

**ECOLOGY OF URBAN LAWNS: THE IMPACT OF  
ESTABLISHMENT AND MANAGEMENT ON PLANT SPECIES  
COMPOSITION, SOIL FOOD WEBS, AND ECOSYSTEM  
FUNCTIONING**

DISSERTATION

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By

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## ABSTRACT

Turfgrass lawns have become a central part of urban and suburban landscapes throughout North America. Although they provide numerous benefits, urban lawns have become chemical input intensive systems with routine and often calendar-based application of water-soluble fertilizers and pesticides. These inputs are expensive and are considered a source of environmental pollution and health risk. However, very little is known about the impacts of chemical inputs on the turfgrass soil ecology and ecosystem functioning. In fact, turfgrass urban lawns are the least studied ecosystems, despite their obvious familiarity to millions of homeowners in North America. Therefore, the environmental impact of chemical inputs associated with manicured urban lawns must be evaluated to provide a sound foundation to build sustainable urban ecosystems.

In this study, we assessed the impact of lawn management practices in Ohio on turfgrass ecosystem using several key ecological indicators, including soil nitrogen pools ( $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$ , and dissolved organic nitrogen), soil organic matter (SOM) content, microbial biomass, and nematode community. We had four specific objectives: 1) to compare turfgrass establishment, nutrient pools, and nematode community in subsoil and topsoil (with or without compost amendment); 2) to determine the effects of nitrogen fertilization on soil nematode community and nutrient pools in lawns established on subsoil and topsoil, with or without compost amendment; 3) to determine long-term effects of management practices on soil

nematode community, organic matter, microbial biomass, and nitrogen pools in experimental plots; and 4) to assess the influence of three predominant home lawn management programs on turfgrass quality, weed and insect infestations, disease incidence, and soil food web structure and functions.

We found that topsoil had higher nitrogen pools, microbial biomass, SOM, nematode abundance and genus numbers compared to the subsoil. In addition, compost amendment resulted in higher levels of soil nutrient pools compared to the subsoil, which were maintained during the course of the one-year study period. Nitrogen fertilization had no impacts on soil nematode community during the first year after turfgrass establishment. Our results also showed that topsoil plots had better turfgrass germination but higher weed infestation than subsoil plots after turfgrass establishment. Overall, long-term organic-fertilizer based turf management resulted in higher soil microbial biomass compared to mineral-fertilizer management or the control. But herbicide, insecticide, or fungicide applications had no significant long-term effect on soil microbial biomass, SOM contents, and any aspect of nematode community. Nematode community was significantly affected by long-term nitrogen application (15 years), as Maturity Index (MI) and Combined MI, were generally lower and Enrichment Index was generally higher under high and medium N-input compared to low N-input management. We also found that homeowners relying on typical do-it-yourself (DIY) programs are unable to achieve the desired levels of turf quality (1.5 for DIY lawns but 3 for professionally managed lawns, on a 0 to 3 scale) and weed control, and chemical input intensive management might negatively affect soil microbial biomass and SOM in urban lawns.

In conclusion, topsoil has higher initial soil nutrients and biota and thus higher turfgrass germination compared to the subsoil. However, higher weed infestation in topsoil plots due to weed seed bank suggests that weed control is important during the early stage of turfgrass establishment on topsoil. Also, compost amendment is an effective way to improve soil nutrient pools and biota, and its impact on soil ecosystem remains during the one-year study period. Long-term organic-fertilizer management benefits soil ecosystem in general compared to mineral-fertilizer management. However, herbicide, insecticide, or fungicide applications have no significant negative effect on soil microbial biomass and soil organic matter over long term. Nitrogen application can impose long-term cumulative effect on turfgrass soil food web rather than short-term impact. Turfgrass soil nematode food web was highly enriched (Enrichment Index were greater than 50 overall) but poorly to moderately structured (Structure Index were smaller than, or, at around 50 overall) irrespective of the management practices used. This represents a relatively disturbed soil food web compared to the natural grasslands and forest ecosystems, which usually possess poorly to moderately enriched but highly structured soil food webs. In addition to the aesthetic lawn quality, homeowners should consider the health of soil food web, resource use efficiency, environmental impacts, and sustainability of the lawn ecosystem, while choosing a lawn care program.

**DEDICATED TO MY PARENTS, HUIZHONG CHENG AND RUITING  
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ALWAYS MOTIVATED ME**

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## TABLE OF CONTENTS

	Page
Abstract .....	ii
Dedication .....	v
Acknowledgments.....	vi
Vita.....	viii
List of Tables.....	xi
List of Figures.....	xiii
 Introduction.....	 1
Chapters:	
1. Literature Review.....	4
1.1 Turfgrass and its management.....	4
1.2 Benefits of turfgrass lawns to the environment and society.....	7
1.3 Negative impacts of turfgrass to the environment and society.....	12
1.4 Ecological indicators of soil quality and functions.....	19
1.5 References.....	25
2. A study of turfgrass establishment and soil ecosystem in lawns established on subsoil or topsoil with or without compost amendment and managed under three rates of nitrogen fertilization .....	33
Abstract.....	33
2.1 Introduction.....	35
2.2 Materials and methods.....	37
2.3 Results.....	41
2.4 Discussion.....	44
2.5 Acknowledgments .....	49
2.6 References.....	50
3. Effects of long-term turfgrass management practices on soil nitrogen pools, microbial biomass, organic matter, and nematode community .....	66
Abstract.....	66
3.1 Introduction.....	67

3.2	Materials and methods.....	71
3.3	Results.....	78
3.4	Discussion.....	80
3.5	Acknowledgments .....	85
3.6	References.....	85
4.	An assessment of the ecology of urban lawns: comparison of home lawn management programs .....	103
	Abstract.....	103
4.1	Introduction.....	104
4.2	Materials and methods.....	108
4.3	Results.....	113
4.4	Discussion.....	115
4.5	Acknowledgments .....	120
4.6	References.....	120
5.	Conclusions and future directions.....	135
	Bibliography.....	140

## LIST OF TABLES

Table	Page
1.1 Most commonly used turfgrass species in North America.....	5
1.2 Temperature comparisons of four types of surfaces on August 20 in College Station, TX.....	11
1.3 Typical maintenance budget for a golf course.....	18
2.1 List of nematode genera identified in four main soil treatments at all sampling times .....	54
2.2 P values obtained from repeated measures analysis (Two-way ANOVA) showing the overall impact of four main soil treatments and three nitrogen application rates on soil nitrogen pools, microbial biomass, soil organic matter, nematode abundance, and nematode community indices after turfgrass establishment.....	56
3.1 Annual application schedule of fertilizers, herbicides, fungicides and insecticides to Kentucky bluegrass plots maintained under different turfgrass management regimes .....	90
3.2 List of nematode genera identified and colonizer-persister scale values (numbers in brackets) assigned in all nine management regimes .....	93
3.3 Long-term effect of 9 turf management regimes applied for 15 years on soil nematode abundance and community indices .....	94
3.4 P values obtained from repeated measures analysis of variance showing the overall long-term impact of turfgrass management regime groups on nematode community, nitrogen pools, microbial biomass N, and soil organic matter.....	96
3.5 Long-term effect of 9 turf management regimes applied for 15 years on soil nitrogen pools and organic matter .....	97
4.1 List of nematode genera identified and the assigned colonizer-persister scale values (numbers in brackets, following Bongers, 1990) from soil samples collected from home lawns across the three management programs.....	125
4.2 Effect of three management programs on nematode abundance and nematode community indices in soil in urban lawns .....	126

4.3	P values obtained from repeated measures analysis of variance showing the overall impact of the three management programs on nematode community, nitrogen pools, microbial biomass N, and soil organic matter in urban lawns.....	127
4.4	Effect of three management programs on soil nitrogen pools, microbial biomass (N), and soil organic matter in urban lawns .....	128

## LIST OF FIGURES

Figure	Page
1.1 Common practices involved in a residential lawn establishment and management.....	6
1.2 Graphic representation of the soil food web indicated by nematode faunal analysis.....	24
2.1 Effect of four main soil treatments on initial soil nutrient pools before turfgrass establishment (first sampling at May 2006).....	57
2.2 Effect of four main soil treatments on initial soil nematode abundance and genus number before turfgrass establishment (first sampling at May 2006).....	58
2.3 Effect of four main soil treatments on soil nitrogen pools, microbial biomass N, and SOM after turfgrass establishment, but before fertilization (second sampling at July 2006).....	59
2.4 Effect of four main soil treatments on soil nematode abundance and community indices after turfgrass establishment, but before fertilization (second sampling at July 2006).....	60
2.5 Comparison of turfgrass germination under four main soil treatments.....	61
2.6 Percentage + SE turfgrass and weed cover under four main soil treatments two months after seeding .....	62
2.7 Effect of four main soil treatments on soil nitrogen pools, microbial biomass N, and SOM during turfgrass maintenance .....	63
2.8 Effect of four main soil treatments on soil nematode abundance and community indices during turfgrass maintenance .....	64
2.9 A) Nematode food web enrichment and structure deduced from faunal analysis under four main soil treatments; B) Temporal progression of the nematode food web under four main soil treatments .....	65
3.1 Effects of N input level on nematode community indices Maturity Index, Combined Maturity Index and Enrichment Index .....	100
3.2 Nematode food web conditions deduced from faunal analysis under 9 different turfgrass management regimes .....	101

3.3	Effects of management groups on microbial biomass nitrogen and soil organic matter .....	102
4.1	Graphic representation of the soil food web indicated by nematode faunal analysis (from Ferris et al., 2001).....	129
4.2	Median of turfgrass quality scores under three management programs in urban lawns .....	130
4.3	Median of infestation levels of major weeds under three management programs in urban lawns .....	131
4.4	Median of rust severity ratings under three management programs in urban lawns .....	132
4.5	Nematode food web enrichment and structure conditions deduced from faunal analysis under three management programs in urban lawns .....	133
4.6	Effects of the three management programs on microbial biomass N (ppm) and soil organic matter (%) in urban lawns .....	134

## INTRODUCTION

Turfgrass lawns have become a central part of urban and suburban landscapes throughout North America. With dense shoots above ground, well-developed root system and large amounts of biomass underground, turfgrass provides many environmental benefits, including soil erosion control, water runoff reduction and leaching protection, contributing to carbon sequestration, moderating temperature, reducing noise, glare, and dust pollution. However, turfgrass lawns increasingly have become chemical input intensive systems with routine and often calendar based application of water-soluble fertilizers and pesticides. These inputs are expensive and are considered a source of environmental pollution and health risk. However, very little is known about the impacts of chemical inputs on the lawn soil ecology and ecosystem functioning. In fact, turfgrass lawns are the least studied ecosystems, despite their obvious familiarity to millions of homeowners in North America. Therefore, the environmental impact of chemical inputs associated with manicured urban lawns must be evaluated to provide a sound foundation to build sustainable urban ecosystems.

