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Biological and Cultural Management of Summer Patch and Necrotic Ring Spot

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BIOLOGICAL AND CULTURAL MANAGEMENT OF
SUMMER PATCH AND NECROTIC RING SPOT

by

Brad Perry Melvin

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ABSTRACT

Biological and cultural management of

Summer Patch and Necrotic Ring Spot

By

Brad Melvin

Bio-organic and slow-release fertility treatments, in addition to a bacteria composite, were examined for management of summer patch (*Magnaporthe poae*) and necrotic ring spot (*Leptosphaeria korrae*) diseases of *Poa* spp. In necrotic ring spot (NRS) testing the treatments were also examined under 3 irrigation regimes (0.25 cm d^{-1}, twice weekly irrigation, and rain only). Factors relating to treatment effects such thatch and rooting were also examined. When combined with 0.25 cm d^{-1} irrigation applied at noon, composted turkey manure or corn-meal/bone-meal/soybean-meal when applied monthly at 48 KgN ha^{-1}, significantly reduced NRS disease incidence. Controlled-release nitrogen as methyleneurea polymers, and a urea based fertilizer (9-4-4) at 48 KgN ha^{-1} also significantly reduced NRS. Areas maintained under 0.25 cm d^{-1} irrigation averaged the least measurable thatch (19.5 mm), however, the twice weekly irrigation regime was found to promote better soil-thatch mixing, as indicated by significantly higher bulk

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density. Application of methyleneurea, or bone-meal/corn-meal/soybean-meal organic fertilizer also significantly reduced thatch thickness. No differences ($P=0.05$) in root density between 0.25 cm d^{-1} and twice weekly irrigation regimes at 5 depths were found after 4 years of irrigation treatments, which contrasts previous assumptions that light daily irrigation results in a shorter root zone than deep irrigation. Summer patch (SP) disease severity was significantly reduced with monthly applications of bone-meal/corn-meal/soybean-meal (less than 20% area diseased) in 3 of 4 field trials and not different from fungicide treated plots in all trials (LSD=0.05). SP was also significantly reduced by urea N alone in 2 of 4 field trials, indicating nutrition may reduce SP in certain instances. Differences in SP and NRS severity between treatments indicated that the form of nitrogen may also play a role in disease suppression. In addition, two bacteria, *Bacillus pumilus* and *Pseudomonas aureofaciens*, when combined with a molasses-based organic carrier, significantly reduced NRS in 3 field trials and SP in 1 of 2 trials. The severity of NRS was reduced by 50 to 100% (as compared to untreated plots) with a composite treatment of *B. pumilus* and *P. aureofaciens* when combined with a molasses-based organic carrier. Significant (LSD=0.05) reduction in NRS was also observed in 2 of 3 trials when the bacteria were applied as washed cells without the organic carrier.

To my loving parents

Warren and Betty Melvin,

and to the rest of my family and friends

for their support and understanding.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Summer patch and necrotic ring spot disease cause extensive damage to *Poa* spp. turfs throughout the United States and in the temperate growing region of North America, respectively. Summer patch, incited by *Magnaporthe poae*, commonly affects annual bluegrass (*Poa annua*) while NRS, incited by *Leptosphaeria korrae*, is more common to Kentucky bluegrass (*Poa pratensis*) in Michigan. Both fungi infect vascular tissue causing root dysfunction which results in extensive damage to the root system with subsequent reduction in water absorption and nutrient uptake.

Summer patch and necrotic ring spot are closely related diseases of *Poa spp*. and were once collectively known as *Fusarium* blight, first described by Couch and Bedford in 1966. It is now known that summer patch is caused by *Magnaporthe poae*, and necrotic ring spot is caused by *Leptosphaeria korrae* (Smiley, 1984a; Landschoot, 1988). Both fungi are Ascomycetes, *L. korrae* is in the order Pleosporales and *M. poae* is in the order Diaporthales (Walker, 1981). Due to earlier confusion involving the causal agents of these diseases, previous studies concerning management practices may not be applicable to either summer patch or necrotic ring spot. Although *L. korrae* and *M. poae* are taxonomically similar, they respond differently to fungicides and environmental conditions, and differ in their pathogenicity to turfgrass species (Smiley *et al.*, 1985). Recent advances in the identification of the fungi associated with these patch diseases have lead to greater credibility in management practices.

Etiology

The causal agents of *Fusarium* blight were initially attributed to *Fusarium tricinctum* and *F. roseum* by Couch & Bedford (1966) although typical frog-eye symptoms were not produced, as a result Koch's postulates were not satisfied and the exact cause of *Fusarium* blight was still under speculation. During the late 1970's the presence of a dark, septate fungus was associated with roots and crowns of symptomatic plants within the patches (Sanders *et al.*, 1980; Worf *et al.*, 1983) and later Koch's postulates were completely satisfied with two ectotrophic fungi isolated from roots and crowns of affected plants, *Leptosphaeria korrae* and *Phialophora graminis* (Deacon) Walker (Chastagner *et al.*, 1984; Smiley & Craven-Fowler, 1984). Smiley (1984) coined the name summer patch for the disease caused by *P. graminicola*. In 1986, Worf also identified *L. korrae* infecting *P. pratensis* in Wisconsin and coined the name necrotic ring spot.

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Previously *L. korrae* was reported only in Australia (Walker and Smith, 1972). *Leptosphaeria korrae* and *L. narmari* (Walker & Smith) were identified as the causal agents of spring dead spot of *Cynodon* spp. turfgrasses in Australia (Smith, 1965). The ecology of these *Leptosphaeria* spp. is similar to that of *Gaeumannomyces graminis* var. *tritici* and *G. graminis* var. *avenae*, which cause take-all of cereals and take-all patch of *Agrostis* spp. turfgrasses (Holden, 1976; Nilsson and Smith, 1981; Walker, 1981). *Leptosphaeria korrae* produces penetration pegs from single lateral and intercalary cells on the mycelium, or from flattened congregations of dark angular cells called hyphopodia (Walker & Smith, 1972; Smiley *et al.*, 1985). Optimal growth of *L. korrae* occurs at 25 C (4-5 mm per day) and at moisture levels greater than -10 mbars (Hammer, 1988). The fungus produces white aerial mycelium which turns dark gray with age when grown on potato dextrose agar. Pseudothecia can be induced on sterile oat grains (Jackson, 1986). Ascospores of *L. korrae* measure (120) 140-170 (180) x 4-5 um, with 7 (15) septae (Walker & Smith, 1972).

Prior to the work of Smiley (1984) no reports of *Phialophora graminicola* had occurred in North America, although it was reported in Europe and Australia as an inhabitant of grasslands (Deacon, 1974). Smiley suggested *P. graminicola* to be the anamorph of *G. cylindrosporus* but his attempts to induce the teleomorph were unsuccessful. The isolates Smiley initially identified as *P. graminicola* were later correctly identified as *Magnaporthe poae* by Landschoot, 1988. More recently, the pathogenicity of several *Gaeumannomyces*-like fungi, isolated from *Poa annua* and *Poa pratensis,* were determined. Landschoot & Jackson, 1990, found *G. incrustans* to be mildly pathogenic to *P. pratensis* and *P. annua*, while *P. graminicola* anamorph (*G. cylindrosporus*) was found to be parasitic but not pathogenic, and *M. poae* to be highly pathogenic. *Magnaporthe poae* was also found to be pathogenic to *Agrostis palustris, Festuca rubra* var. *commutata*, F. *arundinacea*, *Lolium perenne, Hordeum vulgare, Triticum aestivum, Avena sativa,* and *Secale cereale*. *Magnaporthe poae* was re-isolated from diseased plants, confirming its role as a causal agent of summer patch disease.

On potato dextrose agar, *M. poae* produces olive brown appressed mycelium with mycelial strands similar to those of *Gaeumannomyces* spp. (Smiley, 1984). Perithecia can be induced by crossing isolates of different mating types (Landschoot and Jackson, 1990). Optimal growth for *M. poae* occurs at 30 C (8-9 mm per day), which coincides with field reports of increased symptom development when summer temperatures exceed 29 C.

Symptomatology

Both *L. korrae* and *M. poae* produce darkly pigmented runner hyphae which affect roots, stolons and rhizomes in small patches. As infection proceeds, cortical tissues dry and turn black with rot and virulent stains colonize the stele, resulting in vascular system dysfunction. Affected plants may remain asymptomatic until increased stress, after which visible symptoms may occur rapidly (Smiley *et al.*, 1985). Symptoms of necrotic ring spot first appear as small (5-10 cm) circular patches of straw colored turf in late spring and/or late summer to early fall. As infection proceeds outward, the patch becomes necrotic and depressed, which leads to invasion by less susceptible grasses or weeds resulting in typical 'frog-eye' type patches. Individual patches may reach 1 m in diameter but patches often coalesce giving a serpentine appearance. When the disease is active in the cool weather of spring and fall, red to yellow blades of grass appear in the patch. During hot dry weather the affected blades wilt and turn straw colored. At times the disease appears to abate, only to return again the following spring or fall (Worf and Stewart, 1985). Necrotic ring spot is most common on 2-5 year old Kentucky bluegrass turf established from muck sod, but has also been reported on mineral sod, as well as turf established from seed (Chastagner *et al.*, 1988).

Summer patch symptoms begin as chlorosis or yellowing of turf patches that range from 15 cm to 1 m in diameter (Smiley, 1984). Patches may be ring-shaped or in diffuse patterns which are easily confused with other disorders of *Poa annua* such as heat stress, insect damage or other diseases (Landschoot *et al.*, 1989). *Magnaporthe poae* produces darkly pigmented mycelium which can be observed on the root epidermis on symptomatic, as well as asymptomatic plants. At times, large patches become visible with no previous indication of disease activity, and in severe cases, patches will coalesce and destroy large areas of turf (Landschoot *et al.*, 1989). Like necrotic ring spot, areas affected with summer patch become necrotic and are often invaded by weeds or less desirable grasses (Smiley *et al.*, 1985).

Predisposing factors

Both *M. poae* and *L. korrae* grow and spread in soil and thatch (Smiley, 1984a) and infect host tissues 3 to 4 months in advance of symptom development. Although activity of *L. korrae* is greatest in the cool weather of the spring and fall, symptoms can be observed throughout the growing season (Vargas, 1986). Even though the pathogen may be inactive, plants infected by *L. korrae* are weakened and very susceptible to hot-dry periods experienced during the summer, after which symptoms become apparent (Vargas, 1986). Plants infected with *M. poae* also show no sign of symptom expression until stressed by environmental and cultural factors. Although the fungus is present in host tissues months in advance of symptom expression, when temperatures exceed 29 C *M. poae* is able to rapidly invade cortical and vascular cells of the host resulting in necrosis (Landschoot and Jackson, 1990). Landschoot *et al.*, (1989) noted that *M. poae* grows best in temperatures from 25 to 35 C and summer patch symptoms peaked after heavy rains. Optimal growth for

M. poae occurs at 30 C (8-9 mm per day), which coincides with field reports of increased symptom development when summer temperatures exceed 29 C (Kackley *et al.*, 1990). Smiley and Giblin (1986) found that autolysis of nuclei in root cortex cells (root cortical death) of 'Merion' *Poa pratensis* occurred faster at 29 C and was inversely correlated (P=0.05) with percentages of root area colonized with *Phialophora graminicola*, which was later identified as *M. poae* (Landschoot, 1988). Apparently, rapid fungus infection coupled with reduced plant vigor and resistance during periods of high temperatures promote disease severity.

The moisture status of the soil also affects incidence, severity, and timing of symptom expression for both patch diseases. Plants infected with either *L. korrae* or *M. poae* are more susceptible to wilt because of vascular dysfunction, and may be quickly overcome during periods of moisture stress (Smiley *et al.*, 1985; Vargas, 1986). Water deficits have been associated with increased disease severity (Fulton *et al.*, 1974), although Chastagner (1985) and Smiley (1980) related excess water and frequent irrigation with summer patch and necrotic ring spot disease outbreak. Sanders and Cole (1981) stated that both drought or excess moisture stress, appear to predispose bluegrasses to summer patch and necrotic ring spot disease development. Several authors have related disease incidence with heavy rainfall or waterlogged soil (Landschoot *et al.*, 1989; Worf and Stewart, 1986). Smiley (1980) noted that severe disease outbreaks occur after periods of increased moisture, or intermittent periods of wetness and drought. Excess water causes anaerobic conditions in the soil which results in anoxia and ethanol production in roots, and production of phytotoxic compounds such as ethylene and acetic acid in the soil (Lynch, 1978; Wright, 1978). Saturated conditions also significantly increase NO_3-N leaching (Snyder *et al*., 1984; Timmons and Dylla, 1981), and promote denitrification losses when combined with temperatures greater than 30 C (Mancino *et al*., 1988). Surplus soil moisture favors disease development by reducing soil oxygen, resulting in root dysfunction, and promoting nitrogen losses through leaching and denitrification (Garret, 1947). Denitrification has been attributed to reduced host resistance and increased take-all infection of wheat, caused by *Gaeumannomyces graminis* which is very similar to both *M. poae* and *L. korrae* (Cook *et al*., 1968; Garret, 1948; Huber *et al*., 1968). Irrigation practices effect the metabolic activity of the host, which directly influences pathogenesis. Irrigation rates used in automatic systems are often set to meet optimum evaporative demands which often results in over-watering (Snyder *et al*., 1984). Waterlogging reduces stem elongation and leaf expansion, induces stem thickening, causes an increase in senescence of older leaves, and induces production of adventitious roots (Levitt, 1972). Frequent watering has also been associated with shallow rooting, which may expose the roots to adverse conditions of the surface environment (Smiley, 1980).

Moisture deficiencies also adversely effect the physiology of the host (Gates, 1964) and have been related to increased *Fusarium* blight disease severity by several authors (Endo, 1961; Endo and Colbaugh, 1975; Cole, 1976). Vargas (1981) stated that factors which contribute to drought stress such as compacted soil and excessive nitrogen, will predispose plants to infection. Water potentials associated with severe *Fusarium* crown and foot rot of wheat in the Pacific Northwest favor the pathogen, *Fusarium roseum F. SP. cerealis* Culmorum, and are injurious to host physiology, (Cook and Baker, 1983). Culmorum, like *M. poae* and *L. korrae*, establishes itself in host tissues months prior to advanced symptom expression and remains inconspicuous until stress occurs (Cook and Baker, 1983).

Chastagner (1985) noted that necrotic ring spot is most severe in intensely managed turf that is over-fertilized and over-watered, and recommends watering only when the top 2 inches of soil become dry or when the turf turns a blue-green color. Smiley (1980) also stated that turf which is frequently watered and fertilized is more prone to *Fusarium* blight outbreak. However, water deficits are known to limit many of the physiological process of the host (Crafts, 1968; Gates, 1964; Smiley, 1980), which may adversely effect resistance and promote disease development. Root diameters may shrink up to 40% when exposed to moisture stress which causes a disruption between the root and the soil solution (Huck *et al.*, 1970; Weatherly, 1979).

Fertility practices may also have an effect of disease incidence. Timing of nitrogen application has been related to disease outbreak by Turgeon and Meyer (1974), they associated high nitrogen levels early in the season to increase the severity of *Fusarium* blight. High nitrogen fertilization has also been suggested as a predisposing factor to *Fusarium* blight by other authors (Couch, 1976; Smiley, 1977; Turgeon, 1976; Vargas, 1981). Turgeon (1976) reported that nitrogen levels of 6 to 8 pounds per 1,000 square feet per year resulted in severe incidence of *Fusarium* blight. Although, other researchers have noted that nitrogen may not adversely effect *Fusarium* blight disease development. In greenhouse studies performed by Cole (1976) no significant nitrogen fertilizer effects were indicated with regard to expression of *Fusarium* blight. Bean (1966) was also unable to correlate disease severity with high nitrogen levels. Dissimilar findings by numerous researchers concerning the effect of nitrogen on *Fusarium* blight, now known as summer patch and necrotic ring spot, has perplexed cultural management strategists. Conflicting reports on the effect of nitrogen level on *Fusarium* blight, later identified as summer patch and necrotic ring spot, disease outbreaks may be the result of earlier confusion regarding the causal agents and correct identification of the disease under investigation. Smiley (1983) noted that adequate fertility balance appears to be necessary for recuperation of diseased areas. Plant nutrition can affect the physiology of the host by altering hormonal production (Goodwin *et al.*, 1978; Wright, 1978). Smiley (1984a) also noted that symptoms of summer patch and necrotic ring spot occur only when root regeneration rates cannot exceed pathogen infection rates. Landschoot *et al.*, (1989) suggest cultural practices that encourage good rooting will aid in reducing disease severity.

Thatch also significantly contributes to plant stress. When the rate of thatch accumulation exceeds the decomposition rate build-up occurs, which can lead to management problems. Increased thatch accumulation inhibits movement of pesticides, fertilizers, and irrigation, which effects the health of the plant thus favoring disease outbreak (Beard, 1973). Practices which reduce or prevent thatch build-up may also reduce the severity of disease outbreaks by promoting plant health and best use of available nutrients for recovery (Smiley, 1980).

Management

Since the causal agents of *Fusarium* blight have been correctly identified much progress has been made concerning chemical management of summer patch and necrotic ring spot. Studies performed in Washington by Chastagner *et al.*, 1988, showed effective management of necrotic ring spot with one spring application of fenarimol (1.59 or 3.18 Kg a.i. ha^{-1}), propiconazole (3.18 Kg a.i. ha^{-1}), thiophanate-methyl (6.36

Kg a.i. ha^{-1}), and diniconazole (3.18 Kg a.i. ha^{-1}), although yearly applications are required because of recurring outbreaks. Only marginal control was reported with benomyl and triadimefon.

Current preventative management strategies for summer patch consists of application of Rubigan (fenarimol), Banner (propiconazole), or Bayleton (triadimefon) at 6.4 L ha^{-1} when soil temperatures first reach 18.3 C at 5 cm and another application 30 days later (Melvin *et al.*, 1988). Curatively, the benzimidazole fungicides, Tersan 1991 (benomyl) or Fungo 50 (thiophatemethyl) applied at 19.1 L ha^{-1}, halts disease progress although renewed disease activity was reported less than 1 month after application (Vargas, *et al.*, 1988). Repeated application is necessary as long as conditions conducive to disease development persist. Failure of curative fungicide treatments to provide long term disease management may be the result of poor fungicide uptake by the root system which has already been severely damaged by earlier infection (Landschoot *et al.*, 1989). Because of the recurring nature of summer patch and the degree of damage inflicted, this disease is often the target of fungicide programs.

Disease management is an integral part of high quality turfgrass cultivation programs, however extensive use of disease-preventative fungicides for target pests may result in long term changes in the turf system. Plant disease management should begin with sound cultural practices so as to alleviate stress placed upon the host by the environment as well as maintenance practices. However, the reliance on antifungal chemicals probably overshadows cultural methods for disease management. Fungicides may alter the microflora of the turfgrass system (Alexander, 1969). The activity of microflora responsible for litter decomposition is more affected by fungicides than any other group of pesticides (Alexander, 1969). Repeated application of chemicals often do not provide long-term disease control solutions and may result in a reliance on this form of control which may effect non-target plants and organisms (Smiley and Craven, 1977, 1978, 1979). Fungicides have been associated with inducing pathogen resistance, microbe population shifts, thatch accumulation, reduced earthworm activity, lower soil NO_3 N, and lower pH (Smiley *et al.*, 1985; Halisky *et al.*, 1980; Randell *et al.*, 1972; King and Dale, 1977; Wainwright and Pugh, 1974). Smiley and Craven (1979) stated that changes in pH brought about by fungicide use probably have more of an effect on microbe populations than fungicides directly. Fungicides are selected for use against phyto-pathogenic fungi but their activity also effects other micro-organisms (McCallan and Miller, 1958). In addition, fungicides effect organisms antagonistic to the pathogen, causing an increase in pathogen activity (Farley and Lockwood, 1969) which suggests disease outbreaks in turfgrass due to facultative fungal parasites may be the result of the inadvertent suppression of competitive and antagonistic microflora brought about by long term fungicide use. Although synthetic fungicides offer optimum disease control and are easier to use than biocontrol or cultural methods, their use is becoming more controversial and in many areas of the world certain or all fungicides are restricted (Jones, 1985; Rytter *et al.*, 1989). And, although more dollars are spent on fungicides for turf than on any other single crop in the United States (Vargas, 1981), there has been only limited research for development of alternative control methods. A general trend in agriculture research is to develop natural and safe methods of disease control.

This review suggests that plant stress may be alleviated through careful manipulation of cultural practices for the purpose of reducing turf loss due to summer patch and necrotic ring spot. Proper irrigation and fertilization practices may increase root production so as to offset that lost by fungal invasion. These findings suggested that manipulation of cultural activities may reduce disease, and thereby provide an alternative to, or enhance, fungicide management for suppression of necrotic ring spot and summer patch.

The objectives of the following studies were to:

1. Determine the effects of nitrogen, phosphorus and potassium on necrotic ring spot and summer patch.
2. Evaluate bio-organic and slow-release fertility treatments for summer patch and necrotic ring spot

disease management.

3. Determine the effects of bio-organic amendments and slow-release fertilizer, when used under 3 irrigation regimes (daily irrigation, twice weekly irrigation, and rain only) on, necrotic ring spot disease, and thatch characteristics.
4. Determine the effect of 3 irrigation treatments on rooting characteristics of *Poa pratensis*.
5. Screen microbes for antagonism against *L. korrae* and *M. poae in vitro* and test selected organisms for disease management *in vivo*.

CHAPTER II

INFLUENCE OF IRRIGATION AND BIO-ORGANIC AMENDMENTS ON NECROTIC RING SPOT DISEASE OF KENTUCKY BLUEGRASS

Abstract.

