical composition appeared to be less well marked than nitrogen rate. However, as draining capacity increased, *L. perenne* and broad-leaved species were reduced, whilst the number of dead plants and bare patches increased. Figure 38 illustrates the effect of construction type on botanical composition after wear treatment. Bare patches were greatest on freely draining and poorly drained constructions, but were reduced on moderately well-drained pitches. *Lolium perenne* cover was greatest on moderate to well drained constructions, e.g. 'slit drained' and 'slit with sand top'

Figure 37. Botanical composition before wear treatment, October, 1995

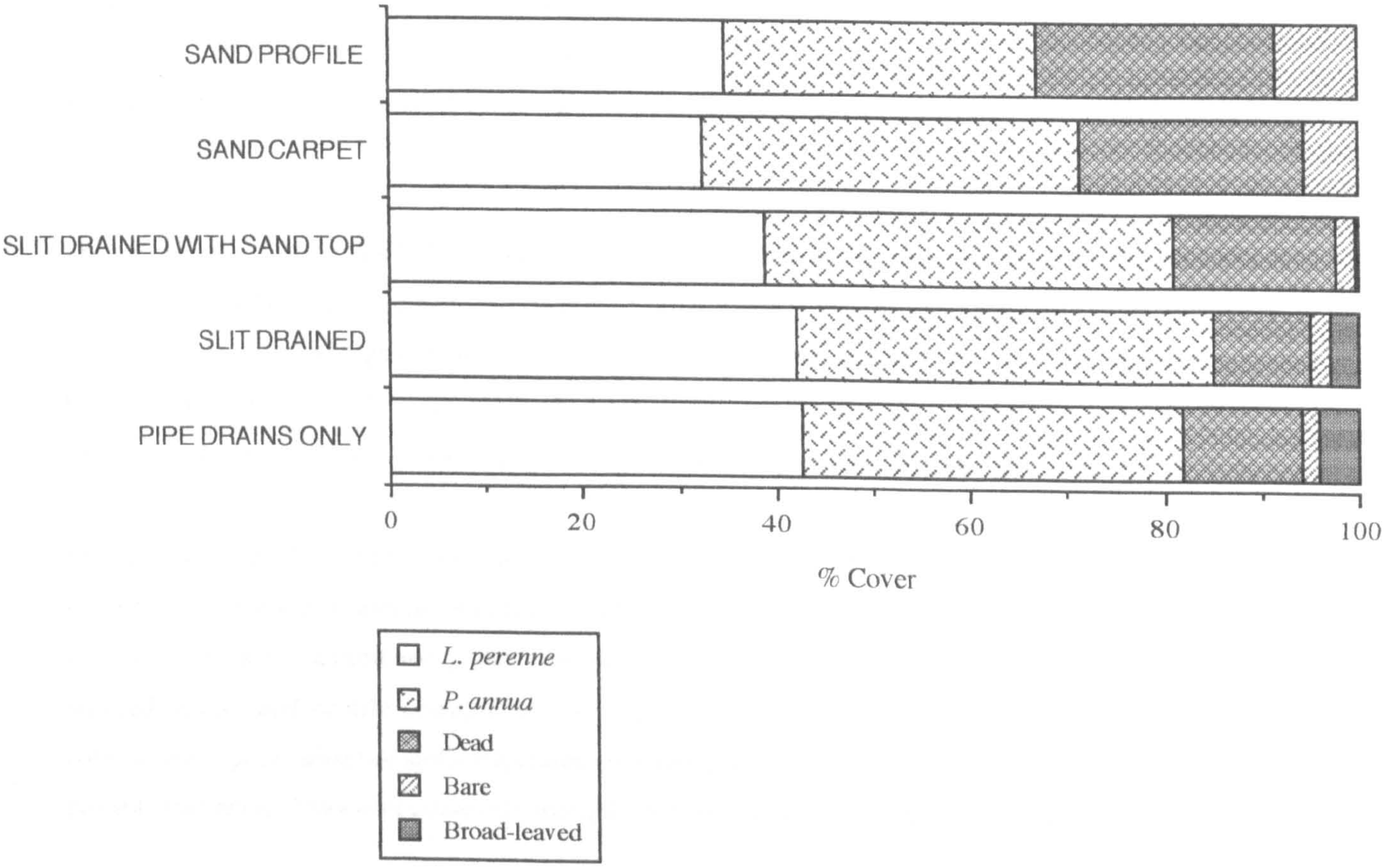
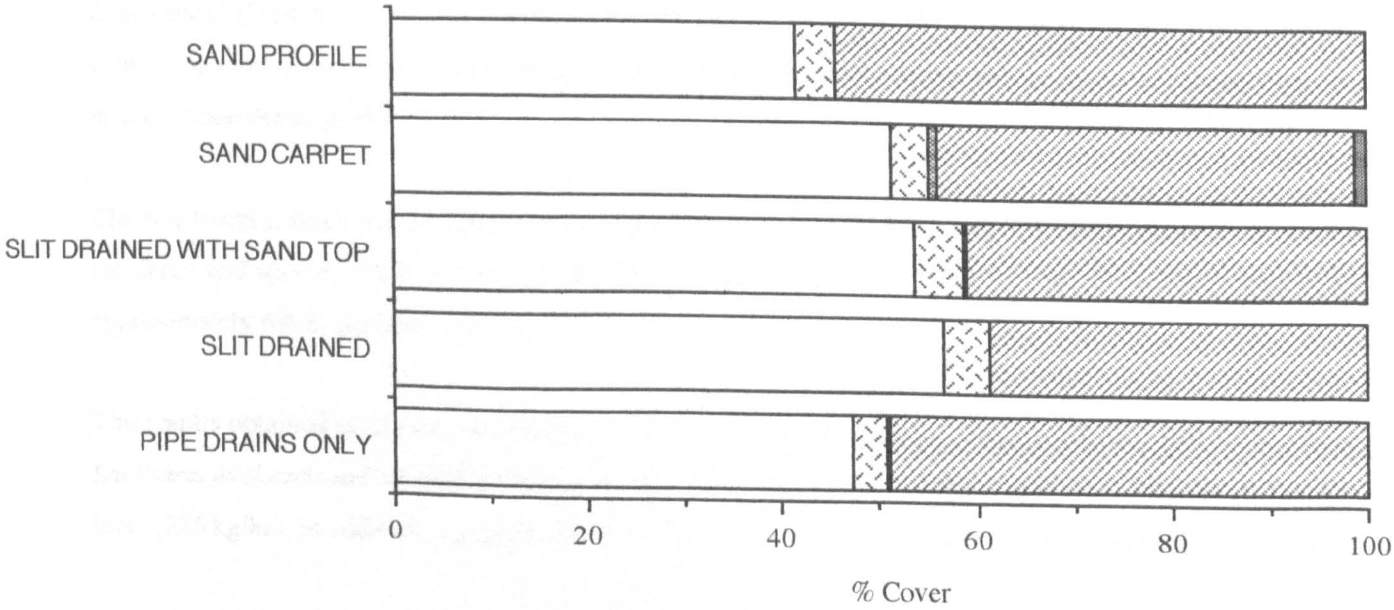


Figure 38. Botanical composition after wear, March, 1995



Discussion

The installation of an appropriate drainage system (depending on financial considerations, soil type and local climate) and the fertiliser regime employed are two of the most important factors in maintenance of surface quality and reduction in pathogen symptom expression. In short, drainage determines the availability of moisture (and nutrients), whilst fertiliser type and rate dictate nutrient levels available to both pathogen and turfgrass plant.

The results obtained from the field trial are encouraging. A nitrogen rate and construction type were identified which successfully reduce symptom expression of both diseases, whilst sustaining maximum turf coverage under wear. As expected high nitrogen rates increase *M. nivale* disease incidence in winter, whilst suppressing *L. fuciformis* in summer (Baldwin, 1990). When N = 225 - 400 kg/ha/annum both diseases were effectively suppressed (*L. fuciformis* cover was approximately 5% and *M. nivale* covers less than 1%).

The severity of *L. fuciformis* was reduced at nil and 25 kg/ha/annum (Figure 27). This is unusual as *L. fuciformis* incidence is greater in less fertile conditions. However, at such low nitrogen rates the condition of the host is severely reduced and possibly unable to sustain a pathogenic population. *L. fuciformis* was also reduced on the sand profile construction over time (Figure 28). Water drains very rapidly through this construction type; as adequate surface moisture is a primary factor in *L. fuciformis* symptom expression it is possible that reduced moisture causes disease reduction on this particular construction type.

Highly fertile conditions encourage *M. nivale* (Figure 31). Disease levels were non-existent/minimal when N = 0 - 225 kg ha/annum. *M. nivale* disease levels were highest on less freely draining constructions, e.g. 'pipe drains only' (Figure 32). On this construction type surface moisture levels are high which favours disease expression in *M. nivale*. Less freely draining construction types retain nitrate longer which may also favour *M. nivale* disease development.

The construction types which appeared to contain both diseases effectively was the sand carpet (nil *M. nivale* incidence and approx. 7% *L. fuciformis*) and slit drained construction (less than 1% *M. nivale* incidence and approximately 6% *L. fuciformis* cover).

The results obtained in the second assessment period (1994/1995) are consistent with the 1993/1994 results. *Laetisaria fuciformis* and *Microdochium nivale* were both significantly reduced under a moderate/high nitrogen level (225 kg/ha). In addition, a pipe/slit drained construction also appeared to effectively manage both diseases.

The botanical composition studies also illustrate that a medium/high nitrogen level (N=225 kg/ha, Figure 36) and a moderately well-draining construction type (pipe/slit construction, Figure 38) not only effectively suppressed the two major pathogenic diseases on sports turf, but also sustained a healthy, vigorous sward under artificial football type wear treatment. High nitrogen levels tend to encourage proliferation of the weed grass species, *Poa annua*. *P. annua* is very susceptible to wear and rips out of the sward with ease, leaving large areas of bare ground. A moderate nitrogen level on a pipe/slit construction, sustained the greatest proportion of *Lolium perenne* which is very tolerant to wear. A pipe/slit construction is freely draining enough to prevent water-logging, but is also able to retain adequate levels of moisture and nutrients for maximum turf growth. Moderate nitrogen input provides the appropriate nutrient level for optimal turf growth, without encouraging broad-leaved weeds and *Poa annua* which render the sward less wear tolerant.

The construction of the pitch is a very important initial management decision. However, not all pitches can be completely reconstructed to improve drainage because of financial and practical constraints, e.g. a basic pipe drainage system may cost £7 000 - £8 000 (1989 price) compared to £80 000 - £100 000 for a pure sand rootzone with a gravel drainage layer (Baker and Canaway, 1990). Drainage was cited by both professional football clubs and local authorities as the leading problem on football pitches (Raikes *et al*, 1994a, b). Existing pitch surfaces can be modified to improve drainage, and so maintain pathogen populations, as part of an effective integrated disease management programme. Regular slitting and aeration combined with careful top-dressing with a sandy compost will make the surface less moisture retentive, resulting in a reduction in disease expression.

Improving pitch drainage properties can be involved and complex. However, the most appropriate nitrogen rate to reduce disease can be incorporated readily and economically into an integrated management strategy. Improved drainage and a balanced fertiliser programme will increase the quality of the pitch and decrease waterlogging therefore reducing potential fixture loss. The resultant increase in turf vigour will also help to ensure improved resistance to disease, weed and pest invasion, whilst reducing reliance on expensive and potentially damaging chemicals.

3.5 Conclusion

The results obtained in this chapter underline the significance of cultural factors in the implementation of a successful integrated disease management strategy for winter sports turf. The appropriate cultural practices chosen for a particular site provide an integral framework to which other management strategies can be successfully added e.g. the use of chemicals and / or biological control. The resulting disease management strategy will help to maintain disease effectively and economically because of flexibility within the strategy design and by reducing over-dependence on costly chemical treatments. The use of IDM based on sound cultural practices will help to reduce the environmental impact of excessive pesticide use and over-fertilisation.

Excessive use of synthetic chemicals can disturb the natural balance within the turfgrass ecosystem. Increased chemical input can cause the death of natural predators and other beneficial invertebrates and micro-organisms (e.g. species which decompose organic material which reduces thatch build up) as well as promoting minor diseases to a more significant status. By its nature a closely mown sward, necessary for grass species used for winter sports turf, is prone to invasion by diseases, weeds and pests. A number of factors including frequent mowing and wear pressure causes loss of photosynthetic capacity and soil compaction can predispose turf to stress, rendering the sward less vigorous and more susceptible to attack by disease. Selection of an appropriate mixture of grass species and cultivars provides the first step in producing a more healthy, better adapted sward, provided the grass is grown in a well prepared, freely-draining seedbed. The use of environmentally and culturally adapted mixtures of grasses will help to create a well-adapted, more diverse and stable turfgrass stand mirroring a 'natural' ecosystem where phytopathological epidemics are rare. By adopting such a strategy, the reliance on costly and potentially hazardous chemicals in areas open to public access is reduced.

In addition to the selection of well adapted grass species, the use of an appropriate fertiliser regime provides another cost-effective method to include in an integrated disease management strategy. A number of pathogens (e.g. red thread, *Laetisaria fuciformis*, dollar spot, *Sclerotinia homoeocarpa* and rust, *Puccinia* spp.) are reduced under increased nitrogen levels, whereas diseases caused by species such as *Fusarium* and *Rhizoctonia* are promoted by higher nitrogen input. The major target pathogens need to by identified and their particular epidemiology determined before any decision regarding fertiliser input can be made. In general, if a balanced fertility programme is employed according to turf use, a more healthy, vigorous sward will result. Such a programme will help to reduce thatch, maintain shoot density and increase recuperative potential thereby creating a sward more resilient to pathogen, weed and pest invasion.

Finally, section 3.4 illustrates the importance of drainage in terms of pathogen symptom expression. A well drained pitch will help to promote a vigorous sward less susceptible to disease attack. How freely draining a pitch construction is will determine the availability of water and nutrients, particularly nitrogen and potassium, to both the turfgrass and fungal pathogens. Therefore, construction type directly effects plant vigour and fungal pathogenicity by dictating moisture and nutrient availability. The installation of a particular drainage system depends on local conditions e.g. soil type and rainfall, and cost. In general, a moderately well drained pitch appears to be effective at reducing disease expression as well as maintaining turf vigour under wear treatment by removal of excess water from the rootzone. The more elaborate and costly pitch construction types can lead to drought stress and lack of nutrients in the turfgrass sward by the rapid leaching of water and vital nutrients through the rootzone.

To conclude, this chapter illustrates the significant effect cultural factors such as grass mixtures, fertiliser regime and drainage play in the reduction of disease and the production of a healthy, well adapted sward. These practices provide the essential basis for successful IDM strategy to which other control methods may be added. Chapter four examines the potential use of biological control agents in the effective reduction of disease on winter sports turf.

Chapter Four :

Biological Disease Control

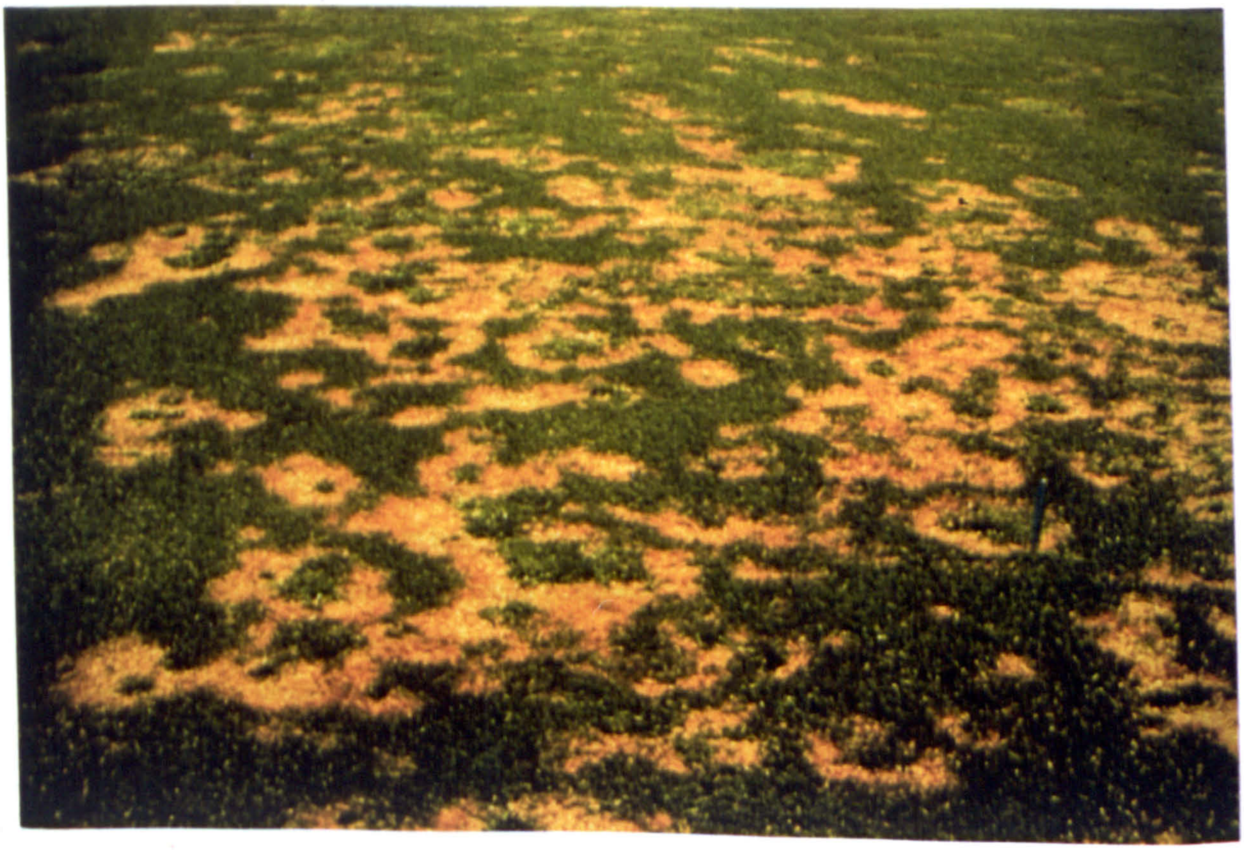
4.0 Biological control of Fusarium patch disease, *Microdochium nivale*, on winter sports turf.

4.1 Introduction

The survey of the major diseases, pests and weeds on winter sports turf (Chapter 2) identified Fusarium patch (*Microdochium nivale*, formerly *Fusarium nivale*) as one of the most economically important diseases on winter sports turf. The disease is prevalent under a high maintenance regime, particularly one with increased nitrogen levels. Of the professional football clubs who responded to the survey, 57% of competition pitches and 45% of training grounds are affected by the disease and between 70-80% of clubs frequently use fungicides for disease control. Of the local authorities who responded, 18% of pitches are effected by *M. nivale* and 29% of the respondents regularly apply fungicides.

Despite the development of effective fungicides, *M. nivale* is probably one of the most damaging and disfiguring winter diseases on turf in Western Europe and the Northern states of the USA (Plate 8). The disease usually first appears as small (50 mm diameter) orange/brown circular spots that can increase rapidly under humid conditions and coalesce to form large irregular scars. Diseased grass can be wet and slimy which may also cause a potentially hazardous playing surface. The disfiguring scars caused by the disease are also prone to invasion by undesirable grasses (e.g. annual meadow grass, *Poa annua*), moss and broad-leaved weeds.

Plate 8. *Microdochium nivale* patches on sports turf.



Successful control of the disease is essential if surface playing quality and turf vigour are to be maintained. In addition to the judicial use of fungicides, a number of cultural methods are also available to assist in the management of the disease (Chapter 3). These include moisture control to avoid humid surface conditions and the careful use of nitrogenous fertilisers and lime; both compounds encourage the disease particularly if they are applied in cool, wet weather. The use of species and cultivar mixtures to create a more diverse, well-adapted sward can also assist the reduction of the disease. The appropriate cultural practices and chemical compounds available to control *M. nivale* are well documented (Baldwin, 1990, Smith *et al*, 1989). However, in order to formulate a more dynamic and readily adaptable integrated control strategy for the disease, an attempt at biological control may be required. The appropriate combination of cultural, chemical and biological control measures within an IDM strategy may assist in the reduction of fungicide input and its associated environmental problems.

The merits of biological control (biocontrol) have been recognised for several centuries (Chapter 1, section 1.6), e.g. the use of predatory ants, *Oecophylla*, to control insect pests in Chinese citrus groves (1200 AD). Despite the advantages of biocontrol (safety, greater cost benefit ratio, less environmental pollution) very few biocontrol agents reach the commercial market place. In the USA, only six biocontrol agents are registered for use. This is probably because of difficulties in effective commercial formulations (e.g. unreliability, limited shelf life, sensitivity to changes in temperature and osmotic pressure) and maintaining consistent benefits. However, it is worth noting that the biocontrol research base is decades behind chemical research in its development programme. Modern synthetic fungicides have been under development since the 1930s whereas biocontrol research oriented toward product development has been pursued for a relatively short time (15 - 20 years). The money invested in biological control research is also marginal compared to the large financial sums invested in chemical control (e.g. approximately $20 - 40 million is associated with the development of a synthetic chemical pesticide (Jacobsen and Backman, 1993)). The environmental effects and potential safety hazards of chemical pesticides have now been fully recognised; these may provide the incentive for more commercial biocontrol research. Pesticides are toxins and occasional examples of misuse and unexpected side effects do occur. It is estimated that there are approximately 200 fatalities and 3000 hospitalisations per year due to pesticides, apart from problems that are unrecognised or not considered serious enough to warrant medical attention (Pimental, 1983 cited by Campbell, 1989).

Due to the rising costs and more stringent tests for novel chemical products, there has been recent commercial interest in biocontrol. A company may test several tens of thousands of chemicals each year and only approximately one in 15 000 might lead to a product. There is now also a suspicion that perhaps most of the effective chemicals have already been found (Campbell, 1989). The use of biocontrol agents in conjunction with cultural practices would help reduce reliance on, and assist in, preservation of these costly and valuable chemical resources. Decreased chemical input will reduce selection pressure on the target pathogen, thereby delaying the onset of fungicide resistance and prolonging the effectiveness of the chemical applied.

The present study seeks to evaluate the potential of a number of known microbial antagonists and indigenous fungi and bacteria for their ability to control Fusarium patch disease both *in vitro* and *in vivo* when used as biocontrol agents on winter sports turf.