In this study, we assessed the impact of lawn establishment and management practices in Ohio on turfgrass ecosystem using several key ecological indicators. These indicators included turfgrass quality, weed and insect infestation, disease incidence, soil organic matter (a key indicator of overall soil quality),  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  (two major forms of N utilized by the plants), dissolved organic nitrogen

(important N reservoir), soil microbial biomass (a key indicator of the microbial activity and nutrient cycling efficiency), and nematode community (a bioindicator of the overall condition and functions of the soil food web). We had four specific objectives:

1) to compare turfgrass establishment, nutrient pools, and nematode community in subsoil and topsoil (with or without compost amendment) before and two months after turfgrass seeding;

2) to determine the effects of nitrogen fertilization on soil nematode community and nutrient pools in lawns established on subsoil and topsoil, with or without compost amendment;

3) to determine long-term effects of management practices on soil nematode community, organic matter, microbial biomass, and nitrogen pools in experimental plots located in central Ohio; and

4) to assess the influence of three predominant home lawn management programs on turfgrass quality, weed and insect infestations, disease incidence, and soil food web structure and functions in Wayne and Holmes counties in Ohio.

For the first and second objectives, a new replicated field plot experiment was established on OARDC campus in April 2006, with four main treatments consisting of subsoil, subsoil+compost, topsoil, and topsoil+compost and three sub-treatments consisting of 0, 10, and 20 g N/m<sup>2</sup>/year. Soil samples were collected 5 times in total: before seeding; after turf establishment but before fertilizer application; and three times, each at 45 day intervals after each fertilizer application, to obtain information on nematode community, NH<sub>4</sub>-N, NO<sub>3</sub>-N, dissolved organic nitrogen (DON), microbial biomass nitrogen (MBN), and soil organic matter (SOM).

For the third objective, an experiment established on Kentucky bluegrass lawn in TruGreen-ChemLawn North Research Center at Delaware, Ohio since 1989 was



used. There were nine management regimes: 1) Untreated Control, 2) Organic a, 3) Organic b, 4) Mineral High-N a, 5) Mineral Low-N, 6) Mineral High-N b, 7) Mineral High-N c, 8) Mineral High-N d, and 9) Mineral Medium-N. Regimes 2 and 3 received organic fertilizers and 4-9 received mineral fertilizers. In addition, pre-emergent herbicide was applied to 5-9; broadleaf herbicide to 3, 5-9; insecticide to 9; and fungicide to 6. Soil samples were taken three times in September 2003, July 2004 and October 2004 to analyze nematode community,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , dissolved organic nitrogen (DON), microbial biomass nitrogen (MBN), and soil organic matter (SOM).

For the fourth objective, twenty-eight home lawns in Wayne and Holmes Counties in Ohio, separated into 3 categories based on management approach (professional, do-it-yourself (DIY), and no-input), were studied. Data on turf quality, weed and insect infestation, and diseases incidence were collected in September 2003 and July 2004. Soil samples were collected in September 2003, July 2004 and October 2004 to analyze nematode community,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , dissolved organic nitrogen (DON), microbial biomass nitrogen (MBN), and soil organic matter (SOM).

Overall, this study will make a significant contribution to the knowledge of the effects of anthropogenic inputs on the ecology and functioning of urban turfgrass ecosystems. Practical application of this study is to deliver data to the “green industry” and homeowners on the optimized lawn establishment and management practices to reduce environmental risks and improve sustainability.

## CHAPTER 1

### LITERATURE REVIEW

#### 1.1 Turfgrass and its management

The term "turf" comes from either the ancient Sankrit word, *darbha*, or the old English word, *torfa*, both of which mean a tuft of grass (Aldous, 1999). In modern definitions, turfgrass may be a grass cover established on a place to prevent erosion and maintain visibility (a roadside); to reduce glare, dust, and temperatures (a lawn or park); to make the surroundings more beautiful (a lawn); and to provide a playing surface for recreation and sports (athletic field or golf course) (Duble, 1996).

Turfgrass has been used to enhance the human environment for several centuries. It plays a very important role in human life, adding beauty to the environment and providing the foundation for many recreational activities. It is estimated that the total turfgrass area, including residential, commercial, and institutional lawns, golf courses, and parks, occupies 163,800 km<sup>2</sup> ( $\pm$  35,850 km<sup>2</sup>) in the U.S. (Milesi et al., 2005), and this area is expanding because of the rapid urbanization (Robbins and Birkenholtz, 2003). In Ohio, there was nearly 10,000 km<sup>2</sup> of turf in 1989 (Sporeleder et al., 1991). Today, turfgrass is the most intensively managed ecosystem in urban landscapes (Wu et al., 2002). The annual value of turf-related services and products is about \$45 billion in the United States (Grewal, 1999). The turfgrass seed market is the second largest seed market whose annual retail sales

are more than \$580 million, only next to hybrid seed corn (Lee, 1996). There are about 16,743 golf courses in the United States (Wu et al., 2002), and about 300 new golf courses are constructed every year. For each new construction, about 60,000 pounds of turfgrass seed is needed for tees, greens, and fairways (Lee, 1996).

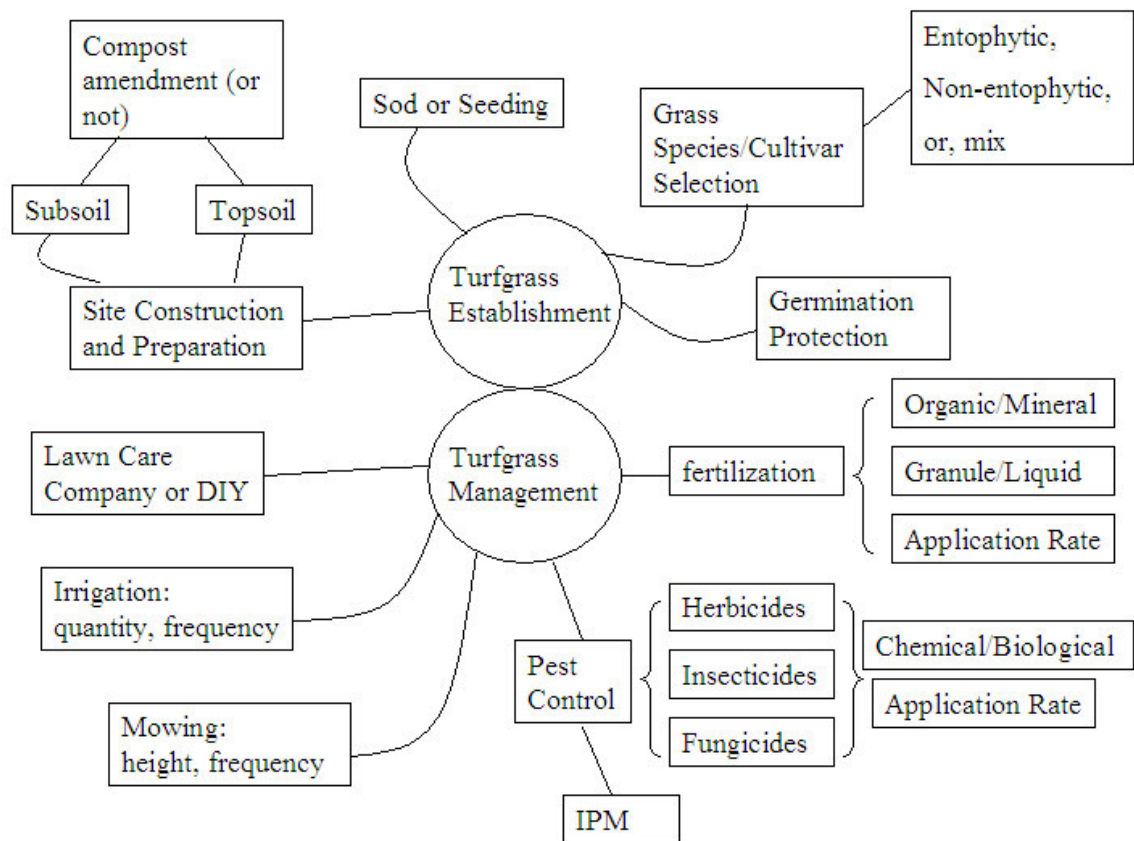
Based on the optimum growth temperature, turfgrass species are usually classified as cool-season (65-75 F°) and warm-season (80-95 F°). The turf industry utilizes about 30 species of grasses for turf, among which 13 are commonly used in North America (Table 1.1) (Vittum et al., 1999; Danneberger, 1993).

Cool-season Grasses	Warm-season Grasses
Kentucky bluegrass ( <i>Poa pratensis</i> )	Bermudagrass ( <i>Cynodon dactylon</i> )
Annual bluegrass ( <i>Poa annua</i> )	Buffalograss ( <i>Buchloe dactyloides</i> )
Perennial ryegrass ( <i>Lolium perenne</i> )	Zoysiagrass ( <i>Zoysia</i> )
Creeping red fescue ( <i>Festuca rubra</i> spp. <i>rubra</i> )	Centipedegrass ( <i>Eremochloa ophiuroides</i> )
Creeping bentgrass ( <i>Agrostis palustris</i> )	St. Augustinegrass ( <i>Stenotaphrum secundatum</i> )
Velvet bentgrass ( <i>Agrostis canina</i> )	Bahiagrass ( <i>Paspalum notatum</i> )
Tall fescue ( <i>Festuca arundinacea</i> )	

**Table 1.1:** Most commonly used turfgrass species in North America (after Vittum et al., 1999; Danneberger, 1993)

Typical processes involved with establishment and management of turfgrass is summarized in Figure 1.1 using residential lawn as an example. Site construction and preparation is usually the first step. The common practices include using the subsoil or topsoil as the basis for lawn establishment. Sometimes, compost or other amendments are included in the soil preparation stage. The method of turfgrass

establishment may be seeding or laying the sod down. Depending on the geographic location and dominating climate conditions, suitable turfgrass species/cultivar are chosen (Table 1.1), which can be entophytic (having symbiosis with beneficial fungi), non-entophytic, or a mix. Temperature and moisture protection before seed germination can be used if seeding is selected. For the management of residential lawns, homeowners either hire professional lawn care companies, or manage lawns themselves. In order to achieve high overall turfgrass quality, irrigation, mowing, fertilization, and pest control practices are usually performed. Irrigation practices can



**Figure 1.1:** Common practices involved in a residential lawn establishment and management.

differ in quantity and frequency. Mowing practices can differ in mowing height, frequency, and clipping removal or not. Fertilizers provide additional macronutrients to soil, removing or relieving nutrient limiting factors, which are usually considered to be N and P. They can differ in type (organic or mineral), formulation (granule or liquid), and application rate. Pest control in turfgrass usually involves herbicides to control weeds, insecticides to control insects, and fungicides to control diseases, as disease in turfgrass is most often caused by various types of fungi (Danneberger, 1993). These pesticides also vary in type (chemical or biological) and application rate.

## **1.2. Benefits of turfgrass lawns to the environment and society**

Turfgrass lawns provide many benefits to the society. Lawns can add to the value or sale price of houses. Even for renters, a green lawn is an important factor that affects their choice of residential location (Duble, 1996). Also, many recreational facilities depend on a uniform, flat and well-maintained turf as the medium for playing, such as golf courses, bowling greens, picnic areas and parks, etc. The United States Congress (2003) has acknowledged positive benefits of turfgrass to our environment: “turfgrass sod in urban areas and communities can aid in the reduction of CO<sub>2</sub> emissions, mitigating the heat island effect, reducing energy consumption and contributing to efforts to reduce global warming trends”. The many environmental benefits of turfgrass lawns are discussed below.