Bio-organic and slow-release fertility treatments were evaluated under 3 irrigation regimes (0.25 cm d^{-1}, twice weekly, and no supplemental irrigation) for potential management of necrotic ring spot (*Leptosphaeria korrae*) of Kentucky bluegrass (*Poa pratensis* L.). Factorial analysis ($P=0.05$) indicate significant differences in disease severity due to both fertility and irrigation treatment. When combined with 0.25 cm d^{-1} irrigation applied at noon, bio-organic amendments composed of either composted turkey manure or corn-meal/bone-meal/soybean-meal when applied monthly at 48 KgN ha^{-1}, significantly reduced disease incidence and provided acceptable disease management over the course of a 3 year field trial. Controlled-release nitrogen as methyleneurea polymers, and a urea based fertilizer (9-4-4) also significantly reduced necrotic ring spot in 2 of 3 years. Increased plant vigor through regular additions of complete fertilizers, and reduced moisture and heat stress as provided by daily noontime irrigation, was associated with disease suppression.

INTRODUCTION

Necrotic ring spot, incited by *Leptosphaeria korrae*, causes severe damage to *Poa spp.* in the temperate growing region of the United States. Necrotic ring spot, along with summer patch (incited by *Magnaporthe poae*), were previously known as *Fusarium* blight, first described by Couch and Bedford in 1966. Infection by *L. korrae* causes root dysfunction resulting in extensive damage to the root system which reduces water absorption and nutrient uptake (Smiley, 1985a). *Leptosphaeria korrae* grows and spreads in soil and thatch, and apparently infects host tissues several months in advance of symptom development (Smiley, 1984). Symptoms of necrotic ring spot first appear as small (5-10 cm) circular patches of straw colored turf in late spring and/or late summer to early fall. As infection proceeds outward, the patch becomes necrotic and depressed, and open to invasion by less susceptible grasses or weeds resulting in typical 'frog-eye' type patches. Individual patches may reach 1 m in diameter but patches often coalesce giving a serpentine appearance. Although activity of *L. korrae* is greatest in the cool weather of the spring and fall, symptoms can be observed throughout the growing season (Vargas, 1986), although at times, plants may remain asymptomatic until increased heat and moisture stress (Smiley, 1984). Even though the pathogen may be inactive, infected plants are weakened and very susceptible to hot-dry periods experienced during the summer, after which symptoms become apparent (Vargas, 1986). Smiley and Giblin (1986) indicated that symptoms of necrotic ring spot occur when root regeneration rates cannot exceed pathogen infection rates. Apparently, rapid fungus infection coupled with reduced plant vigor and resistance during periods of high temperature and moisture stress promote disease severity.

If left unchecked, necrotic ring spot disease often becomes severe enough to warrant expensive renovation of the turfstand. Management with synthetic chemicals has shown to be possible. Studies performed in Washington showed significant disease management with one spring (April or May) application of fenarimol (1.59 or 3.18 Kg a.i. ha^{-1}), propiconazol (3.18 Kg a.i. ha^{-1}), thiophanate-methyl (6.36 Kg a.i.ha), and diniconazole (3.18 Kg a.i. ha^{-1}), although yearly applications are required because of recurring outbreaks (Chastagner *et al.*, 1988). Only marginal control was reported with benomyl and triadimefon. Disease management is an integral part of intensively maintained turfgrass cultivation programs, however extensive use of disease-preventative fungicides for target pests may result in long term changes in the turf system. However, the reliance on antifungal chemicals often overshadows cultural methods for disease management. Repeated application of chemicals will not provide long-term disease control solutions and may result in a reliance on this form of control which may effect non-target plants and organisms

(Smiley and Craven, 1977, 1978, 1979). Fungicides have been associated with inducing pathogen resistance, microbe population shifts, thatch accumulation, reduced earthworm activity, lower soil NO^-_3 N, and lower pH (Smiley *et al.*, 1985b; Halisky *et al.*, 1980; Randell *et al.*, 1972; King and Dale, 1977; Wainwright and Pugh, 1974). Although fungicides are selected for use against phyto-pathogenic fungi, their activity also effects other micro-organisms (McCallan and Miller, 1958) such as pathogen antagonists, causing an increase in pathogen activity (Farley and Lockwood, 1969). A general trend in agriculture research is to develop natural and safe methods of disease control.

Plant disease management should begin with sound cultural practices so as to alleviate stress placed upon the host by the environment, as well as maintenance practices. However, dissimilar findings by numerous researchers concerning environmental conditions associated with *Fusarium* blight, and later with necrotic ring spot, has perplexed cultural disease management strategists. Early investigations concerning the predisposing factors of *Fusarium* blight, associated disease outbreaks with drought stress during hot summer months (Bean, 1966, 1969; Fulton *et al.*, 1974; Smiley, 1977, 1980a; Partyka, 1976; Turgeon, 1976; Vargas, 1981) although outbreaks have also been associated with alternating wet and dry periods, or heavy rainfall followed by sunny days (Fulton *et al.*, 1974; Smiley *et al.*, 1980a). Investigations on *Fusarium* blight in the

Washington, D.C. area by Bean (1966) indicated that the disease is only active during the warmest part of the summer and shaded areas were not affected, he associated high temperature and moisture stress with disease development. Although moisture stress has been associated with *Fusarium* blight, Couch and Bedford (1966) found that soil moisture stress regimes had no significant effect on disease development on seedlings in greenhouse inoculation studies. Conversely, Troll (1969) also performed greenhouse inoculation studies and reported that the moisture equivalence of soils did have a significant effect on disease development on seedlings. Smiley (1980a) associated severe disease outbreaks occurred after periods of increased moisture, or intermittent periods of wetness and drought. Other researchers have also noted that water deficits (Fulton *et al.*, 1974) as well as excesses have been associated with *Fusarium* blight outbreak (Smiley, 1980a). Sanders and Cole (1981) and Smiley (1980a) have indicated that either drought or excess moisture stress, appear to predispose bluegrasses to *Fusarium* blight disease development. In more recent studies concerning necrotic ring spot, Worf and Stewart (1986) associated necrotic ring spot development with heavy rainfall or waterlogged soils. Surplus soil moisture favors disease development by reducing soil oxygen, resulting in root dysfunction, and promoting nitrogen losses through leaching and denitrification (Garret, 1947). The latter has been attributed to reduced host resistance and increased take-all infection of wheat (Cook *et al.*, 1968; Garret, 1948; Huber *et al.*, 1968). In addition, irrigation rates used in automatic systems are often set to meet optimum evaporative demands which often results in over-watering (Snyder *et al.*, 1984). Saturated conditions significantly increase NO^{-}_{3} N leaching (Snyder *et al.*, 1984; Timmons and Dylla, 1981), and promote denitrification losses when combined with high temperatures (>30 C) (Mancino *et al.*, 1988). Excess water has also been associated with shallow rooting, which may expose the roots to adverse conditions of the surface environment (Smiley, 1980a). Chastagner (1985) stated that necrotic ring spot is most severe in intensely managed turf that is over-fertilized and over-watered. Vargas (1981) stated that factors which contribute to drought stress such as compacted soil and excessive nitrogen, predispose plants to infection by *Fusarium* blight. Discrepancies regarding the effect of moisture levels on disease development have contributed to confusion among turf managers when attempting to regulate irrigation for disease management.

High nitrogen fertilization has also been associated with increased susceptibility of turfgrasses to *Fusarium* blight (Couch, 1976; Smiley, 1977; Turgeon, 1976; Vargas, 1981, 1986). Smiley *et al*. (1980b) stated that *Fusarium* blight is more likely to occur in frequently fertilized Kentucky bluegrass. In greenhouse experiments performed by Cutright and Harrison (1970) severity of *Fusarium* blight was correlated with soil temperature of 32 C and high nitrogen nutrient levels, while disease pressure was least when plants were grown at 21 C. Turgeon (1976) reported that nitrogen levels of 288 Kg to 389 KgN ha^{-1} yr promoted severe incidence of *Fusarium* blight. High nitrogen levels early in the season has been shown to increase the severity of *Fusarium* blight of several turfgrass cultivars, although not all cultivars demonstrated increased disease development, 'Kenblue' Kentucky bluegrass (*Poa pratensis* L.) was severely affected regardless of fertility level (Turgeon and Meyer, 1974). Although high levels of nitrogen were associated with an increase in *Fusarium* blight, the level of this element required for significant disease management is outside the range necessary to meet the basic nutritional requirements of the plant (Couch, 1976). Some researchers have noted that nitrogen may not adversely affect disease development. In greenhouse studies performed by Cole (1976) no significant nitrogen fertilizer effects were indicated. Bean (1966) was also unable to correlate disease severity with high levels of nitrogen. Cole (1976) suggests that confusion involving nitrogen fertility in bluegrasses may be due to the recycling of nitrogen through organic matter decay, and reducing nitrogen in a single year will not offset several preceding years of high nitrogen application. Conflicting reports on the effect of nitrogen level on *Fusarium* blight disease outbreaks, later identified as summer patch and necrotic ring spot, may also be the result of earlier confusion regarding the causal agents. Conversely, research with wheat root rot indicate that nitrogen fertilizer stimulated plant growth resulting in increased water extraction which greatly increased water stress both within the plant and soil. The increased water stress favored invasion and colonization of the crown and root areas of the plant as well as reducing soil bacterial antagonism against the *Fusarium* fungus (Cook *et al.*, 1968). This suggests that nitrogen fertilizers may predispose *Poa spp.* to necrotic ring spot development by increasing moisture stress rather than by stimulating the pathogen. These findings suggest that moisture levels and nitrogen fertilizer affects disease incidence, albeit exactly how remains in question. Dissimilar findings concerning the effect of nitrogen on *Fusarium* blight, and later with necrotic ring spot, has left the exact effects of nitrogen fertilizer in question.

Irrigation and fertility practices designed to alleviate host stress may reduce the dependency on synthetic chemicals for management of necrotic ring spot.

Organic amendments can also positively affect soil productivity (Huber and Watson, 1974) which has been related to suppression of plant disease outbreaks (Garret, 1956). Reduced disease expression may be the result of increasing host vigor through controlled-release nitrogen.

Water potentials associated with severe *Fusarium* crown and foot rot of wheat in the Pacific Northwest, favor the pathogen, *Fusarium roseum F. SP. cerealis* Culmorum, and are injurious to host physiology, (Cook and Papendick, 1970; Smiley and Craven-Fowler, 1984). Culmorum, like *L. korrae*, establishes itself in host tissues months prior to advanced symptom expression and remains inconspicuous until stress occurs (Cook and Baker, 1983; Smiley, 1985a). Although, Hammer (1988) showed that *Leptosphaeria korrae* grows best in moist conditions (>-10 mbars) under laboratory conditions, in the field the pathogen may be exposed to the antagonistic effects of microorganisms which are also stimulated by moist conditions. Water deficits also limit many of the physiological process of the host (Crafts, 1968; Gates, 1964; Smiley, 1980a), which would adversely effect the plant's ability to resist infection and disease development.

Since necrotic ring spot is associated with drought and heat stress, irrigation practices should be manipulated so as to reduce moisture and heat stress. Chastagner (1985) recommends watering only when the top 2 inches of soil become dry or when the turf turns a blue-green color, however, irrigating after moisture stress occurs may not reduce disease outbreak since vascular tissues may already be infected with *L. korrae*. In addition, symptom development in *Fusarium* blight has been linked to intermittent wet-dry periods (Fulton *et al.*, 1974; Smiley *et al.*, 1980a). Midday irrigation (syringing) may be more effective in reducing plant stress and is often recommended during hot summer periods to lessen drought stress and provide a cooling effect (Beard, 1973; Turgeon, 1976; Vargas, 1981). These findings indicate that adequate moisture is important in preventing symptoms development, and suggests that an irrigation program designed to increase microbial activity and reduce host stress may also reduce disease severity.

Many turfstands are equipped with modern irrigation systems that can be programmed to supply water at any given time and amount. In addition, several bio-organic amendments are available for use by homeowners and professional turf managers. The objective of the experiments presented here is to evaluate bio-organic amendments, slow-release fertilizer and 9-4-4 urea fertilizer, when applied under 3 irrigation regimes, for necrotic ring spot disease management.

MATERIALS AND METHODS

Several commercially available bio-organic amendments and slow-release nitrogen sources were examined. Bio-organic fertility products containing viable microorganisms were provided by Ringer Corporation (Minneapolis, MN.), and Sustane Corporation (Cannon Falls, MN.), and are labeled Lawn Restore and Sustane, respectively. Lawn Restore is 49% carbon, has a fertilizer analysis of 9-4-4 and consists of various organic and inorganic constituents including feather meal, corn meal, soybean meal and bone meal. Yeast (*Torula spp.*) is the predominant N source. Sustane is aerobically composted turkey manure with a fertility analysis of 5-2-4 and contains 3.5% insoluble nitrogen, ammoniacal nitrogen

1.5%, phosphoric acid (P_2O_5) 2.0%, soluble potash (K_2O) 4.0%, calcium (Ca) 3.7%, iron (Fe) 2.3%, sulfur (S) 2.0%, Magnesium (Mg) 0.8%, manganese (Mn) 0.06%, zinc (Zn) 0.05%, chromium (Cr) 16 ppm, lead (Pb) 12 ppm, nickel (Ni) 22 ppm, cadmium (Cd) 1 ppm. Organic matter analysis conducted by Woods End Laboratory revealed a CEC of 104.4 cmol kg^{-1}. Components analyzed by cation displacement reveal organic matter was responsive for 44.6%, humic acid content 10.8%, and humic acid (as percent of organic matter) 24.2%. Because Lawn Restore and Sustane contain both organic slow-release nitrogen and viable microorganisms, a synthetic slow-release nitrogen source 'Nitroform' was also examined. Nitroform was provided by Nitroform Corporation, Wilmington, DE., and is composed of low-molecular-weight methyleneurea polymers with a fertility analysis of 38-0-0. KLM Bio-systems (Bloomington, MN.) provided a biologically active product, but without nitrogen, known as Biogroundskeeper. This product comes in three separate containers which must be mixed before application and consists of various organic acids and plant growth stimulators, in addition to viable microorganisms. Since Biogroundskeeper does not contain nitrogen, a slow-release synthetic nitrogen fertilizer 'NITRO-26 CRN' was also applied to plots treated with this amendment. NITRO-26 CRN was provided by Growth Products Inc., and is a liquid controlled release nitrogen fertilizer consisting of 20.8% methylene diurea, and small percentages of free urea 5.2%, nitrogen release time is 6 to 10 weeks.

Field plot establishment.

Amendments were applied to a stand of 'Baron/Bristol /Victa' Kentucky bluegrass (*Poa pratensis* L.) located at the Hancock Turfgrass Research Center, Michigan State University, East Lansing, MI. The stand was established from muck sod in 1985 and the turf was maintained at 6.1 cm. Relevant characteristics of the soil are reported in Table 1. Each amendment was examined under 3 different irrigation programs. Irrigation treatments were applied to randomly selected 12.2 x 12.2 m blocks with 3 replications. Amendments were applied to randomly selected 1.8 x 1.8 m plots within each irrigation block. Irrigation treatments consisted of 1) 0.25 cm d^{-1} supplemental irrigation applied at noon, 2) twice weekly irrigation based on 80% of the water lost from an open evaporation pan applied on mondays and thursdays at night, and 3) no supplemental irrigation (rain only). Irrigation treatments began in May and ended in either late October or early November from 1986 to 1990. Irrigation was withheld when plots became saturated due to rainfall. During the early-season drought in 1988, daily irrigation treatments included an additional 0.25 cm at 3 PM to prevent wilt. Irrigation rates and rainfall data were recorded in 1988 and 1989 and are presented in Figures 1 and 2, respectively. Irrigation treatments were initiated in 1986 and application of amendments began in 1987. Nitrogen carrying amendments were applied at 48.8 KgN ha^{-1}, Biogroundskeeper was applied at the recommended rate of 19.1 L ha^{-1}. Amendments were applied monthly beginning in May and ending in October (6 applications) of each year (1987-1989). Granular treatments were preweighed and applied by hand. Biogroundskeeper was applied as a drench with 7.5 L water. Irrigation treatments and amendments were applied to the same plots each year.

Monitoring field plots for disease development. Plots were monitored for necrotic ring spot activity throughout the year and ratings were taken at the height of disease expression. In November, 1985 and May, 1986 the test area was inoculated with wheat seed grown *L. korrae* by former graduate student M. Otto (Otto, 1986). In May 1988, when this study was initiated, symptom expression was pronounced throughout the area. This experiment was designed as a 3 x 6 factorial with 3 irrigation treatments and 6 soil amendments. Disease ratings consisted of counting the number of rings present in each plot and were taken at the end of each growing season at the height of disease activity. Data were subjected to factorial analysis, and the Least significant difference test ($P=0.05$) was used to indicate significant differences between amendments within an irrigation regime, and between irrigation regimes. To determine the effect of 5 years of irrigation treatments on nitrate levels, which may influence disease development, soil samples from unfertilized plots within each irrigation regime were sent to the Michigan State University Soil Testing Lab for analysis.

RESULTS

In 1988, from late May to early August (Figure 1), lack of rainfall resulted in drought conditions causing severe wilting of turf maintained under the 'rain only' irrigation program, while heavy rainfall during mid August and late September resulted in an increase in moisture levels (Figure 3). Even though irrigation rates in the 0.25 cm d^{-1} irrigation regime were increased to 0.50 cm d^{-1} to reduce moisture stress during the early season drought, two, and sometimes 3 times as much supplemental irrigation was applied per week to areas maintained under twice weekly irrigation (Figure 1). Although more irrigation water was applied to plots maintained under twice weekly irrigation than the 0.25 cm d^{-1} irrigation program, soil moisture levels were near equal and thatch moisture levels were generally higher and more consistent in plots receiving daily irrigation (Figure 3). As expected, moisture levels in the soil and thatch of plots maintained under the 'rain only' irrigation program were generally the lowest (Figure 3).

During 1989 rainfall patterns were more typical of those occurring in southern Michigan so differences in water application rates between daily and twice weekly irrigation treatments were not as great, however infrequent rainfall in early July prompted higher amounts of water to be applied to test plots maintained under the twice weekly irrigation regime, which was based on the amount of water lost from open evaporation pan (Figure 2). As in 1988, moisture levels in the soil and thatch in test plots receiving 0.25 cm d^{-1} irrigation at noon were generally higher, and more constant, than areas under the twice weekly and 'rain only' irrigation regimes in 1989 (Figure 4). Since thatch is more susceptible to drying, daily irrigation may be more effective is maintaining constant moisture levels than twice weekly irrigation treatment, with less water.

After 3 years of irrigation treatments (1986-1988), disease ratings taken on 28 September 1988 indicate significant differences between daily and twice weekly irrigation treatment, F=10.96 (table 2). Due to drought, areas not receiving supplemental irrigation were severely wilted and not acceptable for disease rating. Daily irrigation was more effective in reducing disease incidence than twice weekly irrigation. Difference in disease incidence due to fertility amendments was found to be highly significant, F=9.47 (Table 2). Comparison of treatments reveal the bio-organic amendments, Lawn Restore and Sustane had significantly less ring spots than the urea based fertilizer (9-4-4), Nitroform, and untreated control plots (P=0.05).

Disease ratings taken in 1989 again reveal significant differences (F=5.73) in necrotic ring spot incidence between irrigation regimes (Table 3). The average number of rings of all treatments combined with daily irrigation was 0.6, as compared to 1.0 for twice weekly irrigation, and 1.4 with 'rain only' (Table 3). Differences in disease development between amendments was also found to be highly significant (F=28.33). Comparison of treatment means reveal all amendments had significantly less disease than untreated areas (P=0.05).

Final disease rating were taken in 1990, which represents the effects of 5 years of irrigation treatments and 3 years of bio-organic and slow-release amendments. Factorial analysis indicate no significant differences in disease occurrence due to irrigation treatments (F=3.07), although differences due to amendments was found to be highly significant (F=19.94) (table 4). Comparison of treatment means between amendments reveal all amendments had significantly less number of rings than untreated areas (P=0.05).

Data obtained in previous years revealed less disease development in plots receiving daily irrigation. Although differences between irrigation treatments were not as dramatic in 1990, this could have been the result of increased rainfall without periods of extended drought. Increased rainfall during 1990 may have caused the release of nutrients from unused organic matter in non-irrigated areas, which was not released in previous years when conditions were drier. In addition, mineralization of native nitrogen in irrigated check plots, (no supplemental N since 1987) and consequential loss of nitrogen due to leaching, quite possibly created significant nutrient deficiencies which reduced host resistance thus favoring disease development. Similar conclusions have been drawn regarding severity of take-all in wheat (Huber *et al.*, 1968). Results of soil testing performed at the Michigan State University Soil Testing Lab regarding nitrogen levels in unfertilized control plots within each irrigation regime were taken at the conclusion of this study and reveal nonfertilized plots receiving 0.25 cm d irrigation had only 0.80 ppm NO_3, as compared to 1.40 and 1.05 ppm for twice weekly irrigation and non-irrigated unfertilized plots, respectively.

DISCUSSION

The finding presented in this paper clearly indicate that necrotic ring spot can be managed with manipulation of cultural practices such as irrigation programming and fertility. Disease ratings taken at the height of disease activity each year, indicate significant differences in symptom expression due to irrigation treatment and to bio-organic fertility treatments such as Lawn Restore and Sustane. Endo and Colbaugh (1975) noted that leafspot and foot rot of *Poa pratensis*, caused by *Helminthosporium sativum* was increased in drought-affected areas. They showed that spores added to moist crop debris do not germinate and the inhibitory effects can be eliminated after sterilizing or drying the debris. Disease severity in take-all of wheat is also increased or decreased depending upon the form of nitrogen used (Smiley and Cook, 1973; Huber and Watson, 1974; Taylor *et al.*, 1983). Smiley and Cook (1973) showed that *Gaeumannomyces graminis* root infection of wheat is reduced more with fertilizers providing NH_4-N than those providing NO^-_3 N, and also with alfalfa hay rather than wheat straw. It was suggested increased levels of antagonism/competition by microorganisms could be involved in disease reduction with the alfalfa amendment.

