INTEGRATED STRATEGIES FOR BROWN PATCH
(RHIZOCTONIA SOLANI KÜHN) MANAGEMENT
THROUGH ENVIRONMENTAL MONITORING
AND CULTURAL METHODS

by

Michael A. Fidanza

Dissertation submitted to the Faculty of the Graduate School
of The University of Maryland in partial fulfillment
of the requirements for the degree of
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Title of Dissertation: INTEGRATED STRATEGIES FOR BROWN PATCH (RHIZOCTONIA SOLANI KÜHN) MANAGEMENT THROUGH ENVIRONMENTAL MONITORING AND CULTURAL METHODS

Michael A. Fidanza, Doctor of Philosophy, 1995

Dissertation directed by: Peter H. Dernoeden, Professor
Department of Agronomy

Brown patch (Rhizoctonia solani Kühn) is among the most common and destructive diseases of turfgrasses worldwide. Field-based research information is limited regarding brown patch management through cultural practices. Furthermore, the environmental conditions that favor disease development are not well defined. The primary objectives of these investigations were: (1) to assess the impact of cultural practices and reduced frequency of fungicide applications on brown patch severity and turfgrass quality; (2) to determine environmental conditions that promote this disease; and (3) to develop and field evaluate a brown patch forecast model. Field studies were conducted in 'Caravelle' perennial ryegrass (Lolium perenne L.), with fungicide (iprodione)-treated and non-fungicide-treated plots. In a nitrogen (N) source study, turf was subjected to two mowing heights (1.7 versus 4.5 cm) and fertilized (196 kg N ha\(^{-1}\) yr\(^{-1}\)) with one of eight N-sources (Sustane, Ringer Compost Plus, Ringer, isobutylidenediurea,
sulfur-coated urea, methylene urea, ammonium sulfate, or urea). The N-
sources also were evaluated on a perennial ryegrass fairway. In non-
fungicide-treated plots, brown patch was more injurious in low-cut turf in
1991, but in 1992 and 1993 blight was more severe in high-cut turf. While
ammonium sulfate in 1991 and Sustane and Ringer-treated turf in 1992 were
associated with less blighting among non-fungicide-treated plots, no
consistent N-source effects on brown patch severity were observed at the two
locations over a three year period. Summer quality was improved in plots
receiving N plus iprodione, but no single N-source combined with iprodione
was associated with improved disease suppression or turf quality. Brown
patch was reduced with fall-applied natural organic N (i.e., Ringer), when
compared to spring-applied urea in non-fungicide-treated turf in an N-source
application timing study. A third study compared sulfur-coated urea (SCU)
and sodium nitrate applied at two rates (147 or 294 kg N ha\(^{-1}\) yr\(^{-1}\)). The N-
sources were applied alone or with phosphorus (36 or 72 kg P ha\(^{-1}\) yr\(^{-1}\)) and
potassium (75 or 150 kg K ha\(^{-1}\) yr\(^{-1}\)), and these treatments were super-
imposed over two irrigation schedules (AM versus PM). In non-fungicide-
treated turf, brown patch was reduced with AM-irrigation. Lower blight levels
were provided by SCU. Phosphorus and K reduced blight at the high N rate,
regardless of N-source. Iprodione-treated turf that received the high N rate
from SCU plus P and K had the best summer quality. Environmental
conditions were monitored for two years and an environmental favorability
index (EFI) was developed to forecast \(R.\ solani\) infection events. The EFI was
validated by chi-square analysis and multiple regression \((r^2 = 0.70)\), and was
based on relative humidity (RH \(\geq 95\%\) for \(\geq 8\) hrs; mean RH \(\geq 75\%\)), leaf
wetness duration \(\geq 6\) hrs or precipitation \(\geq 12\ mm\), and minimum air (16°C)
and soil (16°C) temperatures. Brown patch outbreaks were forecast with 85% accuracy, and all severe infection events were predicted. A 29% reduction in fungicide use was achieved with forecast-based sprays.
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Associate Professor Thomas R. Turner
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DEDICATION

To my parents, Mark and Victoria Fidanza of Avondale, Pennsylvania.
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INTRODUCTION

*Rhizoctonia solani* Kühn is the incitant of brown patch disease and is among the most destructive turfgrass pathogens worldwide (Burpee and Martin, 1992; Smiley et al., 1992). Brown patch development is favored by periods of warm, humid and moist environmental conditions in cool-season grasses (Smiley et al., 1992). In warm-season grasses, brown patch commonly occurs during cool and moist conditions in the spring when these grasses break dormancy, or as they approach dormancy in the fall (Smiley et al., 1992).

Brown patch was first described by Piper and Coe (1919), who investigated this disease on a creeping bentgrass (*Agrostis palustris* Hudson) putting green in 1913. F.W. Taylor named the disease "brown patch", because his turf garden served as the source of the original diagnostic material (Burpee and Martin, 1992). The first description of the biology and nature of brown patch was provided by Monteith (1926) and Monteith and Dahl (1928, 1932). Burpee and Martin (1992) and Smiley et al. (1992) more recently summarized the current information on the nature of brown patch and the biology of *R. solani* and other *Rhizoctonia* spp. that parasitize turfgrasses.

Brown patch management has traditionally relied on fungicide use since Bordeaux mixture was first applied to putting greens in 1917 (Monteith and Dahl, 1932). Despite having known about brown patch since 1913, there has been remarkably few studies on brown patch management through cultural practices or integrating cultural methods with reduced fungicide inputs.
Information is sparse and several studies report contradictory results on the effects of mowing and fertilization on brown patch. Brown patch was reported as being more severe in *Agrostis* spp. putting greens subjected to low mowing (0.64 versus 1.9 cm) (Rowell, 1951), but Watkins et al. (1990) reported that brown patch was more severe with higher mowing (6.4 versus 2.5 cm) in tall fescue (*Festuca arundinacea* Schreb). Shurtleff (1953) found no blighting differences among mowing heights in colonial bentgrass (*Agrostis tenuis* Sibth.).

In greenhouse studies, brown patch was found to be favored by high nitrogen (N) fertility, and disease development varied with the addition of phosphorus (P) and potassium (K) at different N levels (Bloom and Couch, 1960). There have been no field studies that quantify the relationship of N, P, and K to brown patch and the results described by Bloom and Couch (1960) have not been corroborated. While natural organic N-sources are gaining in popularity for use in turfgrass management, conflicting information exists regarding their effects on brown patch and other turfgrass diseases. Natural organic N-sources were reported to reduce brown patch compared to non-fertilized turf (Nelson and Craft, 1990; Soika and Sanders, 1991) in one-season field studies. Peacock and Daniel (1992), however, found no effect of an organic N-source on brown patch compared to a fertilizer mixture of urea, treble superphosphate and potassium sulfate in a greenhouse study. Green et al. (1994) published the only two-year field study that evaluated the influence of N-sources on brown patch (i.e., large patch) severity in zoysiagrass (*Zoysia japonica* Steud.). They found that large patch severity was not influenced by urea, ureaformaldehyde, poultry litter, sewage sludge, or bovine waste. They also found no influence of N-rate (74 versus 148 kg N
ha\(^{-1}\) yr\(^{-1}\)) on large patch severity. Hence, the reported effects of synthetic organic, slow release, or inorganic N-sources on brown patch is inconclusive. In 1924, Oakley suggested that early morning watering of putting greens may help to reduce brown patch. The influence of irrigation and N application timings, as well as P and K interactions, on this disease, however, have not been field investigated.