4.2 Materials and Methods

4.2.1 Selection of antagonists for biological control potential against *M. nivale*

A number of known antagonists were tested against *Microdochium nivale*. The fungal genus *Trichoderma* is frequently cited as a commonly tested biocontrol species (Papavizas, 1985, Gear, 1986, Kay and Stewart, 1994a, b). Other possible antagonists include the closely related *Gliocladium* spp. (Beale and Pitt, 1990, Ristaino *et al*, 1994, Yuen *et al*, 1994) and bacteria from the genera *Bacillus* and *Pseudomonas* (Renwick *et al*, 1991, Leifert *et al*, 1993, Clarkson and Lucas, 1993). Table 95 summarises the organisms tested and their origins.

Table 95. Microbial species with known antagonistic properties tested against *M. nivale*.

Organism	Source
FUNGI	
Trichoderma koningii	J. Etheridge, Harper Adams Agricultural College, Shropshire
T. viride	J. Etheridge, Harper Adams Agricultural College, Shropshire
T. piliferum	J. Etheridge, Harper Adams Agricultural College, Shropshire
T. polysporum	J. Etheridge, Harper Adams Agricultural College, Shropshire
T. harzianum	J. Etheridge, Harper Adams Agricultural College, Shropshire
T. reesie	C. Armstrong, Liverpool John Moores University
Gliocladium roseum	C. Armstrong, Liverpool John Moores University
G. catenulatum	C. Armstrong, Liverpool John Moores University
Chaetomium globosum	J. Etheridge, Harper Adams Agricultural College, Shropshire
BACTERIA	
Bacillus cereus	Microbiology Dept., Liverpool John Moores University
B. subtilis	Microbiology Dept., Liverpool John Moores University
Pseudomonas aeruginosa	Microbiology Dept., Liverpool John Moores University
P. pumilis	Microbiology Dept., Liverpool John Moores University
P. fluoresens	Microbiology Dept., Liverpool John Moores University
P. putida	Microbiology Dept., Liverpool John Moores University
Enterobacter cloacae	Microbiology Dept., Liverpool John Moores University

4.2.2 Isolation of indigenous antagonists from the turfgrass environment

In addition to known antagonists, a number of native microbes were isolated from the turfgrass environment. Because *M. nivale* initially infects the stem base of turfgrass species near to the soil surface, potential antagonists from both the phylloplane and rhizosphere were isolated. Samples of antagonistic microflora were collected from perennial rye grass, ***Lolium perenne***, which is the major constituent of winter sports turf. The indigenous microflora was sampled in January because micro-organisms isolated within the winter months would be better adapted to the cooler, wetter conditions which favour the incidence of *M. nivale*. The samples were taken from *L. perenne* plants under a high maintenance regime; *M. nivale* incidence and severity are greater under increased nitrogen and top-dressing application.

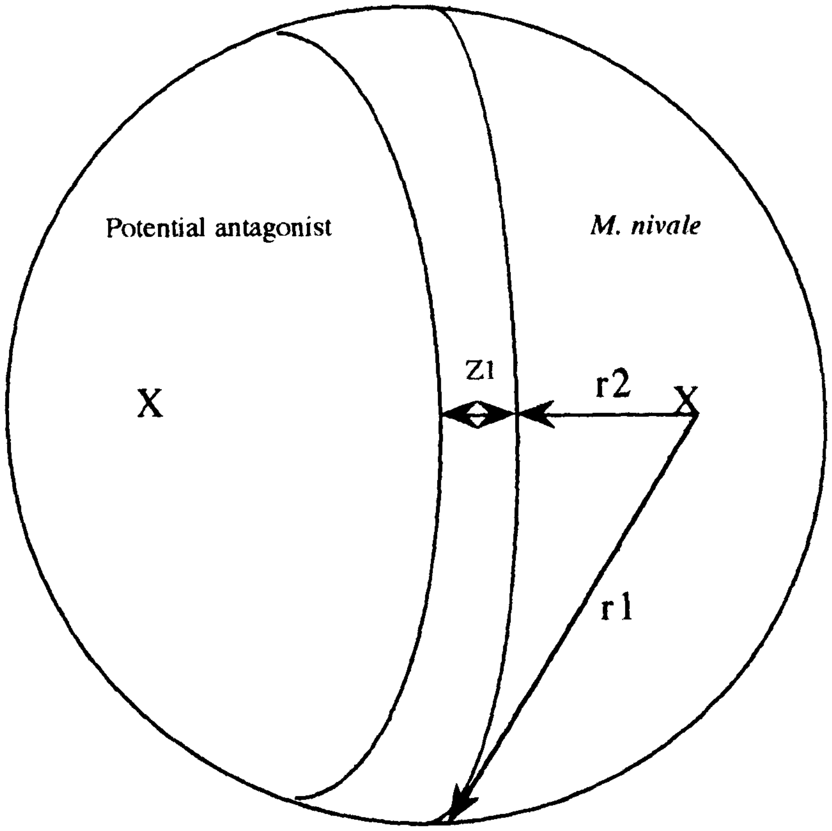
To obtain pure cultures of potential antagonists, the *L. perenne* plants were washed in warm running tap water for three minutes to remove any dead leaves and soil. The plants were then separated into leaves and roots, surface sterilised in a 10% sodium hypochlorite solution for 30 seconds, rinsed twice in sterile distilled water and blotted dry on sterile filter paper. The plant material was plated onto turfgrass extract agar. This agar was prepared from 200 grams of fresh *L. perenne* cuttings which were mixed with one litre of distilled water. To obtain the extract, the mixture was autoclaved (20 minutes at 20 lb / in) and filtered through two layers of muslin. Turfgrass extract agar (TGEA) was prepared by adding 1.5% agar (Oxoid No. 3) to one litre of filtrate before autoclaving again to obtain a sterile media. Pure cultures of each species were obtained by sub-culturing each colony of fungi and bacteria onto a fresh plate of TGEA.

Both the known antagonists and native micro-organisms were screened for activity against *M. nivale in vitro.*

4.2.3 *In vitro* screening of micro-organisms for biological control potential

The *in vitro* tests provided a clear visible result of antagonistic ability, such as inhibition of growth or lysis of the pathogen, to determine if a micro-organism could be used as a potential biological control agent. The tests were relatively quick and easy to perform, enabling a large number of isolates to be screened for activity. All the known antagonists and indigenous species isolated were screened on turfgrass extract agar (TGEA) plates using a dual-culture method. Mycelial plugs (5 mm diameter) of *M. nivale* and the test species were placed 5 cm apart. Four replicate culture plates were used for each antagonist. The plugs were taken from the margin of actively growing colonies of fungi (ten days old). Bacteria were streaked onto plates 5 cm from the pathogen and at right angles to the interacting radii. The plates were incubated at 5° C with a photoperiod of 12 hours. The growth, in mm, of *M. nivale* was recorded every 24 hours for 28 days after inoculation. Antagonistic properties were quantified using two parameters: the percentage inhibition of radial growth ($100 \times (r_1 - r_2) / r_1$) and the width of the inhibition zone (ZI) measured at the smallest distance between colonies (Figure 39).

Figure 39. Parameters for *M. nivale* inhibition: inhibition of radial growth (100 x (r_1 - r_2) / r_1) and width of the inhibition zone (Z1).



The plates were also assessed visually 28 days after inoculation to determine colony interactions.

4.2.4 Identification of antagonistic bacteria and fungi isolated from the turfgrass ecosystem.

4.2.4.1 Bacteria

Gram's stain and shape were used to initially identify bacterial isolates. The gram stain was carried out according to the following method: a smear of bacterial culture was heat fixed onto a clean microscope slide and flooded with crystal violet stain for one minute. After washing with distilled water the slide was flooded with iodine (one minute) then thoroughly washed with distilled water and 70 % alcohol. Finally, the slide was stained with safranine (red) for a further minute and rinsed in distilled water. Gram positive bacteria appear blue/purple under the microscope, whilst gram negative bacteria appear red. Gram negative species were further tested with API 20 NE test strips (API - BioMérieux, UK). The API strips consist of 20 tubes and cupules containing dehydrated media and substrates. Each tube was inoculated with a bacteria suspension in a saline solution that reconstituted the media During the incubation period (24 hours at 15° C) metabolism produced colour changes that were either spontaneous or developed upon the addition of a reagent. The assimilation tests were inoculated with a minimal medium and the bacteria only grew if they were capable of utilising the corresponding substrate. The reactions were read according to the interpretation table provided with the API kit and identification was obtained by the API computer identification software.

Gram positive rods (*Bacillus* spp.) were identified using the lecithovitellin (LV) reaction. Agar was prepared using egg proteins (yellow) and the *Bacillus* species was streaked onto the media surface. The group to which the *Bacillus* species belonged was determined by the organism's ability to produce the appropriate proteases to assimilate the lipoprotein component of egg yolk present within the agar. If a positive reaction occurred the agar turned blue.

4.2.4.2 Fungi

Antagonistic fungi were sent for identification to the Biosystemic Services Department at the International Mycological Institute, Surrey. Following the identification of indigenous antagonists, both native and known micro-organisms which appeared active against *M. nivale* from the *in vitro* screen were then tested *in vivo* in seed-tray experiments.

4.2.5 *In vivo* test of potential antagonists for antifungal activity against *M. nivale*

In vivo testing is the next step in the development of a biocontrol agent because such tests closely imitate the conditions under which the control agent will eventually have to operate. Nine potential antagonists showing high levels of *in vitro* inhibition to *Microdochium nivale* were evaluated for their biological control potential in seed trays (25 cm x 40 cm). Each of the nine treatments were replicated four times in a randomised block design. There were two control treatments comprising a control infected with *M. nivale* and a control without infection. The trays were filled with 60% perennial rye grass, *Lolium perenne* (30% cv. Master, 30% cv. Meteor) and 40% smooth stalked meadow grass, *Poa pratensis* (cv. Limousine), grown on a medium sandy loam (75% sand). The trays were inoculated with the antagonists two weeks before inoculation with the pathogen (January, 1995). Inoculation with filamentous fungi was by use of mycelial discs (10 mm) taken from the growing edge of a colony (on TGEA, 10 days old) which were pushed into the turfgrass stem bases according to the plan shown in Plate 9.

Plate 9. Distribution of agar plugs for inoculation of filamentous fungi onto the turfgrass stem base.

The bacteria and yeast species were applied at the rate of 1 x 10^8 - 1 x 10^9 cells per tray in 20 mls of distilled water and 0.1 ml of the surfactant Tween 80, the latter included to increase cell adhesion to the plant surface. The cells were taken from nutrient broth which had been inoculated with bacteria/yeast and shaken (120 rpm) for 24 hours at 25°C. After inoculation with the antagonists, all the trays were watered (tap water) and covered in clear plastic for seven days. The plastic was removed and the trays were left for an additional week to allow further build up of the antagonist population. Plugs of *M. nivale* were applied (according the method described above for filamentous fungi) two weeks after inoculation with antagonists. The trays were again covered in clear plastic for a week. After removal of the plastic, the trays were assessed for percent cover of *M. nivale* using an area quadrat (described in Plate 1, section 3.1). A final disease assessment was carried out one week later. The results were expressed as percentage area affected by *M. nivale*.

4.3 Results

4.3.1 *In vitro* screening of known antagonists

Of the sixteen known antagonists screened, nine (3 fungi and 6 bacteria) appeared effective at suppressing *M. nivale* when tested on turfgrass extract agar *in vitro* (Table 96).

Table 96. Details of micro-organisms showing antagonistic properties, *in vitro*, against *M. nivale*; mean of 4 replicates (SD). * Antagonists selected for *in vivo* screen, ‡Mode - see following page

Antagonist	Mean percent inhibition (SD)	Zone of inhibition, mm (SD)	‡Mode
FUNGI			
Trichoderma koningii	37.18 (2.02)	0.00 (0.00)	2
T. viride	0.00 (0.00)	0.00 (0.00)	4
T. piliferum	31.46 (1.41)	0.00 (0.00)	4
**T. polysporum*	45.49 (2.44)	2.00 (0.82)	5
T. harzianum	5.50 (3.67)	0.00 (0.00)	3
T. reesie	5.45 (3.94)	0.00 (0.00)	4
**Gliocladium roseum*	14.33 (4.48)	0.00 (0.00)	2
G. catenulatum	4.73 (2.10)	0.00 (0.00)	2
Chaetomium globosum	21.96 (1.44)	0.00 (0.00)	1
BACTERIA			
Bacillus cereus	3.86 (2.75)	2.75 (1.26)	5
B. subtilis	9.52 (5.26)	4.00 (0.00)	5
Pseudomonas pumilis	16.83 (1.00)	5.00 (0.00)	6
**P. aeruginosa*	7.53 (2.02)	7.50 (3.12)	6
P. fluoresens	7.27 (3.32)	7.50 (0.58)	6
P. putida	6.67 (5.77)	10.67 (1.26)	6
**Enterobacter cloacae*	6.75 (3.09)	7.75 (1.26)	6

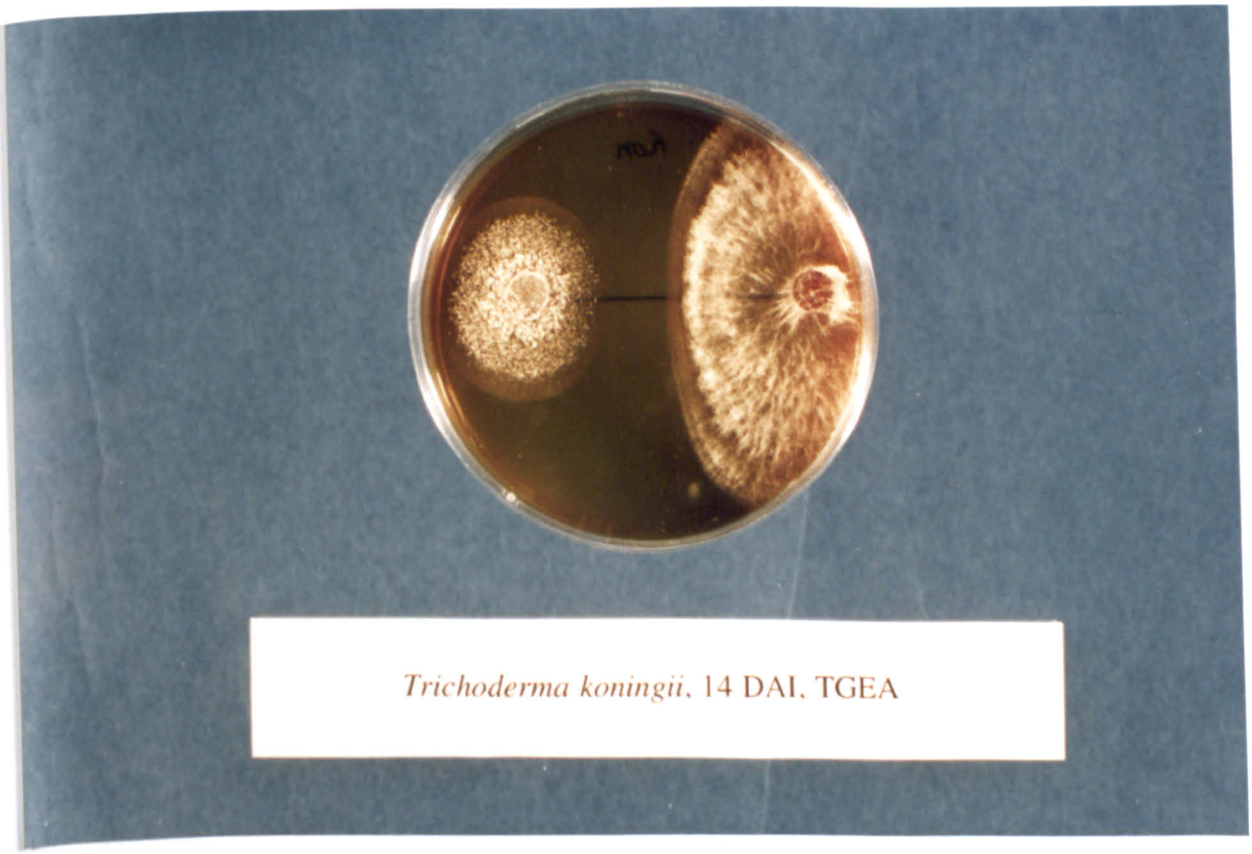
‡ Mode (based on key from Chand and Logan, 1984):

1. Antagonist overgrowing pathogen and pathogen stopped
2. Antagonist overgrowing pathogen but pathogen still growing
3. Pathogen overgrowing antagonist but antagonist still growing
4. Pathogen overgrowing antagonist but antagonist stopped
5. Mutual inhibition, approximately 2 mm in distance
6. Extreme inhibition > 4 mm distance

The following plates illustrate the effectiveness of a bacterial (*Enterobacter cloacae*, Plate 10) and a fungal (*Trichoderma koningii*, Plate 11) antagonist against *M. nivale* after two weeks. In the remaining two weeks of the experiment, the pathogen only grew an additional 2 mm and 9 mm in the presence of *E. cloacae* and *T. koningii* respectively. The mean growth rate in two weeks of *M. nivale*, grown in isolation under identical conditions (TGEA at 5^{o} C), is 42 mm.

Plate 10. *In vitro* inhibition of *M. nivale* by *Enterobacter cloacae*, 14 days after inoculation (DAI)

Plate 11. *In vitro* inhibition of *M. nivale* by *Trichoderma koningii*, 14 DAI



4.3.2 Identification and *in vitro* screen of indigenous antagonists

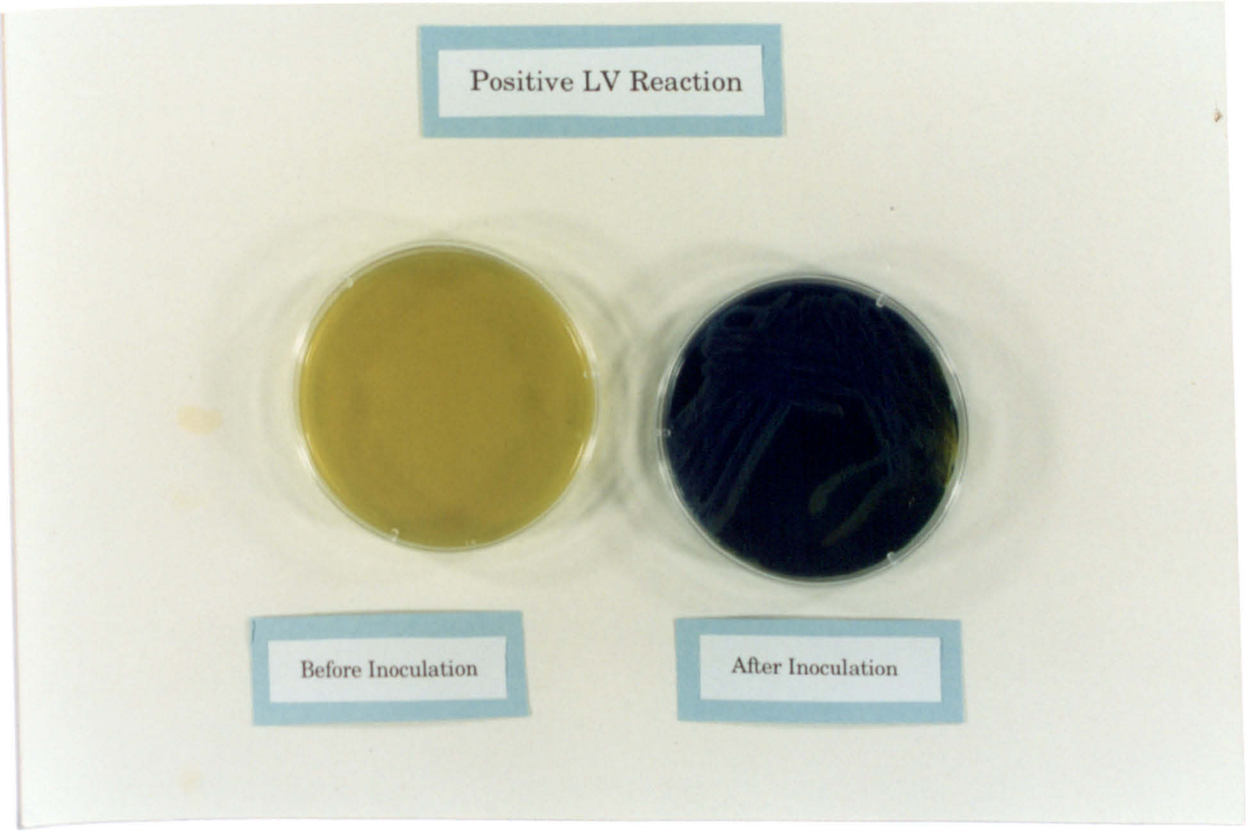
A total of 67 micro-organisms were isolated from the surface of *Lolium perenne*. Phylloplane isolates yielded 17 fungi and 12 bacteria, whilst 16 fungi and 22 bacteria came from the rhizosphere. Following the *in vitro* screen of all the micro-organisms isolated from the surface of *L. perenne*, the most effective bacteria and fungi (Table 99) were identified. The majority of the antagonistic bacteria were identified as belonging to the genus *Pseudomonas*. Table 97 summarises the identification of the antagonistic bacterial species.

Table 97. Identification of indigenous bacterial antagonists against *M. nivale*

Code No.	**Shape**	**Gram stain**	**LV reaction**	**API result**
Phylloplane PB 10	Rod	Negative (red)		*Pseudomonas cepacia*
Rhizosphere RB 3	Rod	Positive (blue/purple)	Positive	
RB 4	Rod	Negative (red)		*Aeromonas sobria*
RB 9	Rod	Negative (red)		*P. fluorescens*
RB 11	Rod	Negative (red)		*Pseudomonas cepacia*
RB 13	Rod	Negative (red)		*Pseudomonas cepacia*

The bacteria RB 3 was gram positive and rod shaped which suggests a *Bacillus* sp. Identification of a *Bacillus* bacterium to species level is very difficult. However the group to which a *Bacillus* species belongs can be determined by a simple biochemical test - the LV reaction (Plate 12). The RB 3 bacterium was LV positive which indicates it belongs to the group 1 *Bacilli*. Five species are present in this group, three of which occur world-wide in many soils - *B. cereus*, *B. cereus var mycoides* and *B. thuringiensis* (the remaining two *Bacilli* are mammalian pathogens - *B. anthracis* and *B. laterosporus*).

Plate 12. Positive LV reaction obtained from isolate RB 3 indicating the organisms ability to produce lecithinase necessary for the assimilation of the lipoprotein component of egg yolk present within the agar.



The results from the International Mycological Institute, IMI, (Table 98) indicated that the majority of the active fungal isolates were members of the genus *Trichoderma*.