Regular application of nitrogen fertilizer likely promote plant vigor. In contrast to studies performed by Turgeon (1976), which indicated that nitrogen levels of 288 KgN ha^{-1} to 389 KgN ha^{-1} yr^{-1} promoted severe incidence of *Fusarium* blight, our studies have shown that 288 KgN ha^{-1} yr^{-1} as organic or slow-release nitrogen reduced symptom expression when applied at 48 kgN ha^{-1} monthly. Since high nitrogen levels early in the season has been shown to increase the severity of *Fusarium* blight (Turgeon and Meyer, 1974) avoiding excessive single applications of nitrogen may reduce disease activity. In our studies adequate fertility balance was found to be necessary for recuperation of diseased areas, which agrees with recommendations of Smiley (1983). Garret (1956) referred to the phenomenon that plants grown in well fertilized soil experience less damage from diseases as the "disease escape mechanism". In addition to the nitrogen effect on plant vigor, daily irrigation may also promote plant vigor during hot-dry periods by providing a cooling effect which reduces heat stress (Sale, 1965; Duff and Beard, 1966; Beard, 1966). Heat stress was associated with necrotic ring spot symptom development in greenhouse experiments performed by Cutright and Harrison (1970), they showed severity of *Fusarium* blight was correlated with soil temperature of 32 C and high nitrogen nutrient levels, while disease pressure was least when plants were grown at 21 C. Although temperatures were not recorded in this study, the cooling effect as provided by daily irrigation at noon has been documented by other researchers (Sale, 1965; Duff and Beard, 1966; Beard, 1966) and undoubtedly had some effect on disease development. Increased plant vigor through daily irrigation was demonstrated in research conducted by Shearman (1987), he found the quality of Kentucky bluegrass was better with daily irrigation as opposed to a twice weekly irrigation program.

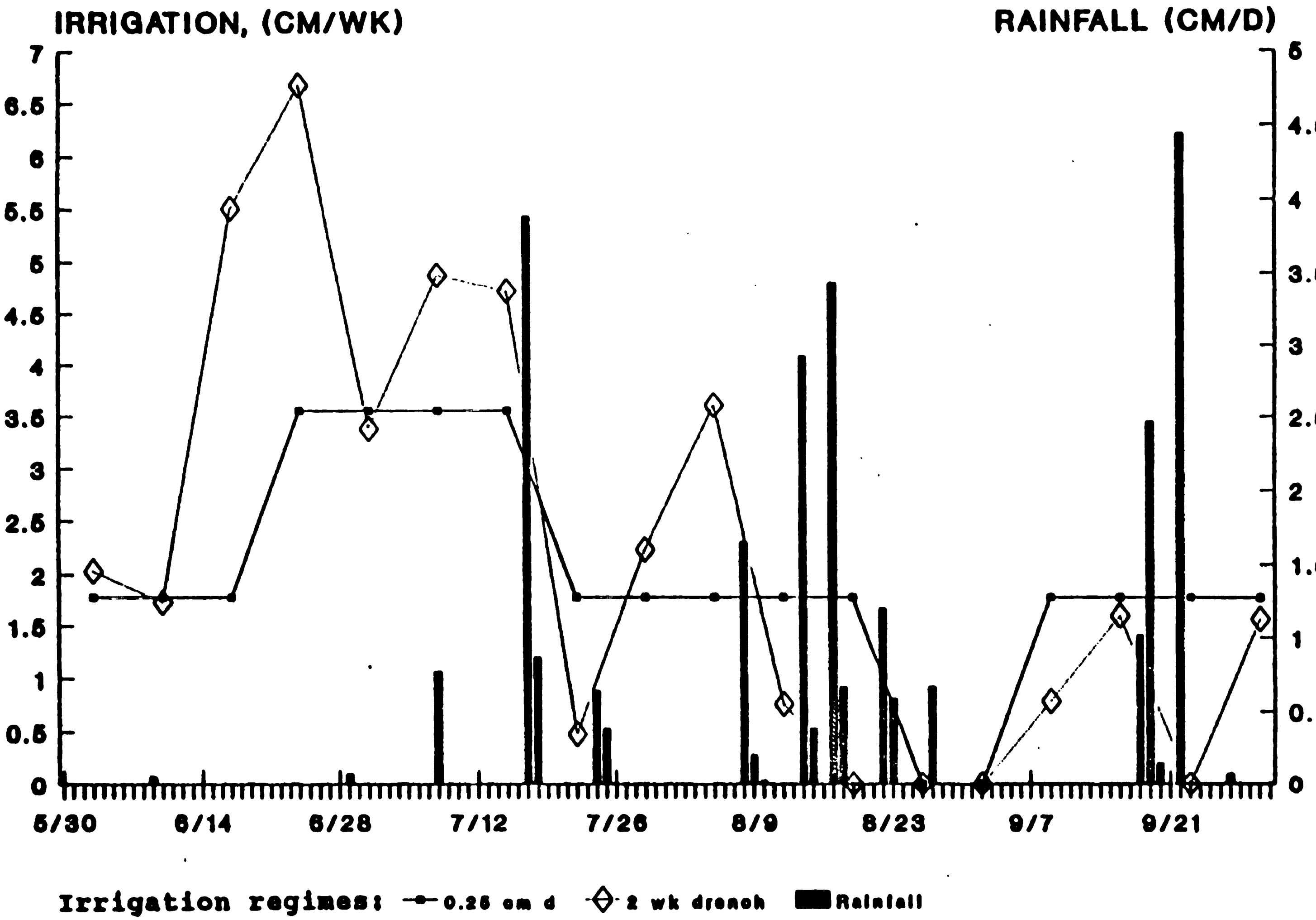
Table 1. Soil analysis of Kentucky bluegrass field trial. Hancock Turfgrass Research Center.

Sand %	60.4
Silt %	22.7
Clay %	16.9
Soil pH	7.5
Phosphorus (Kg ha)	75
Potassium (Kg ha)	132
Calcium (Kg ha)	1971
Magnesium (Kg ha)	394
cec (cmol kg^{-1})	6

* 10 samples taken to 5 cm. Analyzed at the Michigan State University Soil Testing Lab.

[illegible]
Kentucky bluegrass (Poa pratensis) [illegible] 1988 [illegible]
[illegible]

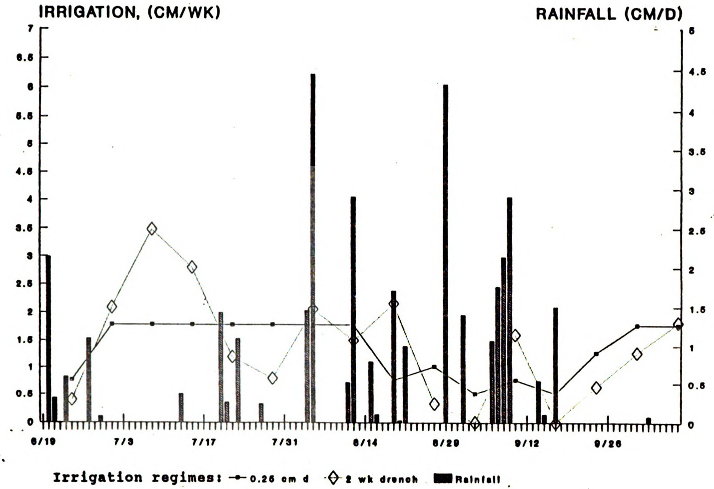
Figure 1. Amount of water applied under 3 irrigation regimes to Kentucky bluegrass (*Poa pratensis*), 1988. Hancock Turfgrass Research Center, Michigan State University, East Lansing, MI.



* When temperatures exceeded 29 C during the early season drought, water provided by daily irrigation treatment was increased to 0.50 cm d, 0.25 cm at noon and another at 3 PM, to prevent wilt. No supplemental irrigation was applied from 20 August to 5 September due to pump failure.

Figure 3. Amount of water applied

Figure 2. Amount of water applied under 3 irrigation regimes to Kentucky bluegrass (*Poa pratensis*), 1989. Hancock Turfgrass Research Center, Michigan State University, East Lansing, MI.



Supplemental irrigation was withheld when plots became saturated due increased rainfall.

Figure 1. Effect of irrigation treatments on [illegible]

Figure 3. Effect of irrigation treatments on soil and thatch moisture levels in Kentucky bluegrass muck sod, 1988. Hancock Turfgrass Research Center, Michigan State University, East Lansing, MI.

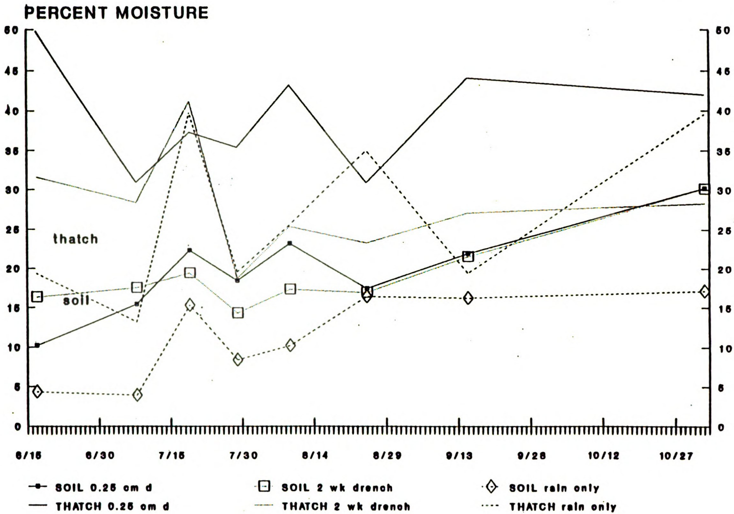


Figure 4: Effect of irrigation treatments on soil [illegible]

Figure 4. Effect of irrigation treatments on soil and thatch moisture levels in Kentucky bluegrass muck sod, 1989. Hancock Turfgrass Research Center, Michigan State University, East Lansing, MI.

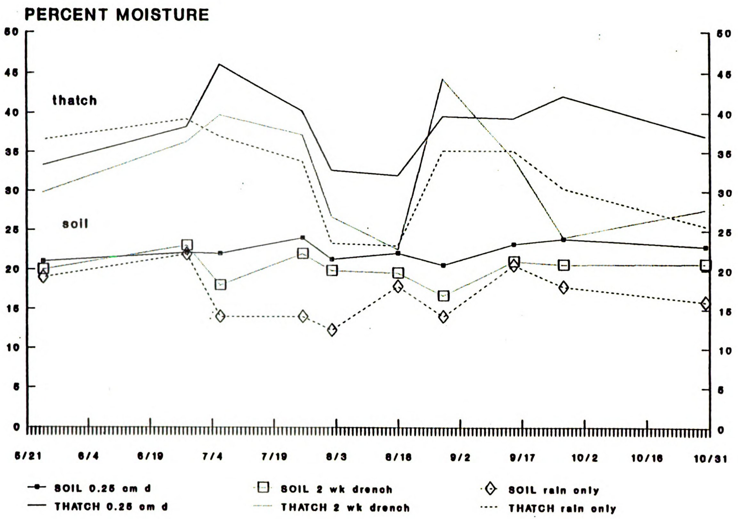


Table 2. Necrotic ring spot severity (number of ring spots per treatment) on Kentucky bluegrass in field plots (Hancock Turfgrass Research Center, M.S.U.) receiving fertility and irrigation treatments. Disease rating, 28 September 1988.

ANALYSIS OF VARIANCE SUMMARY

Source of variation.	df	mean square	F value
Irrigation	1	58.778	10.96*
Error	2	5.361	
Turf amendments	5	11.311	9.47**
T x I	5	1.044	0.87NS
Error	20	1.194	

*,** F significant at P=.05 and .01, respectively.
NS = not significant.

TREATMENT MEANS

Treatment[1]	average number of rings	
0.25 cm d^{-1} irrigation	1.4	
2 wk^{-1} irrigation	4.0	
Rain only	no rating (drought)	
Lawn Restore	0.8	a*
Sustane	1.5	ab
Biogroundskeeper + Nitro 26	2.8	bc
NPK (9-4-4)	3.2	c
Nitroform	3.4	cd
Control	4.7	d

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

[1] Treatments were applied from monthly from May through October (6 applications). Ratings taken at the height of disease activity (which occurred in September) were used for analysis, which was after 5 applications. Fertility treatments were applied at 48.8 KgN ha^{-1}. Biogroundskeeper was applied at 19.1 L ha^{-1}.

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Table 3. Necrotic ring spot severity (number of ring spots per treatment) on Kentucky bluegrass in field plots (Hancock Turfgrass Research Center, M.S.U.) receiving fertility and irrigation treatments. Disease rating, 28 September 1989.

ANALYSIS OF VARIANCE SUMMARY

Source of variation.	df	mean square	F value
Irrigation	2	3.130	5.73*
Error	4	0.546	
Turf amendments	5	7.974	28.33**
T x I	10	0.485	1.72NS
Error	30	0.281	

*,** F significant at P=.05 and .01, respectively.
NS = not significant.

TREATMENT MEANS

Treatment[1]	average number of rings
0.25 cm d^{-1} irrigation	0.6 a*
2 wk^{-1} irrigation	1.0 ab
Rain only	1.4 b
Lawn Restore	0.1 a
Nitroform	0.4 ab
NPK 9-4-4	0.5 ab
Sustane	0.7 b
Biogroundskeeper + Nitro 26	1.8 c
Control	2.6 d

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

[1] Treatments were applied monthly from May through October (6 applications). Ratings taken at the height of disease activity (which occurred in September) were used for analysis, which was after 5 applications. Fertility treatments were applied at 48.8 KgN ha^{-1}. Biogroundskeeper was applied at 19.1 L ha^{-1}.

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Table 4. Necrotic ring spot severity (number of ring spots per treatment) on Kentucky bluegrass in field plots (Hancock Turfgrass Research Center, M.S.U.) receiving fertility and irrigation treatments. Disease rating, 10 November 1990.

ANALYSIS OF VARIANCE SUMMARY

Source of variation.	df	mean square	F value
Irrigation	2	3.130	3.07NS
Error	4	1.019	
Turf amendments	5	19.719	19.94**
I x T	10	1.641	1.66NS
Error	30	0.989	

*,** F significant at P=0.05 and 0.01, respectively.
NS = not significant.

TREATMENT MEANS

Treatment[1]	average number of rings	
0.25 cm d^{-1} irrigation	1.4	
2 wk^{-1} irrigation	1.8	
Rain only	0.9	
Lawn Restore	0.4	a*
Nitroform	0.6	a
9-4-4	0.7	a
Biogroundskeeper + Nitro 26	1.0	a
Sustane	1.2	a
Control	4.3	b

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

[1] Treatments were applied monthly from May through October (6 applications). Fertility treatments were applied at 48.8 KgN ha-1. Biogroundskeeper was applied at 19.1 L ha^{-1}.

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CHAPTER III

EFFECT OF IRRIGATION AND NITROGEN FORM ON THATCH OF KENTUCKY BLUEGRASS

Abstract.

Excessive thatch accumulation is a major problem of modern turfgrass culture. Excessive thatch results in shallow rooting and less drought tolerant turf, which does not respond favorably to intensive management practices. Thatch buildup is a direct result of management practices which produce abundant vegetative growth, however, under conditions which are favorable for decay, the residues of grasses should be readily decomposed. Manipulation of turfgrass management practices may reduce or prevent thatch build-up. Bio-organic, slow-release, and urea fertility treatments, when used in combination with each of 3 irrigation programs, were examined for their effect on thatch characteristics of Kentucky bluegrass (*Poa pratensis* L.) in a field experiment. Irrigation programs consisted of 0.25 cm d^{-1} applied at noon, twice weekly irrigation, and no irrigation. Factorial analysis indicates significant differences in thatch thickness due to irrigation (P=0.01) and fertility (P=0.05) treatment. Areas maintained under 0.25 cm d^{-1} irrigation averaged the least measurable thatch (19.5 mm), however, better soil-thatch mixing, as indicated

by higher bulk density ($P=0.01$), was found in areas receiving twice weekly irrigation. Monthly application of 48 Kg N ha^{-1} slow-release nitrogen as bone-meal/corn-meal/soybean-meal (Lawn Restore), or as short chain methyleneurea polymers (Nitroform) had less thatch than untreated areas. Manipulation of irrigation and fertility practices was shown to have direct effect on thatch characteristics of Kentucky bluegrass.

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INTRODUCTION

An understanding of thatch accumulation is important in developing irrigation and fertility programs for use in turfgrass management. Thatch is formed mostly from sloughed roots, horizontal stems (stolons and rhizomes); from stubble, and also from mature leaf sheaths and blades (Engel, 1954; Wilson 1953; Beard, 1976). Excessive accumulation of undecomposed surface organic matter (thatch) is a major problem of modern turfgrass culture (Ledeboer and Skogley, 1967). Thatch usually accumulates above the soil line and once a mat has developed, new roots seem to form more abundantly in this layer (Ledeboer and Skogley, 1967). This results in shallow rooting and less drought tolerant turf, which does not respond favorably to intensive management practices (Ledeboer and Skogley, 1967). Management problems associated with excessive thatch accumulation include increased disease and insect damage; localized dry spots; restricted movement of pesticides, fertilizers, and irrigation; chlorosis; proneness to scalping; foot printing; and decreased heat, cold, and drought hardiness (Beard, 1973). Thatch also provides a growth medium for facultative parasites including *M. poae* and *L. korrae* (Smiley, 1984). When the rate of thatch accumulation exceeds the rate of decomposition, build-up occurs.

Thatch buildup is a direct result of management practices which produce abundant vegetative growth (Ledeboer and Skogley, 1967). Thatch accumulation depends mostly upon plant growth rate; composition of the plant tissues; amounts and types of pesticides used; and the fertility, aeration, temperature, and moisture in the thatch (Smiley, 1981). Inhibition of the microflora, due to long term use of selected fungicides, has shown to result in thatch buildup (Smiley and Craven, 1978, 1979). Thatch decomposition is apparently affected by irrigation and nitrogen practices. Nitrogen is necessary for decomposition of organic litter (Smiley, 1981). A carbon-nitrogen ratio of at least 25:1 is required for effective decomposition of thatch by microorganisms (Beard, 1973). Organic litter is mostly carbon (Smiley, 1981). Nitrogen can be quickly leached out of the thatch (Hunt, 1978), and the C:N ratio can therefore become rather high (Smiley, 1981). Beard (1976) stated that the frequency of nitrogen application and the type of carrier should be manipulated to keep nitrogen up in the thatch. Frequent light applications of fertilizer were shown to increase thatch decomposition, and factors such as nitrogen application and irrigation can stimulate excess growth if not carefully manipulated (Beard, 1973). Excessive fertility levels greatly increase tissue production rates, but not decomposition rates (Smiley, 1981). Meinhold *et al.*, (1973) showed thatch accumulation in a 'Tifgreen' bermudagrass (*Cynodon dactylon* L. Pers.) turf was greater in

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plots receiving 0.75 kg of N 100 m^{-2} than those receiving 0.25 kg N 100 m^{-2}, two sources of N were examined, ammonium sulfate and activated sewage sludge (Milorganite). The nitrogen source also influenced thatch production. At each rate of N (0.75 kg and 0.25 kg N 100 m^{-2}) plots treated with Milorganite accumulated less thatch than those fertilized with ammonium sulfate (Meinhold *et al.*, 1973).

Irrigation also plays an important role in thatch accumulation (Smiley, 1981). Irrigation rates used in automatic systems are often set to meet optimum evaporative demands which often results in over-watering (Snyder *et al.*, 1984). Waterlogging reduces stem elongation and leaf expansion, induces stem thickening, causes an increase in senescence of older leaves, and induces production of adventitious roots (Levitt, 1972). Shildrick (1985) stated that turfstands with increased thatch should be irrigation frequently because water cannot move from the soil to the thatch due to lack of capillary action, but also suggests that frequent irrigation leads to greater thatch build-up. Beard (1973) suggests that thatch accumulation may be caused by acidification of thatch brought about by frequent irrigation. Edmond and Coles (1958) showed acidic conditions to promote thatch accumulation. Beard (1973) also associated excess water and surface drying with thatch accumulation.

Curative management of thatch accumulation includes mechanical and cultural practices, which have shown to be effective. Mechanical removal of thatch by vertical mowing has shown to be effective in reducing thatch although it may be injurious to the turf (Beard, 1973). Engel and Alderfer (1967) showed topdressing is an effective means of reducing thatch problems. Mechanical and cultural methods are effective, but are costly, time consuming, temporarily detract from appearance, and interfere with use (Ledeboer and Skogley, 1967).

Turfgrass management practices may be manipulated to reduce or prevent thatch build-up (Beard, 1973). Hunt (1978) suggests that thatch decomposition can be increased if nitrogen concentration in the thatch is reduced, however, Beard (1973) indicates that thatch decomposition is accelerated by light, frequent applications of nitrogen.