Public perception and environmental concerns have caused plant disease management strategies to shift toward an increased dependence on cultural methods and reduced dependence on pesticides (Jacobsen and Backman, 1993; Wallace, 1993). Since the number of registered pesticides is decreasing, and pressure from environmental preservation groups to limit pesticide use is increasing, cultural-based plant disease management strategies are in demand (Jacobsen and Backman, 1993). Integrated pest management (IPM) is an accepted practice in turfgrass culture and involves the coordinated use of cultural, chemical, and biological methods to minimize pest damage and maintain acceptable turf quality (Shurtleff et al., 1987). Since brown patch is a major turfgrass disease, and effective management by cultural methods is unknown, it becomes imperative that research-based information is collected to develop an effective IPM program for this disease.

Fungicide use is warranted for high value turfgrass sites, especially during periods conducive for disease development. To improve fungicide use efficiency, their applications should be timed to coincide with environmental conditions that favor disease development (Burpee, 1992). Johnson (1991) listed three criteria needed to determine if a plant disease were suitable for a prediction system as follows: (1) the disease is economically important; (2) the disease levels or disease occurrence are
variable among seasons; and (3) disease management strategies are available and economically feasible to employ. The destructive nature of brown patch, coupled with the seasonal variation in its occurrence among cool- and warm-season grasses, warrant further study into the environmental conditions needed to predict disease onset.

Dickinson (1930) and Dahl (1933) conducted the earliest investigations to elucidate those environmental conditions conducive to brown patch. Based on empirically derived disease risk thresholds established by Rowley (1991), Schumann et al. (1994) developed and tested a weather-based brown patch forecast model on creeping bentgrass. The success of the model to predict brown patch was measured by its ability to aid in fungicide-spray decisions. The weather-based model was shown to help reduce fungicide use, and performance was optimized when used in concert with an enzyme-linked immunoassay technique. The focus of this investigation, however, was to establish through statistical analyses those environmental conditions most conducive to R. solani infection events.

This investigation focused on brown patch disease in perennial ryegrass (Lolium perenne L.). Perennial ryegrass was chosen because it is the primary turfgrass grown on golf course fairways in the Mid-Atlantic region. Perennial ryegrass is very susceptible to brown patch and this disease is among the most commonly targeted for fungicide inputs. Because fairways constitute the largest managed acreage on golf courses, a significant portion of fungicide budgets must be devoted to brown patch control. Perennial ryegrass is a prominent fairway turf in most regions of the U.S.A., and it is often used on athletic fields or as a residential lawn grass in many areas.
There were two basic objectives of this investigation: (1) to identify cultural practices that help reduce disease severity and (2) to statistically document those environmental factors that promote brown patch. The primary approach to the cultural practices investigation was to field evaluate the influence of the following on brown patch and turfgrass quality: mowing height (1.7 versus 4.5 cm) and one of eight N-sources (Sustane, Ringer Compost Plus, Ringer, isobutylidenediurea, sulfur-coated urea, methylene urea, ammonium sulfate, and urea); N application timing (spring versus a fall schedule); and irrigation timing (AM versus PM) with two N-sources (inorganic versus synthetic organic applied alone or with P and K). The aforementioned cultural treatments were applied alone or in combination with iprodione [3-(3, 5-di-chlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidine-carboxamide)] delivered on an extended 21-day spray interval rather than the normal 10 to 14-day interval. The overall goal was to identify cultural management strategies that would provide an acceptable level of brown patch reduction and turf quality compatible with an IPM program.

The environmental monitoring portion of the investigation was initiated without knowledge of the empirical model being developed by Schumann et al. (1994) in Massachusetts. Regardless, the data collected here can be used to corroborate or improve upon their findings since disease pressure typically is greater in Maryland. More importantly, however, the model developed here will be based on more stringently arrived parameters elucidated by statistical analyses, which involved thousands of data points. The primary approaches to the environmental monitoring investigation were as follows: (1) to identify environmental conditions associated with R. solani infection events in perennial ryegrass; (2) to statistically determine key environmental variables
and conditions associated with the infection events; and (3) to develop and field validate a brown patch forecast model. Results of these studies will determine if the forecast model will provide for acceptable brown patch control with reduced fungicide inputs.
I. LITERATURE REVIEW


By 1940, the Mycology Division of the United States Department of Agriculture listed over 1,000 publications dealing with *Rhizoctonia*, and by 1970 that number exceeded 4,000 (Menzies, 1970). *R. solani* is pathogenic to over 200 grass species and causes brown patch or *Rhizoctonia* blight in turfgrasses (Couch, 1973).

Brown patch is considered to be a highly destructive, foliar disease on both cool- and warm-season turfgrasses (Smith et al., 1989). The disease was first described in 1913 on creeping bentgrass (*Agrostis palustris* Hudson) putting greens and was observed in 1914 on creeping red fescue (*Festuca rubra* L.), both near Philadelphia, PA (Piper and Coe, 1919). By 1916 the disease was found in the Washington DC area (Piper and Oakley, 1921). The earliest investigations into the nature and management of brown patch were conducted by Monteith (1926) and Monteith and Dahl (1928, 1932). These studies contributed greatly to developing the science of turfgrass pathology and disease management.

Recently, the biology and lifecycle of *R. solani* as a turfgrass pathogen were reviewed by Burpee and Martin (1992) and Smiley et al. (1992). The
fungus survives as thick-walled mycelial masses during periods when environmental conditions are unfavorable for hyphal growth. These mycelial masses are referred to as either sclerotia or bulbils, and they reside in the upper layers of soil, thatch, and plant debris. They may germinate over a wide temperature range (8 to 40°C), with an optimum germination temperature of 28°C. The optimum temperature for infection and disease development varies among turfgrass species and Rhizoctonia biotypes (i.e., anastomosis group). The fungus is capable of saprophytic growth in soil.

When sclerotia germinate, hyphae spread radially in the upper soil surface or thatch to form a roughly circular colony. During warm, moist and humid conditions, typically from late spring through late summer, hyphae spread over the soil and up onto moist turfgrass sheaths and leaves. Grayish-colored hyphae form an infection cushion, which penetrate the leaf tissue causing cell contents to ooze out into intercellular spaces. Infected leaf tissue appears water-soaked and darkened. Leaves then wilt and turn brown upon exposure to sunlight or drying wind. When plant tissues decompose, sclerotia form on or in dead tissues, and are released into the thatch and soil.