### *1.2.1. Turfgrass protects topsoil loss due to wind and water erosion and improves soil quality*

Soil is the basis of all terrestrial ecosystems. Turfgrass can protect the non-renewable soil resource by controlling erosion caused by wind and water. The dense leaves, thatch, mat and roots of turfgrass provide an excellent cover that reduces soil

erosion, even on severe slopes. With well established and well maintained turfgrass, almost no soil will be lost even in heavy rainstorms. To the surrounding ambient, this means less mud and dust. On a larger viewpoint, it means conservation of topsoil and less sediment pollution of rivers and lakes. A study concluded that a 30-minutes storm producing a 76 mm/h rainfall could cause a soil loss of 223 Kg/ha from bare ground with 8% slope, but with healthy turfgrass cover, the loss were reduced to 10 to 60 Kg/ha (Gross et al., 1991).

Turfgrass is effective at controlling erosion for several reasons. First, it stabilizes the soil surface with large number of plant shoots: 185 million to over 49 billion shoots per acre. Regular mowing of turfgrass can increase shoots compared to ungrazed grassland. Putting and bowling greens mowed at a 4 mm height possess up to 27 billion shoot per acre (Beard and Green, 1994). Second, the turfgrass root system promotes “soil building” by increasing organic matter that is highly effective for binding and decomposing many compounds. A healthy root system can add up to 3 tons of biomass per acre each year. Also, within the turfgrass ecosystem, there is continuous growth and death of roots and other plants tissues. This process provides organic matter to improve the physical condition and the fertility of the soil. Gross et al. (1991) concluded that even low-density turf stands could effectively reduce soil erosion. Therefore, the lateral flow of water is slowed and fewer soil particles are carried away. For this reason, turfgrass offers a cost-efficient method to control wind and water erosion of soil and is therefore called the “bandage for the earth”.

### *1.2.2. Turfgrass absorbs and filters rain and runoff water*

Humans depend on clean water for daily life, food supply and many industrial processes. The turfgrass system can efficiently reduce groundwater and surface contamination by capturing, filtering and even utilizing polluting chemicals. The thatch

layer of turf acts to filter pollutants and chemicals from water. The reason is that mowed turfgrass have dense biomass (canopies) of fine-textured stems and narrow leaves. A mowed turfgrass has a leaf and stem biomass from 400 to 12,000 Kg/acre (Lush, 1990). The leaves over the soil surface intercepts and absorbs raindrop impact and provides a hydraulic resistance to runoff (Krenitsky et al., 1998). In addition, there are about 300 earthworms per square yard turfgrass soil, whose activities create additional macropore space and improves the tilth and structure of the soil (Beard and Green, 1994). As a result, clean and filtered water enters the underground water system down through the turfgrass and the soil profile. After comparing two natural and four man-made materials, Krenitsky et al. (1998) reported that turfgrass sod is the most effective one among the six materials tested (wood excelsior, jute fabric, coconut fiber blanket, coconut strand mat, straw, and turfgrass sod) in terms of runoff control ability, reducing runoff by 54 to 59 percent when compared with others. Another study showed that turfgrass is very effective in reducing sediment transport, even after vertical mowing down the slope of plots (Linde and Watschke, 1997). Studies also suggest that turfgrass could trap and filter water better than crops and forest because it has more active organisms. Therefore, when properly managed, turfgrass is an effective filter that can improve water quality, and it is sometimes called “natural filter”. In practice, some golf courses are now already utilizing municipal wastewater for irrigation.

### *1.2.3. Turfgrass contributes to carbon sequestration and O<sub>2</sub> creation*

Because of the low initial soil organic carbon, high productivity and lack of heavy physical soil disturbance such as tillage, turfgrass gains the ability to sequester atmospheric carbon. A recent study by Qian and Follett (2002) revealed that turfgrass could store atmospheric carbon at a rate of approximately 1 ton of carbon per hectare

per year for up to 25 to 30 years after it is established. This result is similar to a previous carbon sequestration estimation, which is 1.1 ton/ha per year (Gebhart et al., 1994). Consequently, the total sequestration, which is about 20 million tons of carbon per year, will be an amount comparable to the carbon estimated to be sequestered by conservation reserve program lands in the United States (Qian and Follett, 2002).

In addition to the ability to sequester carbon from the atmosphere, turfgrass creates oxygen. A landscape area or yard that is about 40 feet by 50 feet large can generate the oxygen required for one person for an entire year. Therefore, turfgrass contributes to the oxygen in the air as other plants do.

#### *1.2.4. Turfgrass moderates temperature in urban environment*

Turfgrass reduces the extremely high levels of radiant heat found in urban areas. Urban areas may be 5 to 8 °F warmer than nearby rural surroundings where trees and turfgrass cover most of the surface (Duble, 1996). Evapotranspiration is the cooling process of all kinds of plants, including turfgrass. Grasses transpire at a rate that, in energy terms, exceeds the local radiant energy supply (Aldous, 1999). As a result, turfgrass reduces ground surface temperatures. It has been reported that the front lawns of eight houses have the cooling effect of about 70 tons of air conditioning, while the average home has an air-conditioner with only three or four tons capacity. A few degrees difference in temperatures around houses will save much energy and thus millions of dollars. In addition, a study has shown that actively growing *Cynodon* turfgrass is a better cooling surface during summer daytime than other surfaces, including dry soil and a synthetic surface (Table 1.2) (Beard and Green, 1994).



Type of Surface	Maximum daytime surface temperature (°C)	Percent temperature increase over active turfgrass
Actively growing <i>Cynodon</i> turfgrass	31	—
Dry bare soil	39	26%
Brown summer-dormant <i>Cynodon</i> turfgrass	52	68%
Dry synthetic turf	70	126%

**Table 1.2:** Temperature comparisons of four types of surfaces on August 20 in College Station, TX. (after Beard and Green, 1994)

#### *1.2.5. Turfgrass reduces noise, glare and visual pollution*

Turfgrass surfaces absorb harsh sounds much better than normal surfaces such as gravel, pavement or bare ground (Beard and Green, 1994). Undesirable noise levels may be reduced by 20 to 30 percent. Studies show that bluegrass absorbs sound even better than a heavy carpet on a felt pad (Potter, 1998). Also, turfgrass reduces glare. Buildings, concrete walks, and glass reflect significantly more light than turf does. This reflection can cause glare and on sunny days can be visually uncomfortable. Turfgrass surface reflects light to all directions and thus diffuses its intensity.

#### *1.2.6. Turfgrass creates valuable wildlife habitats*

Turfgrass has dense biomass, which can support many kinds of active organisms. Together with shrubs, flowers, and trees, turfgrass surfaces are good habitats for a diverse wildlife population. A study of golf courses and parks in Cincinnati, Ohio, which is reviewed by Beard and Green (1994), indicates that passerine birds benefit from golf courses, even to the extent that some golf courses may be regarded as bird sanctuaries. Therefore, properly designed and managed

turfgrass areas such as golf courses and parks can maintain and promote animal and plant diversity and natural habitats (Beard and Green, 1994).

### **1.3. Negative impacts of turfgrass to the environment and society**

However, in order to meet the high-quality demands, turfgrass is one of the most intensively managed vegetation in urban areas (Wu et al., 2002). Therefore, it now faces a great challenge from public believing that turfgrass maintenance practices will bring deleterious impact to the environment. To be well maintained, turfgrass relies on an overabundance of irrigation, pesticides, fertilizers, gasoline-powered equipment and labor (Austin, 1999). All of these might bring negative impacts to the environment and society. Currently, about 30,000 tons of pesticides are applied to the lawns, golf courses, and gardens each year in the United States to control weeds, insects, and diseases (Li et al., 2000). This amount accounts for more than eight percent of total pesticides used (Halstead et al., 1990). Also, huge amounts of fertilizers are added to turfgrass area. The profits from turfgrass fertilizers account for 25 percent of the total fertilizer industry's profits (Bormann et al., 2001). In addition, chemicals used on residential lawns may be easier to runoff, as most home lawns juxtapose streets, sidewalks and gutters that can directly move water into storm drains which often, again, directly enter the close aquatic system (Armbrust and Peeler, 2002). Between 1983 and 1995, the United States Golf Association funded 98 research projects to address the environmental issues in turfgrass management. Together with other resources, negative impacts to the environment and human health were identified.

### *1.3.1. Potential environmental pollution from turfgrass pesticides*

Pesticides applied to turfgrass have generally higher application rates than those used in agriculture (Armbrust and Peele, 2002). Pesticides are oftentimes broad-spectrum biocides and can harm organisms other than target species. A study suggests a potential for avian exposure to organophosphate (OP) and carbamate (CA) pesticides on golf courses, which may occur several days after an area is treated (Rainwater et al., 1995). Another study reported four cases in which application of the insecticides diazinon and carbofuran killed or debilitated wild birds. The incidents occurred on two golf courses, a home lawn, and a new cornfield, and involved eight species of waterfowl and songbirds (Stone and Gradoni, 1986). The result of Gadon's study (1996) suggested that pesticide exposures are occurring among lawn care applicators, despite the reported routine use of safety measures. Insecticides could adversely affect beneficial insects in addition to problem ones (Haynes, 1988). Once the natural balance is destroyed, continued reliance on insecticides will occur. The environmental fate and risks of pesticides in turfgrass are greatly affected by the specific environmental conditions and management of sites (Wu et al., 2002). Generally, when properly applied, pesticides should have little opportunity to harm the environment (Potter, 1998). However, damages will occur when they are incorrectly used, such as the most common over-application.

According to the US EPA, 95% of the pesticides used on residential lawns are potential carcinogens (American Cancer Society, 1991). In practice, among the 34 most commonly used lawn pesticides, 33 have not been fully tested for human health hazards. And one-third of the most commonly used lawn pesticides were illegally registered for use. Some pesticides labeled "bio-degradable" degrade into compounds even more dangerous than those original ones. Examples include Mancozeb, which

degrades into a substance that is an EPA-classified probable carcinogen (Begley and Hager, 1988). Many pesticides can stay in the environment for a long while. Sears and Chapman (1979) found that about 60% of chlordane and 9% of chlorpyrifos remained in the grass-thatch layer, even after 56 days. Consequently, some pesticides, including chlordane and chlorpyrifos, have been phased out from U.S. market due to human safety and environmental concerns.

There are two major ways through which chemicals may threaten water resources and thus the environment. Runoff, the movement of water over a sloping surface, may carry chemicals directly to surface water. Leaching, the vertical movement of water through the soil profile, may carry pesticides to the groundwater (Vittum et al., 1999). The physical and chemical properties of the pesticides are usually good indicators of the potential for runoff and leaching (Aldous, 1999). Chemicals that have high water solubility, low soil adsorption, and greater persistence are easier to leach and runoff. For instance, a study showed that metalaxyl is easier to leach than chlorothalonil (Wu et al., 2002). Wauchope et al. (1990) found that, generally, pesticide losses in run-off water were a fairly constant fraction of the amounts applied, typically 1-2%, under conditions with similar run-off volumes. However, the frequency of irrigation may have an impact on leaching of pesticides (Starrett et al., 2000).