Beard (1973) suggests biological control through manipulation of cultural activities may enhance decomposition while avoiding excessive stimulation of shoot growth. Decomposition of thatch include factors such as moisture, pH, microorganism populations, aeration, temperature, and carbon-nitrogen ratio (Beard, 1973). Thatch decomposition is performed by microorganisms, as well as microfauna and macrofauna. The fauna assist decomposition of thatch by microbes by physical disruption thereby providing increased surface area for decomposing microorganisms (Smiley, 1981). Fungi initiate thatch decay, followed by bacteria and then nematodes feed on the bacteria and fungi (Tribe, 1960). Starkey (1953) showed that decomposition of thatch is more rapid when organic debris is moist, and

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Ulehlova (1973) showed that dry conditions halts the decomposition process. Because thatch acts as a rooting medium, regular irrigation may be more favorable in thatchy turfs and can have a dramatic effect on quality of the turfstand, (Hurto *et al.*, 1980). Thatch has a low water retention capability, as compared to surface soil, and if not irrigated frequently results in water stress and effects other management practices, (Hurto and Turgeon, 1979).

Engel (1954) stated that under conditions which are favorable for decay, the residues of grasses should be readily decomposed. The purpose of this study was to evaluate irrigation and fertility practices for their effect on thatch characteristics of existing Kentucky bluegrass muck sod. Bio-organic, slow-release, and urea fertility treatments, when used in combination with each of 3 irrigation programs, were examined.

MATERIALS AND METHODS

Testing was performed on a stand of 'Baron/Bristol/ Victa' Kentucky bluegrass (*Poa pratensis* L.) located at the Hancock Turfgrass Research Center, Michigan State University, East Lansing, MI. The stand was established from muck sod in 1985 and the turf was maintained at 6.1 cm. Relevant characteristics of the soil are reported in Table 1. This study was designed as a 3 x 6 factorial. Thatch thickness, bulk density, and percent organic matter was measured in untreated plots as well as plots treated with 5 different fertility amendments under 3 irrigation regimes.

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Irrigation treatments were applied to randomly selected 12.2 x 12.2 m blocks with 3 replications. Fertility amendments were applied to randomly selected 1.8 x 1.8 m plots within each irrigation block. Irrigation treatments consisted of 1) 0.25 cm d^{-1} supplemental irrigation, applied at noon, 2) twice weekly irrigation based on 80% of the water lost from an open evaporation pan, applied on mondays and thursdays at night, and 3) no supplemental irrigation (rain only). Supplemental irrigation treatments were withheld when plots became saturated due to rainfall. During the early-season drought in 1988, daily irrigation treatments included an additional 0.25 cm at 3 PM to prevent wilt. Irrigation treatments began in May and ended in either late October or early November from 1986 to 1990. Fertility treatments were initiated in 1987. Amendments consisted of Lawn Restore, Sustane, Biogroundskeeper + NITRO 26 CRN, Nitroform, 9-4-4 fertilizer analysis. Bio-organic fertility products containing viable microorganisms were provided by Ringer Corporation (Minneapolis, MN.), and Sustane Corporation (Cannon Falls, MN.), and are labeled Lawn Restore and Sustane, respectively. Lawn Restore is 49% carbon, has a fertilizer analysis of 9-4-4 and consists of various organic and inorganic constituents including feather meal, corn meal, soybean meal and bone meal. Yeast (*Torula spp.*) is the predominant N source. Sustane is aerobically composted turkey manure with a fertility analysis of 5-2-4 and contains 3.5% insoluble nitrogen, ammoniacal nitrogen 1.5%, L

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phosphoric acid (P_2O_5) 2.0%, soluble potash (K_2O) 4.0%, calcium (Ca) 3.7%, iron (Fe) 2.3%, sulfur (S) 2.0%, Magnesium (Mg) 0.8%, manganese (Mn) 0.06%, zinc (Zn) 0.05%, chromium (Cr) 16 ppm, lead (Pb) 12 ppm, nickel (Ni) 22 ppm, cadmium (Cd) 1 ppm. Organic matter analysis conducted by Woods End Laboratory revealed a CEC of 104.4 cmol kg^{-1}. Components analyzed by cation displacement reveal organic matter was responsive for 44.6%, humic acid content 10.8%, and humic acid (as percent of organic matter) 24.2%. Because Lawn Restore and Sustane contain both organic slow-release nitrogen and viable microorganisms, a synthetic slow-release nitrogen source 'Nitroform' was also examined. Nitroform was provided by Nor-am Corporation, Wilmington, DE., and is composed of methyleneurea polymers with a fertility analysis of 38-0-0. KLM Bio-systems (Bloomington, MN.) provided a biologically active product, but without nitrogen, known as Biogroundskeeper. This product comes in 3 separate containers which must be mixed before application and consists of various organic acids and plant growth stimulators, in addition to viable microorganisms. Since Biogroundskeeper does not contain nitrogen, a slow-release synthetic nitrogen fertilizer 'NITRO-26 CRN' was also applied to these plots. NITRO-26 CRN was provided by Growth Products Inc., and is a liquid controlled-release nitrogen fertilizer consisting of 20.8% methylene diurea, and small percentages of free urea 5.2%, nitrogen release time is 6 to 10 weeks. Nitrogen carrying amendments were applied at 48.8

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Kg actual N ha^{-1}, Biogroundskeeper was applied at the manufactures recommended rate of 19.1 L ha^{-1}. Amendments were applied monthly beginning in May and ending in October (6 applications) of each year (1987-1989). Granular treatments were preweighed and applied by hand. Liquid treatments were applied as a drench with 7.5 L water. Irrigation treatments and amendments were applied to the same plots each year.

On 26 October 1990, three 43-mm-diameter samples per test plot were collected to a depth of 10 cm with a cup cutter for thatch measurements. Verdure and stem tissue were removed and discarded. Root tissue and soil was removed upward until the first sign of the rhizome layer, the remainder was considered thatch. The uncompressed thickness of the thatch of each plug was measured at 3 points. Data within a sample were averaged, then sample means were averaged to provide plot means for statistical analysis. Samples were dried at 60 C for 24 hr in a forced-air over to determine bulk density. Total carbon was determined by loss on ignition at 700 C. Data were subjected to factorial analysis. Treatment means within an irrigation regime and between regimes were separated using LSD analysis (P=0.05). Measurements represent the influence of 5 years of irrigation and 4 years of fertility treatments on the same plots.

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RESULTS AND DISCUSSION

After 5 years of irrigation treatments and 4 years of fertility treatments, both irrigation and selected fertility amendments caused differences in thatch characteristics of *Poa pratensis* muck sod. Differences in thatch thickness (F=24.74, Table 2), and bulk density (F=15.49, Table 3) between irrigation treatments were found to be highly significant. No differences were indicated with respect to percent organic matter (F=4.72, Table 4). Significant differences in thatch thickness due to fertility treatment were also indicated, F=3.05 (Table 2), but not with regard to bulk density, F=2.96 (Table 3) or percent organic matter, F=1.10 (Table 4). Interaction between irrigation and fertilizers on thatch thickness was not significant, F=0.42. All amendments when used with 0.25 cm d^{-1} irrigation had less thatch thickness than when combined with either of the other irrigation treatments (Table 2). The average thickness in thatch of treatments when used with daily irrigation was 19.5 mm, as compared to 21.9 and 21.8 mm for twice weekly and 'rain only' irrigation programs, respectively (Table 2). Although 80% OPE 2 wk^{-1} irrigation did not reduce thatch thickness, the bulk density was significantly higher in these plots, (F=15.49, Table 3). Apparently daily irrigation was most effective in reducing thatch thickness, while twice weekly irrigation resulted in a less pure thatch layer, as indicated by higher bulk density.

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Analysis of treatment means of thatch thickness within an irrigation regime, indicate plots treated with Lawn Restore or Nitroform had significantly less measurable thatch than the untreated control (P=0.05, Table 2).

No differences between fertility treatments were indicated with respect to bulk density or the percent organic matter of thatch (Tables 3 and 4, respectively).

Data from this study indicates that plots receiving 0.25 cm d^{-1} irrigation had reduced thatch thickness (Table 2). These finding agree with recommendations made by Starkey (1953), who suggested that frequent irrigation may promote thatch decomposition. Wet-dry conditions, as provided by twice weekly irrigation, did not significantly reduce thatch thickness although this irrigation regime did result in a layer of thatch with higher bulk density, which indicates greater mixing with soil. Results also indicate that monthly additions of controlled-release nitrogen such as Lawn Restore, or Nitroform, reduce thatch thickness. These data agree with conclusions from previous research which indicated that both slow-release nitrogen, and frequent application of nitrogen, reduces thatch (Beard, 1973; Berndt, 1990).

Table 1. Soil analysis*, Hancock Turfgrass Research Center test site.

Sand %	60.4
Silt %	22.7
Clay %	16.9
Soil pH	7.5
Phosphorus (Kg ha^{-1})	75
Potassium (Kg ha^{-1})	132
Calcium (Kg ha^{-1})	1971
Magnesium (Kg ha^{-1})	394
cec (cmol kg^{-1})	6

* Analyzed at the Michigan State University Soil Testing Lab.

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Table 2. Effect of bio-organic and slow-release fertilizers combined with irrigation treatments on thatch thickness of 'Baron/Bristol/Victa' Kentucky bluegrass (*Poa pratensis* L.). 26 October 1990.

ANALYSIS OF VARIANCE SUMMARY

Source of variation.	df	mean square	F value
Irrigation	2	33.485	24.74**
Error	4	1.353	
Turf amendments	5	11.616	3.05*
I x T	10	1.484	0.39NS
Error	30	3.807	

*,** F significant at P=0.05 and 0.01, respectively.
NS = not significant.

TREATMENT MEANS

Treatment	average thatch thickness (mm)
0.25 cm d^{-1} irrigation	19.5 a*
2 wk^{-1} irrigation	21.9 b
Rain only	21.8 b
Nitroform	19.4 a
Lawn Restore	20.5 ab
NPK (9-4-4)	21.1 abc
Sustane	21.2 abc
Biogrndskpr + Nitro 26	21.3 bc
Control	22.9 c

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

Treatments were applied monthly from May through October (6 applications). Fertility treatments were applied at 48.8 Kg N ha^{-1}. Biogroundskeeper was applied at 19.1 L ha^{-1}.

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Table 3. Effect of bio-organic and slow-release fertilizers combined with irrigation treatments on thatch bulk density of 'Baron/Bristol/Victa' Kentucky bluegrass (*Poa pratensis* L.). 26 October 1990.

ANALYSIS OF VARIANCE SUMMARY

Source of variation.	df	mean square	F value
Irrigation	2	1559.874	15.49**
Error	4	100.705	
Turf amendments	5	52.983	1.13NS
I x T	10	36.585	0.78NS
Error	30	46.695	

*,** F significant at P=0.05 and 0.01, respectively.
NS = not significant.

TREATMENT MEANS

Treatment	Bulk density, g/cc		
0.25 cm d^{-1} irrigation	0.746 b*		
2 wk^{-1} irrigation	0.913 a		
Rain only	0.757 b		
Lawn Restore	0.748	0.901	0.793
NPK (9-4-4)	0.801	0.879	0.739
Sustane	0.741	0.921	0.795
Biogrndskpr + Nitro 26	0.744	0.954	0.753
Nitroform	0.708	0.846	0.717
Control	0.734	0.977	0.748

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

Treatments were applied monthly from May through October (6 applications). Fertility treatments were applied at 48.8 Kg N ha^{-1}. Biogroundskeeper was applied at 19.1 L ha^{-1}.

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TREATMENT

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Table 4. Effect of bio-organic and slow-release fertilizers combined with irrigation treatments on percent organic matter of thatch of 'Baron/Bristol/Victa' Kentucky bluegrass (*Poa pratensis* L.). 26 October 1990.

ANALYSIS OF VARIANCE SUMMARY

Source of variation.	df	mean square	F value
Irrigation	2	61.859	4.72NS
Error	4	13.096	
Turf amendments	5	5.111	1.10NS
I x T	10	4.059	0.87NS
Error	30	4.654	

*,** F significant at P=0.05 and 0.01, respectively.
NS = not significant.

TREATMENT MEANS

Treatment	Percent organic matter
0.25 cm d^{-1} irrigation	86.9
2 wk^{-1} irrigation	89.7
Rain only	86.5
Lawn Restore	88.5
NPK (9-4-4)	88.6
Sustane	88.4
Biogrndskpr + Nitro 26	87.7
Control	87.2
Nitroform	87.5

Treatments were applied monthly from May through October (6 applications). Fertility treatments were applied at 48.8 Kg N ha^{-1}. Biogroundskeeper was applied at 19.1 L ha^{-1}.

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CHAPTER IV

EFFECT OF DAILY, TWICE WEEKLY, AND NO SUPPLEMENTAL IRRIGATION ON ROOT DISTRIBUTION OF KENTUCKY BLUEGRASS (*POA PRATENSIS* L.) MUCK SOD.

Abstract.

Irrigation rates used in automatic systems are often set to meet optimum evaporative demands of turfgrasses which often results in over-watering. Excess water and frequent irrigation, have been associated with shallow rooting, which may expose the roots to adverse conditions of the surface environment, however frequent irrigation is recommended to reduce several turfgrass diseases. A knowledge of root distribution is necessary when implementing an irrigation program for turfgrass management. Irrigation practices recommended to ensure adequate root distribution in Kentucky bluegrass vary, and remains open to question. The effects of 0.25 cm d^{-1}, twice weekly, and no supplemental (rain only) irrigation treatments on root distribution of Kentucky bluegrass (*Poa pratensis* L.) muck sod were examined. After 3 years of irrigation treatments no significant differences in root density at any depth were indicated between irrigation regimes (P=0.05). Data taken in 1989, four years after initiation of the study, also indicate no significant difference in root densities between irrigation treatments

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at depths of 0 to 5.0 cm, or 5.0 to 10.0 cm. However, higher root density in non-irrigated plots, as compared to daily irrigated plots, was observed at the 10.0 to 15.0 cm profile (P=0.05). Significantly higher root density also occurred in non-irrigated plots at soil profiles of 15.0 to 23.0 cm and 23.0 to 30.5 cm when compared to either daily or twice weekly irrigation. However, no significant differences were indicated between 0.25 cm d^{-1} and twice weekly irrigation treatments (P=0.05).

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INTRODUCTION

A knowledge of root distribution is important when implementing an irrigation program for turfgrass management. Irrigation rates used in automatic systems are often set to meet optimum evaporative demands which often results in over-watering (Snyder *et al.*, 1984). Excess water causes anaerobic conditions in the soil which results in anoxia and ethanol production in roots, and production of phytotoxic compounds such as ethylene and acetic acid in the soil (Lynch, 1978; Wright, 1978). Waterlogging has been shown to reduce stem elongation and leaf expansion, induce stem thickening, cause an increase in senescence of older leaves, and induce production of adventitious roots (Levitt, 1972). Excess water has also been associated with shallow rooting, which may expose the roots to adverse conditions of the surface environment (Smiley, 1980).

Frequent light irrigation is recommended to reduce several turfgrass diseases although it has been reported regular irrigation results in a shorter root zone (Smiley, 1980). However, because the thatch acts as a rooting medium, regular irrigation may be more favorable in thatchy turfs, in this case irrigation practices can have a dramatic effect on quality of the turfstand, (Hurto *et al.*, 1980). Thatch has a low water retention capability, as compared to surface soil, which results in water stress and effects other management practices if not irrigated frequently (Hurto and

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Turgeon, 1979). Shildrick (1985) suggests that turfstands with increased thatch should be irrigated frequently because water cannot move from the soil to the thatch due to lack of capillary action. Shearman (1987) showed that the quality of Kentucky bluegrass (*Poa pratensis* L.) was better under frequent irrigation although water use rate is higher with daily irrigation, as opposed to a twice weekly irrigation program. Chastagner (1985) recommends watering only when the top 2 inches of soil become dry or when the turf turns a blue-green color, however, root diameters may shrink up to 40% when exposed to moisture stress which causes a disruption between the root and the soil solution (Huck *et al*., 1970; Weatherly, 1979). Under drought conditions Kentucky bluegrass was found have 75% of its root mass within 12 cm of the soil surface (Sheffer *et al*., 1987).

Irrigation practices also effects the metabolic activity of the host, which directly influences resistance to disease (Smiley, 1980). Landschoot *et al*., (1989) stated that cultural practices which encourage good rooting will aid in reducing disease severity. Irrigation practices should be developed which promote formation of new root tissue so as to offset that lost by infection. However, irrigation practices recommended to ensure adequate root distribution in Kentucky bluegrass vary, and remains open to question.

The purpose of this study was to test the effects of 0.25 cm d^{-1}, twice weekly, and no supplemental (rain only)

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irrigation treatments on root distribution of Kentucky bluegrass.

MATERIAL AND METHODS

This study was designed as a complete randomized block design with 3 replications. Testing was performed on a 'Baron/Bristol/Victa' Kentucky bluegrass (*Poa pratensis* L.) turfstand located at the Hancock Turfgrass Research Center, Michigan State University, East Lansing, MI. The stand was established from muck sod in 1985 and the turf was maintained at 6.1 cm. Relevant characteristics of the soil are reported in Table 1. Irrigation treatments were applied to randomly selected 12.2 x 12.2 m blocks with 3 replications, and consisted of 1) 0.25 cm d^{-1} supplemental irrigation, applied at noon, 2) twice weekly irrigation based on 80% of the water lost from an open evaporation pan applied on mondays and thursdays at night, and 3) no supplemental irrigation (rain only). Irrigation was withheld when plots became saturated due to rainfall. Irrigation treatments began in May and ended in either late October or early November from 1986 to 1989. Effect of irrigation treatments on root density were determined at 5 soil profiles according to depth, 0-5.0, 5.0-10.0, 10.0-15.0, 15.0-23.0 and 23.0-30.5 cm. This experiment was repeated at the end of the 1988 and 1989 growing season, 2 October 1988 and 15 September 1989.

Three soil cores (2.5 cm diam x 36.0 cm deep) were removed using a Giddings probe (The Giddings Machine

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Company, Fort Collins, CO.) from each irrigation block. Cores were sectioned at the depths listed above and stored at 4 C until washing. Each core section was washed for 15 min. in a root washer (Gillison's Variety Fabrication, Inc., Benzonia, MI.). Root segments were stained with malachite green and stored in 10% methanol until counting on a 22.8 x 21.7 cm grid, with grid lines 2 x 2 cm apart. Root segments were evenly spread across the tray and those segments touching grid lines were counted. Root lengths were determined using a modified Newman-line method (Tennant, 1975) and data are presented as root density. Data within replications were averaged, and analyzed using analysis of variance, treatment means were separated using LSD analysis.

RESULTS AND DISCUSSION

Analysis of variance of data taken in 1988, which represent the effect of 3 years of irrigation treatments on Kentucky bluegrass established from muck sod, indicate no significant differences in root density between irrigation regimes at any depth (P-0.05, Table 2). Data taken from non-irrigated plots in 1988 indicate the effects of drought stress on root distribution of Kentucky bluegrass. The percent of roots in the upper 10.0 cm of the soil profile in non-irrigated plots, which were subjected to drought conditions during 1988, was 65% of the total of all depths tested and corresponds to the results presented by Sheffer *et al.*, (1987) which found 75% of the roots of drought str

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stressed Kentucky bluegrass in the upper 12 cm of the soil profile.

Data taken in 1989, four years after initiation of the study, also indicate no significant difference in root densities between irrigation regimes at depths of 0 to 5.0 cm, or 5.0 to 10.0 cm (Table 2). However, higher root density in non-irrigated plots, as compared to daily irrigated plots, was observed at the 10.0 to 15.0 cm profile (P=0.05). Significantly higher root density also occurred in non-irrigated plots at soil profiles of 15.0 to 23.0 cm and 23.0 to 30.5 cm when compared to daily or twice weekly irrigation. However, no significant differences were indicated between daily and twice weekly irrigation treatments at any depth (P=0.05).

In conclusion, these results indicate reduction in rooting at lower depths (10.0 to 15.0, 15.0 to 23.0, and 23.0 to 30.5 cm) in plots receiving supplemental irrigation, as opposed to 'rain only' plots. No differences were indicated between 0.25 cm d^{-1} and twice weekly deep irrigation. Although, Smiley *et al.*, (1980) reported that frequent light irrigation causes shorter rooting, our findings indicate no differences in root distribution between 0.25 cm d^{-1} irrigation and twice weekly deep irrigation in Kentucky bluegrass muck sod after 4 years treatment.

Table 1. Soil analysis*, Hancock Turfgrass Research Center test site.

Sand %	60.4
Silt %	22.7
Clay %	16.9
Soil pH	7.5
Phosphorus (Kg ha^{-1})	75
Potassium (Kg ha^{-1})	132
Calcium (Kg ha^{-1})	1971
Magnesium (Kg ha^{-1})	394
cec (cmol kg^{-1})	6

* Analyzed at the Michigan State University Soil Testing Lab.

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Table 2. Effect of 0.25 cm d^{-1}, 80% OPE 2 wk^{-1}, and 'rain only' irrigation treatments on rooting characteristics of *Poa pratensis*.

Treatment means, 1988 (root density/cc).

	Irrigation treatment			
Depth (cm)	0.25 cm d^{-1}	2 wk^{-1}	Rain Only	F-value
0-5.0	11.45	11.71	13.38	0.24ns
5.0-10.0	4.22	3.84	6.67	2.75ns
10.0-15.0	2.02	3.51	5.78	5.16ns
15.0-23.0	1.69	2.17	2.71	2.38ns
23.0-30.5	1.74	1.82	2.09	0.32ns

Treatment means, 1989 (root density/cc).

	Irrigation treatment			
Depth (cm)	0.25 cm d^{-1}	2 wk^{-1}	Rain Only	F-value
0-5.0	7.65	8.58	7.94	0.32ns
5.0-10.0	2.27	2.76	3.38	2.19ns
10.0-15.0	1.42 b[#]	2.35 ab	3.64 a	9.87*
15.0-23.0	1.01 b	1.63 b	2.78 a	23.41**
23.0-30.5	0.73 b	1.09 b	2.08 a	10.60*

*,** F significant at P=0.05 and 0.01, respectively.
NS = not significant.