Brown patch symptoms vary depending on turfgrass species and cultivar, level of turfgrass maintenance, soil and environmental conditions, and Rhizoctonia sp. or strain (Smiley et al., 1992). Infected turf will display roughly circular patches of blighted foliar tissue. Tan lesions with dark borders, where necrotic and green tissue meet, are sometimes evident on diseased leaves. On closely mowed cool-season turfgrasses [i.e., creeping bentgrass and colonial bentgrass (Agrostis tenuis Sibth.)], circular or irregular-shaped patches of blighted turf are observed. A darkened, grayish-black border at the patch margin is called a “smoke ring” and may be evident
during early morning hours. The "smoke ring" is a sign that reveals the presence of mycelium actively infecting the leaf tissue, as indicated by water-soaking of leaves on closer inspection. On high-cut cool-season turfgrasses, [i.e., fine fescues (*Festuca* spp.), Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), and tall fescue (*Festuca arundinaceae* Schreb.)] a light brown, circular patch of blighted leaf tissue is the primary symptom and patches often appear without a "smoke ring". Leaf lesions are easily detected on wide leaf blades (i.e., tall fescue), and often fungal mycelium can be observed covering wet leaves during early morning hours. On warm-season turfgrasses [i.e., bermundagrass (*Cynodon dactylon* [L.] Pers.), centipedegrass (*Eremochloa ophiuroides* Munro), St. Augustinegrass (*Stenotaphrum secundatum* Walt.), and zoysiagrass (*Zoysia japonica* Steud.)], blighted patches commonly are observed in the spring when these grasses break dormancy, or in the fall as they approach dormancy. Leaf sheath and basal rots are associated with brown patch in warm-season grasses (Zummo and Plakidas, 1958).

Brown patch management has focused almost exclusively on the use of fungicides since Bordeaux mixture (*CuSO₄* plus lime) was first applied to putting greens in 1917 (Carrier, 1923; Monteith and Dahl, 1932). Although brown patch was among the earliest documented turf diseases (Piper and Coe, 1919), information is sparse regarding brown patch management through cultural practices or the integration of cultural methods with fungicide usage. Integrated pest management (IPM) is an ecological approach to plant pest control (Henneberry et al., 1992), and is considered a broad, multidisciplinary, and systematic method to managing turfgrass pests (Shurtleff et al., 1987). Leslie (1989) defines IPM as the "coordinated use of
pest and environmental information with available pest management strategies to prevent unacceptable levels of plant damage, by the most economical means possible, while minimizing the effect on people and the environment. Integrated pest management programs have made a significant impact on reducing pesticide use in agricultural crops while at the same time ensuring a safe food supply, and supporting soil, water and wildlife conservation efforts (Wallace, 1993).

For a plant disease epidemic to occur, there must be a continuous interaction between host and environment where the environmental conditions favor the pathogen's growth and development over that of the susceptible host (Fry, 1982). For turfgrass disease management, knowledge of the pathogen, environment, and host are critical to implementing successful IPM programs (Bruneau et al., 1992). A key component with plant disease management is to utilize cultural practices that promote healthy and vigorous plants and thereby reduce disease severity. This would reduce fungicide usage, as would properly timing and targeting of their applications (Jacobsen and Backman, 1993). A review of information regarding turfgrass cultural practices and their influence on brown patch and environmental conditions associated with the disease, while somewhat limited, may help identify areas where IPM strategies could be developed.

BROWN PATCH AS INFLUENCED BY CULTURAL PRACTICES

Mowing, fertilization, and irrigation are the primary cultural practices used in maintaining quality, functional turfgrass. The combination of these three factors and their effect on pests, turfgrass growth and development, and
the environment is complex. Some cultural practices have been shown to increase or decrease the severity of many turfgrass diseases (Smiley et al., 1992).

**Mowing.** Mowing is the most basic practice in turfgrass culture, and is defined as a defoliation process in which a portion of the turfgrass leaf is removed (Beard, 1973). Increasing mowing height has been demonstrated to effectively reduce the severity of several turf diseases including the following: dollar spot (*Sclerotinia homoeocarpa* Bennett) (Turgeon and Meyer, 1974; Brede, 1991), Fusarium blight (*Fusarium* spp.) (Turgeon and Meyer, 1974), leaf spot (*Helminthosporium vagans* Drechs.) (Halisky et al., 1966; Lukens, 1970), and summer patch (*Magnaporthe poae* Landschoot and Jackson) (Davis and Demoeden, 1991).

The influence of mowing height and frequency on brown patch incidence and severity was first reported by Rowell (1951). Rowell (1951) observed that brown patch appeared more frequently on an *Agrostis* spp. putting green mowed 2 to 4 times weekly to a height of 0.64 cm when compared to the green's apron, which was mowed at 1.9 cm. Rowell (1951) suggested that the increased blighting in the lower cut turfgrass may be due to the dense vegetative growth and resulting higher humidities within the canopy of the putting surface.

Shurtleff (1953) observed that *Rhizoctonia* mycelium spread more rapidly at higher seeding rates of 'Astoria' colonial bentgrass in a greenhouse study. Turf density may affect disease incidence directly due to larger numbers of target plants, or indirectly through interactions with the environment (Burdon and Chilvers, 1982). Close and frequent mowing favors an increase in leaf blade density (Madison, 1962). This condition may
contribute to increased humidity and moisture in the leaf canopy (Watson, 1972), possibly favoring foliar diseases like brown patch that require warm and humid conditions to develop. In a recent field study, Giesler et al. (1994) reported that brown patch severity increased with higher densities of tall fescue plants. Since canopy air temperature, leaf wetness duration, and relative humidity data were not different at the three densities evaluated, Giesler et al. (1994) concluded that brown patch severity was not influenced by canopy microclimate.

Shurtleff (1953) investigated the effect of cutting height on the incidence of brown patch in a greenhouse study involving five Agrostis spp. and Poa pratensis L. cultivars. He (1953) observed no differences in the amount of infection between cut (1.3 to 1.9 cm) and uncut turfgrasses. Turfgrass age (ranging from 1 month to 8 years) also had no influence on the degree of foliar blighting (Shurtleff, 1953). In a one year field study conducted in Nebraska, brown patch was reported to be more severe in tall fescue mowed at 6.4 cm versus a 2.5 cm height of cut (Watkins et al., 1990). In zoysiagrass, large patch (incitant R. solani) severity was greater when turf was mowed at 1.2 and 2.5 cm when compared to a 4.5 or 5.1 cm height of cut (Green et al., 1994).

In another greenhouse investigation, Shurtleff (1953) subjected six-week old 'Astoria' colonial bentgrass, 'Seaside' creeping bentgrass, and unknown cultivars of Kentucky bluegrass and creeping red fescue to mowing (1.3 to 1.9 cm) 3 days, 1 day, and just prior to fungal inoculation. He (1953) found no differences in amount of foliar blighting among all treatments.

On a putting green containing six species of bentgrass, Shurtleff (1953) examined the role of turfgrass clippings on brown patch incidence. He (1953)
found that *R. solani* mycelium survived up to four months in dry grass tissue, and suggested that *R. solani* was spread by infected clippings.