Table 98. Identification of indigenous fungal species exhibiting anti-fungal activity toward *M. nivale*.

Code No.	IMI Identification
Phylloplane Fungi	
PF 6	Undergoing identification
PF 13, PF 14	*Fusarium* spp.
PF 20	*Trichoderma koningii*
P yeast	unidentified
Rhizosphere Fungi	
RF 6	*T. harzianum* Rifai
RF 11, RF 18	*T. koningii*
RF 17	*T. viride*

Of the sixty-seven indigenous species isolated, fifteen of the micro-organisms were found to be effective antagonists of *M. nivale* when screened *in vitro* (Table 99).

Table 99. Efficacy of indigenous species at controlling *M. nivale*. (* Antagonists selected for *in vivo* screen)

Code no. / antagonist	**Mean (4 replicates) percent inhibition (SD)**	**Mean (4 replicates) zone of inhibition, mm (SD)**	**Mode†**
Phylloplane Fungi			
PF 6	6.70 (5.42)	11.5 (0.71)	6
PF 13, *Fusarium* sp.	42.94 (1.01)	0.00 (0.00)	1
PF 14, *Fusarium* sp.	28.80 (5.35)	0.00 (0.00)	2
*PF 20, *T. koningii*	38.30 (5.80)	6.50 (1.29)	6
*P Yeast, unidentified	42.64 (1.07)	15.25 (1.50)	6
Phylloplane Bacteria			
*PB 10, *P. cepacia*	27.17 (4.14)	1.25 (0.50)	5
Rhizosphere Fungi			
RF 6, *T. harzianum* Rifai	48.84 (5.61)	0.00 (0.00)	1
*RF 11, *T. koningii*	56.86 (1.28)	8.50 (0.58)	6
RF 17, *T. viride*	47.84 (1.15)	3.50 (2.38)	5
RF 18, *T. koningii*	32.50 (2.23)	14.75 (0.50)	6
Rhizosphere Bacteria			
*RB 3, Gp. 1 *Bacillus*	40.76 (6.32)	14.50 (3.11)	6
RB 4, *Aeromonas sobria*	19.75 (0.35)	11.00 (1.41)	6
RB 9, *P. fluoresens*	18.97 (1.12)	7.25 (2.63)	6
RB 11, *P. cepacia*	31.51 (4.38)	2.00 (0.00)	5
RB 13, *P. cepacia*	29.75 (2.23)	5.25 (0.50)	6

† mode - see Table 96 footnote.

4.3.3 *In vivo* test for antifungal activity

Nine antagonists of *M. nivale* showing high levels of *in vitro* inhibition were evaluated for their biological control potential *in vivo*. Two known bacterial (*Pseudomonas aeruginosa*, *Enterobacter cloacae*) and two known fungal antagonists (*Trichoderma polysporum*, *Gliocladium roseum*) were chosen. Of the indigenous species, the yeast and a bacterium and filamentous fungi from both the phylloplane and rhizosphere, exhibiting the greatest inhibition to *M. nivale* growth, were selected. Disease assessments to determine percent area affected were carried out 7 and 14 days after inoculation with *M. nivale*. The data from the *in vivo* screen is shown in Table 100 and Figure 40. All nine antagonists significantly reduced disease severity compared to the positive control ($p = 0.05$). No *M. nivale* symptoms were noted on the negative control trays (Plate 13).

Plate 13. Positive and negative controls used in *in vivo* tests.

Table 100 illustrates the efficacy of the nine antagonists selected at reducing *M. nivale, in vivo*.

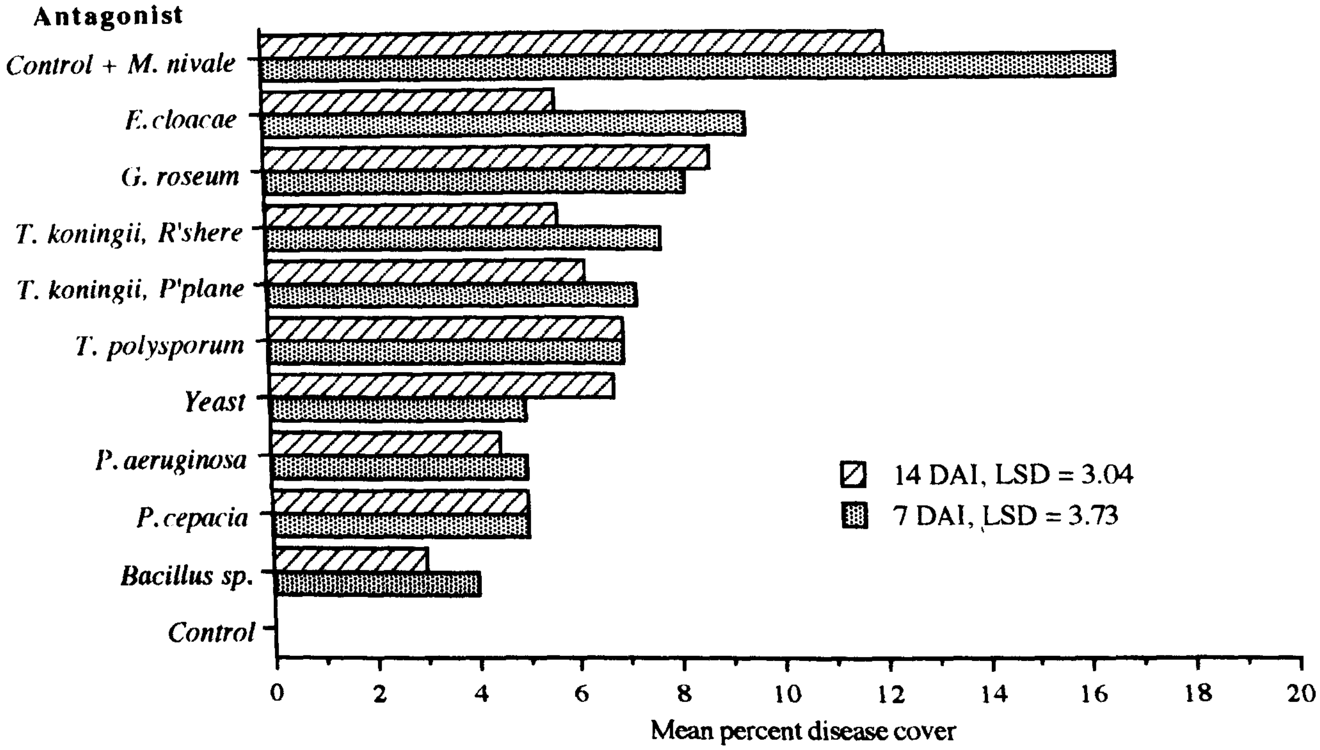
Table 100. Mean percent cover (standard deviation) of *M. nivale* (four replicates) in relation to presence of selected microbial antagonists. Results from *in vivo* tests.

Antagonist	**7 DAI with *M. nivale***	**14 DAI with *M. nivale***
Bacillus sp., rhizosphere	4.00 (2.94)	3.00 (1.41)
Pseudomonas cepacia, phylloplane	5.00 (1.63)	5.00 (2.16)
P. aeruginosa, known	5.00 (1.41)	4.50 (3.11)
Enterobacter cloacae, known	9.50 (4.04)	5.75 (2.22)
Yeast, unidentified, phylloplane	5.00 (2.83)	6.75 (1.71)
Trichoderma koningii, phylloplane	7.25 (1.50)	6.25 (2.75)
T. koningii, rhizosphere	7.75 (2.87)	5.75 (2.50)
T. polysporum, known	7.00 (1.83)	7.00 (1.63)
Gliocladium roseum, known	8.25 (3.40)	8.75 (2.63)
Control + *M. nivale*	16.75 (3.30)	12.25 (1.26)
Control	0.00 (0.00)	0.00 (0.00)
Statistical analysis: Treatment	F_{10} = 10.87, p=0.0001, LSD=3.65	F_{10} = 10.97, p=0.0001, LSD=2.60
Block	F_{10} = 1.60, p=0.21, LSD=3.65	F_{10} = 5.18, p=0.005, LSD=2.60

All the treatments consistently reduced disease levels by at least 43.3 % (*E. cloacae*, 7 DAI) compared to the infected control. A number of bacteria reduced disease by over 70% (group 1 *Bacillus* sp. - 76.1%, *P. aeruginosa* - 70.1%, *Pseudomonas cepacia* - 70.1%).

Figure 40 illustrates the mean values obtained 7 and 14 DAI. No disease was recorded on the negative control, whereas disease cover ranged between 12 - 17% over the seven day assessment period on the positive control. Overall disease severity was reduced throughout the duration of the experiment. The group 1 *Bacillus* sp. (possibly *B. cereus*, *B. cereus var mycoides* or *B. thuringiensis*) consistently appeared to reduce disease levels by the greatest amount when compared to the positive control, 76.1% 7 DAI and 75.5% 14 DAI.

Figure 40. Efficacy of potential antagonists against *Microdochium nivale, in vivo*



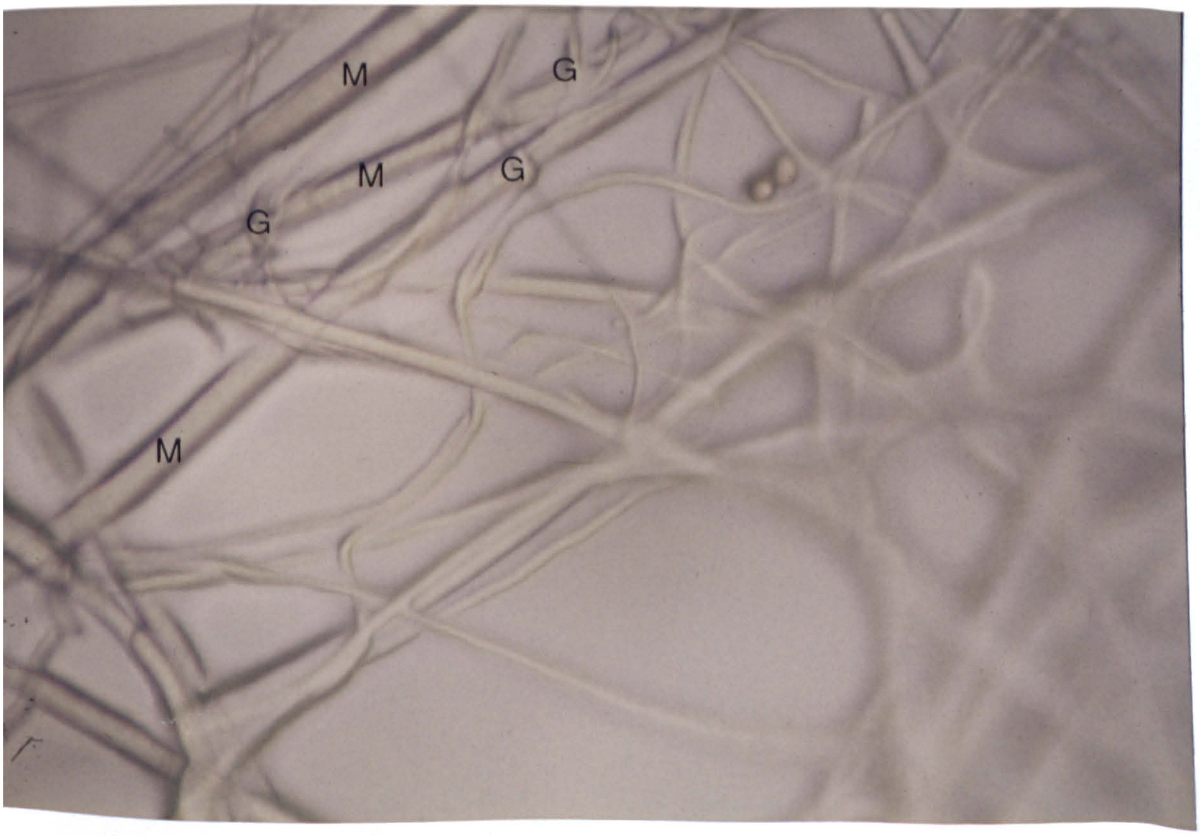
4.4 Discussion

The results obtained from this study are very encouraging. The *in vitro* screen revealed that a number of micro-organisms were antagonistic to *Microdochium nivale* on turfgrass extract agar. The *in vivo* studies confirmed these results and illustrated further that both introduced and indigenous antagonists were capable of suppressing *M. nivale* under field conditions.

From the filamentous fungi tested, the *Trichoderma* spp. appeared the most effective at suppressing *M. nivale*. Of the known antagonists *T. polysporum* and *T. koningii* were the most efficient species when tested *in vitro*; *T. polysporum* is restricted to areas where low temperatures prevail (the experiment was conducted at 5^0 C.), whilst *T. koningii* is effective under a wide range of climatic conditions. Of the native fungi, the vast majority of antagonistic species isolated belonged to the genus *Trichoderma*; *T. koningii* appeared particularly effective *in vitro*. The efficacy of this genus was confirmed in the *in vivo* studies (Figure 40) where the native *T. koningii* and the introduced *T. polysporum* appeared the most antagonistic filamentous fungi to *M. nivale*.

The *Trichoderma* species can be saprophytic or parasitic. They can utilise a wide range of carbon and nitrogen compounds which makes them very effective competitors within their natural environment. *Trichoderma* spp. are widely distributed and occur in nearly all soils and natural habitats. Species are also found on plant root and leaf surfaces. A number of species were isolated from *L. perenne* samples including *T. koningii*, *T. harzianum* Rifai and *T. viride*. The success of *Trichoderma* (and the related genus, *Gliocladium*) as a biocontrol agent maybe because of several modes of antagonism the species are capable of utilising. Four mechanisms for biocontrol by *Trichoderma* and *Gliocladium* are suggested (Papavizas, 1985). These are lysis, antibiosis, competition and mycoparasitism. Lysis involves the production of hydrolytic enzymes including cellulase, glucanase and chitinase. Enzymic activity can cause the disorganisation of host cells, coagulation of cytoplasm and loss of contents from organelles (Lifshitz *et al*, 1986). Antibiotics produced include carbon dioxide, ammonia, hydrogen cyanide and ethylene (volatile) and trichodermin, suzakacillin and dermadine(non-volatile) (Dennis, 1971a, b). The hyphae can also coil around and parasitise other fungi causing disorganisation of host cell contents, illustrated in Plate 14 with *Gliocladium roseum* and *M. nivale*.

Plate 14. Hyphal coiling (mycoparasitism) of *G. roseum* (G - narrow hyphae) around *M. nivale* (M - wide hyphae).



The size of the host hyphae could provide a physical barrier to penetration; if the hyphae of the antagonist were wider than those of the host, penetration would be physically impossible. However, Plate 14 also illustrates that the hyphae of *M. nivale* are wider than those of *Gliocladium roseum*, therefore *M. nivale* was susceptible to mycoparasitism by the *Trichoderma* spp. and *Gliocladium* spp. The results from the *in vitro* studies indicated that *G. roseum*, *G. catenulatum* and *T. koningii* (known antagonists) and the native *T. harzianum* Rifai were capable of overgrowing *M. nivale* and reducing or preventing any further growth, again suggesting that mycoparasitism is contributing to pathogen suppression. *Trichoderma* spp. may also increase plant growth by manufacturing a growth stimulating factor which increases primary production within the plant. The resulting increased growth may render the plant less susceptible to disease attack or if infection does occur, symptoms are partly masked (Windham *et al*, 1985). To date, *Trichoderma* spp. are the most important and widely used fungal biocontrol agents. The species is commercially available in various formulations and is used to control many soil-borne and phylloplane diseases, e.g. F-Stop, a *Trichoderma* product used to control damping off (caused by *Fusarium*, *Rhizoctonia* and *Pythium* spp.) of peas beans and corn.

In addition to the fungal genera *Trichoderma* and *Gliocladium*, *Chaetomium globosum* also appeared effective at arresting the growth of *M. nivale in vitro*. This species produces the antibiotic chaetotomium. The compound is highly insoluble in water and firmly bound to the hyphae (Tveit and Wood, 1955). The inhibition zone produced by *Chaetomium* was less well-defined, presumably because insufficient antibiotic was able to pass into the agar; inhibition was more notable on contact between the two colonies (Table 96). The indigenous phylloplane fungi, PF13 and PF14 also appeared to reduce *M. nivale* growth *in vitro* effectively (Table 99). The strains were later identified as *Fusarium* spp. which suggests cross protection was the inhibitory mechanism involved. Suppression may have occurred either by induction of natural defence mechanisms within the plant or effectively competing with the pathogen for nutrients and space on the leaf surface.

Of all the fungal species tested, the epiphytic yeast species appeared the most effective at suppressing *M. nivale* both *in vitro* and in the *in vivo* study. Little is known about the mode of antagonistic action of yeasts, although antibiotic material has been separated from *Sporobolomyces ruberrimus* (cited by Blakeman and Fokkema, 1982). Nutrient competition also plays a major role in antagonism by *S. roseus* (Janisiewicz *et al*, 1994). Yeasts may well provide suitable biocontrol agents for commercial production as they are relatively easy to culture and tolerant to environmental extremes, e.g. anaerobic conditions.

Overall, the results of the *in vivo* tests indicate the bacterial species (particularly from the genus *Bacillus*) are efficient in reducing the incidence and severity of *M. nivale* infection. The effectiveness of *Bacillus* spp. may be attributable to their ability to form spores which survive passive distribution in conditions not favourable to other bacteria. Members of the genus also possess a wide range of physiological abilities which leads them to be found in almost every conceivable type of natural environment from sub-Arctic soil to thermal springs (Turnball *et al*, 1990). In addition to the competitive abilities of *Bacillus*, the *in vitro* tests also revealed that all the bacterial species screened produced inhibition zones (Table 96 and Table 99). An inhibition zone indicates that diffusible anti-fungal compounds were produced which were effective at arresting the growth of *M. nivale*. In addition to antibiosis, the *Pseudomonas* spp. are also capable of producing siderophores (extracellular low molecular weight compounds) which may assist bacterial growth on the phylloplane. Siderophores are able to absorb ultra violet radiation which may increase persistence of the cells on the leaf surface by reducing sensitivity to extreme environmental conditions (cited by Blakeman and Fokkema, 1982). Siderophores can also act as iron chelating agents, i.e. complex available iron which may inhibit the growth of pathogenic micro-organisms (Duijff *et al*, 1994). Fungitoxic metabolites produced by *Pseudomonas* species include 2,4-diacetylphloroglucinol by *P. fluorescens* (Ownley *et al*, 1992), nitrosguanidine by *P. putida*, pyrrolnitrin by *P. cepacia* (Cartwright and Benson, 1995) and *P. aeruginosa* produces the anti-fungal agent pyocyanin (Cowan and Steel, 1993). In addition to antibiotic production, *P. cepacia* and *P. putida* are also very competitive within the natural environment (cited by Leifert *et al*, 1993). All of the *Pseudomonas* spp. cited above were very effective at suppressing *M. nivale* growth *in vitro*, whilst *P. cepacia* was the most effective biocontrol agent (after the native *Bacillus* sp.) at reducing *M. nivale* severity *in vivo*. The final bacterial species tested was *Enterobacter cloacae* which produced one of the largest inhibition zones of the known antagonists *in vitro* (Table 96). The species was also tested *in vivo*. The mechanism of action has been described as nutrient competition and production of volatile antibiotic compounds such as ammonia (Leifert *et al*, 1993).

Despite the encouraging results obtained from the biocontrol studies and the obvious advantages biocontrol provides (high specificity, reduced cost, possible genetic improvement, increased safety, reduced persistence), there can also be numerous disadvantages. These include possibilities of genetic mutation, product stability/storage problems, patent protection, influence of environmental conditions and speed of action; biofungicides are slow acting compared to chemical control. However, possible improvements could be implemented in antagonist selection and application procedure.

The first step in improving biocontrol is to determine the ecological strategy of the pathogen, e.g. does the pathogen exhibit ruderal characteristics (short-lived, high growth rate, abundant spores, colonises rapidly) or is it a slower growing, more stress tolerant species? The selection of an appropriate biocontrol agent (BCA) should also be approached in the same manner. If a BCA possesses ruderal characteristics it can function as a protectant biofungicide (if in position before infection). Alternatively, a more competitive species can be used as a curative measure when the pathogen has already invaded the host. The pathogen has to be displaced and the resource captured and defended rather than colonised. Many antibiotic producers act as competitors. Alternatively BCAs can reduce pathogen inoculum potential by lysis or parasitism of dormant propagules. Finally, a BCA must be stress tolerant, particularly those used on the leaf surface; fungi are better equipped than most bacteria to persist for extended periods of time because of their ability to produce specialised resting structures. The potential BCAs utilised against *M. nivale* in this *in vivo* study (*Trichoderma* spp., *Gliocladium roseum*, yeast sp., *Bacillus* spp., *Pseudomonas* spp. and *Enterobacter cloacae*) all have a high competitive ability in defending a captured resource (nutrients, oxygen, space). The antagonists used are also capable of antibiosis which further increases their competitive ability. In addition, pathogen inoculation potential can be further reduced by lysis or parasitism of dormant propagules; *Trichoderma* and *Gliocladia* are capable of both lytic enzyme production and mycoparasitism. The metabolic versatility and the ability to degrade a number of organic substrates enables *Trichoderma* and *Gliocladia* to survive in many ecological niches, making them an ideal BCA. The ecological strategy of the pathogen and the proposed BCAs should be the initial consideration in a development programme. There may be several different stages of the pathogen life-cycle which could be attacked and a combination of varying BCAs with different suppression strategies to optimise every possible niche could be used to maximise biocontrol potential.

Successful application of a BCA is crucial if a biocontrol programme is to be accomplished. For example, *Trichoderma* spp. proliferate abundantly in soil when added as young mycelia in contact with a food base (Papavizas, 1985). Young hyphae may produce toxic metabolites when in the presence of a suitable substrate which can be used to their advantage in colonisation of turfgrass plants. Application can be further improved by addition of the BCA to seed. This protects the seed surface and also provides the opportunity for BCAs to become pioneer colonisers of roots and above ground structures, which imparts an early defence mechanism. Seed treatments require a small amount of material applied per unit area and also ensure immediate contact with the target site, making the system more attractive and economically profitable, e.g. 'Quantum 4000 HB', a commercial formulation of *Bacillus subtilis* which is used to inoculate peanut, bean and corn seed against *Rhizoctonia* root rot. Another possible strategy to improve successful application and efficacy of a BCA is to extract the anti-fungal compound and apply directly. Using this method the BCA is less prone to environmental stress. Murray *et al* (1986) reported the inhibition of *M. nivale* spore germination in the presence of gramicidin S extracted from the bacteria *Bacillus brevis*.