Treatments means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

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CHAPTER V

EFFECT OF BIO-ORGANIC AMENDMENTS AND SLOW-RELEASE FERTILIZER ON NECROTIC RING SPOT OF KENTUCKY BLUEGRASS UNDER NATURAL CONDITIONS

Abstract.

Necrotic ring spot, incited by *Leptosphaeria korrae*, causes severe damage to *Poa spp.* in the temperate growing region of the United States. Disease management is an integral part of turfgrass cultivation programs, however extensive use of disease-preventative fungicides for target pests may result in long term changes in the turf system. In this study various bio-organic and slow-release fertility treatments, and the major nutrients (NPK) alone or in combination, were examined for potential management of necrotic ring spot in field testing under natural conditions. Disease ratings indicate that nitrogen form influences necrotic ring spot severity. When applied monthly at 48 Kg N ha^{-1}, plots treated with bio-organic amendments composed of either bone-meal/corn-meal/soybean meal containing microorganisms or aerobically composed turkey manure with microorganisms, had significantly less disease than areas treated with urea N. alone in all trials in which they were compared (P=0.05). The bio-organic amendments significantly reduced disease, as compared to untreated plots, in all trials. Disease severity was also reduced by urea nitrogen alone in 2 of 3 field

experiments, which contrasts earlier indications that nitrogen increases disease severity. And when nitrogen was combined with potassium and phosphorus, disease expression was significantly suppressed in all field trials. Monthly application of fertility treatments containing the major nutrients (NPK) were found to reduce necrotic ring spot disease expression. Adequate fertility balance apparently reduces disease expression and promotes recuperation of diseased areas.

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INTRODUCTION

Necrotic ring spot, incited by *Leptosphaeria korrae*, causes severe damage to *Poa spp.* in the temperate growing region of the United States. This disease, along with summer patch (incited by *Magnaporthe poae*), were previously known as *Fusarium* blight, first described by Couch and Bedford in 1966. Infection by *L. korrae* causes root dysfunction resulting in extensive damage to the root system which reduces water absorption and nutrient uptake (Smiley, 1984). Symptoms of necrotic ring spot first appear as small (5-10 cm) circular patches of straw colored turf in late spring and/or late summer to early fall. As infection proceeds outward, the patch becomes necrotic and depressed, and open to invasion by less susceptible grasses or weeds resulting in typical 'frog-eye' type patches. Individual patches may reach 1 m in diameter but patches often coalesce giving a serpentine appearance. *Leptosphaeria korrae* grows and spreads in soil and thatch, and apparently infects host tissues several months in advance of symptom development (Smiley, 1984). Although activity of *L. korrae* is greatest in the cool weather of the spring and fall, symptoms can be observed throughout the growing season (Vargas, 1986), although at times, plants may remain asymptomatic until heat and moisture stress reduce plant vigor (Smiley, 1984).

Certain turfgrass management practices have also been associated with increases in disease severity. High nitrogen fertilization has been linked to increased susceptibility of turfgrasses to *Fusarium* blight (Couch, 1976; Smiley, 1977; Turgeon, 1976; Vargas, 1981). Turgeon (1976) reported that nitrogen levels of 6 to 8 pounds per 1,000 square feet per year resulted in severe incidence of *Fusarium* blight. Chastagner *et al.*, (1984) stated that necrotic ring spot is most severe in intensely managed turf that is over-fertilized and over-watered. Vargas (1981) stated that factors which contribute to drought stress such as compacted soil and excessive nitrogen, also predispose plants to infection by *Fusarium* blight.

If not properly treated, necrotic ring spot disease often becomes severe enough to warrant expensive renovation of the turfstand. Necrotic ring spot can be managed with fungicides. Studies performed in Washington showed significant disease management with one spring (April or May) application of fenarimol (1.59 or 3.18 Kg a.i. ha^{-1}), propiconazole (3.18 Kg a.i. ha^{-1}), thiophanate-methyl (6.36 Kg a.i. ha), and diniconazole (3.18 Kg a.i. ha^{-1}), although yearly applications are required because of recurring outbreaks (Chastagner *et al.*, 1988). Only marginal control was reported with benomyl and triadimefon. Disease management is an integral part of turfgrass cultivation programs, although the reliance on antifungal chemicals often overshadows cultural methods for disease management. Repeated application of chemicals will not provide long-term disease control solutions and may result in a reliance on this form of control which may effect non-target plants and

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organisms (Smiley and Craven, 1977, 1978, 1979). Fungicides have been associated with inducing pathogen resistance, microbe population shifts, thatch accumulation, reduced earthworm activity, lower soil NO^{-}_{3} N, and lower pH (Smiley and Craven-Fowler, 1979; Halisky *et al.*, 1980; Randell *et al.*, 1972; King and Dale, 1977; Wainwright and Pugh, 1974). Fungicides are selected for use against phyto-pathogenic fungi but their activity also effects other micro-organisms (McCallan and Miller, 1958) such as pathogen antagonists, causing an increase in pathogen activity (Farley and Lockwood, 1969). A general trend in agriculture research is to develop natural and safe methods of disease control.

Addition of organic amendments may provide an alternative to synthetic chemicals for management of necrotic ring spot. Organic amendments have been shown to increase soil productivity (Huber and Watson, 1974), which has been associated with reduced disease severity in other systems (Garrett, 1948). And since nitrogen form has been linked to other plant diseases (Huber and Watson, 1974) the form used to maintain turfgrasses may also have an effect on plant disease. In addition, although high levels of nitrogen were associated with an increase in *Fusarium* blight, Couch (1976) stated the level of this element required for significant disease management is outside the range necessary to meet the basic nutritional requirements of the plant. Although nitrogen has been associated with predisposing turfgrass to necrotic ring spot disease de

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development, the addition of organic or controlled release nitrogen may have a different effect. In addition, the exact effects of nitrogen and major nutrients on necrotic ring spot remains unclear. Some researchers have noted that nitrogen may not adversely effect disease development. In greenhouse studies performed by Cole (1976) no significant nitrogen fertilizer effects were indicated with regard to expression of *Fusarium* blight. Bean (1966) was also unable to correlate disease severity with high nitrogen levels. High nitrogen levels early in the season has been shown to increase the severity of *Fusarium* blight of several turfgrass cultivars, although not all cultivars demonstrated increased disease development, 'Kenblue' Kentucky bluegrass (*Poa pratensis* L.) was severely affected regardless of fertility level (Turgeon and Meyer, 1974). Cole (1976) suggests that confusion involving nitrogen fertility in bluegrasses may be the recycling of nitrogen through organic matter decay, and reducing nitrogen in a single year will not offset several preceding years of high nitrogen application. Conversely, research with wheat root rot indicate that nitrogen fertilizer stimulated plant growth resulting in increased water extraction which greatly increased water stress both within the plant and soil. The increased water stress favored invasion and colonization of the crown and root areas of the plant as well as reducing soil bacterial antagonism against the *Fusarium* fungus (Cook *et al.*, 1968). This suggests that nitrogen fertilizers may

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predispose *Poa spp.* to necrotic ring spot development by increasing moisture stress rather than by stimulating the pathogen. Increased nitrogen loss due to leaching and denitrification has also been attributed to reduced host resistance and increased take-all infection of wheat (Cook *et al.*, 1968; Garrett, 1948; Huber *et al.*, 1968). Conflicting reports on the effect of nitrogen level on *Fusarium* blight disease outbreaks, later identified as summer patch and necrotic ring spot, may be the result of earlier confusion regarding the causal agents.

Dissimilar findings by numerous researchers concerning the effect of nitrogen *on Fusarium* blight, and later with necrotic ring spot, has perplexed cultural disease management strategists. These findings suggest that nitrogen fertilizer affects disease incidence, albeit exactly how remains in question.

Several bio-organic amendments are available for use by homeowners and professional turf managers although only sparse information exists on the influence of these amendments regarding turfgrass diseases. Disease suppression through application of organic amendments has been documented in other systems (Garrett, 1948) however, little information exists on the effects of organic amendments on turfgrass diseases.

In this study various bio-organic and slow-release fertilizers in addition to the major nutrients (NPK) were examined for management of necrotic ring spot.

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MATERIALS AND METHODS

Bio-organic fertility products containing viable microorganisms were provided by Ringer Corporation (Minneapolis, MN.), and Sustane Corporation (Cannon Falls, MN.), and are labeled Lawn Restore and Sustane, respectively. Lawn Restore is 49% carbon, has a fertilizer analysis of 9-4-4 and consists of various organic and inorganic constituents including feather meal, corn meal, soybean meal and bone meal. Yeast (*Torula spp.*) is the predominant N source. For comparison, Ringer Corporation also provided an amendment identical to Lawn Restore, but produced without the addition of micro-organisms, labeled OC-1. Sustane is aerobically composted turkey manure with a fertility analysis of 5-2-4 and contains 3.5% insoluble nitrogen, ammoniacal nitrogen 1.5%, phosphoric acid (P_2O_5) 2.0%, soluble potash (K_2O) 4.0%, calcium (Ca) 3.7%, iron (Fe) 2.3%, sulfur (S) 2.0%, Magnesium (Mg) 0.8%, manganese (Mn) 0.06%, zinc (Zn) 0.05%, chromium (Cr) 16 ppm, lead (Pb) 12 ppm, nickel (Ni) 22 ppm, cadmium (Cd) 1 ppm. Organic matter analysis conducted by Woods End Laboratory revealed a CEC of 104.4 cmol kg^{-1}. Components analyzed by cation displacement reveal organic matter was responsible for 44.6%, humic acid content 10.8%, and humic acid (as percent of organic matter) 24.2%. Because Lawn Restore and Sustane contain organic slow-release nitrogen a synthetic slow-release nitrogen source was also examined. The synthetic fertilizer IBDU (isobutylidene diurea), with addition of phosphorus and potassium, was provided by Vigoro Industries (Winter Haven, FL.). This product has an analysis of 18-3-24, and has a nutrient analysis of ammoniacal nitrogen 1.2%, nitrate nitrogen 6.8%, water soluble urea nitrogen 1.9%, water insoluble isobutylidene nitrogen 8.1%, phosphoric acid (P_2O_5) 3%, potassium as soluble potash (K_2O) 24.0%. Mineral analysis reveals iron (Fe) 1.0%, magnesium (Mg) 1.0%, and a salt index of 4.54 Mg^{-1}. Nitrogen in IBDU depends upon hydrolysis for release.

Field trials were performed at Country Place Condominiums, Northville, MI. from 1988 to 1990, and Yankee Springs Country Club, Yankee Springs, MI. in 1990. Analysis of soil from each test site is presented in Table 1. The Northville site consisted of Kentucky bluegrass muck sod maintained as lawn which was mowed to 6.0 cm once per week and irrigated for 15 minutes 4 nights per week. The Yankee Springs site was seeded in August 1985 with equal parts Baron, Benson and Merit Kentucky bluegrass (*Poa pratensis* L.), and Pennlawn fine fescue (*Festuca rubra* L.). The turf was maintained at 2.9 cm. Test plots at both sites measured 1.8 x 2.7 m and were arranged in a randomized complete block design with 3 replications. The following amendments were tested at both sites; Biogroundskeeper, Sustane, Turf Restore, OC-1, IBDU, and Aqua-Gro. Urea, superphosphate, and soluble potash were applied in combination or individually, and for comparison, at the same ratio as Lawn Restore (9-4-

4). Treatments containing nitrogen were applied at 48.8 Kg actual N ha^{-1}, Aqua-Gro was applied at the manufactures recommended rate of 25.5 L ha^{-1}. Granular treatments were preweighed and applied by hand, liquid amendments were applied as drenches with 7.5 L water. Applications were performed on a monthly basis beginning in May and ending in October (6 applications). Disease incidence was estimated visually at the height of activity in the fall of each year. Ratings consisted of counting the number of rings present in each plot. Data were subjected to analysis of variance and LSD analysis was used to separate treatment means.

RESULTS

Northville, Glen Haven Condominiums, 1988. Statistical analysis (P=0.05) indicates monthly applications of nitrogen had a dramatic effect on disease development. All treatments containing nitrogen had significantly less disease than non-nitrogen treatments (Table 2). Treatments containing slow-release nitrogen performed very well (10% or less area diseased) and were significantly different than the 9-4-4 fertilizer (urea nitrogen) treatment, indicating slow-release nitrogen may be more effective in reducing necrotic ring spot outbreak.

Northville, Country Place Condominiums, 1989. Statistical analysis indicates all treatments had significantly less disease than the untreated control, however many treatments did not provide an acceptable level of disease management

(Table 3). Nitrogen application had a dramatic effect on disease severity in this trial, as all nitrogen treatments had significantly less disease than non-nitrogen treatments. In addition, urea, when combined with phosphorus or potassium, or both, had significantly less disease than areas treated with urea alone.

Northville, Country Place Condominiums, 1990. Data obtained from this site in 1990 were variable due to uneven symptom development within blocks, however, the bio-organic amendments, Lawn Restore and Sustane when used alone, again provided an acceptable level of disease management (less than 5% area diseased) and had significantly less disease than urea alone (Table 4).

Yankee Springs, Yankee Springs C.C., 1990. At this site all treatments had significantly less disease than untreated plots, which averaged 66.7% area diseased (Table 5). Sustane, and the slow-release fertilizer IBDU provided excellent disease management and were significantly different than urea when used alone (P=0.05).

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DISCUSSION

These findings indicate necrotic ring spot responds differently to the form of nitrogen applied. Areas treated with the bio-organic amendments Lawn Restore and Sustane, had significantly less disease than urea alone in the 3 test sites in which they were compared (Tables 3-5). These bio-organic fertility treatments also had significantly less disease than untreated plots at all test sites (Tables 2-5). Even though urea nitrogen alone did not provide the degree of disease suppression as the bio-organic amendments, this treatment did not cause an increase in severity, and actually reduced disease incidence in 2 of 3 field experiments. This contrasts earlier indications that nitrogen increases disease severity (Couch, 1976; Smiley, 1977; Turgeon, 1976; Vargas, 1981). In addition, when nitrogen was combined with potassium and phosphorus, disease expression was significantly suppressed in all field trials (Tables 2-5). In contrast to studies performed by Turgeon (1976), which indicated nitrogen levels of 288 KgN ha^{-1} to 389 KgN ha^{-1} yr^{-1} promoted severe disease incidence, our studies have shown that 288 KgN ha^{-1} yr^{-1} as organic nitrogen, or urea combined with phosphorus and potassium, when applied at monthly intervals at a rate of 48.8 KgN ha^{-1}, reduced symptom expression. Since high nitrogen levels early in the season have been shown to increase the severity of *Fusarium* blight (Turgeon and Meyer, 1974) avoiding excessive single applications of nitrogen may have a differe

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different effect on disease expression. Regular application of nitrogen when combined with phosphorus and potassium, and bio-organic amendments significantly suppressed disease expression in all trials. Adequate fertility balance was found to reduce disease expression and promote recuperation of diseased areas, which agrees with recommendations of Smiley (1983). Disease management through application of bio-organic amendments and fertilizer containing the major nutrients (NPK) may be the result of increased plant vigor. Garret (1956) referred to the phenomenon that plants grown in well fertilized soil experience less damage from diseases as the "disease escape mechanism".

Table 1. Soil tests* of Kentucky bluegrass (*Poa pratensis* L.) field trials.

	Northville	Yankee Springs
Sand %	34.4	74.6
Silt %	28.5	16.7
Clay %	37.1	8.7
Soil pH	8.0	7.1
Phosphorus (Kg ha^{-1})	13	72
Potassium (Kg ha^{-1})	405	259
Calcium (Kg ha^{-1})	11648	1792
Magnesium (Kg ha^{-1})	717	511
cec (cmol kg^{-1})	29	6

Analyzed at the Michigan State University Soil Testing Lab.

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Table 2. Necrotic ring spot severity on Kentucky bluegrass in field plots (Glen Haven Condominiums, Northville, MI.) treated with bio-organic and slow-release fertility treatments. Percent area diseased, 18 November 1988.

TREATMENT	RATE/ha	ave % area diseased	
OC-1	48.8 KgN	4.3	a*
Lawn Restore	48.8 KgN	6.7	a
Sustane	48.8 KgN	10.0	a
NPK (9-4-4)	48.8 KgN	23.3	b
Control		40.0	c

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significant difference test.

Treatments were applied monthly from May through October (6 applications).

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Table 3. Necrotic ring spot severity on Kentucky bluegrass in field plots (Country Place Condominiums, Northville, MI.) treated with bio-organic and slow-release fertility treatments. Disease rating, 18 November 1989.

TREATMENT	RATE/ha	ave % area diseased	
OC-1	48.8 KgN	3.3	a*
Lawn Restore	48.8 KgN	10.0	ab
IBDU	48.8 KgN	10.0	ab
N-P	48.8 KgN, 21.6 KgP	10.0	ab
Sustane	48.8 KgN	11.7	ab
NPK (9-4-4)	48.8 KgN	11.7	ab
Sustane + Aqua-Gro	48.8 KgN, 25.5 L	13.3	b
N-K	48.8 KgN, 21.6 KgK	13.3	b
Urea	48.8 KgN	23.3	c
P-K	21.6 Kg ea.	35.0	d
Aqua-Gro	25.5 L	41.7	de
Potassium	21.6 KgK	48.3	ef
Phosphorus	21.6 KgP	51.7	f
Control		61.7	g

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significant difference test.

Treatments were applied monthly from May through October (6 applications).

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Table 4. Necrotic ring spot severity on Kentucky bluegrass in field plots (Country Place Condominiums, Northville, MI.) treated with bio-organic and slow-release fertility treatments. Disease rating, 30 November 1990.

Treatment	Rate/ha	# of rings	ring size, 0-3	3-6	6-9"	ave % area diseased
Sustane	48.8 KgN	3	3	0	0	3.3 a*
Lawn Restore	48.8 KgN	2	2	0	0	3.3 a
NPK (9-4-4)	48.8 KgN	3	2	1	0	4.7 ab
Sustane + Aqua-Gro	48.8 KgN, 25.5 L	4	2	2	0	6.7 abc
Potassium	21.6 KgK	6	4	2	0	8.3 abc
N + P (9-4-0)	48.8 KgN	6	2	4	0	10.0 abc
P + K (0-4-4)	21.6 Kg ea	7	4	2	1	11.7 abc
IBDU	48.8 KgN	8	3	5	0	12.7 abc
Aqua-Gro	25.5 L	10	6	3	1	13.3 abc
N + K (9-0-4)	48.8 KgN	8	2	5	1	13.3 abc
Phosphorus	21.6 KgP	9	4	2	3	14.3 abc
Urea	48.8 KgN	10	3	3	4	20.0 bc
Control		13	7	6	0	21.7 c

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significance difference test.

Treatments were applied monthly from May through October (6 applications).

Table 5. Necrotic ring spot severity on Kentucky bluegrass in field plots (Yankee Springs C.C., Yankee Springs MI.) treated with bio-organic and slow-release fertility treatments. Disease rating, 2 November 1990.

Treatment	Rate/ha	# of rings	ring size, 0-3	3-6	6-9"	ave % area diseased
Sustane	48.8 KgN	2	0	0	2	2.7 a*
IBDU	48.8 KgN	7	0	0	7	8.3 a
Lawn Restore	48.8 KgN	4	0	0	4	11.7 ab
N + K (9-0-4)	48.8 KgN	9	2	3	4	11.7 ab
N + P (9-4-0)	48.8 KgN	7	0	1	6	15.3 ab
NPK (9-4-4)	48.8 KgN	7	1	1	5	16.0 abc
P + K (0-4-4)	21.6 Kg ea	13	3	6	4	21.7 abc
Urea	48.8 KgN	20	2	8	10	31.0 bc
Phosphorus	21.6 kgP	19	5	5	9	33.3 bc
Potassium	21.6 KgK	15	4	7	4	38.3 c
Control		41	11	12	18	66.7 d

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significance difference test.

Treatments were applied monthly from May through October (6 applications).

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CHAPTER VI

EFFECT OF BIO-ORGANIC AMENDMENTS AND SLOW-RELEASE FERTILIZER ON SUMMER PATCH OF ANNUAL BLUEGRASS

Abstract.

Summer patch disease, incited by the root and crown infecting fungus *Magnaporthe poae*, causes severe turf loss on intensively maintained annual bluegrass turfstands even when fungicide programs are implemented for management of diseases such as anthracnose (*Colletotrichum graminicola*), dollar spot (*Moelerodiscus and Lanzia spp.*) and brown patch (*Rhizoctonia solani* Kuhn). Summer patch often occurs in the same area year after year and requires its own chemical management program. Several bio-organic amendments and slow-release fertilizer treatment were examined for potential disease management on golf course fairways under conditions of normal use and maintenance. When applied monthly at 24.4 KgN ha^{-1} plots treated with bone-meal/corn-meal/soybean-meal containing microorganisms (Turf Restore) significantly reduced symptom expression (less than 20% area diseased) in 3 of 4 field trials and were not different from plots treated with fenarimol in all trials (P=0.05). Integrated management with Turf Restore and fenarimol also significantly reduced disease severity in 3 of 4 trials (P=0.05). Since disease severity was significantly reduced by urea nitrogen alone in 2 of 4 field trials and not

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significantly different in the other 2, this contrasts previous reports which indicate that nitrogen fertilizer increases disease severity. The bio-organic amendments Lawn Restore and Sustane (composted turkey manure) demonstrated significantly better disease management than urea alone in 2 trials (P=0.05), indicating that the form of nitrogen may also have an effect on disease incidence. In all trials, plots treated with Sustane combined with a wetting agent provided an acceptable level of disease management and were not significantly different from plots treated treated with fenarimol.