Rowell (1951) observed that infection of cool-season grasses most frequently occurred through mowing wounds on the leaves. Tips of grass blades were affected first then the infection progressed downward toward the plant crown. Rowell (1951) noted that mowing wounds and guttation droplets produced on wound surfaces appeared to be important to brown patch development. Guttation is a natural process where water is excreted by the plant, and guttation fluids contain organic and inorganic substances (Curtis, 1943). Curtis (1944) observed glutamine present in guttation fluid from perennial ryegrass treated with an ammonium-based fertilizer. Endo and Amacher (1964) reported that guttation fluid from *Agrostis* spp. increased infection and disease severity from *Helminthosporium sorokinianum* (Sacc. in Sorok.). Conversely, dew is the condensation of atmospheric water on the leaf surface, and contains mostly pure water (Monteith, 1957).

Rowell (1951) further observed that *R. solani* mycelium rapidly spreads among infected leaf blades, but failed to spread from leaf to leaf on uncut turfgrass. In greenhouse studies, Shurtleff (1953) observed no infection through mowing wounds. Rather, penetration of the tissue by *R. solani* was through stomates, cuticule, or both, and the method of penetration varied with fungal biotype and turfgrass species.

**Fertility.** Fertilization, specifically nitrogen (N) management, is an important cultural practice affecting turfgrass establishment, quality, function, and maintenance (Madison, 1971). The amount of N applied can influence disease development in turf. Previous research has shown that turf maintained at low N levels was more susceptible to dollar spot (Cook et al.,
1964; Endo, 1966; Markland et al., 1969), and red thread (Laetisaris fuciformis [McAlpine] Burdsall) (Muse and Couch, 1965; Cahill et al., 1983). Take-all patch (Gaeumannomyces graminis [Sacc.] Arx. & D. Oliver var avenae [E.M. Turner] Dennis) also is more severe in poorly nourished (i.e., low soil N and phosphorus levels) turf (Dernoeden, 1987). Conversely, turf maintained at high N levels was more susceptible to anthracnose (Colletotrichum graminicola [Ces.] G.W. Wils.) (Danneberger et al., 1983), Fusarium blight (Turgeon and Meyer, 1974), take-all patch (Goss and Gould, 1967), pink snow mold (Fusarium nivale [Fr.] Ces.) (Madison et al., 1960), and Pythium blight (Pythium spp.) (Moore et al., 1963).

Nitrogen sources applied to turf have different N releasing characteristics (Turner and Hummel, 1992). The effects of inorganic and synthetic organic N-sources were investigated for their influence on anthracnose (Danneberger et al., 1983), spring dead spot (Leptosphaeria korrae Walker and Smith) (Dernoeden et al., 1991), summer patch (Davis and Dernoeden, 1991; Thompson et al., 1993), and take-all patch (Goss and Gould, 1967; Dernoeden, 1987). Ammonium-based N-sources were shown to reduce the severity of all the aforementioned diseases except anthracnose. Natural organic N-sources have been evaluated for their effects on brown patch (Nelson and Craft, 1990; Soika and Sanders, 1991; Peacock and Daniel, 1992), dollar spot (Cook et al., 1964; Markland et al., 1969; Nelson and Craft, 1992), necrotic ring spot (Leptosphaeria korrae Walker and Smith) (Melvin and Vargas, 1994), and Pythium root rot (Pythium spp.) (Thurn and Hummel, 1992).

Early investigations of brown patch on Agrostis spp. putting greens by Oakley (1924, 1925) suggested that a well-screened, loamy compost
topdressing supplemented with an organic N-source, blood meal, or either ammonium sulfate or ammonium phosphate reduced brown patch. Bordeaux (CuSO₄ + lime) application followed by topdressing diseased turf with compost plus ammonium sulfate was suggested as a means of controlling brown patch by Tilford in 1925.

**Natural Organic N.** Turfgrass plants utilize N from natural organic fertilizers after soil microorganisms release N from the organic compounds through the process of mineralization (Turner and Hummel, 1992). There is an increased number of natural organic fertilizers available to the turfgrass industry (Agnew, 1992), and there is interest in using these N-sources in biological turf disease control programs (Nelson, 1992). A decrease in dollar spot severity was reported in turf treated with activated sewage sludge containing cadmium (Cook et al., 1964; Markland et al., 1969), and plant and animal meals and composts (Nelson and Craft, 1992). Thurn and Hummel (1992) reported a suppression of Pythium root rot in a putting green when sewage sludge, brewery waste compost were added to the sand-based root zone mix, when compared to an unamended mix. Melvin and Vargas (1994) reported a decrease in necrotic ring spot severity in Kentucky bluegrass turf fertilized with Ringer Lawn Restore 9N-4P-4K when compared to a fertilizer mixture (9N-4P-4K of urea plus treble superphosphate plus potassium chloride) in two out of three years.

Information is growing regarding the effects of natural organic N sources on brown patch severity in turf. In a one-year field trial, Nelson and Craft (1990) reported that a topdressing mix amended with plant and animal meals, composted animal manures, sewage sludge, or plant debris significantly reduced brown patch severity, when compared to unfertilized
creeping bentgrass. Although no information is given regarding rates or application timings, Nelson and Craft (1990) also reported that plant and animal meals and turkey manure-based composts were as effective in reducing brown patch severity as repeated fungicide applications. Soika and Sanders (1991) also observed in a one-year field study on creeping bentgrass that two Ringer experimental fertilizers (commercially available Ringer Turf Restore 10N-1P-5K was not assessed) and Sustane 5N-1P-3K provided excellent suppression of brown patch compared to unfertilized turf.

In a greenhouse investigation, however, Peacock and Daniel (1992) observed that Ringer Turf Restore 10N-1P-5K, which contained soil bacteria, had no effect on preventing infection by Rhizoctonia spp. on 'Rebel' tall fescue mowed at 5 cm.

The majority of research involving soil organic amendments and composts on reducing Rhizoctonia diseases were conducted on field and vegetable crops (Baker and Martinson, 1970). Organic soil amendments and N-sources, however, have both stimulated and suppressed the saprophytic and parasitic behavior of Rhizoctonia spp. (Baker and Martinson, 1970; Huber and Watson, 1970, 1974). Vorland and Epstein (1994) reported that soil amended with manure and composted animal wastes enhanced suppression to damping-off, caused by R. solani AG-4, compared to N-sources deficient in organic matter. In one of the earliest ecological studies on R. solani, Blair (1943) reported that organic soil supplements (i.e., animal manure and compost, grass and straw meal, and municipal sludge compost) depressed pathogen growth in soil. He (1943) observed that grass meal, with the highest content of decomposed organic matter, had the greatest effect on reducing pathogen growth. Blair (1943) suggested that in unsterilized soil,
organic supplements stimulated other microorganisms to compete with *R. solani* for nutrients and oxygen. Sanford (1947) suggested that reduced activity of *R. solani* in soil was attributed to the antibiotic effects from soil microorganisms caused by the addition of organic soil amendments.