Volatilization can be another route of pesticide loss following application to turfgrass areas. Murphy et al. (1996 a, b) reported volatilization losses of 12.7% for trichlorfon, 11.4% for isazofos, 1% for MCPP, and 8% for triadimefon. Another threat from pesticides is that they may pollute in-door environment. Nishioka et al. (1996) stated that many lawn chemicals are more persistent than previously thought in the in-door environment. A recent study reported that after lawn application, 2,4-D

was detected in the in-door air and on surfaces through out all the homes evaluated. Tracked-in by the homeowner applicator and by dog contributed most for intrusion. Resuspension of floor dust was the major source of 2,4-D in the in-door air and on in-door surfaces, such as table and window sills (Nishioka et al., 2001). In 1989, the National Cancer Institute indicated that children were six times more likely to develop leukemia when pesticides are used around their homes.

### *1.3.2 Potential environmental pollution from turfgrass fertilizers*

Fertilizers for turfgrass are formulated and distributed for use specifically on turfgrass, houseplants and other non-farm areas. They are different from farm fertilizers by having higher nitrogen contents than P and K and also by usually containing some slow-release nitrogen (Carrow, 2001). The two main components of fertilizers that are of the greatest concern to water quality are nitrogen and phosphorus. Nitrogen promotes green, leafy, vegetative growth in plants, while Phosphorus aids in the synthesis of proteins and transfer of energy within the plant. Phosphorus is essential for promoting root growth, stem growth, flowering, fruiting and maturation (Aldous, 1999).

As an anion,  $\text{NO}_3^-$ -N is not tightly held by negatively charged soil organic matter or clay minerals, and it is easy to move through the soil solution via convection, diffusion, and dispersion to groundwater (Haynes, 1986). For example, nitrate concentrations in groundwater on Long Island, NY, increased markedly in the last 30 years. A significant amount of this increase was attributed to lawn and garden fertilizers (Flispe et al., 1984). However, when proper amount of nitrogen fertilizers, determined by both the soil condition and the nutrient level, is applied, usually very little nitrogen leaching would occur (Aldous, 1999). Improper or excessive use of fertilizers may lead to nitrate pollution of water resources. Also, if irrigation is

excessive,  $\text{NO}_3$  leaching will occur regardless of the recommended fertilizer application rate (Exner et al., 1991). From another point of view, nitrate leaching potentials are greatest when total water influx into the soil system is greater than water loss from evapotranspiration (Lee et al., 2003). Studies show that excessive application rates of water-soluble N fertilizers on turfgrasses followed by over-irrigation on sandy soils may cause  $\text{NO}_3$  contamination of groundwater (Brown et al., 1982; Snyder et al., 1984). On immature turf grown on a pure sand rootzone medium, about 7.6 percent of nitrogen leached at an annual application rate of 12 pounds nitrogen per 1,000 square feet (Aldous, 1999). More salinity in the root zone, drought or the combination of the two pressures causes more and high concentrations of nitrate to leach (Aldous, 1999).

Consumption of nitrates may contribute to the formation of methemoglobinemia (blue baby syndrome) in infants, which will reduce the ability of the blood to carry oxygen. Because of this risk potential, US EPA set a drinking water maximum contaminant level (MCL) of 10 mg/L (or ppm) for nitrate measured as nitrogen. Phosphorus is another major concern of turfgrass fertilizer application. It can be quickly retained as insoluble inorganic compounds and sorbed onto soil surface. Therefore, the loss of soluble  $\text{PO}_4^{3-}$  through surface flow and run off may not be high (Balogh and Walker, 1992). However, if phosphorus fertilizer is over applied, the  $\text{PO}_4^{3-}$  runoff can occur. A study has demonstrated that the soluble  $\text{PO}_4^{3-}$  concentration in leachate from golf course greens exceeds the contaminant limits and would cause potential water pollution (Wong et al., 1998). Further more, phosphorus is the major cause of water eutrophication if its concentration is above 0.3mg/L (Petrovic, 1995).

### *1.3.3 Potential threat from lawn-maintenance equipment*

There are more than 50 million gasoline powered lawn and garden implements in use in the United States currently, which include riding and walk-behind mowers, motor tillers, and garden tractors (Zinger and Hecker, 1979). Usually, these equipments utilize two-stroke and four-stroke engines (Priest et al., 2000). Unlike regular automobiles, almost no regulation and standard for emissions are set for these small engines, for example in The U.S. and Australia (Grewal and Grewal, 2005; Priest, 2000). Consequently, emissions per kilogram of fuel from unregulated small engines are higher compared to larger engines (Sawyer et al., 2000). In some areas in the United States, the contribution of lawn mowers to total hydrocarbon emissions was found to be as high as 13% (Priest et al., 2000). However, they are still relatively low polluters, but not negligible as might have been expected (Zinger and Hecker, 1979; Sawyer et al., 2000). Priest et al. (2000) measured emissions of CO, CO<sub>2</sub>, CH<sub>4</sub>, NMHC and NO<sub>x</sub> from 16 in-use lawn mowers and demonstrated that lawn mowers with two-stroke engines emit hydrocarbons at an average rate in excess of seven times the rate of emission from lawn mowers with four-stroke engines. In fact, as early as 1979, Zinger and Hecker already pointed out that two-stroke engines would slowly be phased out of the market due to the high pollution potential.

Another threat may come from the operation of lawn equipments. There are reports regarding trauma from lawn mowers (Logar et al., 1996; Campbell, 2001). In addition, children are a very vulnerable group to get hurt by mowers (Gaglani et al., 1996; Daley and McIntyre, 2000). Also, noise and fuel leakage from these equipments may cause uncomfortable effects and risks.

#### 1.3.4 Cost and labor for maintaining turfgrass

The maintenance of high-quality fine turfgrass is a costly, energy- and labor-intensive business (Gange et al., 1999). In 1993, it is estimated the maintenance expenses ranged from \$58 per acre for roadsides to \$1651 per acre for golf courses (Aldous, 1999). In 1999, the total professional lawn care expense in the U.S. was about \$17.4 billion (Spencer, 2001). Households in the U.S. spent about \$9.6 billion to personally care for their lawns in 2005 increasing from \$8.8 billion in 2004 (National Gardening Association, 2005). Although the huge amount of pesticides and fertilizers applied cost very much, labor and equipments cost even more. Table 1.3 summarizes the typical annual maintenance budget allocation for a 18-hole golf courses in the U.S. (Aldous, 1999).

Item	Budget (dollars)
Labor (salaries, bonus, etc.)	152,500
Water	7,500
Fertilizers	8,000
Pesticides	10,000
Equipments	12,500
Others	59,500
Total	250,000

**Table 1.3:** Typical maintenance budget for a golf course (after Aldous, 1999)

In addition to all the negative impacts from turfgrass discussed above, turfgrass irrigation is a major contributor to urban water overuse (Lant, 1993), which may pose extreme pressure on the scarce water resources.



#### **1.4. Ecological indicators of soil quality and functions**

Little is known about the impacts of chemical inputs on turfgrass soil ecology and ecosystem functioning. In deed, turfgrass lawn ecosystems are the least studied ecosystems, despite their obvious familiarity to millions of homeowners in North America. Therefore, the environmental impact of chemical inputs associated with manicured urban lawns must be evaluated to provide a sound foundation to build sustainable urban ecosystems. There are some important ecological indicators to assess the effects of turfgrass management practices on the structure and function of soil food web. These include: soil organic matter (a key indicator of overall soil quality),  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  (two major forms of N utilized by the plants), dissolved organic nitrogen (important N reservoir), soil microbial biomass (a key indicator of the microbial activity and nutrient cycling efficiency), and nematode community as a bioindicator of the overall condition and functions of the soil food web.

##### *1.4.1 Soil organic matter, microbial biomass, and nitrogen pools*

The soil organic matter (SOM) is derived from plants, microorganasims, and animals, and is capable of decay or the product of decay, or is composed of organic compounds. SOM is generally related to higher levels of soil fertility, greater long-term productivity, and improved tilth (USDA, 1980) and has been redeemed as an indicator for overall soil quality and health and thus has significant impact on soil organisms. SOM helps to form soil aggregates, which are essential for maintainance of soil structure and stability, and C sequestration. It affects the capacity of the soil to act as an environmental buffer by absorbing or transforming chemicals (Marquez et al., 1999). Its dark brown color helps to absorb solar radiation and moderates soil tempreature. Some specific small organic molecules, such as some amino acid forms of N, can be utilized by plants without relying on microbial mineralization (reviewed

by Lipson and Näsholm, 2001). In addition, SOM can serve as a source of N and other nutrients (Higby and Bell, 1999; Kerek, 2001). In turfgrass soil systems, SOM generally accumulates as grass roots grow and die. These accumulations of SOM with time also affect water holding capacity and water movement through the root zone, both of which affect the oxygen distribution in the root-zone (Kerek, 2001). By increasing CEC and soil water holding capacities, SOM reduces leaching and thus increases the potential for utilization of fertilizer N (Kerek et al., 2003).

SOM can be divided into nonliving and living components (Theng, 1987). In soil ecology, microbial biomass refers to the living portion of the soil organic matter, excluding plant roots and soil animals larger than  $5 \times 10^{-3} \mu\text{m}^3$  in size. Microbial biomass and its products may be associated with free primary soil particles (i.e. sand, silt, and clay), aggregates, and macroorganic matter. The association of microbial biomass with these soil constituents and soil characteristics affects not only the amount and persistence of microorganisms, but also the functions and structure of microbial community (Kerek, 2001). Therefore, microbial biomass provides an overall picture of how abundant and how active the soil microbial community is in a specific location (Nannipieri et al. 1990). It is a key variable controlling SOM dynamics, functioning primarily as an agent for transforming and cycling of carbon and associated plant nutrients within the soil. In fact, microbial biomass can respond more quickly to the changes in soil management practices as compared to total soil organic matter (Doran et al. 1996). Therefore, measurement of microbial biomass provides a sensitive indication of organic matter turnover (Goyal, et al., 1999). Soil processes important for maintenance of healthy turfgrass, such as organic matter degradation, nutrient supply, N fixation, mycorrhizal colonization, disease occurrence and suppression, are mediated by the soil microbial biomass (Kerek, 2001). In

addition, microbial biomass can also serve as a labile source of organic matter (Gregorich et al., 1994) and as a source/sink for the major plant nutrients. Therefore, although microbial biomass may comprise only 1 to 3% of SOM and <1% of soil volume, it may be the most important component in terms of turfgrass health and long-term green productivity (Nelson, 1994; Kerek, 2001).