INTRODUCTION

Annual bluegrass (*Poa annua*) is a major component of golf course greens, tees, and fairways in the cool season growing region of North America. Summer patch disease, caused by the root and crown infecting fungus *Magnaporthe poae* (Landschoot and Jackson, 1990) causes severe turf loss on intensively maintained annual bluegrass turfstands even when fungicide programs are implemented for management of diseases such as anthracnose (*Colletotrichum graminicola*), dollar spot (*Moelerodiscus and Lanzia spp.*) and brown patch (*Rhizoctonia solani* Kuhn). Summer patch often occurs in the same area year after year and requires its own chemical management program. *Magnaporthe poae* produces darkly pigmented runner hyphae which affect roots, stolons and rhizomes in small patches. As infection proceeds, cortical tissues dry and turn black with rot and virulent stains colonize the stele, resulting in vascular system dysfunction (Smiley *et al.*, 1985a). Summer patch symptoms begin as chlorosis or yellowing of turf patches that range from 15 cm to 1 m in diameter (Smiley, 1984a). Patches may be ring-shaped or occur in diffuse patterns which are easily confused with other disorders of *Poa annua* such as heat stress, insect damage or other diseases (Landschoot *et al.*, 1989). At times, large patches become visible with no previous indication of disease activity, and in severe cases, patches will coalesce and destroy large areas of turf

(Landschoot *et al.*, 1989). Like necrotic ring spot, areas affected with summer patch become necrotic and are often invaded by weeds or less desirable grasses (Smiley *et al.*, 1985a). Affected plants may remain asymptomatic until increased stress, after which visible symptoms become apparent (Smiley *et al.*, 1985b). Infection by *M. poae* causes root dysfunction resulting in extensive damage to the root system which reduces water absorption and nutrient uptake (Smiley, 1984a). *M. Poae* grows and spreads in soil and thatch, and apparently infects host tissues several months in advance of symptom development (Smiley, 1984b). Because the fungus is present in host tissues months in advance of symptom expression when temperatures exceed 29 C, *M. poae* is able to rapidly invade cortical and vascular cells of the host resulting in necrosis (Landschoot and Jackson, 1990). Landschoot *et al.*, (1989) noted that *M. poae* grows best in temperatures from 25 to 35 C and summer patch symptoms peaked after heavy rains. Optimal growth for *M. poae* occurs at 30 C (8-9 mm per day), which coincides with field reports of increased symptom development when summer temperatures exceed 29 C (Kackley *et al.*, 1990). Smiley and Giblin (1986) found that autolysis of nuclei in root cortex cells (root cortical death) of *Poa pratensis* Merion occurred faster at 29 C and was inversely correlated (P=0.05) with percentages of root area colonized with *Phialophora graminicola*, which was later identified as *M. poae* (Landschoot, 1988).

The moisture status of the soil has also been associated with incidence, severity, and timing of symptom expression. Both moisture deficiency and excesses have been linked to disease development (Sanders and Cole, 1981; Smiley, 1980). Vargas (1981) stated that factors which contribute to drought stress such as compacted soil and excessive nitrogen, will predispose plants to infection. Although Kackley *et al.*, (1990) found no significant difference in disease severity between drought stressed and non-stressed Kentucky bluegrass (*Poa pratensis*) turf maintained at 6.0-7.0 cm, disease development in *Poa annua* may differ. *Poa annua*, as maintained under golf course fairway playing conditions is often mowed at 1.3 cm or less, which is more prone to heat and moisture stress. Plants infected with *M. poae* are more susceptible to wilt because of vascular dysfunction, and may be quickly overcome during periods of moisture stress (Smiley *et al.*, 1985a). Summer patch symptoms have also been associated with heavy rainfall or waterlogged soil (Landschoot *et al.*, 1989; Worf *et al.*, 1986). Apparently moisture stress, either as excess or deficiencies, contribute to disease development. Smiley (1984a) noted symptoms of summer patch and necrotic ring spot occur only when root regeneration rates cannot exceed pathogen infection rates. Apparently, rapid fungus infection coupled with reduced plant vigor and resistance during periods of temperature and moisture stress promote disease severity.

Fertility practices have also been linked to increased disease. High nitrogen fertilization has been associated with increased susceptibility of turfgrasses to *Fusarium* blight (Couch, 1976; Smiley, 1977; Turgeon, 1976; Vargas, 1981). Turgeon (1976) reported that nitrogen levels of 6 to 8 pounds per 1,000 square feet per year resulted in severe incidence of *Fusarium* blight. Timing of nitrogen application may also effect disease incidence. Turgeon and Meyer (1974) associated high nitrogen levels early in the season to increase the severity of *Fusarium* blight.

Because of the recurring nature of summer patch and the degree of damage inflicted, this disease is often the target of fungicide programs. Current preventative management strategies for summer patch consists of Rubigan (fenarimol), Banner (propiconazole), or Bayleton (triadimefon) application at 6.37 L ha^{-1} when soil temperatures reach 18.3 C at a depth of 5.0 cm and another application 30 days later (Melvin *et al.*, 1988). Curatively, the benzimidazole fungicides, Tersan 1991 (benomyl) and Fungo 50 (thiophanate-methyl) applied at 19.1 L ha^{-1}, halts disease progress although renewed disease activity was reported less than one month after application (Vargas *et al.*, 1988). Repeated application is necessary as long as conditions conducive to disease development persist. Failure of curative fungicide treatments to provide long term disease management may be the result of poor fungicide uptake by the root system which has already been severely damaged by earlier infection

(Landschoot *et al.*, 1989). Repeated application of chemicals often may not provide long-term disease control solutions and may result in a reliance on this form of control which may affect non-target plants and organisms (Smiley and Craven, 1977, 1978, 1979). Disease management is an integral part of intensively maintained turfgrass cultivation programs, however extensive use of disease-preventative fungicides for target pests may result in long term changes in the turf system. Fungicides have been associated with inducing pathogen resistance, microbe population shifts, thatch accumulation, reduced earthworm activity, lower soil NO_3 N, and lower pH (Alexander, 1969; Smiley *et al.*, 1985b; Halisky *et al.*, 1980; Randell *et al.*, 1972; King and Dale, 1977; Wainwright and Pugh, 1974). Fungicides are selected for use against phyto-pathogenic fungi but their activity also affects other micro-organisms (McCallan and Miller, 1958). In addition, fungicides may effect organisms antagonistic to the pathogen, causing an increase in pathogen activity (Farley and Lockwood, 1969). Recurrent disease outbreaks in turfgrass due to facultative fungal parasites may be the result of the suppression of competitive and antagonistic microflora due to long term fungicide use.

Plant disease management should begin with sound cultural practices so as to alleviate stress placed upon the host by the environment as well as maintenance practices. However, the reliance on antifungal chemicals probably overshadows cultural methods for disease management. Although synthetic fungicides offer optimum disease control and are easier to use than biocontrol or cultural methods, their use is becoming more controversial and in many areas of the world certain or all fungicides are restricted (Jones, 1985; Rytter *et al.*, 1989). And, although more dollars are spent on fungicides for turf than on any other single crop in the United States (Vargas, 1981), there has been only limited research for development of alternative control methods. A general trend in agriculture research is to develop natural and safe methods of disease control.

Certain fertilization practices may ensure increased plant vigor so as to offset tissues lost by fungal invasion. Addition of bio-organic fertility amendments may provide an alternative to synthetic chemicals for management of necrotic ring spot. Organic amendments may increase soil productivity (Huber and Watson, 1974), which has been associated with reduced disease severity in other systems (Garrett, 1948). Since nitrogen form has been linked to other plant diseases (Huber and Watson, 1974) the form used to maintain turfgrasses may also have an effect on summer patch disease. Although nitrogen has been associated with predisposing turfgrass to summer patch disease development, the addition of organic or controlled release nitrogen may have a different effect. In addition, the exact effects of nitrogen and major nutrients on summer patch remains unclear. Some researchers have noted that nitrogen may not adversely effect *Fusarium* blight disease development. In greenhouse studies performed by Cole (1976) no significant nitrogen fertilizer effects were indicated with regard to expression of *Fusarium* blight. Bean (1966) was also unable to correlate disease severity with high nitrogen levels. Dissimilar findings by numerous researchers concerning the effect of nitrogen on *Fusarium* blight, now known as summer patch and necrotic ring spot, has perplexed cultural disease management strategists. Conversely, a balanced fertility program may increase plant vigor through added nutrition, thereby reducing disease severity. Several bio-organic amendments are available for use by homeowners and professional turf managers which may be effective in reducing disease outbreak. Disease suppression through application of organic amendments has documented in other systems (Garrett, 1948) however, only sparse information exists on the influence of these amendments regarding turfgrass diseases.

This study was designed to test the efficiency of various organic and synthetic nitrogen sources for preventative management of summer patch of intensively maintained annual bluegrass under normal traffic and maintenance. Several bio-organic amendments and slow-release fertilizer, in addition to a wetting agent which may promote water infiltration, were investigated. Since reduced plant vigor has been associated with summer patch outbreaks, the individual and combined effects of urea (NH_4-H), superphosphate (P_2O_5), and potash (K_2O) were also investigated.

MATERIALS AND METHODS

Bio-organic fertility products containing viable microorganisms were provided by Ringer Corporation (Minneapolis, MN.), and Sustane Corporation (Cannon Falls, MN.), and are labeled Turf Restore and Sustane, respectively. Turf Restore is 49% carbon, has a fertilizer analysis of 9-4-4 and consists of various organic and inorganic constituents including feather meal, corn meal, soybean meal and bone meal. Yeast (*Torula spp.*) is the predominant N source. For comparison, Ringer Corporation also provided an amendment identical to Turf Restore, but produced without the addition of micro-organisms, labeled OC-1. Sustane is aerobically composted turkey manure with a fertilizer analysis of 5-2-4 and contains 3.5% insoluble nitrogen, ammoniacal nitrogen 1.5%, phosphoric acid (P_2O_5) 2.0%, soluble potash (K_2O) 4.0%, calcium (Ca) 3.7%, iron (Fe) 2.3%, sulfur (S) 2.0%, Magnesium (Mg) 0.8%, manganese (Mn) 0.06%, zinc (Zn) 0.05%, chromium (Cr) 16 ppm, lead (Pb) 12 ppm, nickel (Ni) 22 ppm, cadmium (Cd) 1 ppm. Organic matter analysis conducted by Woods End Laboratory revealed a CEC of 104.4 cmol kg^{-1}. Components analyzed by cation displacement reveal organic matter was responsive for 44.6%, humic acid content 10.8%, and humic acid (as percent of organic matter) 24.2%. Because Turf Restore and Sustane contain organic slow-release nitrogen a synthetic slow-release nitrogen source was also examined. The synthetic fertilizer IBDU (isobutylidene diurea), with addition of phosphorus and potassium, was provided by Vigoro Industries (Winter Haven, FL.). This product has a fertilizer analysis of 18-3-24, and has a nutrient analysis of ammoniacal nitrogen 1.2%, nitrate nitrogen 6.8%, water soluble urea nitrogen 1.9%, water insoluble isobutylidene diurea 8.1%, phosphoric acid (P_2O_5) 3%, potassium as soluble potash (K_2O) 24.0%. Mineral analysis reveals iron (Fe) 1.0%, magnesium (Mg) 1.0%, and a salt index of 4.35 Mg^{-1}. Nitrogen in IBDU depends upon hydrolysis for release. All testing was performed on intensively maintained annual bluegrass fairways with a history of turf loss due to summer patch. Plots were established at Dearborn (Dearborn Country Club, 1989-90), Grand Rapids (Grand Rapids Elks Golf Course, 1989), and Washtenaw (Washtenaw Country Club, 1989), MI. Results of soil analysis are presented in Table 1.

The following amendments were tested; Sustane, Turf Restore, O.C.-1, and IBDU. O.C.-1 is composed of the same ingredients as Turf Restore except it was produced without the addition of microorganisms. Urea, superphosphate, and potash were applied at the same ratios as the commercially available corn-/soybean-meal organic fertilizer Turf Restore. For comparison with fungicide treatment, fenarimol was also included. Integrated disease management with fenarimol and monthly applications of Turf Restore and IBDU were also investigated.

Treatment application began in May of each year with subsequent applications performed on a monthly basis through September (5 applications). Granular treatments were preweighed and applied by hand. Fenarimol was applied with a CO_2 small-plot sprayer at 30 psi at the recommended rate (0.74 Kg a.i. ha^{-1}) and timing (when soil temperatures at 5 cm reached 18 C) (Melvin *et al.*, 1988). Nitrogen carrying amendments were applied at 24.4 Kg ha^{-1}. Adequate nutrition was maintained in fenarimol treated plots by monthly applications of urea, phosphorus, and potassium at a ratio of 10-3-4 (24.4 KgN ha^{-1}), the same ratio as Turf Restore. All trials were maintained at 1.3 cm and irrigated with an overhead sprinkler. Experimental design was a randomized complete-block with 3 replications; treatments within blocks consisted of plots measuring 1.8 x 2.7 m. Plots were monitored for disease development and at the height of symptom expression ratings were taken. The percentage of area diseased was estimated by visual observation. Data were subjected to analysis of variance, and treatment means were separated using LSD analysis. The causal agent, *M. poae*, was isolated from patches at each test site and identified according to colony morphology and growth rate.

RESULTS

Soil tests revealed adequate levels of phosphorus, potassium, calcium, and magnesium in all trials except at

Dearborn which was phosphorus deficient, 40 Kg ha^{-1} (Table 1). Disease severity varied with location, but always peaked in late August or early September when temperatures were somewhat elevated (Tables 2-5). Disease pressure in untreated control plots was light at Washtenaw in 1989 (Table 2) and Dearborn in 1990 (Table 5), and very pronounced at Dearborn and Grand Rapids in 1989 (Table 3). The disease complex, summer patch/anthracnose (*Colletotrichum graminicola*), was present at Grand Rapids and resulted in severe damage to untreated areas during the 1989 season (Table 4).

Washtenaw Country Club, 1989. Although disease pressure was light at the Washtenaw test site, there was obvious turf loss due to summer patch (Table 2). Only organic or slow-release fertility treatments (Sustane, O.C.-1, Turf Restore and IBDU), when used alone or combined with fenarimol or Aqua-Gro, resulted in significantly less disease than untreated areas (P=0.05). All organic and slow-release fertility treatments averaged less than 5% total area diseased and were not significantly different than the fenarimol + NPK treatment (Table 2). In addition, these amendments had significantly less disease than the 3 of 4 treatments containing fast-release urea nitrogen when not used with fenarimol.

Dearborn Country Club. 1989. Disease pressure at Dearborn in 1989 was extremely heavy, as indicated by over 50% of the untreated plots with visible symptom development (Table 3).

Under advanced disease pressure organic and slow-release fertilizers (with the exception of Sustane without Aqua-Gro), reduced symptoms expression by over 50%, as compared to the untreated control, and were also not significantly different than the fenarimol + NPK treatment. Sustane and Aqua-Gro, although not providing significant control when used alone, again provided an acceptable level of summer patch disease management when used in combination (70% less area diseased than the untreated control, Table 3).

Since no differences were indicated between organic or slow-release fertility treatments and urea in this study, application of nitrogen alone may alleviate symptom expression under conditions of heavy disease pressure. All but 2 nitrogen containing treatments had significantly less symptom development than the untreated control, which suggests increase nutrition and plant vigor may play an important role in reducing symptom development in areas experiencing heavy disease pressure (Table 3).

Grand Rapids Elks G.C. 1989. At Grand Rapids all plants examined positive for *M. Poae* were also found to be infected with anthracnose (*Colletotrichum graminicola*). The combination of both diseases resulted in severe turf loss throughout most of the study area (Table 4). Untreated areas averaged over 50% area diseased and were severely damaged by this disease complex. Even with both diseases active, several treatments reduced symptom development to less than half of the untreated control. The organic fertility treatments, Turf Restore with or without fenarimol, OC-1, and the combination of Sustane + Aqua-Gro provided significant disease reduction as compared to the untreated control and were not significantly different from the fenarimol + NPK treatment (Table 4). Observable trends between slow-release and fast-release nitrogen treatments were not apparent in this study, however, this may be attributed to the presence of both summer patch and anthracnose occurring simultaneously, which spread quickly. **Dearborn C.C. 1990.** When compared to disease pressure during 1989 at this site (Table 3), pressure was only moderate in 1990, which was probably due to only short periods of hot weather, rather than extended heat (Table 5). Although signs of summer patch were visible for several weeks at time, the turf was able to recover between periods of extended heat before severe turf loss incurred. Under moderate disease pressure, Sustane + Aqua-Gro, and fenarimol combined with either Turf Restore or IBDU, provided a significant degree of disease management and had less than 20% area diseased, less than half that of untreated areas (Table 5).

DISCUSSION

When applied preventively, several organic and slow-release fertility treatments demonstrated effective summer patch management. Areas treated with Turf Restore were less than 20% diseased and were not significantly different than plots treated with fenarimol in 3 of 4 trials.

Where summer patch-anthracnose pressure was heavy (Grand Rapids), areas treated with Sustane + Aqua-Gro and Turf Restore showed effective disease management. In all trials plots treated with Sustane combined with Aqua-Gro provided an acceptable level of disease management and were not significantly different from plots treated with fenarimol. It is speculated that enhanced performance of Sustane when used with the wetting agent could be due to more efficient water infiltration thus providing more efficient use of nutrients by the plant. Thatch is inherently hydrophobic and impedes water infiltration which may inhibit nitrogen release from the organic granules.

Findings presented in this paper indicate reduction of summer patch symptom development with monthly application of organic fertility treatments at 24.4 KgN ha^{-1}. Since application of urea nitrogen gave variable results, the form of nitrogen appears to effect summer patch symptom development. The form of nitrogen was also found to be significant in tests concerning take-all of wheat (Huber and Watson, 1974; Smiley, 1974; Taylor *et al.*, 1983). Organic amendments have been shown to increase soil fertility (Garrett, 1956) and microbial activity (Martyniuk and Wagner, 1977) which may increase plant vigor and increase pathogen competition thus countering tissue lost to root rot. Smiley (1983) also suggested that adequate fertility balance is necessary for recuperation of diseased areas and that disease occurs only after root loss exceeds root regeneration. The bio-organic amendments Lawn Restore and Sustane demonstrated significantly better disease management than urea alone in two trials. Slow-release nitrogen as IBDU also significantly reduced disease in 2 of 4 trails, as compared to untreated areas.

Since disease severity was significantly reduced by urea nitrogen alone at 2 of 4 test sites and not significantly different in the other 2, this contrasts earlier indications that nitrogen increases disease severity (Couch, 1976; Smiley, 1977; Turgeon, 1976; Vargas, 1981). Since high nitrogen levels early in the season have been shown to increase the severity of *Fusarium* blight (Turgeon and Meyer, 1974), avoiding excessive single applications of nitrogen may have a different effect on disease activity. These studies have shown that 144 KgN ha^{-1} yr^{-1} of the organic fertility treatment Turf Restore reduced symptom expression when applied at 24.4 kgN ha^{-1} monthly in 3 of 4 field trials. Results of tests involving take-all of wheat, incited by *Gauemannomyces graminis* (which is very similar to *M. poae*), also indicate nitrogen application may maintain yields under severe infection but has little effect on mild infections (Shipton, 1972).

Selected amendments were also shown to be compatible and provide effective disease management when combined with the fungicide fenarimol. Integrated management with the bio-organic fertilizer Turf Restore and fenarimol proved to be effective. Areas treated with this combination provided optimum disease management without signs of toxicity.

These findings indicate that bio-organic and slow-release fertilizers could be considered as an alternative to, or enhance, fungicide management for suppression of summer patch of annual bluegrass.

Table 1. Soil tests* of annual bluegrass (*Poa annua*) field trials.

	Dearborn	Grand Rapids	Washtenaw
SAND %	53.8	59.8	73.8
SILT %	26.7	28.7	15.6
CLAY %	19.4	11.4	10.2
SOIL PH	7.1	7.0	6.8
PHOSPHORUS (Kg ha^{-1})	40	118	184
POTASSIUM (Kg ha^{-1})	580	188	224
CALCIUM (Kg ha^{-1})	3772	3315	2688
MAGNESIUM (Kg ha^{-1})	727	358	394
CEC (cmol kg^{-1})	12	9	8

* 10 samples taken to 5 cm. Analyzed at the Michigan State University Soil Testing Lab.

Table 2. Summer patch severity on annual bluegrass in field plots (Washtenaw Country Club, Ypsilanti, Mi.) naturally infested with *M. poae*, and treated with bio-organic and slow-release fertility treatments. Disease rating, 16 August 1989.

TREATMENT	ave percent area diseased	
Sustane + Aqua-Gro	1.0	a*
O.C.-1	1.7	a
Fenarimol + Turf Restore	1.7	a
Sustane	3.3	a
Turf Restore	4.0	a
Fenarimol + IBDU	4.3	a
IBDU	5.0	ab
Fenarimol + NPK	9.0	abc
Phosphorus	10.0	abc
Aqua-gro	11.3	abc
N-K (10-0-4)	11.7	abc
Potassium	15.7	bc
P-K (0-3-4)	16.7	c
N-P-K (10-3-4)	16.7	c
N-P (10-3-0)	18.3	c
Control	18.3	c
Urea	20.0	c

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

Treatments were applied monthly beginning in May. Treatments containing nitrogen were applied at 24.4 Kg ha^{-1}, P as superphosphate (P_2O_5) was applied at 7.32 Kg ha^{-1}, K as potash (KO_5) was applied at 10.8 Kg ha^{-1}. The wetting agent "Aqua-Gro" was applied at 25.5 L ha^{-1}. Fenarimol (0.74 Kg a.i. ha^{-1}) was applied once in May when soil temperature at 5.0 cm reached 18 C.