When considering compost as part of a plant disease management program, disease suppression often varies with the pathogen, the compost source and process, and degree of decomposition (Hoitink and Fahy, 1986). In early laboratory tests, Allen and Haenseler (1935) reported that *Trichoderma* spp. had an antagonistic effect on the growth of *Rhizoctonia* and *Pythium* spp. Henis et al. (1979) found a higher population of *Trichoderma* spp. present in *Rhizoctonia* suppressive soils, compared to those soils conducive to *Rhizoctonia*-caused diseases. Liu and Baker (1980) also reported increased *Trichoderma* spp. populations in soils suppressive to *R. solani*. Hoitink and Fahy (1986) concluded that the antagonistic activity of soil microorganisms toward *Rhizoctonia* spp. was affected by the type, condition or maturity of the organic matter present in the compost and organic amendments. For example, *Trichoderma* spp. and *Gliocladium* spp. were more antagonistic to soilborne fungi in soil amended with composted hardwood bark, when compared to sphagnum peat-amended soil (Hoitink, 1980; Nelson et al., 1983).

In a greenhouse study involving vegetables, *Rhizoctonia* spp. diseases were reduced in soils amended with composted sewage sludge (Lumsden et al., 1983). They suggested that the increased activity of other microorganisms in the compost-amended soil may have affected the disease-causing ability of the pathogen, since pathogen survival was not altered. Kuter et al. (1988) observed that composted municipal sewage sludge as an amendment for
ornamental plant container media would induce suppression to *Rhizoctonia* damping off, as would composts made from hardwood and pine-bark wastes (Nelson and Hoitink, 1982). Davey and Papavizas (1960) and Papavizas et al. (1962) reported that decomposing organic soil amendments with high carbon:nitrogen (C:N) ratios were more effective in reducing *R. solani* survival than amendments with a low C:N ratio. Davey and Papavizas (1960) also observed that organic amendments and supplemental N were more effective in reducing *R. solani* activity in the absence rather than presence of a host, however, in turfgrass culture the host is always present.

**Inorganic and Synthetic Organic N.** Hearn (1943), reported that brown patch was favored by excess N in the form of ammonium sulfate (N rate not given). Musser (1950) suggested that soft and succulent turfgrass resulting from excessive N applications (N rate not defined) were more susceptible to brown patch compared to N deficient turfgrass. This was corroborated in a one-year field study by Shurtleff (1953). He applied urea at 352 kg N ha$^{-1}$ yr$^{-1}$ in two summer applications to colonial bentgrass, and reported that urea-treated turf exhibited 22% plot area diseased versus 7% in the non-fertilized control. Shurtleff (1953) concluded that high N applications stimulated dense and succulent turfgrass, which was rendered more susceptible to brown patch. He (1953) also stated that the grass blades would be closer together in turf treated with high N and that relative humidity in the plant canopy would be higher.

In a greenhouse study, Shurtleff (1953) used a modified Hoagland's solution to test 15 balanced and unbalanced nutrient solutions to assess their effect on the pathogenicity of *R. solani* on 'Astoria' colonial bentgrass. Contradictory to the field results, he (1953) observed no differences in
disease severity among nutrient solutions. In another greenhouse study, however, Bloom and Couch (1960) subjected 'Seaside' creeping bentgrass to a modified Hoagland's solution supplied by a continuous drip-culture system to provide N at varying concentrations. They used 0.1 (low), normal, and 3.0 (high) times the concentration of N, phosphorus (P), and potassium (K) in the nutrient solution as described by Gallegly and Walker (1949). These N, P, and K concentrations, however, cannot be converted to kg ha$^{-1}$ because plants were grown in sand and fertilized by a continuous drip-culture system. Bloom and Couch (1960) concluded that brown patch development was greater at high N versus normal N levels, and disease was less severe under low N versus normal N levels.

In a one-year field study, Watkins et al. (1990) observed an association between greater brown patch severity in tall fescue and higher application rates of liquid urea, which ranged from 98 to 392 kg N ha$^{-1}$ yr$^{-1}$ applied in May, June, July, August, and September. Watkins et al. (1990) noted that disease symptoms were more pronounced in high-cut tall fescue receiving higher N applications rates. After a two-year field study, Green et al. (1994) reported that no N-source (i.e., urea, ureaformaldehyde, poultry litter, sewage sludge, or bovine waste) or N rate (ie., 74 or 148 kg N ha$^{-1}$ yr$^{-1}$) influenced the severity of large patch in zoysiagrass.

No research data exits regarding the effect of leaf N content, as influenced by N applications, on brown patch severity. Cahill et al. (1983), however, observed that an increase in leaf N content was associated with a decrease in red thread severity.

Research regarding the effects of N-source and rate on the growth and activity of R. solani in soil is more extensive, yet conflicting. Davey and
Papavizas (1963) observed that supplemental N added to soil as ammonium-based N (200 to 400 versus 0 to 100 mg N kg\(^{-1}\) soil) increased the competitive saprophytic activity of \(R. \ solani\) on mature buckwheat (\textit{Fagopyrum esculentum} L.) stem segments. In a field study on vegetable crops, Papavizas et al., (1975) reported a positive correlation between \(R. \ solani\) AG-4 saprophytic activity and inorganic N and ammonium-N, but not nitrate-N. Conversely, in greenhouse studies, survival and saprophytic activity of \(R. \ solani\) was increased with nitrate-N, but decreased with ammonium-N (Papavizas, 1969). In an earlier study, Allington (1936), reported that greater numbers of \(R. \ solani\) sclerotia were formed in water agar amended with sodium nitrate versus urea, ammonium nitrate, or calcium nitrate. Sclerotia formation in water agar increased with an increasing N concentration (Allington, 1936).

**Phosphorus (P) and Potassium (K).** Turner (1986) extensively reviewed the literature on the subject of turfgrass fertilization and disease. He (1986) concluded that P and K applications either reduced or had a limited influence on turfgrass disease severity, and this influence varied with the amount of N applied. A balanced N, P, and K fertility program was shown to reduce the severity of dollar spot (Couch and Bloom, 1960), Fusarium blight (Curtright and Harrison, 1970), Ophiobolus patch (Goss and Gould, 1967), and stripe smut (\textit{Ustilago striiformis} [West.] Niessl.) (Hull et al., 1979).

Bloom and Couch (1960) reported no difference in brown patch development on turf grown at high or low levels of P and K alone, however the disease was affected by varying N levels in combination with P and K. As previously noted, these N, P, and K concentrations cannot be converted to kg ha\(^{-1}\). They (1960) observed that plants grown with low N and normal P and K
levels exhibited reduced plant vigor and had less brown patch damage. Bloom and Couch (1960) concluded that reduced plant vigor actually accentuated disease proneness. They (1960) further concluded that while high N with normal P and K levels increased plant vigor, it also was associated with greater brown patch development. Disease proneness, however, was offset in turf treated with high N plus high P and K (Bloom and Couch, 1960).

The effects of P and K on the activity of *R. solani* in soil is unclear. In a laboratory investigation conducted in glass tubes, Das and Western (1959) observed an increase in *R. solani* growth in sterilized soil subjected to a balanced fertilizer and the highest rate of P (12.9 kg P ha\(^{-1}\)) compared to lower rates of P (1.6 to 6.5 kg P ha\(^{-1}\)). In sterilized soil, *R. solani* growth decreased with the highest rate of N (13.0 kg N ha\(^{-1}\)) and K (12.2 kg K ha\(^{-1}\)) compared to lower rates of N (1.6 to 6.5 kg N ha\(^{-1}\)) and K (1.5 to 6.1 kg K ha\(^{-1}\)). Papavizas and Davey (1961), however, reported no apparent effect on the saprophytic activity of *R. solani* with P added to field soil.