Nitrogen is the most important macronutrient for plant growth. Sufficient N helps maintain shoot density and moderates shoot growth rate, and improves recuperative potential from wear, environmental stress, disease, etc., and to a lesser extent, color (Beard, 1982). Although N is very abundant in the atmosphere (as N<sub>2</sub>) and in soil (as organic forms), it cannot be used directly by most plants, which only are able to utilize mineral forms of N (mostly NH<sub>4</sub>-N and NO<sub>3</sub>-N). Therefore, the pools of NH<sub>4</sub>-N and NO<sub>3</sub>-N in soil are critical for turfgrass growth and health (Danneberger, 1993). Dissolved organic nitrogen (DON) is an increasingly important focus of ecological studies that seek to understand the controls over N cycling within, and N losses from, ecosystems (Neff et al., 2003). DON typically constitutes between 10 and 70% of the total dissolved N in terrestrial ecosystems (Willett et al., 2004). DON can play multiple roles in ecosystems, in part because it contains compounds that are both labile (easily degraded by plants or microorganisms) and recalcitrant (not easily utilized by plants or microorganisms), which behave in fundamentally different ways (Neff et al., 2003).

#### *1.4.2 Nematode community as a bioindicator for the soil environment*

Bioindicator is biota that are developed as indicators (index or measurement endpoint) of the quality of the environment, the biotic component, or humans within an ecosystem. In broad sense, there are four main types of indicators, which are not mutually exclusive, including ecosystem health assessment; human effects; human

interventions; and human health and well-being. Bioindicators that encompass several aspects have greater chance to be implemented over the long term (Burger, 2006).

Nematodes inhabit virtually all ecosystems including marine, freshwater, and terrestrial environments. Taxonomically they belong to the phylum Nemata that includes free-living nematodes and plant and animal parasites (Platt, 1994). In general nematodes are microscopic, usually between 80µm and 1 mm in length, with the exception of some animal parasitic nematodes, which are rather large and can be seen by naked eye (Wallace et al., 1996). Some nematodes are considered as important pests of plants and animals while others contribute to nutrient cycling (Ferris and Matute, 2003) and control of plant pests and pathogens (Grewal et al., 2005).

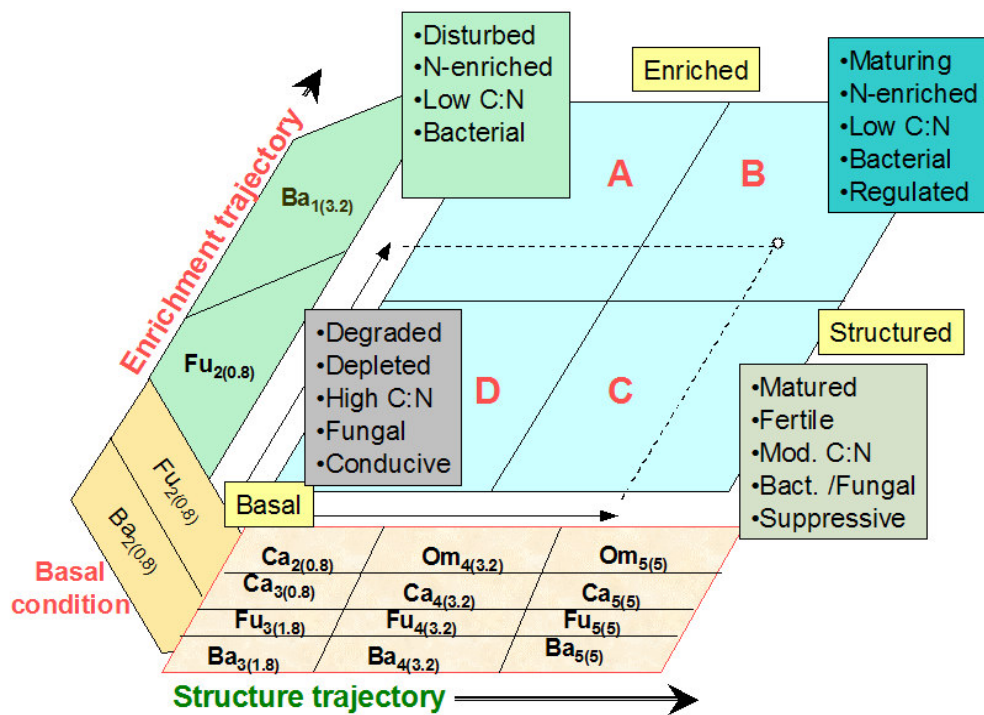
The soil food web is composed of interacting soil organisms including bacteria, fungi, nematodes, annelids and arthropods, and is dependent primarily on autotrophic input from plants or other external sources (Ferris and Bongers, 2006). Assessment of soil health through complete analysis of such a diverse group of organisms may require multiple extraction and culture techniques, which is technically challenging (Ritz and Trudgill, 1999; Ferris and Bongers, 2006). Alternate to this is the use of bioindicators of soil ecological status. The indicator used should reflect the structure and function of ecological processes and must respond to soil conditions with considerable sensitivity (Neher, 2001).

Nematodes have been evaluated for their use as bioindicators due to several attributes they possess. They are the most numerous component of the microfauna and are considered as the most abundant and diverse invertebrates present in soil ecosystem (Yeates, 1979). Although nematodes represent a relatively small amount

of biomass in the soil, their occurrence across multiple trophic levels is vitally important in the soil environment (Barker and Koenning, 1998). They occupy central positions in soil, appearing at multiple trophic levels, including bacterivores, fungivores, plant parasites, predators, and omnivores (Yeates et al., 1993). Since nematodes depend on the continuity of soil water films for movement, their activities are largely controlled by soil physical, chemical, and biological conditions (Yeates and Bongers, 1999). Also, nematodes are in direct contact with dissolved chemicals in the soil solution through their permeable cuticle and can react rapidly to disturbances and contaminants. Since their feeding habits are clearly related to oral structure, their trophic roles are readily inferred. Thus, nematodes have the potential to provide meaningful insights into the condition of soil food web, environmental disturbance and pollution. In addition to this, nematodes are easy to extract from the soil using simple extraction procedures (Ritz and Trudgill, 1999). Each soil sample contains an abundance and diversity of nematodes and, consequently, has high intrinsic information value (Bongers and Ferris, 1999; Yeates et al., 1993).

Yeates et al. (1993) categorized nematodes into five generally recognized trophic groups: bacterivores, fungivores, predators, omnivores and plant parasites. Bongers (1990) classified nematodes along a colonizer-persister (c-p) continuum of 1-5. Nematodes with c-p value one are short lived, have high fecundity, and response rapidly to available nutrient flush, while those of c-p value five have large body size, longer life span, low fecundity, are susceptible to disturbance and are predominantly omnivores and predators (Bongers, 1990). C-p classifications of nematodes lead to the formation of the maturity index (MI), which is the weighted mean of c-p values across the entire free-living nematode community and assesses the impact of disturbance in a habitat (Bongers, 1990; Bongers and Bongers, 1998; Neher, 1999).

The development of MI represented a significant advancement in interpreting the relationships between the ecology of nematode communities and functions of the soil ecosystem (Neher et. al., 2005). Ferris et al. (2001) observed that the most abundant nematode taxa under stressed conditions are in c-p 2, while the enrichment opportunists (c-p 1) respond positively to disturbances that result in enrichment of the food web. Therefore, Ferris et al. (2001) assigned weights to indicator nematode guilds representing basal, enriched and structured conditions of the soil food web.



**Figure 1.2:** Graphic representation of the soil food web indicated by nematode faunal analysis (from Ferris et al., 2001).  $Ba_x$  (bacterivores),  $Fu_x$  (fungivores),  $Ca_x$  (carnivores, or predators),  $Om_x$  (omnivores) (where value of  $x = 1-5$  on the cp scale) represents various functional guilds. Indicator guilds of soil food web condition (basal, structured, enriched) are designated and weightings of the guilds (numbers in parenthesis) along the structure and enrichment trajectories are provided, for determination of the enrichment index (EI) and structure index (SI) of the food web.

This concept leads to the development of food web indices including enrichment (EI) and structure index (SI). EI describes whether the soil environment is nutrient enriched (high EI) or depleted (low EI). SI represents an aggregation of functional guilds with c-p values ranging from 3-5 and describes whether the soil ecosystem is structured (high SI) with greater trophic links or degraded (low SI) with fewer trophic links (Ferris et al., 2001). Plotting of EI and SI provide a model framework of nematode faunal analysis as an indicator of the likely conditions of the soil food web (Figure 1.2). In later studies use of these indices provided critical information about below ground processes in terrestrial ecosystems (Bulluck et al., 2002; Ferris and Matute, 2003; Neher et al., 2005).

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## CHAPTER 2

### A STUDY OF TURFGRASS ESTABLISHMENT AND SOIL ECOSYSTEM IN LAWNS ESTABLISHED ON SUBSOIL OR TOPSOIL WITH OR WITHOUT COMPOST AMENDMENT AND MANAGED UNDER THREE RATES OF NITROGEN FERTILIZATION

#### **Abstract**

With expansion in urbanization, the area under turfgrass is rapidly increasing in the U.S. However, during new development, it is a common practice for builders to scrape off topsoil and establish new lawns on subsoil. We compared the dynamics of soil organic matter, microbial biomass, nitrogen pools, and nematode community in tall fescue lawns established on either subsoil or topsoil with or without compost amendment and managed under three nitrogen fertilization rates. We also studied the effect of the soil treatments on turfgrass establishment and weed infestation.

Experimental plots were established in Spring 2006 by excavating soil to a depth of about 40 cm and then refilling with native subsoil or topsoil with or without compost (a mixture of sawdust and a by-product of wastewater treatment). After turfgrass establishment, plots were managed under three rates of N fertilization (0, 10, and 20 g N/m<sup>2</sup>/year) and fertilizers were applied three times a year. There were 4 replications for each treatment, and all 48 plots were arranged in a randomized block design. Our results showed that turfgrass germination was better on topsoil plots compared to the

subsoil plots, but weed infestation was much higher in topsoil than subsoil plots after turfgrass establishment. Initial levels of macronutrients, total C, and SOM were higher in topsoil than subsoil plots, and were generally increased by compost amendment. After turfgrass establishment, N pools, microbial biomass, and SOM were generally lower in subsoil plots compared to topsoil plots, and were higher in plots with compost amendment than those without throughout the study period. Total and free-living nematode abundances were higher in topsoil than the subsoil, and both were also higher in plots with compost amendment than those without. However, nematode maturity index and combined maturity index were both lower in plots with compost amendment than those without. Food web enrichment index was generally higher in topsoil compared to the subsoil, and was higher in plots with compost amendment than those without. Structure index was generally lower in subsoil and subsoil+compost plots, compared to the topsoil and topsoil+compost plots. Nematode food webs in the subsoil plots were poorly enriched and poorly structured, but those in subsoil+compost plots were highly enriched and poorly structured. Soil food webs in topsoil and topsoil+compost plots were highly enriched and poorly to moderately structured. The temporal progression of the nematode food web showed that EI increased in subsoil plots and decreased in subsoil+compost plots overtime, whereas the SI remained steady. In contrast, in topsoil and topsoil+compost plots, both EI and SI decreased overtime. We conclude that topsoil has higher nitrogen pools, microbial biomass, SOM, nematode abundance and genus numbers compared to the subsoil. Our results also indicate that compost amendment can maintain high soil nutrient pools and its impact on soil food web remains during the one-year study period.