In addition to the direct application of BCAs and/or their anti-fungal metabolites, a number of cultural practices to increase native antagonistic microflora can also be employed. Using *Trichoderma* as an example, if dry conditions within the soil are maintained, populations of the fungus decrease. *Trichoderma* activity is favoured by acidic soil conditions which is particularly beneficial for the control of *M. nivale* because the disease is encouraged under alkaline conditions. Finally, the addition of organic materials will help to reduce fungistasis (prevention of spore germination and hyphal growth) and so increase the potential of antagonistic *Trichoderma* spp. Application of compost may also introduce large populations of other antagonistic micro-organisms, which may also effectively suppress disease.

The success of biological control can be further enhanced by the use of recent advances in biotechnology. Production of new strains of BCA for establishing effective biological and chemical control can be attained by inducing fungicide-tolerant stable biotypes. This is achieved by exposing the BCA to high levels of pesticides and selecting the surviving colonies. As a result of pesticide-tolerant BCAs, both biocontrol and chemicals can be used in an integrated disease management strategy, e.g. the use of benomyl-tolerant *Trichoderma harzianum* against *Pythium* disease on turfgrass (Brown and Cranshaw, 1989). Mutagenesis has also been successful in increasing enzyme production to develop new 'hyper-antagonistic' biotypes. The application of techniques for protoplast fusion and gene cloning will result in the further development of new technologies for genetic manipulation and improvement of BCAs and perhaps also provide a more commercial incentive.

To summarise, the next step in formulating a successful biocontrol programme for *M. nivale* on sports turf is to conduct a detailed ecological strategy of the pathogen (see following chapter) and select a number of BCAs identified from this study with different modes of antagonism to apply at vulnerable stages during the pathogens' life-cycle. Following these initial steps, an effective delivery system needs to be developed and tested along with the efficacy of the BCAs selected under field conditions. By the integration of pesticide-tolerant BCAs and the use of chemical control at a reduced level it may be possible to successfully manage *M. nivale* on sports turf. The use of biocontrol will help to reduce reliance on chemical control, thereby delaying the onset of resistance and prolonging the efficacy of expensive, valuable chemical resources.

4.5 Conclusion

The results from the study indicate that *M. nivale* on winter sports is a suitable candidate for biological control. A number of introduced and native micro-organisms appear to suppress the disease both *in vitro* and within the turfgrass system itself. Sports turf provides an ideal environment for the implementation of successful biocontrol. The area involved is relatively small and the system is more 'contained' (compared to a number of agricultural systems) thus the turfgrass manager has a greater influence over abiotic conditions which can be manipulated to encourage the proliferation of BCAs. It is unlikely that biocontrol alone will be effective at reducing turfgrass diseases below a damaging level and chemical control still provides a very powerful tool against disease. However, a transition from chemical to chemical/biological control appears inevitable. The development of a microbial BCA is estimated at $5m and takes three years compared with $40-80m and 8-12 years for a pesticide. Studies project that by the end of the century, the annual first world market for microbial pesticides will grow from the current $33-45m to $6-8b (Woodhead *et al*, 1990).

Before the realisation of the potentially disastrous side effects of pesticides there was no incentive for biocontrol research, because of the success of these effective and relatively cheap chemicals. The environmental effects and potential safety hazards of chemical pesticides have now been fully recognised which may provide the incentive for more commercial biocontrol research, e.g. the use of current biotechnology to produce pesticide resistant BCAs.

To conclude, the use of fungicide tolerant BCAs in conjunction with decreased levels of chemical input may effectively reduce *M. nivale*. The implementation of cultural practices to promote a more vigorous turfgrass sward and encourage native antagonistic microflora whilst reducing pathogen inoculum potential as part of an IDM plan will also help to economically and efficiently reduce the disease on winter sports turf. The combination of biological, cultural and chemical control measures to manage turfgrass diseases are discussed in the following chapter.

Chapter Five:

An Integrated Disease Management Strategy For Winter Sports Turf

5.0 An integrated disease management (IDM) strategy for winter sports turf.

The survey ('Major diseases, pests and weeds on winter sports turf'), discussed in chapter two, revealed that red thread (*Laetisaria fuciformis*) and fusarium patch (*Microdochium nivale*) were the most significant diseases on both moderate and high maintenance winter sports turf. The previous two chapters (chapter 3 - 'Cultural control' and chapter 4 - 'Biological control') have illustrated that a number of cultural practices and possible biocontrol agents are available which reduce the incidence of both diseases on winter sports turf. The following section attempts to integrate the results obtained from this study with a number of recognised beneficial management practices which may help to reduce disease incidence and severity whilst maintaining turf quality and vigour.

5.1 Introduction

Integrated disease management is a broad, multidisciplinary and systematic approach to controlling disease. All types of control methods (biological, cultural, chemical, genetic and legislative) are utilised. Use of IDM strategies should result in effective and economic disease suppression with a minimum effect on non-target organisms and the environment. Plate 15 illustrates that there are a number of pieces to the IDM 'puzzle'. These pieces are interlocked and must be fitted together in a certain way depending on site, disease potential and environmental conditions.

Plate 15. Integrated disease management 'puzzle' (Shurtleef *et al*, 1987)

This integration of techniques must be compatible with sound turf management practices. The cost of control measured over a period of years must also be considered. The management strategies selected should be economical and practical based on labour, equipment and money available. Successful IDM is based on understanding the biology and ecology of the turfgrass community to be protected and the pathogens to be controlled.

5.2 The target pathogens

The initial step in a successful IDM strategy is correct identification of the disease-causing agent. Accurate identification is very important because the control of one disease may encourage another, e.g. increasing nitrogen rate to control red thread could stimulate the expression of Fusarium patch symptoms. Following a positive identification, a detailed understanding of the pathogen's life-cycle and ecology should be determined; particularly if the use of biocontrol is considered, which can be applied when the pathogen is most susceptible to microbial attack. The following sections examine the biology and epidemiology of the two major diseases on winter sports turf - red thread and Fusarium patch.

5.2.1 *Laetisaria fuciformis*, red thread

Red thread is caused by *Laetisaria fuciformis* (anamorph *Isaria fuciformis*). The pathogenic fungus was first described by Berkeley (1873) who discovered the disease on cereals in Australia; in 1916 the disease was noted in England and named *Corticium fuciforme* (Bahuon, 1985). Serious injury to turf attributed to red thread was recognised in the U.S. in 1934 (Erwin, 1941). Burdsall (1979) showed that more than one fungus makes up the disease. Stalpers and Loerakker (1982) described three pink species of Corticiacae (Basidiomyces) making up the disease complex on turfgrass. *L. fuciformis* (responsible for red thread) and two *Limonomyces* spp. responsible for pink patch. Kaplan and Jackson (1983) recorded that *L. fuciformis* was the predominant group in the complex. Red thread is now recognised to be of widespread distribution on sports turf and agricultural grasses in the cooler humid regions of Australasia, N. America, N. Europe and the U.K (Smith *et al*, 1989).

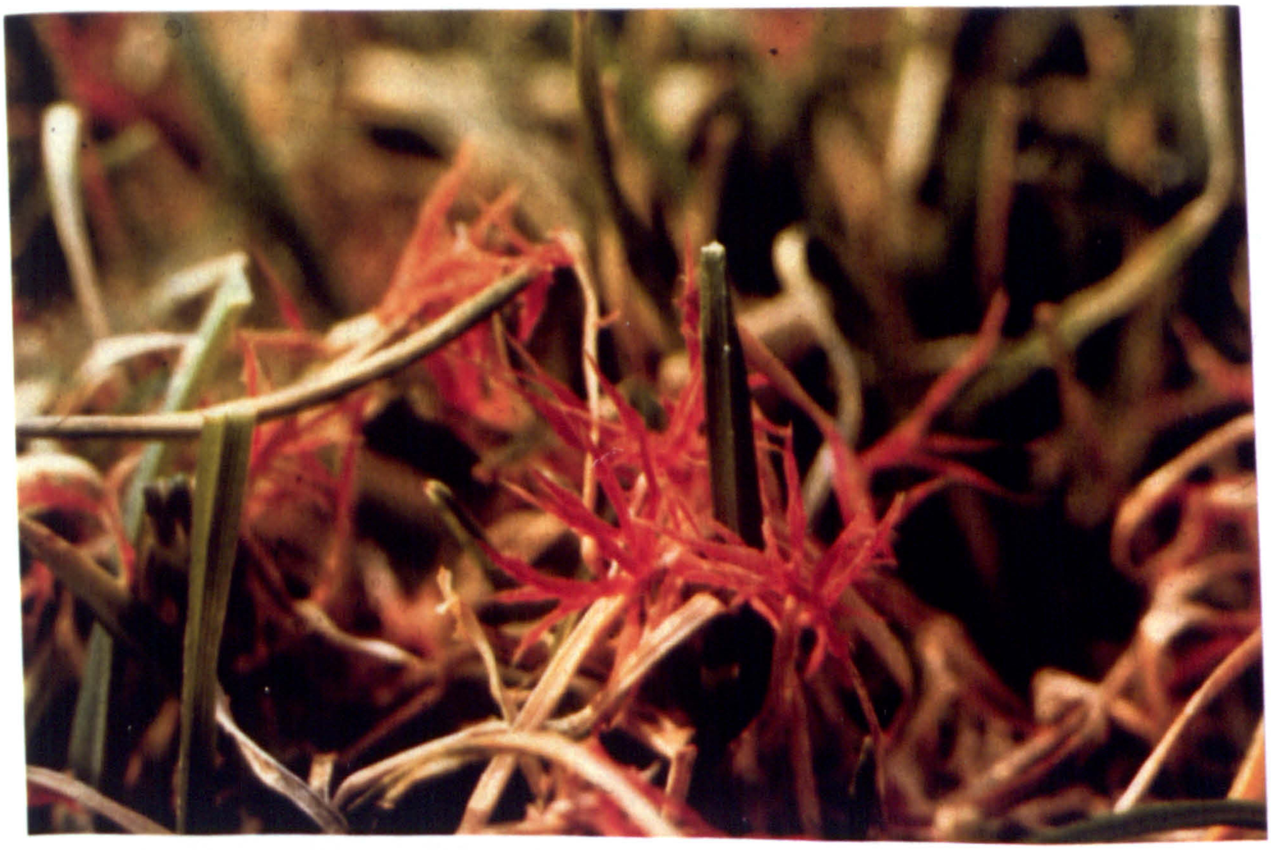
Symptoms

Circular or irregularly shaped, small to large patches (5-50 cms in diameter) of infected grass become water soaked and die rapidly (Plate 16). The tan colour of dead leaves may be the first symptom observed. The patches may coalesce to form large areas of infected turf. Only the foliage is infected and death usually proceeds from the leaf tip downward.

Plate 16. Characteristic dead patches in red thread infected turf.

In humid conditions the fungus produces distinct mycelial structures; pink to red or orange fungal growth called red threads (sclerotia) which may extend up to 10 mm beyond the end of the leaf tip (Plate 17) (Smiley, 1992). The red threads resemble spear points when simple but often have short branches which resemble a small seaweed, *Fucus* hence *fuciforme* (Bennet, 1935).

Plate 17. Red thread needles (sclerotia) of the fungi on perennial rye grass



Causal Agent

Laetisaria fuciformis, formerly *Corticium fuciforme*, causes red thread. The fungus forms a web-like pale reddish mycelium that surrounds and connects the leaf blades. Antler-like processes, sclerotia, develop beyond the leaf tips. Cottony flocks are pink and brittle and consist of masses of anthroconidia. The anthroconidia are hyaline, ellipsoid to cylindrical (5-17 x 10-47 μm). Tiny basidiocarps may also be produced on dead infected tissue. Hyphae are multinucleate and do not have clamp connections (Smiley, 1992).

Disease Cycle

The fungus survives unfavourable periods as sclerotia on infected leaves or lying in the thatch. These threads survive high (32° C) or low (-20° C) temperatures and remain viable for up to two years when dry. The pathogen is spread locally by anthroconidia, up to 12 million can be produced per square inch (Hims *et al*, 1984), or sclerotia transported by running water, equipment, people and animals. The anthroconidia and infected plant debris may also become windborne and bring about long distance dissemination. The importance of basidiocarps in the disease cycle is uncertain. A film of moisture over the leaf surface is necessary for the germination of mycelia in the sclerotia and anthroconidia (and possibly basidiospores). The fungus may kill leaves within two days of primary infection (Smiley 1992).

Epidemiology

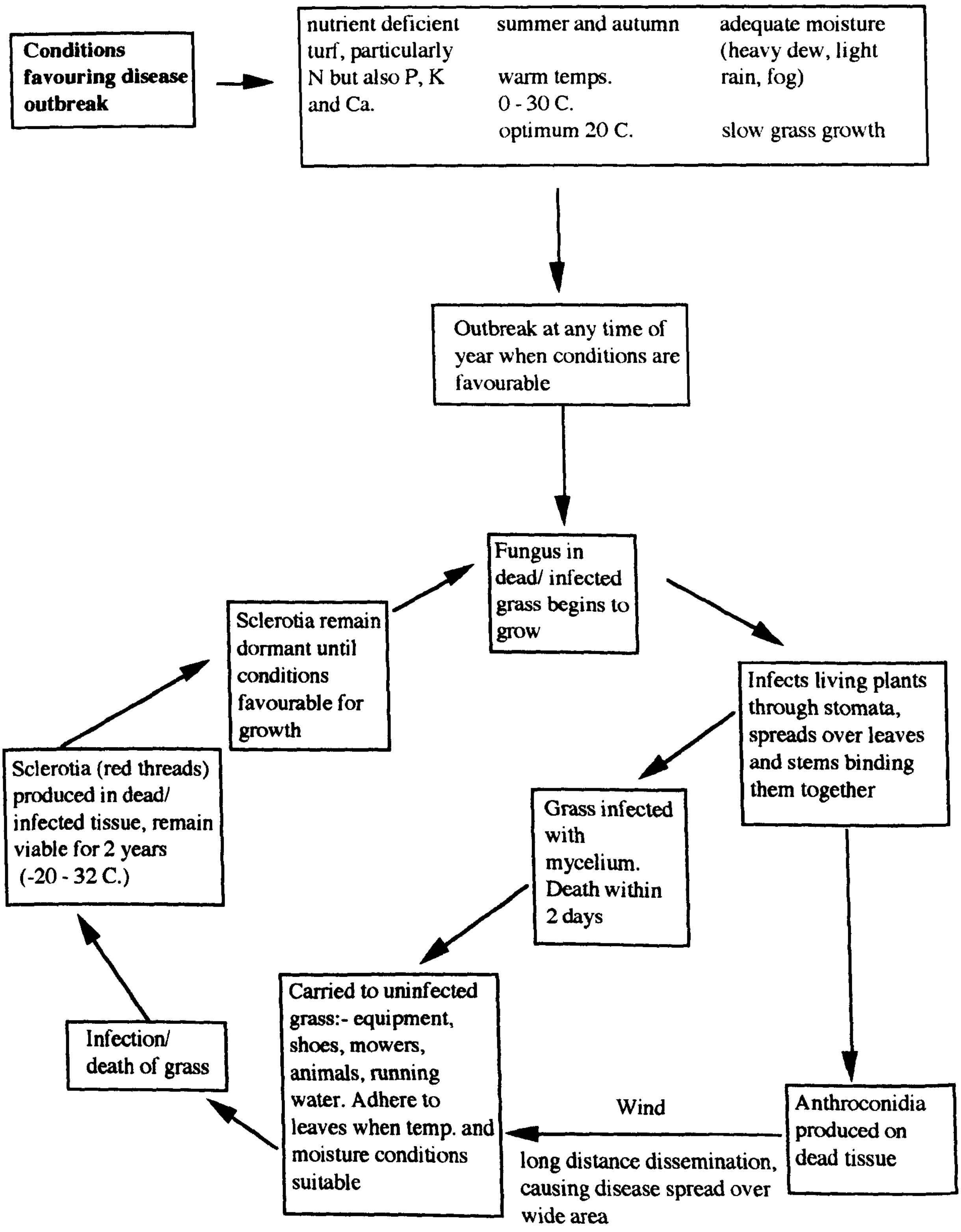
Red thread is especially prevalent during the spring and autumn on slow growing nitrogen deficient turf, particularly on sandy soils (Hims *et al*, 1984). However O'Neill (1985b) has noted a widespread occurrence on well-fertilised turf. It is most severe when potassium, phosphorous and calcium as well as nitrogen are deficient (Muse and Couch, 1965, Goss and Gould, 1971). It may cause severe damage to *Agrostis, Festuca, Lolium* and *Poa* spp. in humid and cool temperate regions of the world (Smith *et al*, 1989). Damage largely depends on the state of the turf as well as environmental conditions. Attacks can be transient or far more severe, although after infection the fungus remains in the turf in a dormant condition ready to resume active growth or produce spores for dissemination when appropriate weather conditions ensue. Thus the disease may not only become worse in succeeding years but it may also extend extensively in the area, so that even mild attacks cause problems (Bennet, 1935). Prolonged periods of moisture-saturated air promote rapid growth and infection by the disease. Heavy dews, light rains and fog are especially favourable for disease development. The pathogen is capable of growth at temperatures between 0 and 30° C (Smiley, 1992); the disease has been noted in hot summers and under receding snow cover (O'Neill, 1985b), although the optimum temperature for growth is 20° C (Hims *et al*, 1984).

Figure 41 provides a summary of the epidemiology and life cycle of red thread disease.

Figure 41. Summary of disease cycle and epidemiology of red thread

Red thread, *Laetisaria fuciformis*

Facultative saprophyte



5.2.2 *Microdochium nivale*, Fusarium Patch Disease.

Pink snow mould and ***Fusarium*** patch are caused by *Microdochium nivale*. The diseases have been recognised since the mid-1800s (Sanders and Cole, 1981). Pink snow mould is used to describe the disease associated with snow melt; ***Fusarium*** patch describes the disease when it occurs without snow cover. The disease can occur all year in cool, humid regions, e.g. N. Europe and N. America (Dahl, 1933) and damages nearly all grass species. ***Fusarium*** patch is the most common disfiguring disease on fine turf and is also commonly found on coarser turf, e.g. football pitches and cricket outfields (Smith *et al*, 1989).

Symptoms

Circular patches of affected turf may develop whenever prolonged periods of cool wet weather occur. The disease usually only attacks leaves but when conditions are favourable for longer periods, it spreads to the stems and crowns (Dahl, 1933). The patches first appear as small, water soaked spots less than 5 cm in diameter; they then rapidly change colour from orange-brown (Plate 18) to dark brown and finally light grey.

Plate 18. Circular patches of Fusarium patch disease.

The spots may enlarge indefinitely and coalesce (Plate 19). Under snow cover or in very wet conditions, a thin fluffy covering of white mycelium may be seen on matted leaves. On exposure to sunlight, spores are produced and the matrix of spores and mycelia turn pink.

Plate 19. Large irregular scars of Fusarium patch formed when circular spots coalesce under favourable conditions.

Causal Agent

M. nivale (teleomorph *Monographella nivalis*), formerly named *Fusarium nivale* and *Gerlachia nivalis*, causes *Fusarium* patch and pink snow mould. The fungus produces a septate mycelium without clamp connections. Salmon pink sporodochia are produced in abundance when temperatures are cool, whilst the conidia (2.5-5.0 x 10-30 μm) are mostly one- to three-septate and lack a typical *Fusarium* foot cell.

Disease Cycle

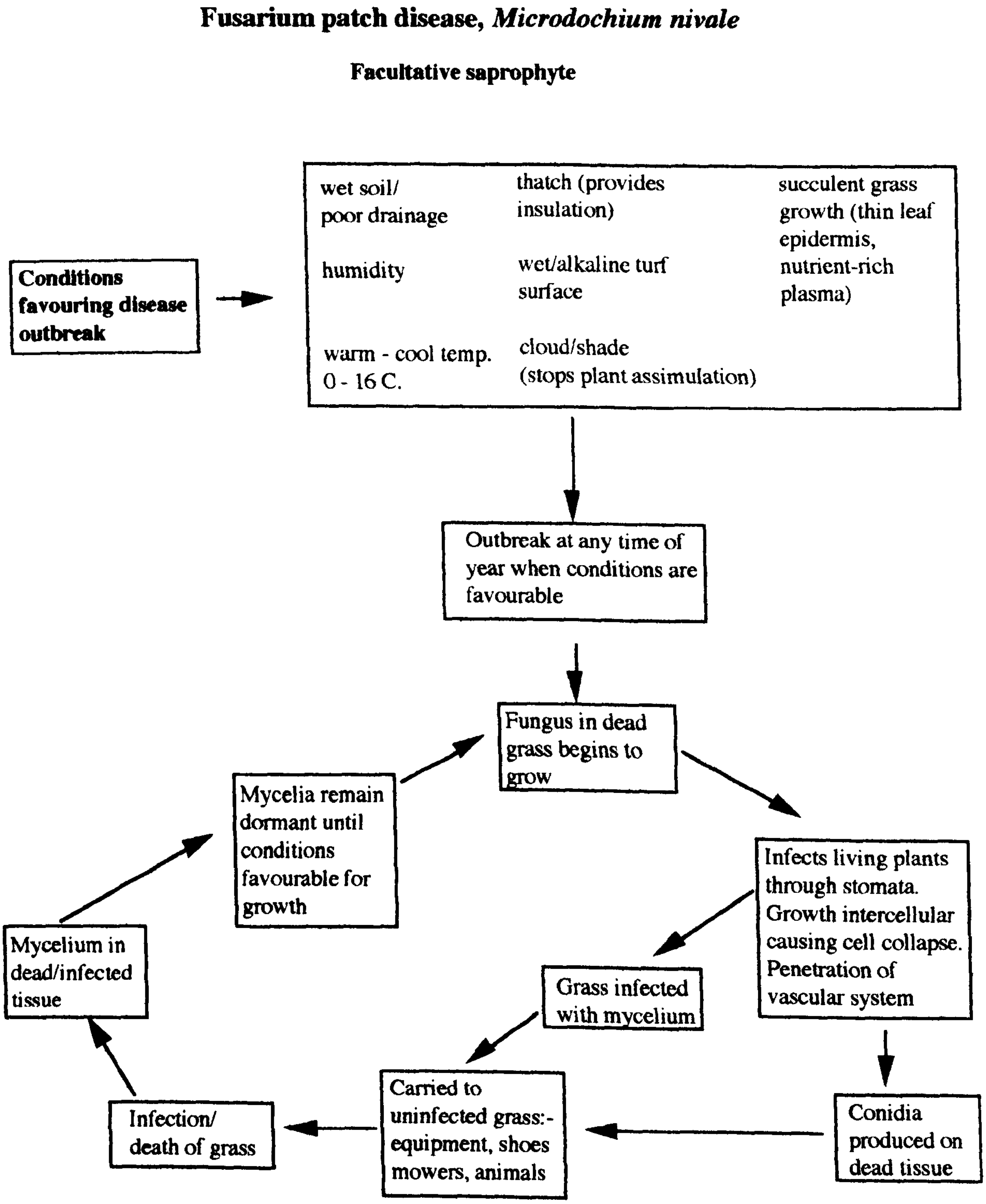
Details of the development of *Fusarium* patch have been understood for over sixty years (Sanders and Cole, 1981). *M. nivale* survives unfavourable periods in infected plants and in dead debris. When conditions are favourable, mycelia of the pathogen grow from infected debris or from germinating conidia to infect leaves. Histological studies indicate that mycelia develop along the outside of the leaf, penetrate the stomatal opening, and then grow through the inter-cellular spaces. Following the collapse of cells the fungus then penetrates the vascular system (Sanders and Cole, 1981). Initial growth of the fungus is slow and infections may go undetected for several weeks. Infection spreads rapidly under wet conditions and between 0° C and 16° C. The disease becomes inactive as the turf grass canopy dries during sunny warm periods. Spores and infected debris are easily carried on equipment wheels, mowers, animals and shoes.