**Soil pH.** The effect of pH on the growth and development of an *R. solani* isolate from turf was first investigated by Monteith (1926). He observed that *R. solani* growth was most rapid in agar with pH's ranging from 4.8 to 7.0, when compared to a pH range of 1.8 to 3.6 or 8.2 to 9.8.

Soil reaction can influence growth of *R. solani*, as well as turf growth and disease susceptibility. All these factors are closely related to soil fertility programs (Smiley et al., 1992). Hearn (1943) reported that *R. solani* growth and activity occurred in Texas soils with a pH range 6.0 to 8.2, with optimum growth occurring at pH = 7.0 (methodologies not reported). Similarly, Blair
(1943) observed the growth of *R. solani* hyphae in soil ranging from a pH 5.8 to 8.1, with optimum growth at neutral pH.

In a greenhouse study, Bloom and Couch (1960) observed that brown patch severity was greater on 'Seaside' creeping bentgrass subjected to high N and nutrient solution pH's of 5.6 and 9.0 versus a pH of 4.0. Under low N, pH had no apparent affect on disease development (Bloom and Couch, 1960). Brown patch, however, was greater in the acidic (pH ≤ 5.6) range when plants were subjected to balanced N + P + K nutrition (Bloom and Couch, 1960). As stated previously, Bloom and Couch (1960) supplied the nutrient solution to plants in a continuous drip-culture system and therefore the levels of N, P and K used cannot be extrapolated to kg ha⁻¹. In another greenhouse study, soil pH had no significant effect on disease severity in centipedegrass (incitant *R. solani* AG-2-2) (Haygood et al., 1989).

Kaufman and Williams (1965) reported that the population of soil fungi antagonistic to *R. solani* was not influenced by soil pH, or P and K fertilization. Chet and Baker (1980) observed that acidified or naturally acidified soils were suppressive to *R. solani*, and that suppressive populations of *Trichoderma harzianum* Rifai were greater in acid soils. Furthermore, in vitro growth of *T. harzianum* was enhanced more than *R. solani* growth under acidic (pH ≤ 6.5) conditions (Chet and Baker, 1980). Papavizas (1969) observed that nitrate-N increased and ammonium-N decreased the survivability of *R. solani* in soil. This effect did not appear to be related to changes in soil pH because sodium nitrate and ammonium nitrate increased the survivability of *R. solani* over ammonium chloride-treated and unfertilized soil (Papavizas, 1969).

**Irrigation.** In addition to mowing and fertilization, irrigation is another cultural practice in turfgrass management that exerts a great influence on turf
growth, quality, and microclimate (Watson, 1972). For many plant diseases, moisture on the plant and in soil is necessary for infection and disease development (Rotem and Palti, 1969; Yarwood, 1978). Irrigation timing, frequency, and duration have been shown to influence turf growth and disease development. For example, pink snow mold incidence was reduced in turf receiving morning irrigation (Madison et al., 1960), and deep but infrequent irrigation was shown to reduce summer patch severity (Davis and Dernoeden, 1991). Melvin and Vargas (1994) reported that light, daily irrigation (2.5 to 5.0 mm day\(^{-1}\)) reduced necrotic ring spot severity. In general, for turfgrass disease management, the turf should be irrigated in the early morning to reduce the leaf wetness period (Smiley et al., 1992).

Information is limited concerning the influence of irrigation and soil moisture on brown patch. In 1924, Oakley recommended watering in the early morning to reduce brown patch incidence and enhance recovery of diseased putting green turf. Piper and Oakley (1921) observed that poorly drained putting greens were more susceptible to brown patch than well drained turf. In a greenhouse study, however, there were no brown patch severity differences in 'Seaside' creeping bentgrass subjected to five soil moisture levels ranging from field capacity to permanent wilting point (Couch and Bloom, 1958; Bloom and Couch, 1960).

In warm-season turfgrasses, brown patch is enhanced by irrigation practices that favor saturated soil conditions. For example, Haygood et al. (1989) reported that brown patch severity was greater in centipedegrass grown at higher moisture levels (i.e., 73% sheath rot at 19% soil moisture versus 16% sheath rot at 4% soil moisture). Since disease severity was greater with zoysiagrass subjected to saturated soil conditions, Green et al.
(1994) suggested that relative humidity or surface moisture in the thatch, and not the plant canopy, influenced the infection process in zoysiagrass.

Poor soil oxygen conditions caused by excessive soil moisture tends to limit the growth of *R. solani* (Baker and Martinson, 1970). Blair (1943) subjected soil to a range of 30 to 80% saturation capacity, and observed greater *R. solani* growth in soil at 30% saturation. Das and Western (1959) also observed that *R. solani* grew best at 40% of saturation when soil was subjected to a range of 40 to 90% saturation capacities. Papavizas and Davey (1961) reported higher saprophytic activity by *R. solani* in soils with 20 to 50% versus 60 to 90% moisture-holding capacity. In a laboratory investigation, a decrease in soil relative humidity from 99 to 96% resulted in an 80 to 85% reduction in *R. solani* growth (Dube et al., 1971).

ENVIRONMENTAL CONDITIONS ASSOCIATED WITH BROWN PATCH

The relationship between the environment and plant disease was thoroughly reviewed by Colhoun (1973). This relationship involves temperature, moisture, light and soil conditions and their interactions with the host and pathogen. An actively growing pathogen, susceptible host, and periods of high temperature and humidity with extensive leaf surface moisture conditions are necessary for brown patch development (Smiley et al., 1992). Optimum temperature range for the growth of turfgrass isolates of *R. solani* was reported to be 25 to 30°C on potato dextrose agar (PDA) by Monteith and Dahl (1928) and 20 to 25°C by Traquair and Smith (1981). For *R. solani* anastomosis groups AG-1 to AG-10, Burpee and Martin (1992) reported optimum temperature range for growth was 18 to 28°C on PDA.
Dickinson (1930) was the first to extensively study environmental conditions associated with brown patch on putting green turf. He (1930) concluded that at least a 45 minute temperature period of 17.7 to 20.0°C followed by a temperature increase of 26.6 to 29.4°C was necessary to stimulate *R. solani* sclerotia germination. He (1930) reported that parasitism of turf began at 22.5°C and ceased at 32°C. Dickinson (1930) also observed that sclerotia would germinate if a rise in temperature to a range of 17.7 to 20.0°C was maintained for 8 to 10 hours. Dickinson (1930) noted that sclerotia "were destroyed" when air temperatures fell below 16.5°C. He (1930) concluded that since sclerotia are present on the soil surface and on the turfgrass plants, they were affected more by air than soil temperatures. Dickinson (1930) noted that brown patch symptoms often appeared following afternoon watering on hot days when the temperature dropped from 26.4 to 34.6°C during the day to 15.4 to 20.9°C at night.