## 2.1. Introduction

Urban and suburban sprawl is rapidly increasing not only in Ohio but also around many other cities throughout the United States. This sprawl is associated with the loss of farmlands, forests, and open lands. Simmons (1997) reported that in 1990's the average size of new homes was twice its size in 1950's. Sprawl in combination with a preference for a larger lot size increases the total area under turfgrass lawns (Robbins and Birkenholtz, 2003). Milesi *et al.* (2005) estimated the total turfgrass area in the U.S. including residential, commercial, and institutional lawns, golf courses, and parks at 163,800 km<sup>2</sup> ( $\pm$  35,850 km<sup>2</sup>), and in Ohio there was nearly 0.97 million ha of turf in 1989 (Sporeleder et al., 1991). Unfortunately, the expansion in turfgrass lawn area is associated with increase in chemical fertilizer and pesticide inputs, which are viewed as a source of environmental pollution.

Before the establishment of a turfgrass lawn, the forest, open land or agrarian soil undergoes tremendous changes, including the removal of vegetation, stripping of topsoil, compaction by construction equipment, and sometimes the addition of imported fill (Cogger, 2005). Therefore, urban soils are generally referred to as "anthropogenic soils" because of the tremendous disturbance caused by human activity (Penizek and Rohoskova, 2006). It is now a common practice for builders to scrape the ground of its organic rich topsoil and build the new lawn on subsoil, which is mainly the mineral soil defining the "B" horizon (Schaetzl and Anderson, 2005), such as clay, loess, or muck. In addition to low nutrient levels, the subsoil usually has poor water infiltration ability, which results in compaction and anaerobic conditions. These conditions lead to challenges in growing the turfgrass on this nutritionally, structurally, and biologically compromised soil. Unfortunately, little is known about nutrient pools and structure and function of food webs in urban soils.

We used the soil nematode community to compare the structure and function of the soil food web in lawns established on subsoil and topsoil overtime, since nematodes are known as a useful environmental bioindicator for assessing the conditions of soil environment (Ritz and Trudgill, 1999; Neher, 2001). We also quantified soil organic matter (a key indicator of overall soil quality),  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  (two major forms of N utilized by the plants), dissolved organic nitrogen (important N reservoir), and microbial biomass (a key indicator of the microbial activity and nutrient cycling efficiency) in the lawns established on topsoil and subsoil. As compost amendment can improve soil physical properties including bulk density, soil aggregate stability, porosity, and infiltration (reviewed by Cogger, 2005), we included compost as a soil conditioning treatment at the time of plot establishment. We further included three rates of nitrogen fertilization as a post-establishment management regime.

The specific objectives of this study were to: 1) assess the differences among the four soil treatments practiced in urban lawn development (subsoil, subsoil with compost amendment, topsoil, and topsoil with compost amendment) regarding the initial soil nutrient status and nematode food web; 2) assess turfgrass germination and establishment on the four soil treatments; 3) determine soil nitrogen pools, microbial biomass, SOM, and nematode community dynamics under four soil treatments during the course of turfgrass establishment and maintenance; and 4) evaluate the effects of N fertilization on turfgrass soil N pools, organic matter, microbial biomass and nematode food web. Our hypotheses are that topsoil has more nutrients, higher nematode abundance, and more diverse nematode community compared to subsoil during the course of turfgrass establishment and maintenance; the addition of compost amendment can increase most soil nutrient pools, nematode abundance and food web

diversity during the course of turfgrass establishment and maintenance; and higher N input will result in nematode community shift favoring the abundance of opportunistic species.

## **2.2. Materials and Methods**

### *2.2.1. Experimental design*

The site for the study was located on the campus of the Ohio Agricultural and Research Development Center in Wooster, Ohio. The site was an unused land area covered by natural vegetation. We established experimental plots representing four main treatments: subsoil (S), subsoil+compost (SC), topsoil (T), and topsoil+compost (TC). Plots were established by excavating soil using an excavator (BobCat) to a depth of about 40 cm and then refilling with native subsoil (below 30 cm) and topsoil (top 0-15 cm) collected from the same area, with or without compost (a mixture of sawdust and a by-product of wastewater treatment), mixed at 4:1 ratio. Entophytic tall fescue seeds (purchased from Oliger Seed Company, Akron, OH) were applied in plots at the rate of 0.035 kg/m<sup>2</sup> in May 2006. Photos showing turfgrass germination and establishment were taken two weeks after seeding and data on turfgrass percentage, weeds and bare-ground cover were recorded two months after seeding. Due to the high weed infestation in some plots, concentrated liquid herbicide (Bayer Advanced All-in-One Weed Killer) was applied one time only and the same turfgrass seeds (entophytic tall fescue) were over seeded to fill bare ground (occupied by weeds before herbicide application) where needed.

After the establishment of turfgrass, we imposed three sub-treatments: 0, low, and high rate of fertilizer application (0, 10, and 20 g N/m<sup>2</sup>/year, respectively) on each plot. Nitrogen fertilizer (Tyler's Sulphur Coated Urea, 38-0-0) was applied three

times in August 2006, October 2006, and March 2007 at one third of annual dose mentioned above. There were 4 replications for each treatment. In total, there were 48 plots, which were randomly arranged into 4 blocks. Each plot was  $1.7 \times 2.1 \text{ m}^2$ , and was separated with a buffer area (2.5m wide) to minimize possible contamination. In addition, all plots were raised above the surface and defined with wood frames with a 4-degree cross-angle slope for the purpose of a future runoff study.

### *2.2.2. Soil sampling*

Plots were sampled five times: once before seeding (May 2006) to obtain the base-line data on the 4 main soil treatments; once before fertilizer application (July 2006) to detect the changes during turf establishment and also to obtain the base-line data before fertilizer application; and three times after fertilizer application at 45 day intervals in October 2006, November 2006, and May 2007.

Eight soil cores along cross-angle transects were taken from each plot with a 3 cm diameter soil probe to a depth up to 15 cm. The core samples were mixed to make one composite sample for each plot in order to reduce the variance associated with aggregated spatial patterns of nematodes in soil (Barker and Campbell, 1981). Soil samples were placed in polyethylene bags to prevent water loss and were kept in a cooler while in transit to the laboratory and during handling. Samples were stored at 4°C before analysis to minimize changes in nematode populations and biochemical reactions (Barker et al., 1969).

### *2.2.3. Extraction and identification of nematodes*

Nematodes were isolated from soil samples following the Baermann funnel technique (Flegg and Hooper, 1970). Ten grams of soil from each composite sample was placed on each funnel. After 72 hours, nematodes in the water were collected in plastic vials through a rubber tube attached beneath each funnel. Nematodes were

allowed to settle for at least 12 h at 4 °C and then the upper layer of water was discarded carefully without disturbing the nematodes until about 5 ml of suspension remained. The nematodes were killed and fixed using 5 ml boiling TAF solution (70 ml formaldehyde + 20 ml triethanolamine + 910 ml distilled water) in a fume hood (Shepherd, 1970). Finally, nematodes were identified and counted using a stereomicroscope. All nematodes were identified to at least the genus level using published keys (Goodey, 1963; Mai and Lyon, 1975). They were then assigned to a trophic group (plant parasites, fungivores, bacterivores, omnivores or predators) according to Yeates et al. (1993) and a colonizer-persister (c-p) value was assigned according to Bongers (1990). Nematode numbers were not corrected for extraction efficiency, which is about 85% for the method used (Grewal, 1991).

#### *2.2.4. Soil analysis*

For the first sampling only, soil samples were sent to STAR LAB at OARDC Campus for standard soil nutrient analysis, including P, K, Ca, Mg, Soil Organic Matter (SOM), Total C, Total N, and NO<sub>3</sub>-N.

For all other samples, SOM expressed as a percentage, was measured by calculating the weight loss during ignition (Storer, 1984). NH<sub>4</sub>-N, NO<sub>3</sub>-N, and dissolved organic nitrogen (DON) were extracted from soil by adding 0.5 M K<sub>2</sub>SO<sub>4</sub> solution, and were digested by alkaline persulfate oxidation (Cabrera and Beare, 1993). They were then determined using a modification of the indophenol blue technique in microtiter plates (Sims et al., 1995). The concentration of DON in filtrates is calculated as the difference between total nitrogen and mineral nitrogen. Microbial biomass nitrogen (MBN) is determined using a modification of the chloroform fumigation method described by Brookes et al. (1985). A 10 g of coarsely screened soil is fumigated with chloroform in the dark for 48 hours and extracted again

with 0.5 M K<sub>2</sub>SO<sub>4</sub> solution. The extract is filtered and digested by alkaline persulfate oxidation (Cabrera and Beare 1993) and the concentration of total nitrogen in the digested filtrate is determined using the modified indophenol blue technique (Sims et al., 1995). MBN is calculated as the difference between total extractable nitrogen from unfumigated and fumigated soil samples, assuming extraction efficiency for MBN of 0.45 (Jenkinson, 1988). The concentration of each of the nitrogen pools is expressed as ppm.

#### 2.2.5. Statistical analysis

Analysis of variance (PROC GLM, SAS Release 9.1, SAS Institute, Cary, NC) was performed separately on soil and nematode data for the first and second samplings. Repeated measures analysis of variance (Two-way ANOVA) was performed on soil and nematode data for the last three samplings to obtain *p*-values for soil treatment and N application rate using the appropriate error terms in the model. In addition, Fisher LSD was used for mean comparisons within each sampling time for all data. Nematode population data were transformed as  $\ln(x+1)$  prior to statistical analysis to normalize the variance. An alpha level  $\leq 0.05$  was considered significant. Soil nematode community indices were calculated as below.

Maturity Index (MI), considering free-living nematodes only, was calculated using the formula  $MI = (\sum v_i f_i) / n$ , where  $v_i$  is the c-p value assigned to nematode genus  $i$ ,  $f_i$  is the frequency of nematode genus  $i$ , and  $n$  is the total number of individuals in the soil sample (Bongers, 1990). Plant parasitic index (PPI) was calculated based only on plant parasitic nematodes as  $PPI = (\sum v_i f_i) / n$  where  $v_i$  is the c-p value for the plant-parasitic nematode genus  $i$ , and  $f_i$  is the frequency of plant-parasitic nematode genus  $i$ , and  $n$  is the total number of individuals in the soil sample (Bongers, 1990).

The enrichment index (EI) and structure index (SI) provide information for the enrichment and structure of the soil food web and were calculated according to Ferris et al. (2001). First of all, basal components ( $b$ ) of the food web (fungal and bacterial feeders in the c-p 2 guild) were calculated as  $b = \sum k_b n_b$  where  $k_b$  is the weighted constant for the guild, and  $n$  is the number of individuals in that guild. Then enrichment ( $e$ ) and structure ( $s$ ) components were calculated, using nematode guilds indicative of enrichment (bacterivores in c-p 1, and fungivores of c-p 2), and structure (bacterivores in c-p 3-5, fungivores c-p 3-5, omnivores of c-p 3-5, and predatory nematodes of c-p 2-5). Finally the EI was calculated as  $100 * e/(e + b)$ , and the SI as  $100 * s/(s + b)$ .