Epidemiology

Disease is most severe when heavily thatched, stressed turf is growing slowly (Sanders and Cole, 1981). These conditions prevail during cool (0-8° C) and wet periods or under heavy mulches that cover unfrozen turf. Alternate thawing and snow cover, short periods of cold followed by mild conditions (Holmes and Channon, 1975), repeated frosts, cold fogs and light drizzling rain are particularly favourable for leaf to leaf spread of the fungus. When humidity or surface moisture is low, the rate of spread is very slow (Smiley, 1992). High nitrogen fertility which promotes succulent grass with a thinner epidermis can increase susceptibility, whereas high levels of potassium tend to suppress the disease (Goss and Gould, 1968). Dahl (1933) recorded an increase in disease with high nitrogen input; upto 90% of the plot was affected. The disease is favoured by poor drainage and by long leaf blades that become matted down producing pockets of high humidity. *Poa annua* (and a number of other weed grass spp.) and *Agrostis* spp. are severely affected although *P. pratensis, Lolium perenne* and *Festuca* spp. can also be affected (Smiley, 1992). The disease can occur on all soils from sand to clay, although the heavier, fertile, less freely draining soils are more prone to attack. Recovery from the disease on sandy soils may take longer because of a lack of nutrient and water supplies (Smith *et al*, 1989). The disease is more active in shady/cloudy conditions or where light is absent, e.g. under snow. In the absence of light, plant assimilation stops but respiration continues and carbohydrate sources become depleted, rendering the plants more susceptible to disease attack (Dahl, 1933). The disease can also be more severe over buried heating systems (Smith *et al*, 1989). Weeds frequently colonise the weakened patches as the grass is less competitive (Dahl, 1933).

Figure 42 provides a brief summary of the life-cycle and epidemiology of Fusarium patch disease.

Figure 42. Summary of disease cycle and epidemiology of Fusarium patch



5.3 Integrated disease management

Following identification of the disease-causing organism, an effective integrated disease management strategy can be devised. This involves the co-ordinated use of multiple tactics into an integrated system. These strategies encompass cultural, biological and chemical control. The basis of any successful disease management plan is appropriate cultural management. Disease susceptibility in turf is primarily governed by environmental and cultural factors associated with turfgrass management. For disease outbreak to occur, three conditions are necessary: a susceptible host, a virulent pathogen and a favourable environment. Good cultural procedures help to ensure optimum conditions for turfgrass growth, whilst creating an unfavourable environment for pathogen dissemination. The management factors that influence turfgrass diseases include construction/establishment, species selection, fertilisation, irrigation, drainage and mowing.

5.3.1 Cultural practices.

1. Location and construction

The initial decision for the turfgrass manager to consider is pitch location. The most appropriate site has well-drained, fertile soil and good air circulation. Pitch construction largely depends on use, indigenous soil type and financial resources available. Turf quality and vigour will be greater on a well-drained pitch, making disease incidence less likely. Results obtained in chapter 3 (cultural control, section 3.4) concerning the effect of construction type on disease incidence, indicate that red thread was greatest on the 'sand profile', whilst Fusarium patch incidence was increased on the heavier, more fertile, less freely-draining soil. Overall, a moderately well-drained pitch, e.g. 'pipe and slit drainage', reduced incidence and severity of both diseases whilst maintaining turf vigour when subjected to artificial football-type wear treatment during the winter.

Initial turf growth and vigour will be increased if grown in a well prepared seedbed. Seedbed preparation should result in a firm granular soil for rapid establishment and a root zone possessing adequate infiltration, aeration and drainage properties. Good soil preparation to ensure a well established sward and reduced disease incidence comprises of the following steps:

A. Control of persistent weeds (use of a broad-spectrum herbicide, e.g. glyphosphate).
B. Removal of rocks and debris.
C. Ploughing/cultivation to produce a reasonably fine tilth.
D. Surface grading to smooth out the seedbed surface.
E. Complete fertilisers with balanced proportions of N, P_2O_5 and K_2O should be harrowed in prior to seeding/turfing.

Seedling diseases can be a major problem during pitch establishment. During the seeding process, a number of these diseases (*Rhizoctonia*, *Fusarium* and *Pythium* spp.) can be reduced by sowing at the optimum rate for the selected seed mix (see next section). The rate of sowing depends on sward purpose and the grass species used. Disease outbreak is caused by high seedling densities from planting at increased seed rates coupled with excessive irrigation. Finally, the optimum time to sow for good establishment is between spring (April) and late summer (August) when soil temperatures are warm.

2. Species/cultivar choice.

The majority of cultural practices discussed in chapter 3 to reduce disease outbreak focused on the use of species and cultivar mixtures. The initial choice of turfgrass species and cultivars is fundamental in terms of disease management. A susceptible host is one of the three prerequisites for disease outbreak (the remaining two being a virulent pathogen and favourable conditions). Certain grass species are more susceptible to disease than others, e.g. *Lolium perenne*, perennial rye grass, is more susceptible to red thread, whereas *Agrostis* spp. are more susceptible to Fusarium patch. In addition, certain perennial rye grass cultivars are available that are more tolerant to red thread; cvs. Prester and Juwel were more tolerant to red thread when grown in monoculture compared to cvs. Entrar and Cartel (section 3.3)

In addition to the variation in susceptibility between individual species/cultivars, results from chapter 3 also illustrate that red thread and Fusarium patch incidence can be reduced by utilising species mixtures and cultivar blends (section 3.1 and 3.3). Mixtures of turfgrass species/cultivars mimic the diversity and stability of a natural ecosystem where disease epidemics are rare. Section 3.1 illustrates the particular effectiveness of species mixtures at suppressing both diseases. Disease incidence was lowest when a 50% *Lolium perenne* and 50% *Poa pratensis*, (smooth stalked meadow grass) seed mixture was sown. This trend was also noted when cultivar mixtures were used to decrease red thread on perennial rye grass (section 3.3). The effects however, were not as clearly marked; probably because the use of cultivars alone does not produce a plant community as genetically diverse as species mixtures. However, cultivar blends did appear moderately effective at reducing red thread when disease severity was low.

Disease attack in the summer may predispose the turf to be less vigorous during the winter months. Section 3.2 illustrates that red thread tolerant perennial rye grass cultivars also appear more wear tolerant under artificial football-type wear treatment, for example, cultivars Brightstar, Quickstart and Gen90, making these a good cultivar choice both in terms of disease management and increasing wear resistance.

Species/cultivars should be selected which possess good agronomic qualities as well as being environmentally and culturally adapted to the site location. The blend should also be developed for a specific use, e.g. maintenance level, degree of shading. The choice of cultivars grown should be frequently altered to prevent disease susceptibility developing, e.g. in a blend of three cultivars, two resistant and one susceptible, the susceptible cultivar will become eliminated over time reducing the genetic diversity by a third.

3. Fertiliser regime.

Results obtained in Chapter 3, section 3.4 demonstrate that red thread is reduced under high nitrogen levels whereas Fusarium patch is increased. A moderate - high level of nitrogen application, (N = 225 kg per hectare per year), appeared to manage both diseases effectively whilst maintaining turf vigour and surface quality during wear treatment in the winter when applied in light frequent applications throughout the growing season. Excessive use of nitrogen promotes tissue succulence and thinner cell walls which are easily penetrated by fungal pathogens. Increased nitrogen input may also divert carbohydrates and other important biochemicals, synthesised by plants to resist pathogen attack, into growth processes devoted to biomass production which may reduce the capacity of the plant to resist fungal invasion. Conversely, turfgrasses grown in nutrient-poor soil, lack vigour and are more prone to severe damage from red thread. Disease levels tend to increase if application of fertiliser is high in soluble nitrogen but unbalanced with respect to phosphate and potassium. In general, a balanced $N:P_2O_5:K_2O$ fertiliser, e.g. 3:1:2, applied at the appropriate time will help to manage disease outbreak. Organic nitrogen sources (e.g. bonemeal and dried blood) compared to inorganic (e.g. ammonium sulphate) also tend to increase disease (Smith *et al*, 1989). Acidifying nitrogen fertilisers (e.g. ammonium sulphate), have been shown to reduce the severity of Fusarium patch which is increased in more alkaline soil conditions (Smith *et al*, 1989). Minimum fertiliser rates needed to sustain turf quality should be applied; the use of soil and tissue tests provide a reliable guide to the appropriate application rates. Soil tests also indicate soil pH, which should be 6.5 - 7.0 for optimum turfgrass growth.

4. Irrigation

Irrigation late in the evening should be avoided to reduce leaf wetness and hence decrease fungal spore germination and mycelial growth. Irrigating in the morning will help to reduce the potential for disease outbreak. Turf should be irrigated deeply (soil wetted to a depth of 10 - 15 cms) at the first sign of wilting. Frequent, light applications of water should be avoided to further prevent disease spread; this discourages root development and predisposes turf to injury when extended periods of drought occur. Turfgrasses grown under wet conditions develop succulent tissues and thinner cell walls, which are more easily penetrated by fungal pathogens.

5. Drainage

Drainage should be improved by aeration to increase oxygen in the soil and improve root growth. A more extensive healthy root system will help to increase turf vigour and quality, rendering the sward more resistant to disease invasion. Aeration not only improves root growth and soil air supply but also relieves soil compaction and improves surface drainage. Aeration will lead to improved soil structure, increased drought resistance and assist thatch reduction which will help to decrease disease probability.

6. Mowing

Mowing too short or too frequently increases disease invasion. Mowing creates wounds for entry by pathogenic fungi. A blunt mower increases the number and size of wounds, whereas wounds caused by a sharp mower are cleaner and heal faster rather than the tearing and shredding caused by a blunt blades. A high mowing height should be maintained within the species adapted range. The mowing height should be raised during periods of environmental stress and disease outbreak. Increased mowing height reduces depletion of carbohydrate reserves by increasing leaf area available for photosynthesis; carbohydrates are used by plants to recover from injury. However, increased mowing height also provides nutrients and insulation for disease growth.

For reducing disease damage, winter sports turf should be maintained at 2.5 - 4.0 cms (1 - 1.5 inches). Mowing also spreads spores and fungal mycelium of some pathogens, e.g. red thread. Hence, when foliar pathogens are active, mowing when leaves are completely dry will help to reduce disease spread. Removal of cuttings will also help to reduce disease inoculum, e.g. red thread sclerotia.

Adherence to sound cultural practice is essential to reduce disease severity in turf. The turfgrass environment, however, is not static and managers must continually modify cultural practices to encourage vigorous growing conditions. To maintain these conditions, the turfgrass manager must continually monitor the nutrient and pH status of the soil, adjust mowing heights, judiciously irrigate, overseed with disease resistant cultivars, manipulate different sources of nitrogen fertiliser and control thatch and compaction.

5.3.2 Biological control

Following the implementation of sound cultural practices within an IDM strategy, the use of other control measures may also be considered. A possible alternative to the use of chemical agents is biological control. Monocultures or species mixtures of micro-organisms are deployed to either reduce pathogen activity or enhance plant disease tolerance. This approach to disease control has been successful on an experimental basis as the results in Chapter 4 describe. A number of bacterial and fungal antagonists, both introduced and indigenous, appeared effective at suppressing Fusarium patch in the initial *in vitro* assay and more significantly in the *in vivo* test under field conditions. Bacteria of the genera *Bacillus* and *Pseudomonas* and members of the fungal genus *Trichoderma* were particularly effective, probably because of their competitive abilities, e.g. antibiotic production, lysis, nutrient competition and mycoparasitism. In addition, sports turf provides an ideal environment for the implementation of successful biocontrol. The area involved is relatively small and the system is more 'contained' (compared to a number of agricultural systems), thus the turfgrass manager has a greater influence over abiotic conditions which can be manipulated to encourage proliferation of the biocontrol agent whilst reducing pathogen inoculation potential.

In addition to the application of microbial antagonists there are also a number of other approaches to biocontrol on turfgrass. The soil contains numerous beneficial fungi and bacteria which are responsible for increasing plant nutrient availability and for protecting plants from pathogen invasion. Biological control attempts to exploit these beneficial microbial attributes in order to minimise disease damage. For example, the application of composts or other organic matter may introduce large populations of antagonistic micro-organisms. Similarly, cultural practices may reduce disease development by altering the soil and thatch microbial communities by changing the environment in favour of the antagonistic microflora to the detriment of the pathogen. Biocontrol may be achieved either through the application of microbial inoculants or through the manipulation of native antagonists present in disease-suppressive soils/composts.

Biocontrol occurs by the microbial destruction of pathogen propagules and the prevention of inoculum formation through the action of mycoparasites. Antagonists capable of antibiosis may also reduce pathogen populations within the soil. Some biocontrol agents can also induce natural defence mechanisms in plants, a phenomenon referred to as 'cross protection' or 'induced resistance'. For example, the *in vitro* assay utilised to identify possible indigenous microbes for the control of Fusarium patch (Chapter 4) illustrated the efficacy of non-pathogenic *Fusaria* at reducing Fusarium patch growth.

Biological control agents must be compatible with other management inputs. They must be tolerant of fungicides, insecticides, herbicides and fertilisers currently used in management programs. Compatibility could be increased by extracting the anti-fungal compound from the antagonist and applying directly onto turfgrass or by producing pesticide-tolerant biotypes by exposure to high chemical levels followed by selection of the surviving colonies.

Despite the experimental success of using microbial antagonists against turfgrass diseases, biocontrol is still very much in the developmental stages. The judicial and timely use of fungicides provides the turfgrass manager with a powerful, fast-acting tool to reduce the detrimental impact of disease outbreak on turfgrass vigour, surface quality and aesthetic appearance.

5.3.3 Chemical control

Despite cultural and biological control measures, when conditions are favourable disease outbreak is likely to occur, e.g. in prolonged cool and wet weather, Fusarium patch attack is extremely probable. If the need arises, outbreaks can be controlled fairly easily and rapidly with fungicides, provided they are used judiciously and in a safe, efficient manner. The efficacy of fungicides can be increased if the following simple steps are adhered to: apply the correct dosage, use only clean water (contaminants such as organic material and clay could reduce chemical efficacy) and ensure all spraying equipment is clean.

The major disadvantages of chemical use are the possibility of fungicide resistance and detrimental effects on beneficial non-target organisms. A reduction in non-essential fungicide use will reduce inhibition of beneficial invertebrates and microbes essential in the decomposition and nutrient recycling processes. Certain fungicides also alter soil pH which could inhibit microbial activity. Formulation influences pesticide fate and losses. Wettable powders, dusts and micro-granules are generally most susceptible to surface and leaching losses. The use of spot treatments will also help to reduce the chemical load within the turfgrass ecosystem.

Repeated application of fungicides with the same mode of action may lead to the development of resistant strains within the pathogen population. There are two types of fungicides: contact and systemic. Contact fungicides, (e.g. dicarboximides - iprodione, vinclozolin) form a protective shield around the outside of the plant. The contact fungicides have the general disadvantage of being exposed to weathering and photo-decomposition, and on turfgrass, mowing provides an additional hazard. Turf is also irrigated frequently which will also wash the fungicide of the leaf surface. Contact fungicides need constant reapplication to protect new foliage. The systemic fungicides, (e.g. benzimidazoles - benomyl, carbendazim, thiobendazole, thiophanate-methyl) also provide an external barrier to infection but are absorbed and translocated throughout the plant. Systemic fungicides can provide protection for up to four weeks, depending on soil type and disease pressure.

Resistance is more common in systemic fungicides because of their specific mode of action; whereas for multi-site (contact) fungicides resistance to occur, numerous genes controlling many sites of action would have to mutate naturally. Resistance to benzimidazole systemic fungicides usually occurs within the second or third season of chemical use (Vargas, 1994), e.g. benomyl (and dicarboximide) resistant strains of Fusarium patch have been reported in New Zealand (Pennucci, 1990). A further disadvantage is a number of benzimidazole systemic fungicides used to manage Fusarium patch can also predispose the turf to leaf spot (*Helminthosporium* spp.) invasion (Vargas, 1994).

To minimise the likelihood of fungicide resistance occurring, the following principles should be adhered to:

1. Deploy all appropriate cultural and biological disease control methods available.
2. Use fungicides in a careful and judicious manner only when other means of disease control have not been effective. The use of 'calendar' spraying is rarely justified (and costly).
3. Alternate the choice of fungicides between different chemical groups.

To summarise, fungicide resistance can be reduced by decreasing the frequency and extent of chemical treatment, avoiding persistent chemicals and incorporating the use of different chemical classes at different times of the year. Table 101 provides a possible guide for fungicide use based on a three year rotation to prevent resistance developing in red thread and Fusarium patch in the UK.

Table 101. A guide for effective fungicide use on sports turf in the UK.

Year	**Winter / Spring**	**Summer / Autumn**	**Autumn / Winter**
1	Chlorothalonil† (Contact)	Benzimidazoles (Systemic)	Dicarboximides (Contact)
2	Benzimidazoles (Systemic)	Dicarboximides (Contact)	Chlorothalonil† (Contact)
3	Dicarboximides (Contact)	Chlorothalonil† (Contact)	Benzimidazoles (Systemic)

†different mode of action to dicarboximides.

5.3.4 Other disease management strategies

In addition to cultural, biological and chemical control methods, a number of other control tactics can also be incorporated into a disease management strategy. These include disease monitoring and the use of prediction models.

Constant monitoring of the turf will ensure that disease outbreaks are discovered before they become severe. Monitoring will also enable more informed decisions to be made regarding the timing and application of biocontrol agents, fungicides, insecticides and herbicides as well as identifying the optimum time to apply fertiliser, irrigate and mow.

Predictive models for guiding management actions have proved useful for several plant diseases. Many farmers rely on predictive models in controlling apple scab and leaf spot on peanuts and sugar beet (cited by Shane, 1994). Predictive systems for these diseases use weather data and leaf wetness to determine the potential for disease infection and development. Temperature, moisture and humidity have profound effects on pathogen activity and on the efficacy of applied fungicides. It is difficult, however, to judge the effects of weather on turfgrass pathogens and to always use fungicides most effectively. In the US at present, predictive models have been developed for anthracnose (*Colletotrichum graminicola*), dollar spot (*Lanzia* and *Moellerodiscus* spp.), Pythium blight (*Pythium* spp.) and brown patch (*Rhizoctonia solani*) diseases on turfgrass. As with other disease models, predictions are based on weather data, (e.g. air temperature, humidity and rainfall), soil temperature and leaf wetness.

Most current predictive models do not allow for factors such as inoculum pressure, soil type, cultivar resistance, soil fertility and irrigation. These factors can all have a profound effect on disease epidemics which is why constant monitoring and correct diagnosis of disease is integral to successful turfgrass management. Most predictive models assume that a pathogen is present at the monitored site in sufficient amounts to produce disease if appropriate environmental parameters are met. If the pathogen is not present, such models over-predict disease risk and result in the unnecessary use of fungicide. The development of rapid diagnostic techniques, such as antibody assays, (e.g. ELISA), will aid in the refinement of predictive models.

Recently in the US, electronic weather data collection instruments with the capability to calculate indices using various models have become available. Irrigation on many golf courses is now being controlled by microcomputers linked to automatic weather stations. The incorporation of models for disease, pest and weed prediction into such systems will be a natural follow-on development. In the UK considerable work is still needed to establish historical databases for weather data and to accumulate field observations that are required for the implementation and evaluation of disease-predicting models for turfgrass.

From the topics already discussed in this chapter, formulation of a successful and feasible disease management strategy for turfgrass is a complex and involved process. The following section summarises a number of beneficial practices (both previously known and those identified in Chapters 3 and 4) into an integrated disease management strategy for winter sports turf.

5.4 An integrated disease management strategy for red thread and Fusarium patch on winter sports turf in the UK

The survey results in Chapter 2 reveal a number of differences between disease management on high maintenance turf (professional football clubs) where ground staff are only responsible for the competition pitch and training ground as compared with local authorities who may be responsible for the maintenance of over one hundred pitches. Results from the survey indicate that a number of local authorities store over 250 l or kgs of pesticides that are used regularly on the 8,000 - 9,000 football pitches in the UK. In addition to public concern about the hazards involved, a number of other problems arise from chemical use. These include the inconvenience of bulky spraying equipment, expense, extermination of natural enemies and the possibility of chemical resistance developing within the pathogen population. The development of IDM on local authority land would help decrease extensive emphasis on chemical control.

Although local authority pitches receive lower management inputs than professional grounds (due to financial restrictions and the number of pitches involved) IDM principles can still apply. Such long-term strategies prove cost-effective and are site specific. In the case of local authorities, selection of an appropriate grass species/cultivar mixture for the use pattern of the site would be a beneficial initial management decision. Figure 43 provides a summary of a possible IDM strategy (depending on resources available) for local authorities to help reduce red thread and Fusarium patch. Disease control should start with providing a good surface and sub-surface drainage plus a well prepared fertile seed bed. Seed should be of locally adapted, good quality disease-resistant grasses. Other cultural controls include a balanced fertiliser regime, increased mowing height and deep infrequent irrigation if needed (or possible). Thatch removal and aeration may be warranted if thatch is over 2 cms and compaction is a problem. Light penetration and air movement across the turf surface may be increased by selectively pruning dense trees and shrubs. More light and air will result in the turf drying more rapidly which will help reduce the severity of disease attack. Diseases are rarely unsightly enough to warrant chemical measures and if sound management procedures are adhered to incidence and severity of disease will be reduced further.