Table 3. Summer patch severity on annual bluegrass in field plots (Dearborn Country Club, Dearborn, Mi.) naturally infested with *M. poae*, and treated with bio-organic and slow-release fertility treatments. Disease rating, 29 August, 1989.

TREATMENT	ave percent area diseased	
Fenarimol + IBDU	11.7	a*
Sustane + Aqua-gro	15.0	a
IBDU	17.3	a
Fenarimol + NPK	18.3	ab
Fenarimol + Turf Restore	19.3	ab
Turf Restore	26.7	abc
Urea	28.3	abcd
N-K (10-0-4)	28.3	abcd
N-P-K (10-3-4)	28.3	abcd
N-P (10-3-0)	33.3	abcde
Sustane	41.7	bcde
Phosphorus	50.0	cde
Aqua-gro	51.7	de
P-K (0-3-4)	53.3	e
Control	55.0	e
Potassium	56.7	e

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

Treatments were applied monthly beginning in May. Treatments containing nitrogen were applied at 24.4 Kg ha^{-1}, P as superphosphate (P_2O_5) was applied at 7.32 Kg ha^{-1}, K as potash (KO_5) was applied at 10.8 Kg ha^{-1}. The wetting agent "Aqua-Gro" was applied at 25.5 L ha^{-1}. Fenarimol (0.74 Kg a.i. ha^{-1}) was applied once in May when soil temperature at 5.0 cm reached 18 C.

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Table 4. Summer patch/anthracnose disease severity on annual bluegrass in field plots (Grand Rapids Elks Golf Course, MI.) naturally infested with *M. poae/Colletotrichum graminicola*, and treated with bio-organic and slow-release fertility treatments. Disease rating, 15 August 1989.

TREATMENT	ave percent area diseased	
N-P (10-3-0)	11.7	a*
Sustane + Aqua-Gro	16.7	ab
Fenarimol + NPK	20.0	abc
Turf Restore	20.0	abc
Urea	20.0	abc
O.C.-1	26.7	abcd
Fenarimol + Turf Restore	26.7	abcd
Fenarimol + IBDU	31.7	abcde
P-K (0-3-4)	35.0	abcde
N-P-K (10-3-4)	41.7	abcde
Phosphorus	43.3	abcde
IBDU	46.7	bcde
N-K (10-0-4)	46.7	bcde
Potassium	50.0	cde
Sustane	50.7	cde
Control	55.0	de
Aqua-Gro	63.3	e

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

Treatments were applied monthly beginning in May. Treatments containing nitrogen were applied at 24.4 Kg ha^{-1}, P as superphosphate (P_2O_5) was applied at 7.32 Kg ha^{-1}, K as potash (KO_5) was applied at 10.8 Kg ha. The wetting agent "Aqua-Gro" was applied at 25.5 L ha^{-1}. Fenarimol (0.74 Kg a.i. ha^{-1}) was applied once in May when soil temperature at 5.0 cm reached 18 C.

Table 5. Summer patch severity on annual bluegrass in field plots (Dearborn Country Club, Dearborn, Mi.) naturally infested with *M. poae*, and treated with bio-organic and slow-release fertility treatments. Disease rating, 9 September 1990.

TREATMENT	ave percent area diseased	
Fenarimol + Turf Restore	6.7	a*
Fenarimol + IBDU	10.7	ab
Sustane	13.3	ab
Potassium	13.3	ab
Sustane + Aqua-gro	15.0	abc
N-P (10-3-0)	15.0	abc
Phosphorus	16.7	abcd
Fenarimol + NPK	18.3	abcde
Turf Restore	20.0	abcde
P-K (0-3-4)	20.0	abcde
N-P-K (10-3-4)	21.7	abcde
IBDU	26.7	bcde
N-K (10-0-4)	30.0	cde
Control	31.7	de
Urea	33.3	e
Aqua-gro	33.3	e

* Treatment means followed by the same letter are not significantly different, P=0.05, Least significant difference test.

Treatments were applied monthly beginning in May. Treatments containing nitrogen were applied at 24.4 Kg ha^{-1}, P as superphosphate (P_2O_5) was applied at 0.15 Kg ha^{-1}, K as potash (KO_5) was applied at 7.32 Kg ha^{-1}. The wetting agent "Aqua-Gro" was applied at 25.5 L ha^{-1}. Fenarimol (0.74 Kg a.i. ha^{-1}) was applied once in May when soil temperature at 5.0 cm reached 18 C.

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CHAPTER VII

EXAMINATION OF *BACILLUS PUMILUS* AND *PSEUDOMONAS AUREOFACIENS* FOR BIOLOGICAL CONTROL OF NECROTIC RING SPOT OF *POA PRATENSIS* AND SUMMER PATCH OF *POA ANNUA*

Abstract.

Reports of decline in necrotic ring spot (*Leptosphaeria korrae*) activity following several years of activity has been noted in turfstands of Kentucky bluegrass (*Poa pratensis* L.) by several researchers. Natural decline in disease activity may be due to the buildup of a disease suppressive microflora. Using the paired culture technique, approximately 300 bacteria, fungi, and Actinomycetes, which were isolated from areas recovering from necrotic ring spot disease, were screened for inhibition to *L. korrae* and *Magnaporthe poae*, the causal agents of necrotic ring spot and summer patch of *Poa spp.*, respectively. Thirty-five isolates demonstrated inhibition to one or both pathogens. Two bacteria, *Bacillus pumilus* and *Pseudomonas aureofaciens*, suppressed growth of both pathogens by 94 to 100% on agar and were chosen for testing on naturally infected turfstands. In field testing at 3 locations, the severity of disease outbreak caused by *L. korrae* of Kentucky bluegrass was significantly reduced (50 to 100%, as compared to untreated areas) with a composite treatment of *B. pumilus*

and *P. aureofaciens* when combined with a molasses-based organic carrier (P=0.05). This treatment also reduced summer patch outbreak (*M. poae*) of annual bluegrass (*P. pratensis*) in 1 of 2 field tests (P=0.05). *B. pumilus* and *P. aureofaciens* also significantly reduced necrotic ring spot outbreak in 2 of 3 trials when applied as washed cells without the molasses-based carrier (P=0.05). These findings indicate that numerous bacteria, fungi, and Actinomycetes are capable of pathogen suppression on agar and may be partly responsible for decline of necrotic ring spot. And 2 of the isolates, *B. pumilus* and *P. aureofaciens* show potential as biocontrol agents for necrotic ring spot, and summer patch management.

INTRODUCTION

Necrotic ring spot, incited by *Leptosphaeria korrae* (Smiley and Craven-Fowler, 1984) and summer patch incited by *Magnaporthe poae* (Landschoot and Jackson, 1989), are two of the most damaging diseases of *Poa spp.* in North America. If left unchecked these diseases often cause severe turf loss even on intensively managed stands. Although, instances of necrotic ring spot decline has been noted by several researchers (Smiley and Craven-Fowler, 1984; Worf and Stewart, 1985). This phenomenon may be the result of a build-up of antagonistic microorganisms, as is the case with take-all decline of *Triticum spp.* Take-all decline has been associated with build-up of fluoroescent *Pseudomonads*, spore-forming bacteria (*Bacillus spp.*), and other bacteria (Asher and Shipton, 1981; Cook and Rovira, 1975). Shipton *et al.*, (1973) suggested the spore-forming bacteria, which were present in soils experiencing take-all decline, may be partly responsible for the suppressive effect since antagonism was not lost after heating soil to 70 C but was lost after autoclaving. In other tests it was shown that antagonism may be due to a specific microflora which develops after infection, and is destroyed after heating to 70 C (Cook and Rovira, 1976). It is now accepted that both types of antagonism exists and that both are destroyed after autoclaving, indicating biological factors are involved. This suggests necrotic ring spot decline may be related to the buildup of certain microorganisms, and management may be possible through isolation and re-application of such microorganisms to diseased areas.

In this study, bacteria, Actinomycetes, and fungi were isolated from areas recovering from necrotic ring spot and screened for inhibition of *L. korrae* and *M. poae in vitro*. Based on the degree of inhibition and growth rate, two bacteria were chosen for field studies on turfstands naturally infected with either *L. korrae* or *M. poae*.

MATERIALS AND METHODS

Using the dilution-plate technique with selective agar (Wollum, 1982), microorganisms for study were isolated from soil and thatch from areas of Kentucky bluegrass recovering from necrotic ring spot disease, located at the Hancock Turfgrass Research Center, Michigan State University, East Lansing, Mi. Isolations were performed on various dates throughout the year. Separate 1 g samples of soil and thatch were diluted in 9 ml 0.85% sterile saline solution, followed by serial dilution with additional 9 ml saline aliquots until of final dilution of 10^{-4} was reached. One ml from the final dilution was added as inoculum to petri dishes containing 14 ml molten agar held at 45 C. Selective agar was used for each microbe type, with 4 replications. Nutrient agar was used for bacteria (Wollum, 1982), potato dextrose agar amended with penicillin and streptomycin (50 ug ml each) was used for fungi (Bakerspigel and Miller, 1953), and starch-caesin agar amended with penicillin, polymixyin B sulfate, cycloheximide and nystatin (1, 1, 50,

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50 ug ml, respectively) was used for Actinomycetes (Williams and Davies, 1965). Plates were incubated at 21 C in an inverted position. Representative colony types from each plate were transferred to fresh plates of the respective agar media and maintained as stock cultures for pathogen inhibition studies.

Using the paired culture technique (Roberts and Lumsden, 1990) the percentage of inhibition on the mycelial growth of *M. poae* and *L. korrae* was determined. Approximately 300 bacteria, actinomycete, and fungi isolates were screened for inhibition toward the pathogens. Each isolate was streaked down the center of a potato dextrose agar plate with an inoculation loop. After 2 days growth, one agar plug (6 mm) each of *L. korrae* and *M. poae* was aseptically transferred to either side of the streak at a distance of 25 mm. The plates were incubated at 21 C in an inverted position, and monitored daily for zones of inhibition between the pathogens and isolates. The percentage of growth inhibition was calculated after seven days incubation and is presented in Table 1. The percentage of growth inhibition of *L. korrae* and *M. poae* was calculated with the formula, 1-(B/A) x 100, where A equaled the increase in radius of colonies of either *L. korrae* or *M. poae* on plates containing the fungi only and B equaled the decrease in colony radius of the fungi on plates paired with test organisms (Roberts and Lumsden, 1990). Isolates demonstrating inhibition to the pathogens were identified to genus according to standard staining and physiological tests as outlined in Bergey's Manual of Determinative Bacteriology. Two bacteria were selected for field testing based on their ability to inhibit the pathogens on agar and rate of growth, *Bacillus pumilus* and *Pseudomonas aureofaciens*. These isolates were identified to species according to cellular fatty acids (Microcheck, Inc., Northfield, VT.).

The chosen bacteria were examined as a composite in field trials for management of necrotic ring spot and summer patch. In 1990 curative studies were performed on Kentucky bluegrass (*Poa pratensis* L.) turfstands heavily diseased with necrotic ring spot located at Country Place Condominiums, Northville, MI., Yankee Springs Country Club, Yankee Springs, MI., and the Hancock Turfgrass Research Center, Michigan State University, East Lansing, Mi. Testing at Northville was performed on Kentucky bluegrass established from muck sod and maintained as lawn which was mowed to 6.3 cm once per week and irrigated for 15 minutes 4 nights per week. The Yankee Springs site was maintained under golf course fairway playing conditions, and was established from seed in August 1985 with equal parts 'Baron, Benson, Merit' Kentucky bluegrass (*Poa pratensis* L.), and 'Pennlawn' fine fescue (*Festuca rubra* L.). The turf was maintained at 2.8 cm. Test plots at both sites measured 1.8 x 2.7 m and were arranged in a randomized complete block design with three replications.

The turfstand at the Hancock Turfgrass Research Center was also maintained as lawn, and was established from 'Baron, Bristol, Victa' Kentucky bluegrass muck sod in 1985 and mowed to 6.1 cm twice per week. This study was performed as a 3 x 5 factorial. Disease ratings were recorded in untreated and treated plots maintained under each of 3 different irrigation regimes. Irrigation treatments consisted of 1) 0.25 cm d^{-1} supplemental irrigation, applied at noon, 2) twice weekly irrigation based on 80% of the water lost from an open evaporation pan, applied on mondays and wednesdays at night, and 3) no supplemental irrigation 'rain only'. Supplemental irrigation treatments were withheld when plots became saturated due to rainfall. Irrigation treatments were applied to randomly selected 12.2 x 12.2 m blocks with 3 replications. Treatments (all test sites) consisted of 1) *B. pumilus* and *P. aureofaciens* cultured in a molasses-based organic broth and with enough of the organic amendment to supply 48.8 KgN ha^{-1}, 2) *B. pumilus* and *P. aureofaciens* as washed cells, 3) molasses-based organic fertilizer applied at 48.8 KgN ha^{-1}, 4) culture filtrate of *B. pumilus* and *P. aureofaciens*, and 5) an untreated control. Treatments were applied to randomly selected 1.8 x 1.8 m plots within each irrigation block. Treatments at all sites were applied monthly, beginning in May and ending in October (6 applications). Disease pressure was heavy and uniform at all test sites prior to treatment application. Disease severity was recorded with respect to size and total number of active ring spots, and the percentage of area diseased, as estimated by visual observation. Data from the Hancock Turfgrass Research Center field trial were subjected to factorial analysis, and treatment means within an irrigation regime were separated using the Least significant difference test (P=0.05). Data from the Northville and Yankee Springs trials were analyzed using analysis of variance and LSD analysis. Soil analysis of each test site is presented in Table 2.

The bacteria were examined for management of summer patch of annual bluegrass (*Poa annua*) in field tests performed on golf course fairways under normal traffic and maintenance, and were located at Dearborn Country Club, Dearborn, MI., and Forest Lake Country Club, Bloomfield Hills. Both test areas have a history of severe summer patch outbreaks and were irrigated with an overhead sprinkler and maintained at 1.3 cm. Experimental design was a completely randomized block design with plots measuring 1.8 x 2.7 m with 3 replications. The same treatments which were included in necrotic ring spot field trials were also included in summer patch trials, although only 5 applications were made rather than 6. Treatment application at the summer patch test sites began in May and ended in September, although the height of disease activity occurred in late August at Bloomfield Hills and early September at Dearborn, and therefore the data presented were taken after only 4 applications. In these trials the molasses-based amendment was

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was applied at 24.4 KgN ha^{-1}, as opposed to 48.8 KgN ha^{-1} in necrotic ring spot trails. These rates of nitrogen are within the suggested ranges for each grass type (Beard, 1973). Summer patch disease ratings were taken as percentage of plot area diseased, as estimated visually. Data were analyzed using analysis of variance and Least significant difference test (P=0.05). Soil analysis of summer patch test sites are presented in Table 3.

Preparation of bacteria inoculum and treatment application was the same for both summer patch and necrotic ring spot field trials. Inoculum was provided by addition of bacteria from nutrient agar stock cultures to sterilized broths made up of the molasses-based carrier. The granular molasses-based organic amendment has a fertilizer analysis of 12-4-8, and was provided by Ringer Corporation, Minneapolis, MN. Broths were prepared by adding 48 g molasses-based amendment to 1 L distilled water and autoclaving for 20 min. *B. pumilus* and *P. aureofaciens* were incubated in separate broths for 2 days in shake culture at 21 C. Inoculum for the washed cells treatment was provided by culturing the bacteria in tripticase soy broth (39g L^{-1}) in shake culture at 21 C for 2 days. After incubation, the cells were concentrated by centrifuging (4000 rpm) the broth, the cells were then stored at 10 C until application. The filtrate was recovered and stored at 10 C until application. Application was performed within 24 hr from treatment preparation. Upon application, samples were taken from

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from treatment broths to determine the number of colony forming units of *B. pumilus* and *P. aureofaciens* using the dilution-plate technique (Wollum, 1982). The samples were added to 9 ml 0.85% sterile saline solution followed by serial dilution with additional 9 ml aliquots of saline solution until a final dilution of 10^{-4} was reached. One ml from the 10^{-4} dilution was added to molten nutrient agar held at 45 C, (3 replications). After 3 days incubation at 21 C in an inverted position, colonies of *B. pumilus* and *P. aureofaciens* were counted.

Broths of *B. pumilus* and *P. aureofaciens* were applied to test plots as a composite by thoroughly mixing just prior to application. The culture filtrates were also mixed just prior to application. Mixtures were divided evenly between plots (666 ml/plot) and applied as a drench with 7.5 L water. Washed cells of *B. pumilus* and *P. aureofaciens* were dispersed in 1 L sterile distilled water, divided evenly (333 ml/plot), and also applied as a drench with 7.5 L water. The molasses-based amendment was preweighed and applied by hand.

RESULTS

The paired culture technique revealed 35 isolates demonstrated inhibition toward either *L. korrae* or *M. poae* (Table 1). Twelve of the isolates were bacteria, 12 were Actinomycetes, and 2 were fungi (both *Trichoderma spp.*). Most of the bacteria were *Bacillus spp.* or *Pseudomonas spp.*

and of the Actinomycetes isolated, only *Streptomyces spp.* demonstrated inhibition. Based on degree of inhibition and growth rate, two bacteria were chosen for field testing, *Bacillus pumilus* and *Pseudomonas aureofaciens*. These bacteria were selected for testing because they are known to be ubiquitous and abundant in soil, have a rapid growth rate, and similar species have been shown to reduce other plant diseases by production of inhibitory compounds. *Bacillus spp.* have been shown to produce an array of antibiotics, including bacillomycin, polymyxin B (*B. polymyxa*), tunicamycin (*B. cereus*), (Landy *et al.*, 1948; Paulus and Gray, 1964; Kamogashira *et al.*, 1988). Several isolates of *B. pumilus* were found to be inhibitory to fungal root pathogens, and *Bacillus* spp. generally had higher survival rates in most soils tested and over a wider range of temperatures (30-80 C) when compared to *Streptomyces* and *Pseudomonas* spp. In addition, the ability of *Bacillus* spp. to produce spores may enable them to survive storage and transfer to new soils better than non-spore forming bacteria (Broadbent *et al.*, 1971). *Pseudomonas spp.* have been shown to produce phenazines, including *P. aureofaciens* by several researchers (Chang and Blackwood, 1969; Gurusiddaiah *et al.*, 1986; Toohey *et al.*, 1965). Both *Bacillus* spp. and *Pseudomonas* spp. have been associated with suppressive soils (Shipton *et al.*, 1973; Cook and Rovira, 1976), and several species of Pseudomonas have been shown to reduce take-all disease of wheat (Weller and Cook, 1983).

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The ability of *B. pumilus* and *P. aureofaciens* to utilize the nutrients present in the molasses-based organic fertilizer was demonstrated using the dilution-plate technique. Estimation of colony forming units of each bacteria present in the molasses-based broth upon application, reveal this amendment supported near equal densities of *P. aureofaciens* as that of TSB and slightly less of *B. pumilus*. Colony forming units of *P. aureofaciens* per 1 ml molasses-based broth averaged 1.24×10^7, and those of *B. pumilus* averaged 1.58×10^5. Bacteria populations in the washed cells treatment (cultured in TSB) averaged 3.66×10^7 ml *P. aureofaciens*, and 2.15×10^6 ml *B. pumilus* after resuspension with 1 L sterile distilled water upon application.

Factorial analysis of disease ratings taken at the Hancock Turfgrass Research Center indicate highly significant differences in disease severity due to bacteria treatments (F=37.83) (Table 4). Separation of treatment means within an irrigation regime reveal *B. pumilus* and *P. aureofaciens,* when cultured in and applied with the molasses-based amendment (48.8 KgN ha^{-1}), significantly reduced necrotic ring spot disease under 0.25 cm d^{-1}, twice weekly, and 'rain only' irrigation regimes, as compared to untreated controls within the respective irrigation regime (P-0.05) (Table 4). This treatment provided 100% disease suppression in daily and 'rain only' areas, and averaged only 0.7 rings spots with twice weekly irrigation. However

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the bacteria, when applied without the molasses-based carrier (washed cells), were only different from untreated plots in the 'rain only' irrigation regime (P=0.05) (Table 4). In addition the bacteria, when combined with the molasses-based carrier, had significantly less disease than the bacteria only (washed cells) treatment in all irrigation regimes. Since the molasses-based amendment was not indicated to be different from the molasses carrier with bacteria, it appears that monthly application of organic fertilizer alone may be responsible for disease suppression, however no significant differences were indicated between the molasses-based amendment and the culture filtrate treatment (filtrates of TSB cultured *B. pumilus* and *P. aureofaciens*) in any irrigation regime (P=0.05). Plots treated with culture filtrates had significantly less disease than untreated plots in daily and 'rain only' irrigation regimes (Table 4). This suggests that the compounds responsible for pathogen inhibition, which were contained in the filtrate, may also play a role in disease suppression. Since the TSB treatment alone did not reduce disease expression and was significantly different from the culture filtrates in each irrigation regime, this also suggests that the compounds inhibitory to *L. korrae* were present in the culture filtrate, and the mere application of nutrients as provided by the culture filtrates were not responsible for disease suppression. Findings from this field trial indicate enhanced disease suppression when the bacteria were applied in a molasses-based culture broth and with enough of the amendment to provide 48.8 KgN ha^{-1}.

Field testing performed on Kentucky bluegrass maintained as golf course fairway at Yankee Springs, showed all treatments were significantly different from untreated areas with regard to both the number of rings present and percent area diseased, although no differences between treatments were indicated (P=0.05) (Table 5). These results contradict those obtained from the trial at the Hancock Turfgrass Research Center and suggest that monthly application of nutrients, as provided by all treatments, play an important role in disease suppression. Lack of differences may also be partly due to the lower mowing height of Kentucky bluegrass maintained as fairway (2.86 cm) which increases the effect of heat and moisture stress (Beard, 1973). Increased heat stress and infrequent irrigation may have adversely affected survival of the introduced bacteria.