## **2.3. Results**

### *2.3.1. Pre-turf establishment soil nutrient pools and nematode abundance (first sampling)*

All soil nutrient pools and nematode abundance were significantly different ( $P < 0.001$ ) for the 4 main soil treatments (Figure 2.1 and 2.2). The initial Ca, P, K, Total C, Total N,  $\text{NO}_3\text{-N}$  and SOM contents were significantly higher in topsoil than in subsoil plots, except for Mg. Compost amendment significantly increased initial Ca, P, K, Mg, Total C, Total N, and SOM in both subsoil and topsoil plots. Since soil pHs are all slightly below 7 (data not presented), Total C here mainly refers to Total Organic C. Initial nematode abundance and genus number were significantly higher in topsoil than in subsoil plots, but were lower in plots with compost amendment than those without (Figure 2.2). There were too few nematodes in subsoil plots to calculate meaningful food web indices. Nematode genera identified in each soil treatment at each sampling time are given in Table 2.1.

### *2.3.2. Post-turf establishment soil nitrogen pools, microbial biomass, SOM, and nematode community (second sampling)*

Soil nitrogen pools, microbial biomass, SOM, nematode abundance and community indices were significantly different ( $P < 0.001$ ) for the 4 main soil treatments (Figure 2.3 and 2.4). Among these,  $\text{NO}_3\text{-N}$ , DON, microbial biomass, and SOM were significantly higher in topsoil than in subsoil plots. We suspect the initial high  $\text{NH}_4\text{-N}$  in subsoil is an error in analysis. DON, microbial biomass and SOM were significantly higher in plots with compost amendment than those without. For nematode community, the total nematode abundance and FLN abundance were both higher in topsoil compared to the subsoil, and higher in plots with compost amendment than those without (Figure 2.4). Similar trend was found for food web enrichment index. However, MI and Combined MI were not different between subsoil and topsoil and were both lower in plots with compost amendment than those without. Food web structure index was significantly lower in subsoil and subsoil+compost plots, compared to in topsoil and topsoil+compost plots.

Regarding turfgrass germination/establishment, two weeks after seeding, topsoil and topsoil+compost had higher grass cover compared to subsoil and subsoil+compost treatments, but weed infestation was much higher in topsoil and topsoil+compost than subsoil and subsoil+compost treatments (Figure 2.5). But two months after seeding, turfgrass cover on subsoil and subsoil+compost plots became significantly higher due to lower weed infestation (Figure 2.6).

### *2.3.3. Impacts of soil treatments and nitrogen fertilization on soil nitrogen pools, microbial biomass, SOM, and nematode community during the course of turfgrass maintenance*



Significant differences ( $P < 0.01$ ) were found among 4 main soil treatments for soil nitrogen pools, microbial biomass, SOM, and nematode abundance and community indices overall during the course of three post-turfgrass establishment sampling times (Table 2.2). Specifically,  $\text{NO}_3\text{-N}$ , microbial biomass, and SOM were significantly higher in topsoil than in subsoil. Similar trend was found for DON, but it was not significant (Figure 2.7). DON, microbial biomass and SOM were significantly higher in plots with compost amendment than those without (Figure 2.7). Total nematode abundance, FLN abundance, and PPN abundance were all higher in topsoil compared to the subsoil, and were higher in plots with compost amendment than those without, except for PPN abundance where possible unreliable data was obtained in Topsoil+Compost treatment in October 2006 samples (Figure 2.8). Similarly, nematode genera number was higher in topsoil compared to the subsoil, but was generally lower in plots with compost amendment than those without (Figure 2.8). However, MI and Combined MI were generally at the same level in subsoil and topsoil and both were lower in plots with compost amendment than those without. Enrichment index was generally higher in topsoil compared to subsoil, and was higher in plots with compost amendment than those without (Figure 2.8). Structure index was generally lower in subsoil and subsoil+compost plots, compared to the topsoil and topsoil+compost plots (Figure 2.8).

Significant differences were found only in soil  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  pools among the three N fertilization rates overall during the course of the three sampling times (Table 2.2). However, the differences were not consistent for the three sampling times. In addition, the soil and N interaction term in  $\text{NO}_3\text{-N}$ , MI, and Combined MI was found to be significant in the two-way ANOVA overall during the three sampling times (Table 2.2).

#### 2.3.4. Soil food web condition

Since the EI and SI were not different among various N application rates at any sampling time, soil faunal analysis was performed based on the four main soil treatments for the last four sampling times and the results are presented in Figure 2.9. Majority of the food webs under subsoil and subsoil+compost plots were poorly structured (Quadrats A and D) compared to the topsoil and topsoil+compost plots (Figure 2.9 A). Compost amendment drove the food web towards more enriched status (from Quadrat D to A), especially in subsoil treatment. The temporal progression of the food web indicated by nematode faunal analysis under four soil treatments (Figure 2.9 B) showed that EI increased in subsoil plots and decreased in subsoil+compost plots overtime, whereas the SI remained steady. In contrast, in topsoil and topsoil+compost plots, both EI and SI decreased overtime.

#### 2.4. Discussion

The initial soil analysis generated meaningful base-line data on soil nutrient pools and nematode abundance in the four main soil treatments. First, macronutrients Ca, P, K, Total C, and N (Total N and NO<sub>3</sub>-N) and SOM contents were significantly lower in subsoil than in topsoil plots. These findings are consistent with a previous study on macronutrient comparison between subsoil and topsoil (Ervio and Palko, 1984). However, higher Mg content was detected in subsoil compared to topsoil. Similar finding was also noted by Kuhlmann and Baumgartel (1991). Since compost amendment usually provides plant nutrients (Cogger, 2005), it is not surprising to see the increase in initial Ca, P, K, Mg, Total C, Total N, and SOM contents in treatments with compost. These findings are consistent with the results of other studies where compost amendments generally increased the nutrients and SOM availability in soils

(Cuevas et al., 2000; Aggelides and Londra, 2000; Egashira et al., 2003). To the best of our knowledge there is no report on nematode community in subsoils, thus our results provide a novel observation that initial nematode abundance and genus number are significantly lower in subsoil than in topsoil plots, which may be due to the fact that subsoil is usually very compacted and lacks food sources for nematodes. For plant-parasitic nematodes, this is especially true since plant root density is usually lower in the subsoil than in topsoil (Rey et al., 2002). This finding is also in general agreement with the fact that most soil microorganisms and microarthropods are found in the top 10 cm of soil (Rey et al., 2002; Coulson et al., 1995). However, an interesting finding is that initial nematode abundance and genus number were reduced by compost amendment. A probable cause of this suppression may be the accumulation of nitrogenous compounds in the soil after compost addition (Nahar et al., 2006; Abawi and Widmer, 2000). In addition, as the compost used in this study is a mix of sawdust and a by-product of wastewater treatment, it is impossible to rule out the presence of toxic substances in the compost.

Turfgrass germination was better on topsoil plots compared to subsoil plots, but topsoil plots were invaded rapidly by weeds. Weed infestation was much lower in subsoil plots than topsoil plots, probably due to the lack of weed seed bank. As our turfgrass management plan for this study was not to use any chemical pesticides, two months after seeding, turfgrass cover on subsoil and subsoil+compost plots became significantly higher due to lower weed infestation. This finding suggests that weed control is important during the early stage of turfgrass establishment on topsoil.

The purpose of our later samplings was to compare soil nitrogen pools, microbial biomass, SOM, and nematode community dynamics in the four main soil treatments during turfgrass establishment and the effects of three N fertilization rates

on these above parameters during the course of turfgrass maintenance. N pools, microbial biomass, and SOM generally remained lower in the subsoil plots compared to topsoil plots throughout the study period, suggesting that even after one year of maintenance, the original differences in subsoil and topsoil still remained. With compost amendment, DON, microbial biomass, and SOM were higher compared to the no compost plots during the course of turfgrass establishment and maintenance. Similarly, nematode abundance (especially of free-living nematodes) remained higher in topsoil than in subsoil plots throughout the study period. This raises another interesting question that how long does it take for nematode community in subsoil to develop abundance and trophic diversity similar to that in topsoil, under the influence of turfgrass growth and maintenance.

Nematode community responded rapidly to compost amendment. Generally, organic matter inputs in the form of compost, animal manures and cover crops increase energy availability for the soil microbes thereby enhancing microbial activity and biomass (Lundquist et al., 1999; Gunapala and Scow, 1998; Powlson et al., 1987; Alon and Steinberger, 1999). The increase in microbial biomass and SOM caused by compost amendment was also observed in the current study as discussed above. Therefore, the observed increase in the abundance of total nematodes and free-living nematodes could be attributed to increases in their food availability (Ferris et al., 1999 and 2001; Griffiths et al., 1994; Nahar et al., 2006; Bulluck et al., 2002). However, both nematode MI and CMI were lower in plots with compost amendment in our study. Similar findings have been reported by Bulluck III et al. (2002). The reason for lower MI and CMI could be that low c-p value bacterivore nematodes can respond most rapidly to the increased food resources in soil brought by compost amendment (Bulluck III et al., 2002). In deed, in our study, the increase in total nematode

abundance was mainly attributed to the increase in low c-p value nematodes. With the relatively greater increase in low c-p value bacterivore nematodes, the MI and CMI are lowered, reflecting a disturbed soil food web (Bongers, 1990; Bongers and Bongers, 1998).

Significant differences were found in soil  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  pools among three N fertilization rates overall during the course of this study, whereas no-input plots generally had lower  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  pools compared to plots with N inputs. However, no differences were noted for nematode abundance and community indices under different N application rates overall during the study period. In contrast, different results were found in our another study comparing long-term effects of nine different turfgrass management regimes (Chapter 3), where no differences in N pools were noted among N application rates, but MI, CMI, and EI were generally affected by N rates. The possible reason for these different findings could be that all plots in the long-term study were established on agricultural field soils, where initial soil biota and nutrient pools were probably very abundant. In fact, for  $\text{NO}_3\text{-N}$ , MI, and CMI, the soil and nitrogen interaction terms were found to be significant in explaining the variance of data, suggesting that difference in the initial soil nutrient pools in the two studies could play a role for the differences. In addition, the N application could impose long-term (after 15-year continuous management in the study discussed in Chapter 3) cumulative effect on nematode food web rather than short-term (45 days after each fertilization in this study) impact. The long-term effect may reflect a relatively stable shift of nematode food web rather than a temporary change. This is in fact one of the major difference between this study and our previous study detecting the long-term management effects after 15 years (Chapter 3).