High maintenance turf such as professional football club pitches require the full spectrum of cultural and chemical disease control measures outlined in Figure 44 (again as with local authorities, financial resources may be a limiting factor). Proper and timely planting, fertilisation, mowing, irrigation, thatch removal and aeration practices are needed to maintain turf vigour, density and uniformity required for maximum usage.

In addition to the management procedures outlined above for professional football clubs and local authorities, Figures 43-44 illustrate the importance of constant monitoring of the turf by experienced ground staff to detect early signs of disease so prompt action can be taken.

Figure 43. An IDM strategy for red thread and Fusarium patch on medium/low maintenance winter sports turf in the UK.

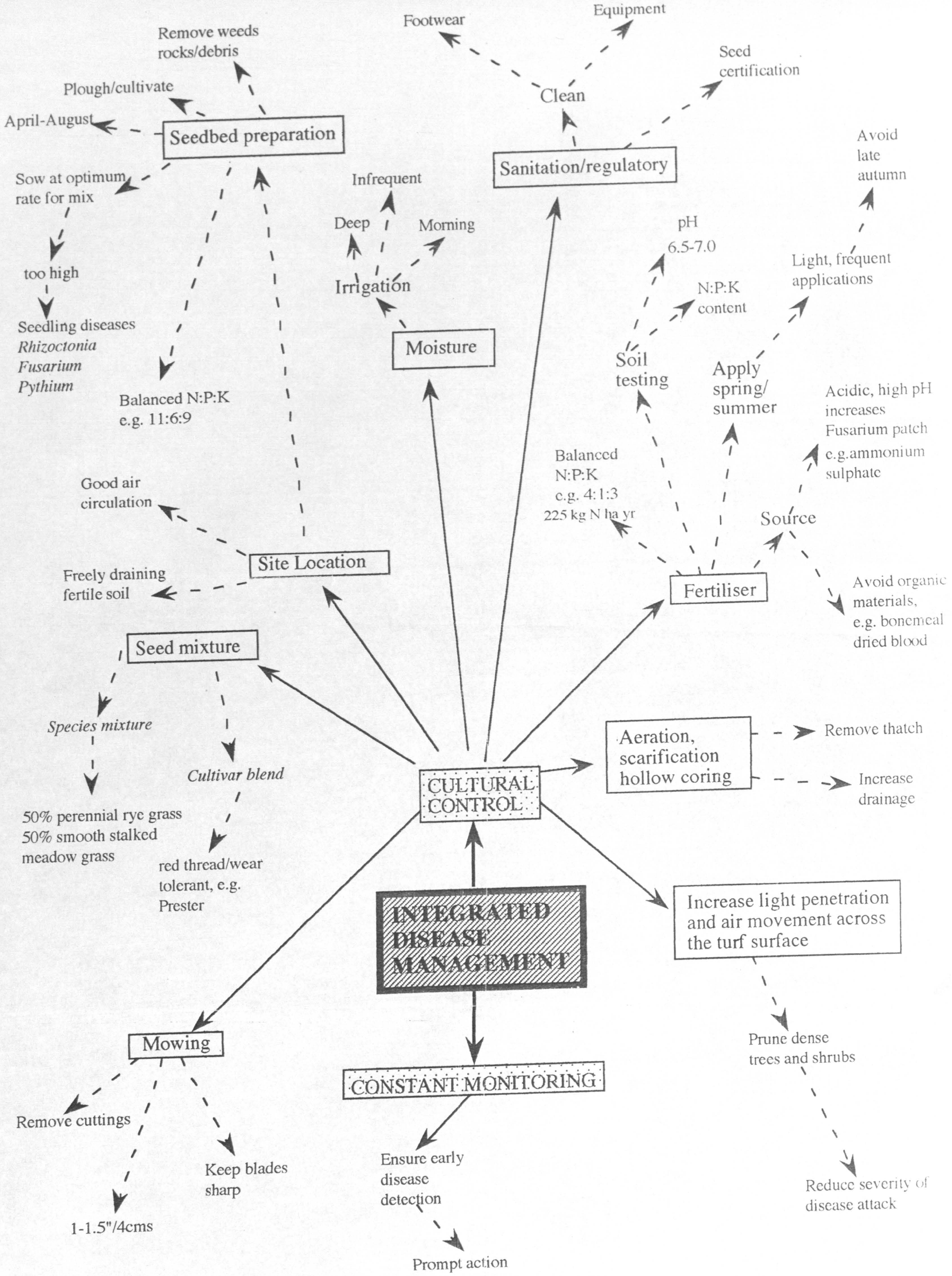
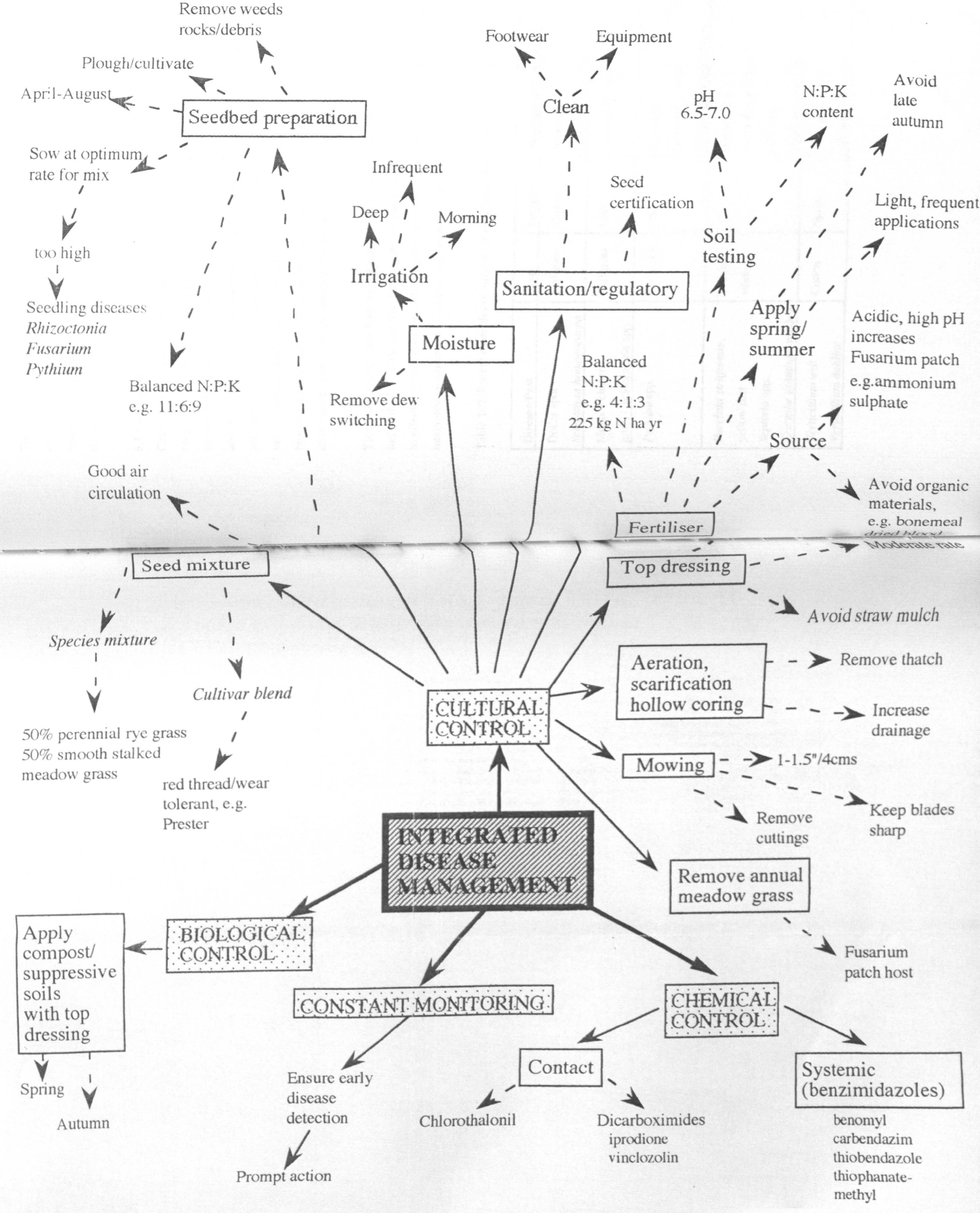


Figure 44. An IDM strategy for red thread & Fusarium patch on high maintenance winter sports turf in the UK



The previous figures illustrate how IDM can be applied to winter sports turf on both high and medium/low maintenance pitches to reduce red thread and Fusarium patch. The following section summarises the necessary components of an IDM strategy and provides further examples of successful IDM adopted throughout the world on turfgrass as well as a number of other horticultural and agricultural crops.

5.5 Conclusion

Chemical cost, pesticide resistance, environmental concerns and the use of residual pesticides with a narrow range of activity have re-emphasised the importance of judicial and efficient use of pesticides and management practices. Integrated turfgrass management uses all available methods to keep disease at an acceptable level, whilst maintaining turf quality and vigour. Early disease detection, accurate identification and familiarisation with symptoms and life-cycle characteristics are essential. All management tools such as use of adapted grasses as well as appropriate cultural methods, chemicals, sanitary practices and the use of biocontrol agents should be considered when developing a disease management strategy. Chemicals may be an integrated part of the programme but should not take precedence over other measures.

This chapter illustrates how an integrated disease management strategy can be formulated for winter sports turf in the UK. IDM can also be adopted for use on a number of other horticultural and agricultural products to effectively and economically suppress disease. Table 102 highlights further recent examples of effective integrated management in controlling a number of pests and diseases on a variety of crops.

Table 102. Recent examples of successful integrated disease/pest management.

Disease/Pest	**Crop**	**Location**	**Management Strategy**	**Reference**
Dollar spot *Sclerotinia homoeocarpa*	Turfgrass	Canada	Benomyl Hollow tine coring	Liu *et al*, 1995
Masked chafer grub, *Cyclocephala* spp.	Turfgrass	USA	Pheromone traps	Potter and Haynes, 1993
Pythium spp.	Turfgrass	USA	Benomyl Benomyl tolerant *Trichoderma harzianum*	Brown and Cranshaw, 1989
Puccinia striiformis, yellow rust *Septoria* spp. *Erisyphe graminis*, mildew	Winter wheat	UK	Fungicides Growth regulators Nitrogen Resistant cultivars	Dawson *et al*, 1990
Verticillium wilt *Verticillium dahliae*	Cotton	Spain	Soil solarization Resistant cultivars	Melero-Vara *et al*, 1995

Table 102 continued......

Fusarium wilt *Fusarium oxysporum*	Date palm	Algeria	Regulation Soil fumigation Suppressive soils Tolerant cultivars	Brac de la Perriere *et al*, 1995
Fusarium oxysporum f. sp. *cumini* *Macrophomia phaseolina*, dry root rot	Cumin	India	Soil solarization Irrigation Soil amendments	Lodha, 1995
Fusarium oxysporum f. sp. *cyclaminis*	Cyclamen	Italy	Antagonistic *Fusaria* Fungicides	Minuto *et al*, 1995
Acari spp., mites	Apples	Nova Scotia	Monitoring Growth regulators Biocontrol - fungal pathogens and predatory mites	Hardman *et al*, 1995

The examples cited in Table 102 and the results from this study illustrate integrated disease and pest management (IDPM) provides a successful, efficient and profitable approach to pest control. IDPM programmes have an outstanding track record throughout the world in reduction of pesticide use, ensuring safe food supplies and amenity areas as well as aiding water and wildlife conservation. IDPM provides a broad, multidisciplinary and systematic approach to controlling all pests using several types of control methods - biological, cultural, chemical and regulatory.

The previous chapters have highlighted the ecological benefits of IDM and how a vigorous, healthy turf sward can be maintained without excessive chemical and fertiliser input. The following chapter outlines the possible economic benefits and recent advances in IDM, the importance of IDM on sports turf and recommends possible future studies regarding IDM on sports turf.

Chapter Six:

General Discussion

6.0 Discussion

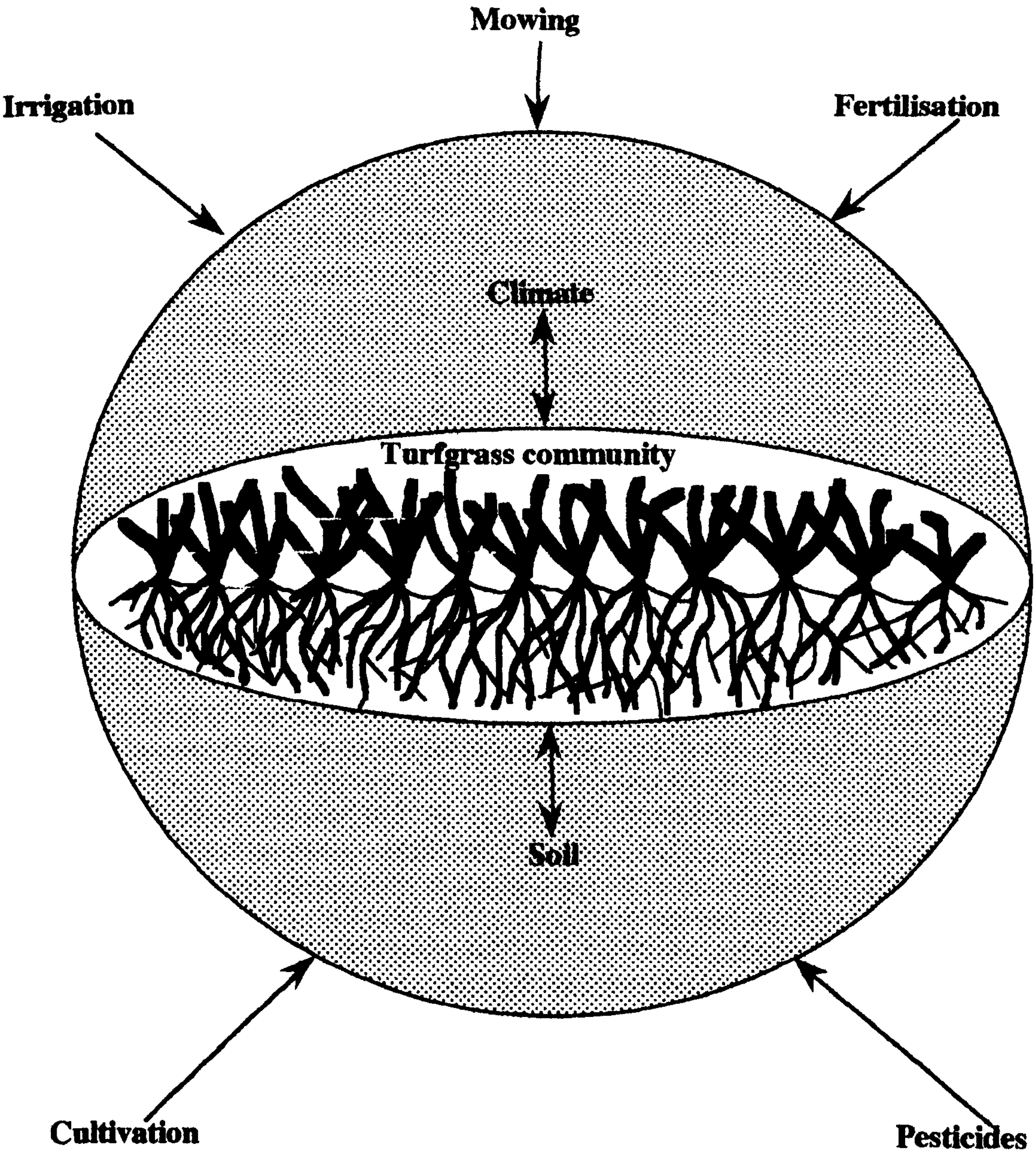
Pathogenic diseases are one of the most significant factors in reducing turf appearance, vigour and surface quality. The previous chapters have illustrated the impact of disease on sports turf and the number of cultural and biological control methods which effectively reduce disease. Disease can be a particular problem on high maintenance pitches because the majority of pitches are re-sown each spring; this results in no significant history of co-evolution between plants and pathogens. In natural ecosystems co-evolution allows for the selection of resistant/susceptible and avirulence/virulence loci in frequencies that enable host and pathogen to co-exist. When turfgrass stands are resown each year, evolution of the host population is frozen and there are no opportunities for disease to influence resistant gene frequencies.

Although there is no significant co-evolution between pathogen and turfgrass, the primary cause of disease symptom expression is, in fact, mismanagement. This arises through selection of poorly adapted turfgrasses, improper establishment, errors in primary cultural procedures (e.g., fertilisation, irrigation and mowing), failure to employ proper cultivation and associated practices and mistakes in fungicide selection and use. Turfgrass culture is largely a matter of selecting plant genotypes that are compatible with the natural environment, then modifying the environment through cultural practices to promote the survival and growth of the plants. Figure 45 illustrates that the basis of turfgrass culture is the modification of a natural environment to ensure turf is maintained at an appropriate quality.

Conflicts do arise between the culture of turf and its' use. Optimal growth of turf occurs in well-aerated soils with adequate moisture and nutrients; however, winter sports turf is subjected to intense use which compacts the soil and causes extensive injury to the turfgrass plant. The demand for low-growing, dense turfgrass which exhibits rapid recuperative growth ultimately results in small plants which are less stress tolerant and more susceptible to disease, pest and weed invasion.

The most efficient approach to disease problems is undoubtedly provided by adopting a good general management strategy for winter sports turf. This will provide a playing surface of good quality and ensure a healthy and vigorous sward less prone to disease attack. The aim of disease management is to prevent disease incidence rather than relying on the use of fungicides to control a problem, since fungicide treatment will prove very expensive for the pitch area involved. If fungicides have to be used, this should only be to treat an existing problem and the use of preventative spray treatments should be discouraged because fungicides will kill many non-target beneficial organisms in addition to disease-causing fungi. An additional problem is selection of resistant strains within the pathogen population by repeated fungicide exposure.

Figure 45. The importance of cultural practices on turfgrass (adapted from Turgeon, 1985).



The implementation of appropriate management practices within an integrated management strategy provides not only an efficient and adaptable alternative to fungicides but also a long term economic solution to disease control. The following section provides a summary of the approximate costs of effective disease management strategies identified within this study compared to the cost of chemical control.

6.1 The cost of IDM

Investment in a well-drained pitch and selection of good quality grasses which receive a balanced fertiliser and irrigation regime, will result in a healthy, vigorous sward less prone to disease, pest and weed invasion. Such investment will also promote a better quality playing surface, reducing the risk of match postponement. By investing in sound management practices resulting in reduced disease levels, the need for chemical control will decrease; every fungicide application avoided is money saved, e.g. Couch and Smith (1991) reported that an 'average' golf club in the US spent 48% of the pesticide budget on fungicides. Savings from reduced pesticide input can then be used to invest in better quality grasses and improved drainage.

A number of cultural practices were identified in Chapter 3 which reduce both red thread and Fusarium patch on winter sports turf. The following section gives an indication of how investing in drainage, good quality grasses and the appropriate fertiliser regime (practices that reduce disease incidence) can decrease reliance on costly chemicals. (*NOTE*: the following costs do not include labour, equipment maintenance charges and other application costs incurred. They provide a direct indication of how the components within an IDM strategy provide an efficient, economic alternative to the costly practice of 'blanket calendar spraying').

1. Construction type (Chapter 3, section 3.4)

Games on winter sports turf (e.g. Association football, rugby and hockey) are played when the soil is often wetter than field capacity and when grass growth is minimal. In the absence of good surface drainage, games affected by wet weather either have to be postponed or played when the surface is excessively soft or wet. Such actions place extreme pressure on the turfgrass plants. Choice of construction type largely depends on financial resources available and site location, e.g. a poorly drained pitch in a high rainfall area will not provide as much use as an undrained pitch located on naturally permeable soil in a low rainfall area. The construction system chosen should sustain a high quality surface under intensive usage. Comparison of five different constructions for football ranging from 'pipe drains only' to a 'sand profile' design indicated that a relatively simple and inexpensive pipe and slit drainage system effectively reduced severity of red thread in the summer and Fusarium patch in the winter; the quality and vigour of the sward was also maintained under artificial football-type wear treatment. The botanical composition after wear (Chapter 3, 3.4, Figure 38) indicates that the pipe and slit construction also sustained the largest proportion of perennial rye grass and fewer bare patches; the more expensive 'sand profile' proved the least effective under wear. The greatest proportion of bare areas and the highest incidence of red thread occurred on this construction type. Table 103 compares the cost of the pipe and slit drainage construction and the sand profile.

Table 103. Approximate installation and maintenance costs and estimated carrying capacities for 'slit drainage' and 'sand profile' constructions (1991 prices, pounds sterling)

Construction type	Capital cost	Inclusive of irrigation	Maintenance cost (per annum)	Maximum winter usage (hours/week)	Games per season
Pipe/slit drainage	23, 000	-	2, 500	3 - 4	75 - 125
Sand profile	85, 000	100, 000	6, 000	5 - 7	125 - 175

Table 103 illustrates that increase in usage is not proportional to the increase in capital cost. When the high cost of construction is added onto maintenance cost, the installation of a sand profile construction can only be justified if the highest quality natural turf surface is demanded and if play has to be guaranteed under all weather conditions, e.g. national stadia and professional football clubs. (cited by Adams and Gibbs, 1994).

2. Grasses sown (Chapter 3, 3.1 - 3.3)

The selection of an appropriate grass mix, depending on use and maintenance level required, will greatly influence the likelihood of disease outbreak. Cultivar and species mixtures can be easily exploited to provide a potentially cheap, simple and effective means of controlling pathogens and will also ensure against other unspecialised diseases that occur sporadically. The introduction of mixtures is also a strategy that can be used in conjunction with other control measures. If poor quality grasses are grown, the performance of the turf will be limited to those grasses, irrespective of how good the subsequent management is. Inexpensive grasses can be very costly if they wear away quickly, require extra maintenance and invariably need early replacement. Investment in good quality grasses which wear well and result in a healthy, vigorous sward will also help to reduce disease incidence (Chapter 3, 3.2). The cost of the appropriate grass mix subject to use and maintenance level, is dependent on the area involved. There are no specifications for football pitch size although the pitch length should be between 90 - 120 m and the width 45 - 90 m The 'average' area of a football pitch is approximately 1 hectare (including surround).