Disease ratings taken at Northville indicate that only *B. pumilus* and *P. aureofaciens* when applied with the molasses-based amendment had significantly less disease than the untreated control with respect to both number of ring spots and percent area diseased (P=0.05) (Table 6). This treatment provided effective management of necrotic ring spot and averaged only 0.7 ring spots and 3.3% area diseased. In this field trial significantly less disease incidence occurred in plots treated with culture filtrates than those treated with only TSB (P=0.05). These findings are similar to those obtained from the Hancock Turfgrass Research Center which indicate greater disease suppression with culture filtrates than with broth only. From this it appears that cultural conditions such as mowing height and frequency of irrigation may have an effect on treatment performance.

Examination of *B. pumilus* and *P. aureofaciens* for management of summer patch of annual bluegrass gave variable results. Results obtained from field testing at Dearborn reveal no significant differences between treatments, although areas treated with bacteria only (washed cells), molasses-based organic fertilizer, or the culture filtrates suppressed disease expression by more than 50%, as compared to untreated control plots (P=0.05) (Table 7). These findings indicate that summer patch disease may respond differently to the bacteria treatments than necrotic ring spot. No apparent differences were indicated between treatments providing nutrients (TSB or molasses) and washed cells (no nutrients), or between culture filtrate and TSB only.

Field testing at Bloomfield Hills revealed only those plots treated with *B. pumilus* and *P. aureofaciens* in combination with the molasses-based organic carrier, had significantly less disease incidence than untreated plots (P=0.05) (Table 8). At this site, plots treated with the bacteria on the molasses carrier averaged only 7.3% area diseased, as opposed to 23.3% in untreated plots (Table 8). Results from this study were similar to those of the Dearborn trial regarding absence of differences between culture filtrate and TSB only, and nutrient vs. non-nutrient treatments.

DISCUSSION

Results from necrotic ring spot field testing indicate that *P. aureofaciens* and *B. pumilus* provide variable disease suppression (significant in 2 of 5 areas tested) when used alone (without supplemental organic nitrogen). However, when the bacteria were applied with a suitable organic carrier, effective management of necrotic ring spot was observed in all necrotic ring spot test areas and at 1 of 2 summer patch sites. Failure of the bacteria/molasses carrier treatment to provide significant control at both summer patch sites is not readily apparent, although difference in disease pressure within the study area may be caused by local conditions; ie. traffic, compaction, thatch, or irrigation coverage, which could have lead to variability. The reduced effectiveness of the bacteria treatments to suppress summer patch outbreaks may be in part due to environmental conditions which heavily favor pathogenesis. Due to the low cutting height (1.3 cm) of high quality *Poa annua* fairways, heat stress is more pronounced than that of Kentucky bluegrass lawns which were maintained at 6.1 cm (Beard 1973). In addition, increased root infection by *M. poae* has been associated with periods of hot weather (Smiley and

Giblin, 1986).

The molasses-based amendment, when used as culture broth is an effective growth medium for both test bacteria which may provide a source of nutrition after application, thus increasing chances of establishment. Application of antagonistic microorganisms with a suitable nutrient source to increase establishment is well documented in other systems. Using molasses and brewer's yeast, Papavizas *et al.*, (1984) obtained higher propagules of *Trichoderma* spp. in soil than when the antagonist was applied without a food base. Mihuta *et al.*, (1986) also demonstrated increased germination and growth of *Trichoderma* spp. when applied with a cellulose gel which acted as a food base for the antagonist. Hadar *et al.*, (1984) also noted increased establishment of *Trichoderma* spp. when applied with cellulose gel in studies on biocontrol of damping off caused by *Pythium* spp.

Application of *B. pumilus* and *P. aureofaciens* as a composite without an organic carrier provided significant disease management in 2 of 5 trials which suggests some potential, although future investigations may provide a more complete understanding. Both bacteria, *Bacillus* and *Pseudomonas* spp. have also been associated with suppressive soils in other systems (Shipton *et al.*, 1973; Cook and Rovira, 1976). The findings presented in this paper show that *B. pumilus* and *P. aureofaciens* were effective in reducing disease outbreak (necrotic ring spot) only when applied with a suitable organic carrier.

Since the molasses-based amendment was found to be equally effective as the molasses carrier when combined with *B. pumilus* and *P. aureofaciens*, disease suppression also appeared to be related to sufficient nutrient input (48.8 KgN ha^{-1}). The molasses-based organic fertility treatment when used alone, resulted in significant disease suppression in 4 of 5 areas tested and was only different from the molasses amendment with bacteria or the bacteria alone (washed cells) treatments in 1 trial. Application of culture filtrate was also found to have an effect on disease incidence. This treatment had significantly less necrotic ring spot disease than untreated areas in 2 of 3 necrotic ring spot trials and 1 of 2 summer patch trials. Compounds present in the bacteria filtrates appeared to have some effect on necrotic ring spot disease since this treatment was different from TSB alone in 2 of 3 necrotic ring spot trials. Since no difference was observed between these treatments in summer patch testing, the culture filtrates appeared to have less of an effect on this disease.

In conclusion, this study shows that disease severity appears to be related to 1) introduction of antagonistic bacteria, through application of *B. pumilus* and *P. aureofaciens*, 2) nutrient input, through monthly application of an molasses-based organic fertilizer, and 3) compounds present in culture filtrates.

Table 1. Percent inhibition* of *L. korrae* and *M. poae* by microorganisms isolated from Kentucky bluegrass (*Poa pratensis* L.) recovering from necrotic ring spot.

		L. korrae	*M. poae*
Bacteria	**isolate**		
Bacillus spp.	II-4-S	50.0	35.0
\` '	C-8	60.0	25.0
\` '	II-11-T	00.0	100.0
\` '	C-12	45.0	00.0
\` '	III-6-S	30.0	00.0
\` '	VII-3-S	50.0	12.5
\` '	VII-5-T	50.0	12.5
B. pumilus	VI-6-S	94.1	94.1
Pseudomonas spp.,	III-4-S	00.0	65.0
\` '	III-7-S	15.0	00.0
\` '	I-6-T	80.0	80.0
\` '	W-1	50.0	50.0
\` '	VII-5-S	00.0	25.0
P. aureofaciens,	IV-7-T	100.0	100.0
Flavobacterium spp.	IV-5-S	65.0	60.0
\` '	VIII-7-T	65.0	75.0
*Alcaligenes spp.***	VI-5-S	85.0	100.0
\` ' **	IX-5-T	55.0	70.0
Arthrobacter spp.	W-4	80.0	80.0
Xanthomonas spp.	A-10	90.0	90.0
Actinomycetes			
Streptomyces spp.	I-1-T	68.8	37.5
\` '	A-1	22.7	50.0
\` '	A-7	25.0	54.5
\` '	A-8	20.4	00.0
\` '	A-11	19.3	00.0
\` '	A-12	30.0	15.0
\` '	A-16	25.0	45.0
\` '	A-19	21.6	77.3
\` '	A-20	30.0	30.0
\` '	C-106	20.0	40.0
\` '	D-12	60.0	90.0
\` '	E-10	00.0	75.0
Fungi.			
Trichoderma spp.	TC-1	Fast growing, covers plate.	
Trichoderma spp.	A-22	Fast growing, covers plate.	

* Percentage of growth inhibition was measured using the formula, 1-(B/A) x 100, where A equaled the increase in radius of the pathogens on plates containing the fungi only, and B equaled the decrease in colony radius of the pathogens on plates paired with test organisms.

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Table 2. Soil analysis* of necrotic ring spot test sites.

	Northville	Yankee Springs	Hancock Turfcenter
Sand %	34.4	74.6	60.4
Silt %	28.5	16.7	22.7
Clay %	37.1	8.7	16.9
Soil pH	8.0	7.1	7.5
Phosphorus (Kg ha)	13	72	75
Potassium (Kg ha)	405	259	132
Calcium (Kg ha)	11648	1792	1971
Magnesium (Kg ha)	712	511	394
cec (cmol kg^{-1})	29	6	6

* Analyzed at the Michigan State University Soil Testing Lab.

Table 3. Soil analysis* of summer patch tests sites, 1990.

	Bloomfield Hills	Dearborn
Sand %	80.6	53.8
Silt %	14.0	26.7
Clay %	5.4	19.4
Soil pH	6.7	7.1
Phosphorus (Kg ha)	261	40
Potassium (Kg ha)	386	580
Calcium (Kg ha)	1792	3772
Magnesium (Kg ha)	305	727
CEC (cmol kg^{-1})	6	12

* Analyzed at the Michigan State University Soil Testing Lab.

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Table 4. Necrotic ring spot severity on Kentucky bluegrass in field plots amended with bacteria treatments (*Bacillus pumilus* and *Pseudomonas aureofaciens*) under 3 irrigation regimes. Disease rating (number of ring spots per plot), 10 November 1990. Hancock Turfgrass Research Center, Michigan State University.

ANALYSIS OF VARIANCE SUMMARY

Source of variation.	df	mean square	F value
Irrigation	2	0.685	0.14NS
Error	4	4.741	
Treatments	5	37.130	37.83**
I x T	10	2.241	2.28*
Error	30	0.981	

*,** F significant at P=0.05 and 0.01, respectively.
NS = not significant.

TREATMENT MEANS

Treatment[1]	Irrigation regime 0.25 cm d^{-1}		2 wk^{-1}		rain only	
1. Bacteria + molasses carrier	0.0	a*	0.7	a	0.0	a
2. Molasses carrier only	0.0	a	1.3	ab	0.3	ab
3. Bacteria culture filtrate	1.0	a	1.7	abc	1.7	bc
4. Bacteria (washed cells)	4.3	b	2.7	bcd	2.3	c
5. Control	5.3	b	3.3	cd	4.3	d
6. TSB	5.3	b	4.0	d	6.0	e
ave	2.6		2.3		2.4	

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significant difference test.

[1] Treatments applied monthly from May through October (6 applications). 1) Bacteria composite (bacteria in molasses broth, 666 ml/plot) with molasses-based carrier, 48.8 KgN ha^{-1}. 2) Molasses-based carrier (12-4-8), 48.8 KgN ha^{-1}. 3) Composite of bacteria culture filtrates, 666 ml/plot. 4) *B. pumilus* and *P. aureofaciens* washed cells applied as a composite after resuspension in distilled water, 666 ml/plot. 6) TSB (Tripticase Soy Broth), 666 ml/plot.

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Table 5. Necrotic ring spot severity on Kentucky bluegrass in field plots (Yankee Springs, MI.) treated with *Bacillus pumilus* and *Pseudomonas aureofaciens*. Disease rating, 2 November 1990.

Treatment[1]	#	ave rings		ring size, 0-3	3-6	6-9"	ave % area diseased	
1. Bacteria (washed cells)		4.7	a	0	5	2	16.0	a
2. TSB		3.3	a	1	3	6	16.7	a
3. Bacteria + molasses carrier		4.3	a	5	1	7	20.7	a
4. Bacteria culture filtrate		6.3	a	0	6	13	31.7	a
5. Molasses carrier only		6.7	a	4	6	10	32.3	a
6. Control		13.7	b	11	12	18	66.7	b

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significant difference test.

1 Treatments applied monthly from May through October (6 applications). 1) *B. pumilus* and *P. aureofaciens* washed cells applied as a composite after resuspension in distilled water, 666 ml/plot. 2) TSB (Tripticase Soy Broth), 666 ml/plot. 3) Bacteria composite (bacteria in molasses broth, 666 ml/plot) with molasses-based carrier, 48.8 KgN ha^{-1}. 4). Composite of bacteria culture filtrates, 666 ml/plot. 5) Molasses-based organic carrier (12-4-8), 48.8 KgN ha^{-1}.

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Table 6. Necrotic ring spot severity on Kentucky bluegrass in field plots (Northville, MI.) treated with *Bacillus pumilus* and *Pseudomonas aureofaciens*. Disease rating, 30 November 1990.

Treatment[1]	ave # rings	ring size, 0-3	3-6	6-9"	ave % area diseased
1. Bacteria + molasses carrier	0.7 a*	1	1	0	3.3 a
2. Bacteria culture filtrate	2.0 ab	3	3	0	13.3 ab
3. Molasses carrier only	3.0 abc	3	4	2	15.0 ab
4. Bacteria (washed cells)	4.7 bcd	8	3	3	16.7 ab
5. Control	4.3 bc	7	6	0	21.7 b
6. TSB	7.3 d	6	9	7	38.3 c

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significant difference test.

[1] Treatments applied monthly from May through October (6 applications). 1) Bacteria composite (bacteria in molasses broth, 666 ml/plot) with molasses-based carrier, 48.8 KgN ha^{-1}. 2). Composite of bacteria culture filtrates, 666 ml/plot. 3) Molasses-based carrier (12-4-8), 48.8 KgN ha^{-1}. 4) *B. pumilus* and *P. aureofaciens* washed cells applied as a composite after resuspension in distilled water, 666 ml/plot. 6) TSB (Tripticase Soy Broth), 666 ml/plot.

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Table 7. Summer patch severity on annual bluegrass in field plots (Dearborn Country Club, Dearborn, MI.) treated with *Bacillus pumilus* and *Pseudomonas aureofaciens*. Disease rating, 4 September 1990.

Treatment[1]	ave % area diseased
1. Molasses carrier only	10.0 a*
2. Bacteria culture filtrate	13.3 a
3. Bacteria (washed cells)	15.0 a
4. Bacteria + molasses carrier	18.3 ab
5. TSB	20.0 ab
6. Control	31.7 b

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significant difference test.

[1] Treatments applied monthly from May through September (5 applications). Ratings taken at the height of disease activity (which occurred before the September application) were used for analysis, which was after 4 applications. 1) Molasses-based carrier (12-4-8), 48.8 KgN ha^{-1}. 2) Composite of bacteria culture filtrates, 666 ml/plot. 3) *B. pumilus* and *P. aureofaciens* washed cells applied as a composite after resuspension in distilled water, 666 ml/plot. 4) Bacteria composite (bacteria in molasses broth, 666 ml/plot) with molasses-based carrier, 48.8 KgN ha^{-1}. 5) TSB (Tripticase Soy Broth), 666 ml/plot.

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Table 8. Summer patch severity on annual bluegrass in field plots (Forest Lake Country Club, Bloomfield Hills, MI.) treated with *Bacillus pumilus* and *Pseudomonas aureofaciens*. Disease rating, 27 August 1990.

Treatment[1]	ave % area diseased	
1. Bacteria + molasses carrier	7.3	a*
2. Bacteria culture filtrate	13.4	ab
3. Bacteria (washed cells)	18.3	ab
4. Control	21.7	b
5. Molasses carrier only	23.3	b
6. TSB	23.3	b

* Treatment means followed by the same letter are not significantly different from each other, P=0.05, Least significant difference test.

[1] Treatments were applied monthly from May through September (5 applications). Ratings taken at the height of disease activity (which occurred in August) were used for analysis, which was after 4 applications. 1) Bacteria composite (bacteria in molasses broth, 666 ml/plot) with molasses-based carrier, 48.8 KgN ha^{-1}. 2) Composite of bacteria culture filtrates, 666 ml/plot. 3) *B. pumilus* and *P. aureofaciens* washed cells applied as a composite after resuspension in distilled water, 666 ml/plot. 5) Molasses-based carrier (12-4-8), 48.8 KgN ha^{-1}. 6) TSB (Tripticase Soy Broth), 666 ml/plot.

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CHAPTER VIII

SUMMARY AND CONCLUSIONS

An understanding of the effects of environmental and cultural factors on summer patch and necrotic ring spot disease development is important when selecting a management program for *Poa spp*. turfgrasses. Factors such as, drought, overwatering or heavy rainfall, heat stress, and fertility, have been associated with disease severity, although the exact effects of irrigation and fertility is controversial. Although chemical management has been established, cultural methods of disease suppression, such as irrigation and fertility treatments should be employed to prevent disease or to enhance the overall management program. From experiments presented here, light daily irrigation (0.25 cm d^{-1}, at noon) and selected bio-organic and slow-release fertilizers were shown to provide effective management of necrotic ring spot. Selected amendments also reduced summer patch severity when used under conditions of normal traffic and maintenance. Suppression of necrotic ring spot is attributed to increased plant vigor and reduced heat stress. Most products when combined with daily irrigation had less thatch and disease development than when combined with twice weekly irrigation or no supplemental irrigation.

In 1958, Davey and Papavizas showed reduced *Rhizoctonia* infection of beans after amendments with mature grain

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straws, eg. Barley straw, sudangrass, and oat straw, and suggested the suppressive effect could be related to shifts in microorganisms in the soil and bean rhizosphere brought about by the amendments. Application of organic matter was found to control soilborne diseases such as *Phymatotrichum* root rot of cotton (King *et al.* 1934), *Phytophthora* root rot of avocado (Bingham *et al.* 1958), *Rhizoctonia* disease of potatos (Sanford, 1947) and of sugar beets (Williams and Ririe, 1957), and take-all of wheat (Stumbo *et al.* 1942). Blair (1943) found that wheat straw and dried grass suppressed growth of *Rhizoctonia* in fertile soil and non-fertile sand. Suppression of *Rhizoctonia* was attributed to rapid assimilation of nitrogen by the cellulose-decomposing microflora which resulted in starvation and inhibition of the pathogen. Sanford (1947) reduced *Rhizoctonia solani* infection in potatos grown in artificially infested soils with corn meal.

Irrigation treatments were found to influence the severity of necrotic ring spot. With adequate nutrition, as provided by bio-organic and slow-release fertilizers, effective disease management was achieved when soil and thatch was kept moist through daily light irrigation, as opposed to wet-dry conditions which occurred under twice weekly irrigation. Cook and Papendick (1970) demonstrated water potentials of -10 mbars or higher lysed germ tubes of *Fusarium roseum F. SP. cerealis* 'Culmorum' or converted them into new chlamydospores, and proposed that Culmorum infections were greater in drier soils because of less bacterial antagonism. Most Actinomycetes and fungi are active below -8 to -10 mbars (Griffin, 1963) and probably are not responsible for lysis of *Fusarium roseum F. SP. cerealis* Culmorum. Couch and Bloom (1960) associated water stress with *Sclerotinia* dollar spot infection. Bean (1969) stated that *Fusarium* blight is correlated with dry spots and that disease severity can be greatly reduced by proper irrigation. Smiley and Thompson (1985) showed that frequently watered non-wilted turf had less crown rot and leaf blight, caused by *Fusarium graminearum, F. equiseti, F. sambucinum, F. culmorum, F. heterosporum and F. poae*, than drought-stress turf. They concluded that routine watering of bluegrass during summer is likely to minimize the severity of *Fusarium* crown rots, and that heavy watering, especially at night after periods of drought, could increase the severity of *Fusarium* crown rots. Light frequent irrigation not only has been shown to reduce several turfgrass fungal diseases (Bean, 1969; Endo and Colbaugh, 1975) and is well documented as a method of reducing heat stress (Beard, 1973; Vargas, 1981; Turgeon, 1976).

In studies performed to test microbes isolated from areas recovering from necrotic ring spot for pathogen inhibition, numerous bacteria were found to produce zones of inhibition between themselves and *L. korrae* and *M. poae* on agar, indicating production of inhibitory compounds on agar. In tests with *Pseudomonas spp.* isolated from wheat grown in soils naturally suppressive to take-all, several strains were found to be inhibitory to *Gaeumannomyces graminis var. tritici* in *in vitro*, and significantly reduced take-all when applied as wheat seed treatment (Weller and Cook, 1983). Antibiosis tests are routinely used to test for production of inhibitory compounds for biological control (Asher and Shipton, 1981). Although production of antibiotics by specific bacteria has been suggested as a mode of action in the suppression of *Gaeumannomyces* on roots, the relationship between antibiotic production on agar and in the field is controversial. It is established that production of antibiotics for disease suppression may be only one of several mechanisms (Asher and Shipton, 1981). In these studies *Bacillu pumilus* and *Pseudomonas aureofaciens*, demonstrated an advanced degree of inhibition to the pathogens in laboratory testing and when combined with an organic carrier, significantly reduced necrotic ring spot incidence in field testing, and showed potential for summer patch disease management. These experiments have demonstrated that numerous bacteria capable of producing inhibitory substances are present in test plots showing disease recovery and selected isolates when reintroduced to diseased areas demonstrate a degree of disease suppression, albeit more so with necrotic ring spot than summer patch. Annual bluegrass may not respond to bacteria treatments because of increased stress brought about by the lower mowing height (1.3 cm), reduced drought tolerance, and higher traffic than Kentucky bluegrass lawn sites which were maintained at 6.1 cm.

These studies have shown that adequate irrigation and added nutrition through application of bio-organic and synthetic fertilizers reduce severity of necrotic ring spot and summer patch. Field testing has indicated the importance of increase plant vigor, through addition of nitrogen and adequate moisture provided by daily irrigation, in reducing disease severity.

Daily irrigation and amendments such as Lawn Restore and Nitroform were also found to significantly reduce thatch, which can lead to poor water infiltration rates and harbor disease causing organisms. In addition, the bulk density was positively affected twice weekly irrigation. Appearently daily irrigation and organic amendments stimulate the decomposition process.

The findings presented in this study indicate that daily irrigation and selected fertility amendments, reduce thatch, ensure adequate rooting and reduce necrotic ring spot and summer patch incidence. The methods and fertility treatments employed in these studies are readily available to turf managers, and may provide an immediate alternative to, or enhance, disease management with synthetic chemicals.

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