Dahl (1933) found that *R. solani* sclerotia did not require a decrease in temperature to germinate except when maintained at 36°C before and after chilling. Dahl (1933) observed that sclerotia germinated at temperatures as low as 8 to 12°C. Shurtleff (1953) reported the temperature range for sclerotia germination to be 15.6 to 37.0°C at 98% relative humidity, while Dahl (1933) reported that sclerotia germinate over a temperature range from 8 to 40°C. Dahl (1933) also reported that the optimum temperature for sclerotia production was 28 to 32°C. Allington (1936) reported that *R. solani* sclerotia formation in water agar was optimum at pH 7, and observed that sclerotia were tolerant of acid (pH = 4 to 6), but not alkaline (pH = 8) conditions.
Brown patch was observed in southern California on Kentucky bluegrass and creeping bentgrass when air temperature reached a range of 26.4 to 34.9°C (Endo, 1961). In a greenhouse study, *R. solani* infection of 'Seaside' creeping bentgrass was optimum between air temperatures of 21.0 and 26.8°C (Endo, 1963). In the midwest, brown patch was observed in Kentucky bluegrass when air temperatures ranged from 15 to 25°C (Joyner et al., 1977). On pearlwort (*Sagina procumbens* L.) in Australia, Kerr (1956) reported brown patch occurred when relative humidity was high (i.e., ≥ 93%) and minimum air temperatures ranged from 17.5 to 20.0°C.

Based on field observations in Rhode Island, Shurtleff (1953) concluded that colonial bentgrass must be covered with a film of moisture for at least 15 hr for *R. solani* to penetrate the leaf blade and cause injury. In laboratory tests, 8 to 10 hours of leaf wetness were necessary for *R. solani* infection of pearlwort at 25°C (Kerr, 1956). In a greenhouse study, Rowley (1991) reported that 8 to 12 hours of leaf wetness was necessary for *R. solani* to infect creeping bentgrass grown at 12°C.

In warm season grasses, Hearn (1943) reported brown patch occurred in Texas when air temperatures ranged from 22 to 34°C. Optimum temperature for large patch (i.e., brown patch) in zoysiagrass was 20 to 25 °C in Kansas (Green et al., 1994) and 24°C in Arkansas (Dale, 1978). For St. Augustinegrass and centipedegrass, the optimum air temperature for brown patch development was reported to be 26°C (Haygood and Martin, 1987).

Shurtleff (1953) found that the optimum growth rate of *R. solani* through soil occurred at 19 to 27°C. *Rhizoctonia* sp. isolated from southern California were pathogenic to Kentucky bluegrass and creeping bentgrass seedlings at a soil temperature of 12.8°C (Endo, 1961). In a controlled growth chamber
study, Endo (1963) also found severe foliar infection in 'Seaside' creeping bentgrass occurred at soil temperatures of 13.0 and 29.5°C with two different R. solani strains.

Zarlengo et al. (1994) investigated the effects of light and shade on brown patch development in 10 tall fescue cultivars. Tall fescue grown in shade exhibited significantly greater brown patch (R. solani AG-1 IA) injury than sun-grown cultivars (Zarlengo et al., 1994). The morphological (i.e., fewer tillers, less shoot and root growth) and physiological (i.e., decrease in carbohydrate reserves, thin cell walls and high internal cell water content) effects of shading, and not the shade environment, had the greatest influence on disease severity (Zarlengo et al., 1994).

TURFGRASS DISEASE DETECTION AND FORECASTING

Advances in computer technology have made it possible to improve environmental and plant disease monitoring and measuring techniques. Hence, the development of disease detection methods and epidemic prediction models have been improved (Rouse and Teng, 1984; Teng and Rouse, 1984). Plant pathologists have been exploiting recent advances in computer technology to develop disease prediction and disease management systems (Krause and Massie, 1975; Jones et al., 1984, Latin et al., 1987). Disease forecast models have been developed for many agronomic and horticultural crops (Zadoks, 1984; Campbell and Madden, 1991). Plant disease epidemic forecast methods may be based on pathogen populations (i.e., amount of initial and secondary inoculum) or environmental
conditions favorable for disease development (Bourke, 1970; Young et al., 1978; Madden and Ellis, 1988; Campbell and Madden, 1991).

Weather-based disease forecasting systems were developed for Pythium blight (*Pythium aphanidermatum* [Edson] Fitzp.) (Nutter et al., 1983), dollar spot (Hall, 1984), anthracnose (Danneberger et al., 1984), and brown patch (Schumann et al., 1994). In a three-year study, Nutter et al. (1983) developed a Pythium blight forecast model for creeping bentgrass golf course fairways in Pennsylvania based on air temperature and relative humidity recorded from a hygrothermograph. They (1983) observed that Pythium blight epidemics occurred when maximum daily air temperatures were ≥ 30°C with ≥ 14 hr of relative humidity ≥ 90%, and a minimum air temperature ≥ 20°C during the required humidity period. Hall (1984) developed a dollar spot infection model for creeping bentgrass putting greens based on air temperature and precipitation. He (1984) concluded that two consecutive wet days with average air temperature ≥ 22°C or three or more consecutive wet days and ≥ 15°C average air temperature were the conditions necessary to initiate an infection period. Hall (1984) used the dollar spot infection model to time fungicide applications, which resulted in dollar spot control equal to a calendar-based fungicide spray program. Danneberger et al. (1984) developed a second-order regression model combining air temperature and leaf wetness duration to predict anthracnose in annual bluegrass (*Poa annua* var. *reptans* [Hauskins] Timm.). Danneberger et al. (1984) observed that the pathogen was damaging to annual bluegrass at air temperatures between 16 and 28°C, and was most injurious at 22°C with ≥ 20 hr leaf wetness duration.

The first reported brown patch forecast system was related directly to air temperature, and was developed at the Arlington Turf Gardens, Rossyln,
VA (Dahl, 1933). Over five consecutive summer periods, Dahl (1933) observed that brown patch occurred on 82% of days when the minimum air temperature was ≥ 21°C. Unfortunately, Dahl (1933) did not include any environmental records or brown patch incidence data in his report. Recently, Rowley (1991) and Schumann et al. (1994) developed a weather-based brown patch forecast model for creeping bentgrass putting greens in Massachusetts. They (1994) determined that the environmental conditions conducive to brown patch occurrence were as follows: relative humidity ≥ 95% for a duration of ≥ 10 hr; precipitation ≥ 2.54 mm within 36 hr; minimum and average air temperatures of ≥ 15 and ≥ 20 °C, respectively; and minimum and average soil temperatures of ≥ 18 and ≥ 21°C, respectively. Schumann et al. (1994) evaluated forecast-driven brown patch fungicide applications versus calendar sprays in Massachusetts, New Jersey and Georgia. They (1994) reported weather-based, immunoassay-based, and weather-plus immunoassay-based sprays resulted in a 10, 28, and 40% reduction in fungicide use, respectively when compared to a standard calendar spray schedule.