Results obtained in Chapter 3 indicate that disease severity is reduced when diversity is increased in the sward (3.1, 3.3). A possible mix to sow might be a blend different cultivars of perennial rye grass and smooth stalked meadow grass. Table 104 lists some grass mixtures available for use on winter sports turf and the approximate cost (pounds sterling).

Table 104 The cost of grass mixtures for use on winter sports turf (1995 prices)

Seed Mix	**Cost (pounds sterling) per hectare**	**Recommended sowing rate (kg/ha)**
Olympic Sportsground Mixture, A7. (British Seed Houses) 25% Meteor perennial rye grass 25% Hermes perennial rye grass 15% Julia smooth stalked meadow grass 12.5% Frida chewings fescue 12.5% Olivia chewings fescue 10% Highland browntop bent	583.60	200
Premier Sport (Designer Mixtures) 30% Master perennial rye grass 30% Elka perennial rye grass 20% Cindy strong creeping red fescue 15% Miracle smooth stalked meadow grass 5% Highland browntop bent	1215.00	500
Quicksport (Designer Mixtures) 40% Master perennial rye grass 40% Rival perennial rye grass 20% Commodore strong creeping red fescue	990.00	500
J7 (Johnson's Seeds) 40% Cartel perennial rye grass 40% Surprise perennial rye grass 10% Jupiter slender red fescue 10% Boreal creeping red fescue	374.40-520.00	180-250

3. Fertiliser regime (Chapter 3, 3.4)

Nitrogen level is a significant factor in turfgrass disease symptom expression. Fusarium patch severity increases under elevated levels of nitrogen, whilst red thread was reduced. A balanced fertiliser regime was identified which appeared to effectively suppress both diseases (225 kg N ha^{-1} a^{-1} applied in the ratio of 4:1:3 with phosphorous and potassium); turf quality and vigour were also maintained when subject to wear treatment. Light, frequent applications throughout the growing season promoted a healthy sward, although late autumn applications of nitrogen should be avoided to prevent Fusarium patch developing in the winter.

The annual cost of applying a balanced fertiliser regime to a winter sports pitch (1 hectare) would be between approximately £400 - £980 depending on maintenance level (personal communication D. Lawson, the Sports Turf Research Institute).

4. Fungicides

Early detection, accurate diagnosis and prompt treatment all help to increase the efficacy of fungicides. IDM encourages the use of chemicals wisely. The cost of applying fungicides to one hectare (the size of an 'average' football pitch plus surround) can vary depending on the active ingredient involved and the class of chemical used. Table 105 provides an approximate guide to the cost of treating Fusarium patch and red thread on a winter sports pitch (1 hectare).

Table 105. Approximate cost (1995 prices, pounds sterling) of fungicides recommended for use against Fusarium patch and red thread on winter sports turf, (personal communication, G. Yelland, Rigby Taylor Ltd.).

Product	**Turf disease**	**Rate (l / ha)**	**Cost/ha**
Rimidin (Systemic)	Red thread	10	819.00
	Fusarium patch	6.5	532.35
Rovral Green (Contact)	Red thread	20	597.20
	Fusarium patch	20	597.20
Daconil Turf (Contact)	Red thread	30	537.90
	Fusarium patch	30	537.90
Greenshield (Contact and systemic)	Red thread	30	600.90
	Fusarium patch	30	600.90
Vitesse (Contact and systemic)	Red thread	20	564.52
	Fusarium patch	20	564.52

Fungicides provide a versatile and powerful tool but detrimental effects, as well as economic cost, can result from their overuse. Turfgrass lacks the complexity of natural grassland and is relatively susceptible to pesticide induced changes, e.g. reduced populations of natural antagonists/predators, enhanced microbial degradation and an imbalance in decomposition causing a build up of thatch. Excessive thatch results in decreased percolation of pesticide, thereby reducing chemical efficacy; IDM provides a workable alternative that can break the cycle of fungicide -> thatch build up -> increased fungicide. However, if reduced chemical control was not incorporated, i.e. fungicide use was completely suspended, IDM efficacy would deteriorate and costs would rise due to increased labour for extra cultural practices and the constant need to replace severely diseased turf.

The above examples concerning drainage, seed, fertiliser and fungicide costs illustrate how initial investment in construction (depending on site and financial resources available), appropriate good quality seed mixture and a balanced fertiliser regime will save money and reduce the need for costly, inconvenient and potentially dangerous chemical applications. Every incidence of disease outbreak treated chemically could cost between £530-£820. Therefore investing in improved drainage, quality seed and fertiliser, (all practices which will help reduce disease incidence), will result in a healthy, vigorous sward less prone to disease invasion and more tolerant of wear. This would appear to be the most efficient approach to disease management in terms of economics, safety and the potentially deleterious effects associated with the overuse of fungicides.

Despite the identification of a number of beneficial supplements/alternatives to reduce disease without relying on fungicides within this study, a number of possible improvements and recommendations for future work in this area could be considered.

6.2 Recommendations for future work

This study has explored a number of alternative management strategies which appear to maintain the major diseases (red thread and Fusarium patch) on winter sports turf effectively. Table 106 provides a brief summary of the cultural and biological practices identified within the study which effectively reduce disease on winter sports turf.

Table 106. Summary of beneficial cultural and biological practices identified from this study.

Investigation	**Beneficial results obtained**
CULTURAL DISEASE CONTROL The effect of monocultures and dual species mixtures on disease	50% perennial rye grass/50% smooth stalked meadow grass reduced red thread by 86% and Fusarium patch by 80%
The effect of red thread incidence on wear tolerance of monostands of perennial rye grass cultivars under three different nitrogen levels	Red thread tolerant cultivars appear more resistant to wear. Wear tolerance was also increased under a moderate nitrogen level (150 kg ha^{-1} yr^{-1}). Cultivars Gen90, Brightstar, Quickstart, Barrage and DelDwarf - disease and wear tolerant under low (75), medium (150) and high (225) nitrogen regimes
Effects of blends of perennial rye grass cultivars on red thread incidence on different soil types	Triple-blend swards appeared more tolerant to red thread than bi- / mono-blends, when disease levels were moderate to low, on both sandy and silty loam soils. Red thread severity was generally lower on the silty loam, probably because of increased nutrient levels. Frequent alteration of cultivars sown may prevent pathogen adaptation.
The effect of nitrogen level on disease incidence on different constructions for football	A moderate/high nitrogen rate (N=225 kg ha yr) appeared to reduce red thread and Fusarium patch incidence and sustain maximum turf cover under wear treatment. Pipe/slit drainage construction type also appeared the most effective at suppressing both diseases and maintaining maximum turf cover under wear.
BIOLOGICAL DISEASE CONTROL Biological control of Fusarium patch disease	A number of indigenous and introduced micro-organisms suppressed Fusarium patch growth *in vitro* and under field conditions. Bacteria of the genera *Bacillus* and *Pseudomonas* and members of the fungal genus *Trichoderma* were particularly effective, decreasing pathogen growth *in vivo* by approximately 70%.

Although a number of possible cultural and biological practices have been identified which could be incorporated in an IDM strategy, improvements and recommendations for future work should also be considered. Despite the identification of an optimum seed mixture for disease control (50% perennial rye grass, 50% smooth stalked meadow grass), increased efficacy could perhaps be obtained by utilising two or three different cultivars of each species to increase diversity further. In addition, the species mixture which effectively suppress disease will have little value if it is unable to tolerate wear. Wear tolerance is one of the most important requirements for winter sports turf. A number of multi species/cultivar mixtures could be subjected to artificial football-type wear treatment throughout the winter months to identify not only the optimum species mixture in terms of disease tolerance but also the most wear-resistant. The evolutionary dilemma created by species/cultivar mixtures could also be enhanced with fungicides applied to seed. Treating seeds of a particular component of the seed mix with different fungicides and mixing them prior to sowing, will obtain a stand of randomised distribution of single fungicides. Such treatment can then be applied separately to components of the host mixture thus increasing the heterogeneity of disease control mechanisms. A further advantage is that a particular fungicide can be applied to a different host component in different years adding a further dynamic element to the confusion of the pathogen. Economic and environmental cost is kept low because of the reduced amount of fungicide required. Disease management would also be improved because seed treatment reduces the initial inoculum and spread of the epidemic at a stage when the host mixture itself has little effect. Varietal and chemical components thus help to protect each other against rapid evolution of the pathogen.

A number of cultivars of species used for winter games pitches exist with good agronomic qualities, e.g. cleanness of cut, shoot density, leaf fineness and 'greenness' but they are not specifically bred for disease resistance (although a number of perennial rye grass cultivars appear tolerant to red thread disease). Miedaner *et al* (1995) noted the most effective method of reducing root rot caused by ***Microdochium nivale*** (the causal agent of Fusarium patch on turf) in winter rye, was by host resistance from selected hybrids. As well as breeding directly for disease resistance, genetic differences in nutrient absorption could be exploited to promote a healthier more vigorous sward less prone to disease attack, e.g. Liu (1995a, b) noted genetic differences in phosphorus and potassium absorption existed between turfgrasses both at species and cultivar level.

The biological control investigation identified a number of micro-organisms which appear effective at reducing pathogen growth *in vivo*. Efficacy, however, should also be tested under a moderate/high maintenance regime, under appropriate cultural conditions on winter sports turf. In addition, mixtures of different bacterial and fungal antagonists could be applied at different times throughout the life cycle of the pathogen in order to optimise disease suppression. Biological control of red thread, either through direct inoculation of microbial antagonists or the formulation of a suppressive soil/compost, would also provide a worthwhile component to incorporate into an IDM strategy, thereby reducing further the need for costly, potentially harmful chemicals. Identification of possible suppressive agents for red thread could be determined by the same method utilised for Fusarium patch, i.e. initial *in vitro* assay to identify possible antagonists and provide an indication of mode of action, followed by subsequent *in vivo* and field testing. Biocontrol of Fusarium patch could also be effected by the formulation of a suppressive organic soil amendment. Other possible research priorities for the biocontrol of turfgrass diseases may include: a) genetic manipulation of the antagonist genome to enhance ability to adapt to various environmental conditions and to tolerate fungicides, b) the development of fermentation technology and delivery systems, two processes that will require long-term commitment by researchers and industry together before any practical applications can be achieved and c) the development of computerised models to understand the effect of the micro-environment on the survival and proliferation of biocontrol agents in the soil and on plant surfaces.

In addition to improvements and possible research priorities regarding the topics already studied, a number of other possible components of an IDM strategy could be investigated. Chemical control provides a fast efficient way to reduce turfgrass diseases although overuse of fungicides can cause numerous problems, (e.g., detrimental effects to beneficial non-target organisms and development of resistant strains within the pathogen population). Reduced fungicide applications, however, applied in conjunction with the full spectrum of cultural and biological controls, combined with monitoring practices may also provide an appropriate level of disease control. By decreasing the frequency and extent of chemical treatment and using different classes of chemicals at different times of the year, the deleterious effects of chemical overuse would be reduced, whilst maintaining turf quality. A long-term investigation gradually reducing fungicide input whilst increasing alternative disease control management strategies could be conducted on moderate to high maintenance winter sports pitches to produce a refined, workable IDM strategy (Chapter 5, 5.4, Figs 3-4).

Several cultural, chemical and biological management strategies could be integrated to successfully control diseases on winter sports turf. However, control efficacy could also be improved by the implementation of disease prediction models. Predictive models for guiding management actions have proved useful for many plant diseases, (e.g. the control of apple scab and leaf spot on sugar beet and peanuts (cited by Shane, 1994) Predictive systems are based on weather data and leaf wetness to determine potential for disease infection and development. Temperature, moisture and humidity have profound effects on pathogen activity and on the efficacy of applied fungicides. In the US prediction models have been developed for dollar spot (*Lanzia* and *Moellerodiscus* spp.), brown patch (*Rhizoctonia solani*), anthracnose (*Colletotrichum graminicola*) and Pythium blight (*Pythium* spp.) on turfgrass. The development and use of prediction models within an IDM strategy in the UK would facilitate the more efficient use of costly fungicides and reduce the detrimental effects caused by overuse.

In addition to diseases on winter sports turf, the principles of integrated management could be applied to weed and pest problems both on winter sports turf and fine turf (used on golf and bowling greens, tees and fairways). Chemical input is generally higher on fine turf because of the high maintenance required for a fine surface which results in increased stress levels within the turf, rendering it more susceptible to disease, pest and weed problems. The results from the survey (Chapter 2) revealed that weeds were the major problem on winter sports turf. Between 50 and 75% of competition pitches and training grounds were affected by clover, plantain and annual meadow grass; the majority of cases were treated with herbicides. Of the local authorities who responded to the survey, plantain, dandelion and clover were the major weed problems; over 75% of pitches affected and 72 - 82 % of cases were treated chemically, hence it would appear that integrated management of weeds is also a research priority on winter sports turf.

Despite the need for integrated weed, pest and disease control on sports turf utilising a range of control and monitoring practices, a number of recent advances within biocontrol technology will help further to reduce reliance on chemical control. The following section briefly discusses this novel technology and its implications for IDM.

6.3 Recent advances in IDM

The major advances in biocontrol technology can be categorised into three main groups:

1) Genetic engineering of the biocontrol agent (BCA) to improve efficacy.

2) Extraction of extracellular compounds from the BCA for use against disease, compared to the application of the antagonist itself. This is particularly useful for antibiotic producing bacteria; bacterial antagonists are less resistant than other biocontrol agents (yeasts and filamentous fungi) to adverse environmental conditions, e.g. humidity and ultra-violet radiation (Levy and Carmelli, 1995).

3) The formulation of organic turf amendments.

Table 107 summarises recent examples of advances in biotechnology which will help improve biological control efficacy.

Table 107. Recent advances in biological control technology.

Biotechnology	**Example**	**Reference**
Genetic engineering	Deletion of EGT (enzyme - ecdysteroid glucosyltransferase) from baculovirus genome. Insects infected with EGT (-) baculovirus display accelerated mortality and feeding arrest normally associated with pupation and ecdysis (moulting)	O' Reilly, 1995
	Allele replacement in non-antibiotic producing strain of *Pseudomonas aureofaciens* for control of *Phytophthora megasperma* root rot of asparagus	Carruthers *et al*, 1995
Extraction of extra-cellular compounds	Epiphytic fungus, *Sporothrix flocculosa*, suppress spore germination and biomass growth in *Botrytis cinerea* and *Fusarium oxysporum* f. sp. *radicus-lycopersici*	Hajlaou *et al*, 1994
Organic amendments	Hydrolysed poultry, feathermeal, bloodmeal, wheatgerm, potassium sulphate and bonemeal contain micro-organisms antagonistic to dollar spot, *Sclerotinia homoeocarpa*, on creeping bentgrass. Thatch decomposition and nutrient transformations within the soil also improved	Liu *et al*, 1995a, b
	Addition of fungus, *Phaeotheca dimorphosa*, stimulate populations of *Trichoderma harzianum* for the successful control of damping off, *Cylindrocladium scoparium*, of red pine, *Pinus resinosa*	Yang *et al*, 1995

Table 107 indicates how biological control technology has advanced. The efficacy of a number of antagonists can be improved by genetic engineering whilst the direct application of antibiotics will help reduce reliance on chemical control. Finally, the application of organic amendments to reduce disease is particularly useful to turf managers because suppressive soils can be incorporated with top dressing applications, saving both time and money, reducing the need for expensive fungicides.

6.4 Conclusion

Disease management represents a significant challenge for turfgrass managers, which is made particularly demanding by the perennial nature of the turfgrass sward as well as the pathogenic organisms. The majority of disease-causing organisms are always present in the sward and rarely is the pathogen's presence or population level limiting for disease development. As a result, the principal factors determining the incidence and severity of turfgrass diseases are environmental factors, plant stress that influences the susceptibility of the turfgrass plant and pathogen activity. Although a number of cultural practices can be manipulated to minimise losses from fungal diseases, there is a reliance on fungicide applications for adequate management. However, there is still a requirement for pesticides if turf quality is to be maintained, but cultural and biological controls can be utilised in IDM strategies, both as alternatives and supplements to chemical use. Reduced chemical application rates combined with other control strategies will achieve a high degree of reliability and efficacy from the pesticide applied. Cultural practices, e.g. the use of disease tolerant cultivars, a balanced fertiliser regime and increased mowing height, may not be efficient in isolation but can be combined with other controls to create a highly adaptable disease management system.

Over-dependence on chemical control will result in numerous problems arising. These include the development of fungicide resistant strains within the pathogen population, e.g. resistance of dollar spot (*Sclerotinia homoeocarpa*) on turfgrass in the US to benzimidazoles and dicarboximates resulted in the need for new fungicides; sterol demethylation inhibitor (DMI) became available in 1979 and its use increased rapidly which inevitably resulted in resistance. Serious outbreaks of dollar spot now occur following repeated applications of DMI fungicides (Golembiewski *et al*, 1995). Other problems include deleterious effects on non-target organisms, particularly those involved in carbon and nitrogen cycling, enhancement on non-target diseases and the selection of fungicide-degrading micro-organisms. In order to reduce fungicide dependency and to prevent many of the undesirable biological and environmental effects of excessive fungicide use, integrated disease management (IDM) offers an alternative management practice, although successful IDM will not occur by banning or severely restricting pesticide use.

To be successful, established IDM practices based firmly upon IDM principles should be utilised, e.g. disease monitoring, use of resistant species/cultivars, knowledge of disease history and local weather conditions and turf growth and development. Goals should include conserving/encouraging natural antagonists and avoiding secondary disease problems through the use of non-disruptive and mutually compatible biological, cultural and chemical methods. Workable alternative methods are incorporated gradually as they are developed, and chemically dependant techniques are abandoned as they are no longer needed. Efficacy is not compromised and movement away from chemical dependency results. Emphasis is placed on the monitoring-analysis-treatment process. Furthermore, the people required to make the programme work (e.g., grounds maintenance staff) should also control IDM design and direction.

Turfgrass provides an ideal playing surface for sport. Turf provides a durable surface which when injured recovers rapidly by growing into damaged areas; turfgrass also provides optimum footing for athletes and a relatively soft cushion when they fall onto the surface. Diseases are one of the most important factors in reducing turfgrass quality and aesthetic appearance and efficient control is vital if surface quality is to be maintained. IDM on turf functions as a stress management system, rendering the turf less susceptible to disease, able to compete more successfully with weeds and tolerate higher levels of invertebrate pests without damage.

Chapter Seven:

References

7.0 References

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Chapter Eight:

Appendices

APPENDIX 1

SURVEY OF MAJOR PESTS & DISEASES OF WINTER SPORTS PITCHES

The Sports Turf Research Institute, in conjunction with Liverpool John Moores University, are currently investigating possible control strategies for the major pest and disease problems affecting football pitches.

The aim of this survey is to identify and assess the magnitude of specific problems in order to develop an integrated pest and disease control strategy for optimum turf management of winter sports pitches.

This research has received the full support of the Football League, Football Association and Scottish Football League. It would be greatly appreciated if you could complete the questionnaire and return it in the sae provided as soon as possible.

Please accept our thanks for your assistance in anticipation of your help. We look forward to hearing from you.

Please answer the following questions for both the competition pitch and the training ground.

GENERAL INFORMATION

[1] Name: --------------------------------

[2] Football club----------------------------

[3] Position at the club:------------------------------------

[4] Telephone number (inc. STD code):-----------------------------

DISEASES, PESTS, WEEDS & OTHER PROBLEMS

Please fill in the following tables as fully as possible for both the competition pitch and the training ground.

DISEASES

Note: CP = competition pitch; TG = training ground

DISEASE	INCIDENCE		SEVERITY	DISTRIBUTION	TIME OF YEAR	CONTROL MEASURES	
	Never ——> common 1 ————> 10 (enter 1 to 10)		Mild ——> severe 1 ————> 10 (enter 1 to 10)	1. Isolated patches 2. Large areas 3. Grouped patches 4. Other (enter 1, 2, 3 or 4)	Spring Summer Autumn Winter (enter Sp, Su, A or W)	Chemical used (see pesticide log book) and frequency of spray	Other maintenance operations
Fusarium	CP						
	TG						
Leaf spot	CP						
	TG						
Rust	CP						
	TG						
Red thread	CP						
	TG						
Seedling disease	CP						
	TG						
Other (specify) ________	CP						
	TG						

PESTS

Note: CP = competition pitch; TG = training ground

PEST	INCIDENCE		SEVERITY	DISTRIBUTION	TIME OF YEAR	CONTROL MEASURES	
	Never ——> common 1 ————> 10 (enter 1 to 10)		Mild ——> severe 1 ————> 10 (enter 1 to 10)	1. Isolated patches 2. Large areas 3. Grouped patches 4. Other (enter 1, 2, 3 or 4)	Spring Summer Autumn Winter (enter Sp, Su, A or W)	Chemical used (see pesticide log book) and frequency of spray	Other maintenance operations
Leatherjackets	CP						
	TG						
Chafers	CP						
	TG						
Fever fly	CP						
	TG						
Earthworm casting	CP						
	TG						
Mammals	CP						
	TG						
Other (specify) ____________	CP						
	TG						

WEEDS

Note: CP = competition pitch; TG = training ground

WEEDS		INCIDENCE	SEVERITY	DISTRIBUTION	TIME OF YEAR	CONTROL MEASURES	
		Never ——> common 1 ————> 10 (enter 1 to 10)	Mild ——> severe 1 ————> 10 (enter 1 to 10)	1. Isolated patches 2. Large areas 3. Grouped patches 4. Other (enter 1, 2, 3 or 4)	Spring Summer Autumn Winter (enter Sp, Su, A or W)	Chemical used (see pesticide log book) and frequency of spray	Other maintenance operations
Clover	CP						
	TG						
Speedwell	CP						
	TG						
Plantain	CP						
	TG						
Annual meadow-grass	CP						
	TG						
Algae	CP						
	TG						
Moss	CP						
	TG						
Lichens	CP						
	TG						
Other (specify)	CP						
	TG						

USE OF PESTICIDE AND RELEVANT LEGISLATION

The following questions apply to the person responsible for applying pesticides to the pitches.

[4] Have you received any appropriate training such as:

[a] specific pesticide training courses	YES/NO
[b] general training, e.g. IOG/BIGGA/NTC workshops	YES/NO
[c] other (please specify):	
[d] none	YES/NO

[5] Do you hold the NPTC Certificate of Competence for applying pesticides?	YES/NO

[6] How are your pesticides stored?

[a] locked cupboard	YES/NO
[b] specially designed store, e.g. Portastor/Chemsafe	YES/NO
[c] purpose built building	YES/NO
[d] other (please specify	

[7] What is the quantity of pesticide you currently have in store?

(Please tick)	0-5 kg or litres	☐
	6-10 kg or litres	☐
	11-20 kg or litres	☐
	21-50 kg or litres	☐
	51-100 kg or litres	☐
	101-250 kg or litres	☐
	over 251 kg or litres	☐

[8] Disposal of unwanted pesticides:	Unwanted pesticide concentrate	Dilute pesticides	Empty containers
[a] removed by licenced water disposal company	☐	☐	☐
[b] return to manufacturer	☐	☐	☐
[c] in dustbin/down sink	☐	☐	☐
[e] burial	☐	☐	☐
[f] burning	☐	☐	☐
[g] other (please specify)			

[9] Which types of spraying equipment do you use?
(Please tick)

[a] tractor mounted ☐

[b] knapsack ☐

[c] walkover type ☐

[d] droplet applicator (CDA) ☐

[e] other (please specify) ☐

GENERAL PROBLEMS

[10] From the following list please choose 5 of the most important problems which affect the pitch. Please enter number 1 in the box next to the most important, number 2 next to the second most important and so on, to the fifth most important problem.

	Competition pitch	Training ground
[1] Drainage	☐	☐
[2] Wear	☐	☐
[3] Disease (please name)	☐	☐
[4] Insect pest (please name)	☐	☐
[5] Weeds (please name)	☐	☐
[6] Earthworms	☐	☐
[7] Algae	☐	☐
[8] Lichens	☐	☐
[9] Moss	☐	☐
[10] Slugs/snails	☐	☐
[11] Dog injury	☐	☐
[12] Drought	☐	☐
[13] Nutrition balance	☐	☐
[14] Irrigation problems	☐	☐
[15] Mechanical injury	☐	☐
[16] Renovation	☐	☐
[17] Thatch	☐	☐
[18] Soil compaction	☐	☐
[19] Vandalism	☐	☐
[20] Other (please specify)	☐	☐

Please use the space below to make any additional comments to the above questions or for further information which you feel is relevant.

For any assistance required in completing the questionnaire, please do not hesitate to contact Carmen Raikes at Liverpool John Moores University (tel: 051 231 2367; fax: 051 298 1014). Alternatively, contact Neil Baldwin at the Sports Turf Research Institute (tel: 0274 565131; fax: 0274 561891).

When complete please return the questionnaire in the SAE provided to:

Carmen Raikes
Liverpool John Moores University
School of Biological & Earth Sciences
Byrom Street
Liverpool
L3 3AF

Thank you for your assistance.

APPENDIX II

ADMINISTERED QUESTIONNAIRE ON GENERAL MANAGEMENT PRACTICES AT PROFESSIONAL FOOTBALL CLUBS

PLEASE ANSWER THE FOLLOWING QUESTIONS FOR BOTH THE FIRST TEAM COMPETITION PITCH AND THE TRAINING GROUND:

GENERAL INFORMATION

About yourself

[1] Name and position at the club: ______________________________

[2] Football club: ______________________________

[3] Telephone number (inc. STD code): ______________________________

About the pitch	**Competition pitch**	**Training ground**
[1] Is there an underground heating system in operation? (circle as appropriate)	YES/NO	YES/NO
[2] On average how many hours (1 game = $1^{1}/_{2}$ hr) per week is the pitch used during the season?	☐	☐
[3] Please tick the construction type which best fits your pitch:		
[a] Soil	☐	☐
[b] Sand carpet/Prunty Mulqueen specification	☐	☐
[c] "Cell" system	☐	☐
[d] Other (please specify)	☐	☐
[4] Is the pitch reinforced with:		
[a] Fibresand	☐	☐
[b] Netlon	☐	☐
[c] Other type (please specify)	☐	☐

	Competition pitch	**Training ground**
[5] What is the age of the pitch or date of last major renovation?	☐	☐
[6] Does the pitch have any type of drainage system installed? (please circle) If NO, go straight to Q.8.	YES/NO	YES/NO
[7] Please tick the drainage system which best describes your situation		
[a] Pipe drainage	☐	☐
[b] Slit drainage	☐	☐
[c] Other (please specify)	☐	☐

SOIL TYPE
[8] Is the soil (please circle 1 to 10):

LIGHT (sandy)				MEDIUM (loam)				HEAVY (clay)		
1	2	3	4	5	6	7	8	9	10	Competition pitch
1	2	3	4	5	6	7	8	9	10	Training ground

[9] Is the soil pH approx. (please circle)

ACID ⟵ NEUTRAL ⟶ BASIC
pH scale

4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	Competition pitch
4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	Training ground

If not known, please tick ☐

[10] Is the pitch prone to waterlogging (please circle 1 to 10)

NEVER				OCCASIONALLY				OFTEN		
1	2	3	4	5	6	7	8	9	10	Competition pitch
1	2	3	4	5	6	7	8	9	10	Training ground

	Competition pitch	Training ground
[11] Approximate number of games lost in 'average' season due to: [a] waterlogging		
[b] frost		
GRASS		
[12] Was the pitch established from (please tick): [a] seed	☐	☐
[b] turf	☐	☐
[13] Please state the approximate percentage of the following species in the current sward:		
[a] perennial ryegrass	%	%
[b] smooth-stalked meadow-grass	%	%
[c] bent	%	%
[d] fescue	%	%
[e] other	%	%
Percentages should total 100%	100%	100%
[14] For each species please state the cultivar (variety) used/sown (consult seed mixtures purchased): [a] perennial ryegrass		
[b] smooth-stalked meadow-grass		
[c] bent		
[d] fescue		
CURRENT GENERAL MANAGEMENT		
Mowing		
[15] How often is the pitch mown (please tick)?		
Summer: [a] approx. twice a week	☐	☐
[b] approx. once a week	☐	☐
[c] approx. once in 2 weeks	☐	☐
[d] approx. monthly	☐	☐
[e] other (specify)		
Winter: [a] please specify		

		Competition pitch	Training ground
[16] Are the cuttings (please tick):			
	[a] returned	☐	☐
	[b] removed	☐	☐
[17] Height of cut (please tick):			
Summer:	[a] less than 1"	☐	☐
	[b] 1-2"	☐	☐
	[c] 2-3"	☐	☐
	[d] 3"+	☐	☐
Winter:	[a] less than 1"	☐	☐
	[b] 1-2"	☐	☐
	[c] 2-3"	☐	☐
	[d] 3"+	☐	☐

Fertiliser/top dressing

[18] Please fill in the following table, noting the proportions of nitrogen, phosphorus and potassium used, e.g. 20:10:10

Competition pitch

	N P K	Frequency of application
Autumn	: :	
Winter	: :	
Spring	: :	

Training ground

	N P K	Frequency of application
Autumn	: :	
Winter	: :	
Spring	: :	

	Competition pitch	Training ground
[19] Please state the name of sand used:	______________	______________
[20] Where do you obtain the sand from? (state outlet)	______________	______________
[21] How many tonnes per pitch are used?	______________	______________

	Competition pitch	Training ground
[22] Please tick the frequency of spiking (aeration):		
[a] approx. once a week	☐	☐
[b] approx. twice a week	☐	☐
[c] approx. three times a week	☐	☐
[d] approx. once monthly	☐	☐
[e] approx. once every two months	☐	☐
[f] other (specify)	☐	☐
____________________		____________________
[23] Please tick the frequency of Verti-Draining:		
[a] every 3 seasons	☐	☐
[b] every 2 seasons	☐	☐
[c] every season	☐	☐
[d] twice per season	☐	☐
[e] other (specify)	☐	☐
____________________		____________________
[f] never	☐	☐
Irrigation		
[24] Is the pitch irrigated (please circle):	YES/NO	YES/NO
[25] If 'YES' is the system (please tick):		
[a] manual (e.g. by hand, travelling sprinkler)	☐	☐
[b] automatic (pop-up sprinkler system)	☐	☐
[26] Is the pitch prone to drought? (please circle)	YES/NO	YES/NO
[27] If 'YES' are wetting agents used (if so please state which)?	YES/NO	YES/NO

	Competition pitch	Training ground
Thatch		
[28] Are there problems with excessive thatch on the pitch, i.e. greater than ½": (please circle)	YES/NO	YES/NO
[29] If 'YES' please describe the control measures taken:		
OTHER INFORMATION		
White lining/marking out		
[30] Please tick which method is used for marking out:		
[a] caustic lime	☐	☐
[b] weed killer, e.g. Gramoxone or Roundup)	☐	☐
[c] white paint, e.g. Indeline	☐	☐
[d] other (please specify)		
Repairs/renovations		
[31] Please tick any renovation practice carried out at the end of the season:		
[a] reseeding	☐	☐
[b] returfing	☐	☐
[32] Are there problems with the turf easily ripping out during play, i.e. due to shallow rooting? (please circle)	YES/NO	YES/NO
[33] Is the pitch surrounded by high stands which cause excessive shading? (please circle)	YES/NO	YES/NO

APPENDIX III

SURVEY OF MAJOR PESTS, DISEASES AND WEEDS OF WINTER SPORTS PITCHES MANAGED/MAINTAINED BY LOCAL AUTHORITIES

The Sports Turf Research Institute, in conjunction with Liverpool John Moores University, are currently investigating possible control strategies for the major pest, disease and weed problems affecting football pitches.

The aim of this survey is to identify and assess the magnitude of specific problems in order to develop an integrated pest and disease control strategy for optimum turf management of winter sports pitches.

This research has received the full support of The National Playing Fields Association, The Sports Council, The Football Association, The Football League and the Scottish Football League. It would be greatly appreciated if you could complete the questionnaire and return to me in the self addressed envelope provided (within the next four weeks, i.e. by mid-May 1993).

Please accept our thanks in anticipation of your help. We look forward to hearing from you.

Please answer the following questions with regard to the non-education (i.e. public use) full-size 11-a-side pitches.

GENERAL INFORMATION

About yourself

[1] Name and position held within local authority:---

[2] Name of local authority:--

[3] Telephone number (incl. STD code):---

[4] How many full-size (11-a-side) football pitches used by municipal facilities are you responsible for

(**NOT** schools, colleges or other areas)?---

PESTS, DISEASE AND WEED PROBLEMS

Please fill in the following table as fully as possible:

From the following list of diseases, pests and weeds, please tick if any of your pitches are affected and if chemical and/or cultural (maintenance operations) control measures are taken.

	Are any pitches affected (please tick)	Chemical control measures (please tick)	Cultural control measures (please tick)
Fusarium			
Leaf spot			
Red thread			
Rust			
Seedling disease			
Other disease (specify)			
________________			
Leatherjacket			
Chafers			
Fever fly			
Earthworm casting			
Dogs			
Other mammals			
Other pest (specify)			
________________			
Clover			
Speedwell			
Knotweed			
Plantain			
Dandelion			
Annual meadow-grass			
Other weed (specify)			
________________			

USE OF PESTICIDE AND RELEVANT LEGISLATION

The following questions apply to use of groundstaff.

[5] Have they received any appropriate training such as:

[a] specific pesticide training courses	YES/NO
[b] general training, e.g. IOG/BIGGA/NTC workshops	YES/NO
[c] other (please specify):	
[d] none	YES/NO

[6] Do any hold the NPTC Certificate of Competence for applying pesticides?	YES/NO

[7] How are pesticides stored?

[a] locked cupboard	YES/NO
[b] specially designed store, e.g. Portastor/Chemsafe	YES/NO
[c] purpose built building	YES/NO
[d] other (please specify	

[8] What is the quantity of pesticide (used specifically for turf maintenance) currently in store?

(Please tick)	0-5 kg or litres	☐
	6-10 kg or litres	☐
	11-20 kg or litres	☐
	21-50 kg or litres	☐
	51-100 kg or litres	☐
	101-250 kg or litres	☐
	over 251 kg or litres	☐

[9] Disposal of unwanted pesticides:	Unwanted pesticide concentrate	Dilute pesticides	Empty containers
[a] removed by licenced water disposal company	☐	☐	☐
[b] return to manufacturer	☐	☐	☐
[c] in dustbin/down sink	☐	☐	☐
[d] burial	☐	☐	☐
[e] burning	☐	☐	☐
[f] other (please specify)			

[10] Which types of spraying equipment do groundstaff use?
(Please tick)

[a] tractor mounted ☐

[b] knapsack ☐

[c] walkover type ☐

[d] droplet applicator (CDA) ☐

[e] other (please specify)

GENERAL INFORMATION

For the following questions please enter the number of pitches which fall into the relevant categories.

For example, suppose you were responsible for 50 pitches, in the case of question 11, "on average, how many hours per week are the pitches scheduled for use (excluding training) during the playing season", you may fill it in like this, noting that the total number of figures (21 + 24 + 5 + 0, in this example) always equals the total number of pitches, i.e. 50 in this case.

1.5 hours	3 hours	9 hours	Other (specify)	Not known
21	24	5	0	

[11] On average, how many hours per week are the pitches scheduled for use (excluding training) during the playing season:

1.5 hours	3 hours	9 hours	Other (specify)	Not known

[12] How many pitches have the following construction types:

Soil only	Sand/soil mix	Sand carpet	Other (specify)	Not known

[13] Please estimate how many pitches were constructed within the last 10 years: ____________

[14] How many pitches have the following drainage system:

No system	Pipe drainage	Slit/sand slit	Other (specify)	Not known

SOIL TYPE

[15] How many pitches have the following soil types:

Light (sandy)	Medium (loam)	Heavy (clay)	Not known

[16] How many pitches are prone to waterlogging (STANDING WATER ON THE SURFACE) preventing play:

Never	Occasionally	Often	Not known

[17] Please state the number of pitches which receive the following approximate mowing regimes:

	Twice weekly	Weekly	Fort-nightly	Monthly	Never	Other	Not known
Summer April-July							
Autumn Aug-Sept							
Winter Oct-March							

[18] How many pitches have the following height of cut within which the pitches are maintained:

	Less than 1" (25 mm)	1"–2" (25-50 mm)	2.1"–3" (51-75 mm)	Greater than 3"	Not known
Summer					
Autumn					
Winter					

[19] How many pitches receive the following spiking (aeration) regimes:

	Twice weekly	Weekly	Fort-nightly	Monthly	Never	Other	Not known
Playing season							
Close season							

[20] How many pitches receive the following Verti-Draining regimes:

Every 3 season	Every 2 seasons	Every season	Twice per season	Never	Other (specify)	Not known

[21] How many pitches are irrigated regularly in:

Close season	Playing season	Not known

[22] Please tick which of the following chemicals you use for marking out:

Caustic lime	
Pesticide	
White paint	
None	
Other (specify)	
Do not know	

[23] How many pitches approximately receive any renovation or repairs: ____________

[24] Which weeks approximately (e.g. first in March) do you reseed/returf the damaged areas on the majority of pitches: ____________

[25] What species and varieties of grasses are used in repair work:

____

[26] What is the current specification of species and cultivars (seed mixture) for sowing a totally new pitch surface: ____________

[27] Fertiliser application

[a] On average, how often is fertiliser applied:

None	Once a year	Twice per year	Other (please specify)	Not known

[b] What type of fertiliser do you apply:

Compound	Nitrogen only	Other (please specify)	Not known

OTHER PROBLEMS

From the following list please pick 5 of the most important and common problems which affect the majority of the pitches and list them in order of importance (1 = most important, 5 = least important).

[1] Drainage ☐
[2] Wear ☐
[3] Disease (please name) ☐
[4] Insect pest (please name) ☐
[5] Weeds (please name) ☐
[6] Earthworms ☐
[7] Slugs/snails ☐
[8] Dog fouling/injury ☐
[9] Moles ☐
[10] Birds ☐
[11] Drought ☐
[12] Nutrition balance ☐
[13] Chemical burns ☐
[14] Irrigation problems ☐
[15] Mechanical injury ☐
[16] Renovation ☐
[17] Thatch ☐
[18] Soil compaction ☐
[19] Vandalism ☐
[20] Other (please specify)

Please use the space below to make any additional comments to the above questions or for further information which you feel is relevant.

For any assistance required in completing the questionnaire, please do not hesitate to contact Carmen Raikes at Liverpool John Moores University (tel: 051 231 2367; fax: 051 298 1014). Alternatively, contact Mike Canaway at the Sports Turf Research Institute (tel: 0274 565131; fax: 0274 561891).

When complete please return the questionnaire in the SAE provided to:

Carmen Raikes
Liverpool John Moores University
School of Biological & Earth Sciences
Byrom Street
Liverpool
L3 3AF

Thank you for your assistance.

Appendix IV.

Methods of Soil Analysis

Soil preparation.

Soil samples were dried at 30 ^{0}C., ground to break any aggregates and sieved through a 2 mm mesh size sieve.

pH measurement.

A 20 ml volume of sieved soil was transferred to a 100 ml beaker. 50 ml of distilled water were added, the contents stirred and left for one hour at 20 ^{0}C. The contents were re-stirred and the pH measured with a pH electrode calibrated with pH 4.0 and 7.0 buffer solutions.

Acetic acid soil extract.

A 10 ml volume of sieved soil was transferred to a screw top jar. 100 ml of 0.5 M acetic acid solution was added and the sealed jars shaken for one hour at 20 ^{0}C. The contents were then filtered through 15.0 cm Whatman No. 1 paper and the filtrate kept for phosphate and potassium analysis.

Phosphate.

5 ml of filtrate was pipetted into a 100 ml flask and approximately 80 ml of deionised water was added. 5 ml of mixed reagent (see below) was added immediately and the contents shaken. The solution was made up to 100 ml with deionised water. After twenty minutes the absorbence of the solution was measured at 882 mm on a spectrophotometer with a 2 cm path cell. The absorbence was then converted to soil P_2O_5 content using the spectrophotometer conversion table.

Potassium.

The potassium level was determined with a flame photometer equipped with a potassium light filter. The photometer was pre-calibrated with 0.5 M acetic acid solution and 20 μg/ml on 0.5 M acetic acid. A conversion table was used to determine the soil K_20 from the emission value.

Mixed reagent.

140 ml of ammonium molybdate solution and 60 ml of ascorbic acid solution.

Ammonium molybdate solution	Ascorbic acid solution
12 g ammonium molybdate / 300 ml	1.2 g ascorbic acid / 60 ml
0.2743 g antimony potassium tartrate /100 ml	
140 ml conc. sulphuric acid / 1000 ml	

Analysis of soil nitrogen by the Kjeldahl system distilling unit.

1 g of air dried soil was sieved (size: 2 mm) into a Kjeldahl tube, 1 ml of Kjeldahl CK (3.5 K_2SO_4; 0.4 $CuSO_4$) and 6 ml of concentrated H_2SO_4 was added. The tube was heated at 420 ^{0}C. in a digest block until the contents were clear and then for a further hour. The contents were cooled and approximately 5 ml of water were added. 50 % w/v of NaOH were added and steam distilled into 10 ml 1% basic acid solution for four minutes. The solution was titrated with 0.01 M H_2SO_4 using three drops of methyl red/methyl blue as an indicator (colour change - green to purple).

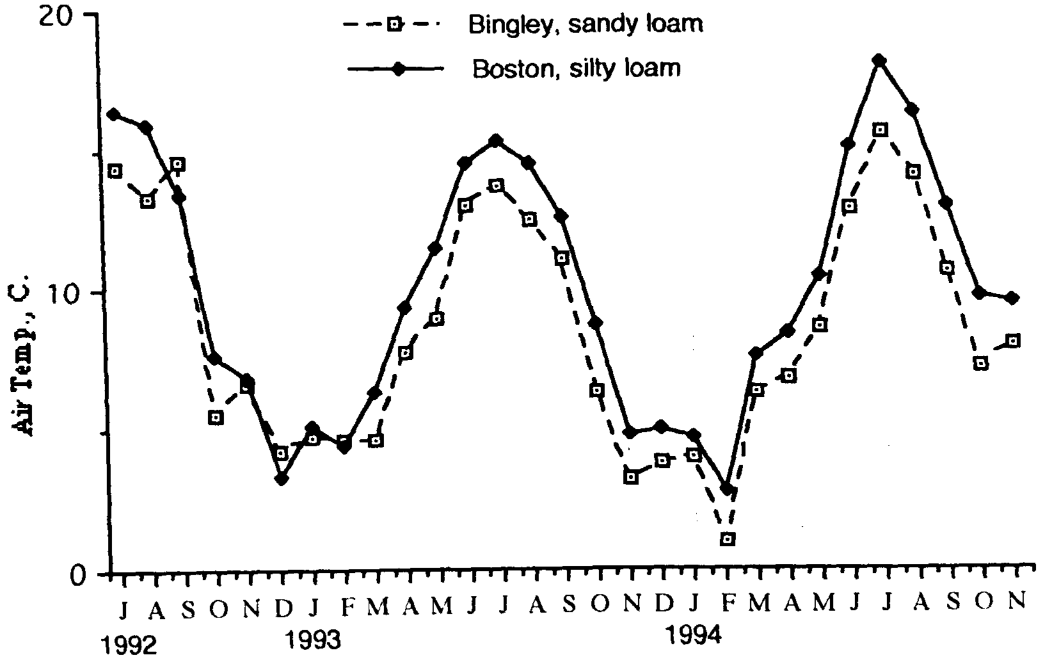
The total % nitrogen = mls acid x 0.02802 / weight of soil

Appendix V.

Meteorological data from July, 1992 - November, 1994 for Bingley and Boston.

Month	Bingley, sandy loam						Boston, silty loam					
	Air temp. ^{0}C			Rainfall mm			Air temp. ^{0}C			Rainfall mm		
	1992	1993	1994	1992	1993	1994	1992	1993	1994	1992	1993	1994
Jan.		4.7	4.0		113	136		5.1	4.7		54	88
Feb.		4.6	1.0		16	66		4.4	2.8		17	48
Mar.		4.6	6.3		10	97		6.3	7.6		21	44
April		7.7	6.8		10	70		9.3	8.4		78	51
May		8.9	8.6		96	27		11.5	10.5		50	47
June		13.0	12.9		31	19		14.5	15.1		35	17
July	14.4	13.7	15.6	60	65	41	16.4	15.3	18.1	104	68	35
Aug.	13.3	12.5	14.1	85	75	68	15.9	14.5	16.3	102	48	55
Sep.	14.6	11.1	10.7	63	137	82	13.4	12.6	13.0	84	102	120
Oct.	5.5	6.3	7.2	75	42	85	7.6	8.7	9.7	81	76	58
Nov.	6.6	3.2	8.0	137	45	115	6.8	4.8	9.5	55	67	40
Dec.	4.2	3.8		79	200		3.3	5.0		45	87	

Mean monthly air temperatures for both trial sites.



Mean monthly rainfall for both trial sites.