Recent advances in molecular biology and biotechnology have led to the development of antibodies that detect nucleic acid or proteins of plant pathogens (Clark, 1981). As a result, enzyme-linked immunosorbent assay (ELISA) methods were developed for plant disease detection and diagnosis (Miller and Martin, 1988). Plant pathogens can be detected and their population quantified with ELISA methods prior to the appearance of disease symptoms (Miller and Martin, 1988). Plant pathogen concentrations can be evaluated against established disease threshold levels and therefore facilitate decisions on disease management strategies (Miller, 1982).
Rittenberg et al. (1988) reviewed commercially available ELISA technology for dollar spot, brown patch, and Pythium blight detection on turfgrasses. A double-sandwich antibody reaction was used to detect the fungal pathogens as described by Miller and Martin (1988). Detection of turfgrass disease epidemics using ELISA were demonstrated by Shane (1991), Baldwin (1993), and Schumann et al. (1994). Shane (1991) concluded that the ELISA method was useful for verifying a Pythium blight diagnosis, however, pathogen quantification was not consistent. Baldwin (1993) reported a reduction in fungicide use when sprays were based on ELISA dollar spot detection results, when compared to traditional visual disease assessment methods. Schumann et al. (1994) concluded that fungicide applications could be reduced and acceptable brown patch control achieved by combining weather-based disease forecasts with ELISA-based confirmation of pathogen levels.

OTHER FACTORS

Information is limited regarding the relationship among plant parasitic nematode population densities, turf growth and fungal diseases. Also, while cultural practices influence turf growth and therefore determine the carbohydrate status of grasses, the association between carbohydrate levels and disease incidence is seldom documented in turf disease research.

**Plant Parasitic Nematodes.** Nematodes are microscopic, unsegmented, mostly translucent, aerobic animals that live primarily in soil (Agrios, 1978). The number of living nematodes in a hectare of soil 15 cm deep in a humid, temperate region is estimated at $2.5 \times 10^9$ (Danneberger,
In turfgrass ecosystems, most nematodes are saprophytic, surviving on decaying organic matter in soil (Madison, 1971). Several nematode species are obligate parasites of turfgrass (Smiley et al., 1992). Parasitic nematodes generally feed on turfgrass roots using a hollow, needle-like structure called the stylet. This feeding behavior causes root injury from mechanical penetration and from nematode secretions used to digest the contents of plant cells (Heald and Perry, 1969). Root injury caused by parasitic nematode feeding pre-disposes weakened plant roots to pathogenic fungi and bacteria. Injury from plant parasitic nematode feeding, however, may not be seen until the turfgrass is subjected to environmental stress (Shurtleff et al., 1987).

Few published reports are available concerning an association between plant parasitic nematodes and fungal diseases of turf. Pepper (1965) reported that the free-living nematode Panagrolaimus spp. was associated with melting-out (Helminthosporium vagans Drechs.) in Kentucky bluegrass lawns in North Dakota. Vargas and Laughlin (1972) reported that Fusarium blight was more severe in seedling Kentucky bluegrass in the presence of the stunt nematode Tylenchorhynchus dubius (Butschli) Filipjev. In Kentucky bluegrass sod fields, high populations of plant parasitic nematodes and F. roseum suggested a possible interaction between these nematodes and the development of Fusarium blight (Cole et al., 1973). No attempt, however, was made to correlate F. roseum and nematode populations (Cole et al., 1973). Although high plant parasitic nematode populations and severe dollar spot were observed in heavily thatched Kentucky bluegrass turf, a relationship between plant parasitic nematode levels and disease incidence could not be determined (Halisky et al., 1981).
A limited amount of information is available on the influence of cultural practices on plant parasitic nematode population densities in turfgrasses. Nematode population counts of Belonolaimus longicaudatus Rau from field and greenhouse studies on 'Tifgreen' bermudagrass suggested that organic N-sources (Milorganite or activated sewage sludge) suppressed plant parasitic nematode populations compared to inorganic N (ammonium nitrate) (Heald and Burton, 1968). It was suggested that fertilizers and organic amendments assist in creating soil conditions favorable for an increase in soil microorganisms and predators necessary to suppress plant parasitic nematode population densities (Heald and Perry, 1969; Sikora, 1992). Rodriguez-Kabana (1986) reported that additions of organic manures with a low carbon:nitrogen ratio, which release ammonia in soil, were associated with an increase in soil microbial activity and a reduction in plant parasitic nematode population densities in several field and vegetable crops.

**Carbohydrate Reserves In Turfgrasses.** Turfgrasses utilize carbohydrate reserves for growth and maintenance processes during periods when carbohydrate consumption exceeds production from photosynthesis (Turgeon, 1985). In cool-season grasses, carbohydrates are stored as fructans (composed of monosaccharide units of glucose and fructose) primarily in the stem and leaf bases (Hull, 1992). Grasses belonging to the genus Lolium store carbohydrates predominantly in the form of short-chain fructans (Smith, 1972). Maximum carbohydrate accumulation and storage occurs when there is high light intensity and during periods of decreased shoot growth and increased photosynthesis (Beard, 1973). Carbohydrate reserves are reduced by close and repeated mowing, and this effect is exacerbated because low mowing also increases soil temperatures.
The result is a reduction in carbohydrate reserves in crown tissues, which are needed to support new shoot growth (Sullivan and Sprague, 1943; Alberda, 1957). Carbohydrate reserves also are used for shoot regrowth following injury from environmental or mechanical stress, and disease (Youngner, 1969; Beard, 1973).

Carbohydrate content of turfgrasses, as influenced by cultural practices and environmental factors, have been investigated. McKee et al. (1969) reported high N application rates promoted turf growth and therefore reduced carbohydrate reserves. Zanoni et al. (1969) observed that a high rate of N applied during periods of increased soil temperature also reduced carbohydrate reserves. Watschke and Waddington (1974) observed rapid shoot growth in the spring promoted by a fast release N-source reduced carbohydrate reserves prior to the summer. Carbohydrate reserves also were decreased during high temperature periods when a slow release N-source stimulated turf growth (Watschke and Waddington, 1974). They observed carbohydrate levels fluctuated less from two applications of slow release N (i.e., IBDU, Uramite, Urex, and Milorganite applied at 244 kg N ha\(^{-1}\) yr\(^{-1}\)) or nine applications of urea (applied at 146 kg N ha\(^{-1}\) yr\(^{-1}\)) in the summer when compared to a single application (244 kg N ha\(^{-1}\) yr\(^{-1}\)) of a slow release N-source. In turf subjected to high N application rates, fructose and glucose concentrations were shown to be typically lower than sucrose levels (Westhafter et al., 1982).

Turfgrasses respond more favorably to injury and stresses when carbohydrate levels are high (Watschke et al., 1970). Davis and Demoeden (1991) evaluated the effects of mowing height and N-source on summer patch in field grown Kentucky bluegrass. They (1991) reported higher total
nonstructural carbohydrate (TNC) levels in turf mowed at 7.6 cm versus 3.8 cm. Since summer patch was more damaging in low-mowed turf, a depletion in carbohydrate reserves may have contributed to more injury (Davis and Demoeden, 1991). There were, however, no differences in TNC levels among plants fertilized with urea, sulfur-coated urea, ammonium chloride, or sodium nitrate.