High EI represents the availability of new resources due to organism mortality, turnover, or favorable shifts in the environment (Odum, 1985). With the addition of compost amendment, EI increased. But high EI in turfgrass soils may also be maintained by continuous return of grass clippings, which is also considered as a high N source (Kopp and Guillard, 2002). Structure index, which represents the diversity of trophic links in a nematode food web, was generally lower in subsoil and subsoil+compost plots compared to the topsoil and topsoil+compost plots during the course of turfgrass establishment and maintenance. This is in general agreement with the lower abundance of high c-p value nematodes found in the subsoil and subsoil+compost plots as discussed above. Compost amendment did not increase SI significantly probably because low c-p value bacterivore nematode population was stimulated faster by compost than high c-p value nematode population (Bulluck III et al., 2002). Faunal profile analysis combining EI and SI indicated that food webs in subsoil plots were poorly enriched and poorly structured, while food webs in subsoil+compost plots were highly enriched and poorly structured. In contrast, soil food webs in both topsoil and topsoil+compost plots were highly enriched and poorly to moderately structured. However, soil food webs in undisturbed natural grasslands and forest ecosystems are usually poorly to moderately enriched but highly structured due to the relative dominance of high c-p value nematodes (De Goede and Bongers, 1998; Ferris et al., 2001). Therefore, as a comparison, soil food web in turfgrass ecosystems indicates a relatively disturbed food web with poor structure compared to the natural grasslands and forest ecosystems.

The temporal progression of nematode food web generated several interesting findings. First, EI increased significantly in subsoil plots during the one-year study period. As we found in this study, SOM, which is considered to affect the capacity of

the soil to act as an environmental buffer by absorbing or transforming chemicals (Marquez et al., 1999), is low in subsoil plots. Thus, the enrichment impacts from fertilization and return of grass clippings could be more easily reflected in subsoil. This could also explain why SI in subsoil plots kept steady even after one year of turfgrass establishment and maintenance. For the relative decrease of EI in subsoil+compost and topsoil+compost plots, it is possible that the initial positive impact of compost amendment is gradually disappearing. In addition, SI decreased in both topsoil and topsoil+compost plots, suggesting the decrease in relative abundance of high c-p value nematodes during the study period. This is probably due to the continuous physical disturbance caused by soil compaction due to mowing activities, and chemical disturbance caused by fertilization and clippings returns. Another interesting finding is that all the soil food webs indicated by EI and SI tended to move towards each other during the course of turfgrass establishment and maintenance. Although it might be the temporary shift at the early stage of the nematode food web recovery, we suspect this suggests a homogenizing force of turfgrass on the soil food web, which is an evidence of bottom-up control. To test this hypothesis, long-term monitoring of nematode food web conditions needs to be performed.

## **2.5. Acknowledgment**

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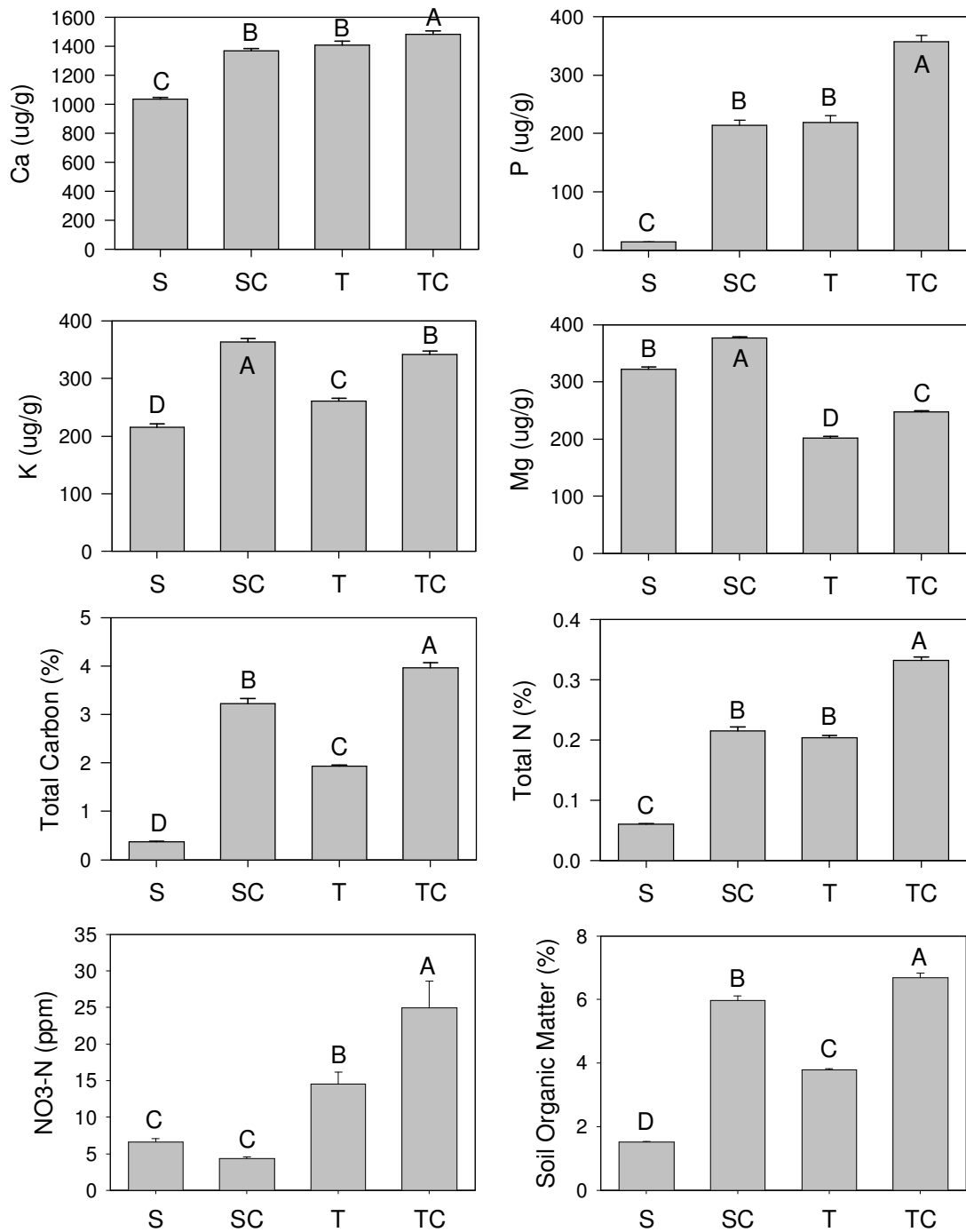
**Table 2.1:** List of nematode genera identified in four main soil treatments at all sampling times

S=Subsoil; SC=Subsoil+Compost; T=Topsoil; TC=Topsoil+Compost

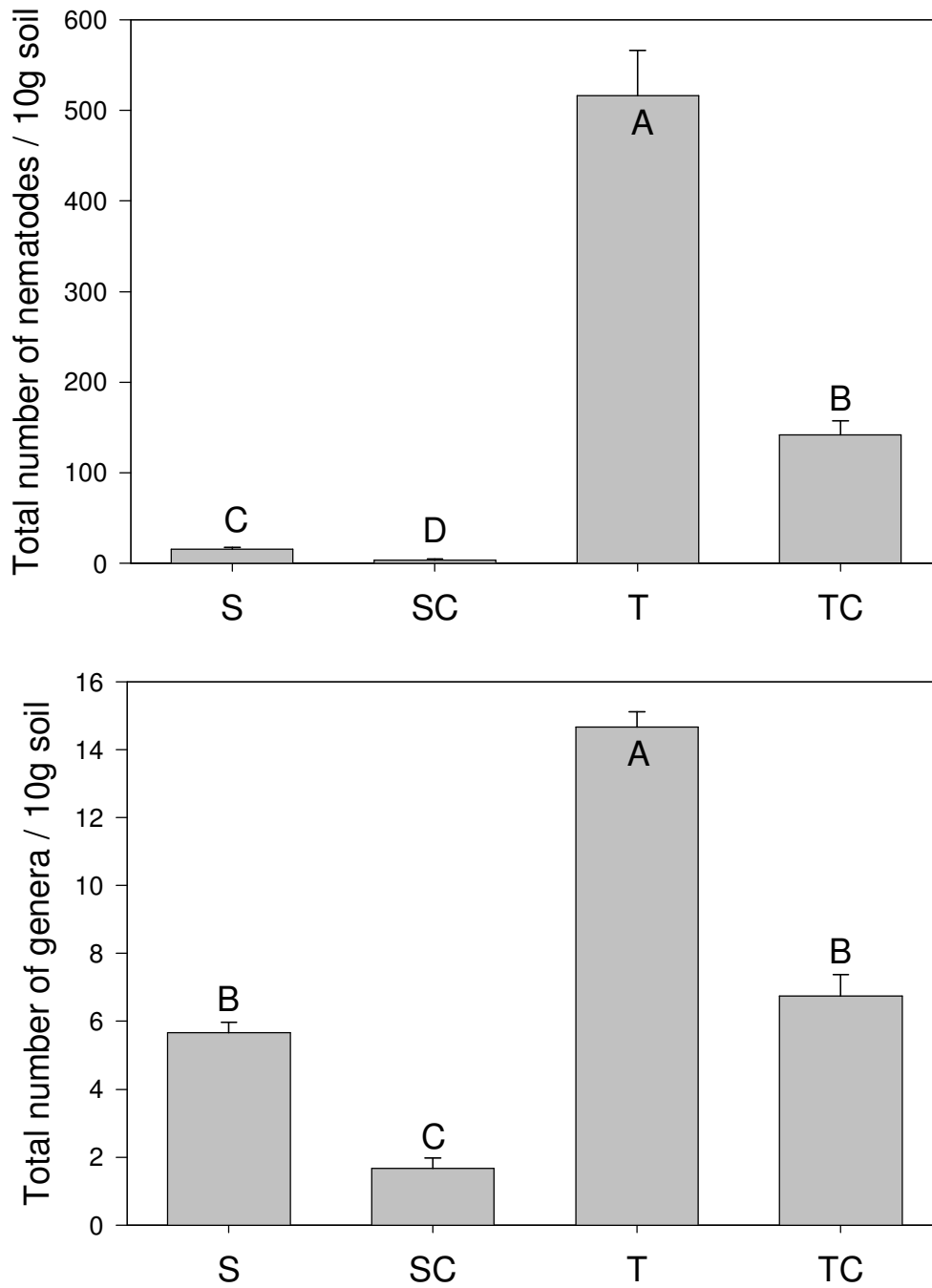


<i>Parameter</i>	<i>Soil treatment</i>	<i>Nitrogen application</i>	<i>Soil * Nitrogen</i>
NH <sub>4</sub> -N	0.0073 †	0.0059	0.55
NO <sub>3</sub> -N	<.0001	<.0001	0.0098
Dissolved Organic N (DON)	<.0001	0.56	0.53
Microbial Biomass (N)	<.0001	0.47	0.65
Soil Organic Matter (SOM)	<.0001	0.08	0.40
Total nematode abundance	<.0001	0.79	0.12
Total genera number	<.0001	0.96	0.39
Free-living nematode (FLN) abundance	<.0001	0.45	0.23
Plant-parasitic nematode (PPN) abundance	<.0001	0.32	0.13
Maturity Index	<.0001	0.16	0.030
Plant-parasitic Index	<.0001	0.60	0.20
Combined Maturity Index	<.0001	0.17	0.024
Enrichment Index	<.0001	0.15	0.087
Structure Index	<.0001	0.87	0.81

**Table 2.2:** P values obtained from repeated measures analysis (Two-way ANOVA) showing the overall impact of four main soil treatments and three nitrogen application rates on soil nitrogen pools, microbial biomass, soil organic matter, nematode abundance, and nematode community indices after turfgrass establishment

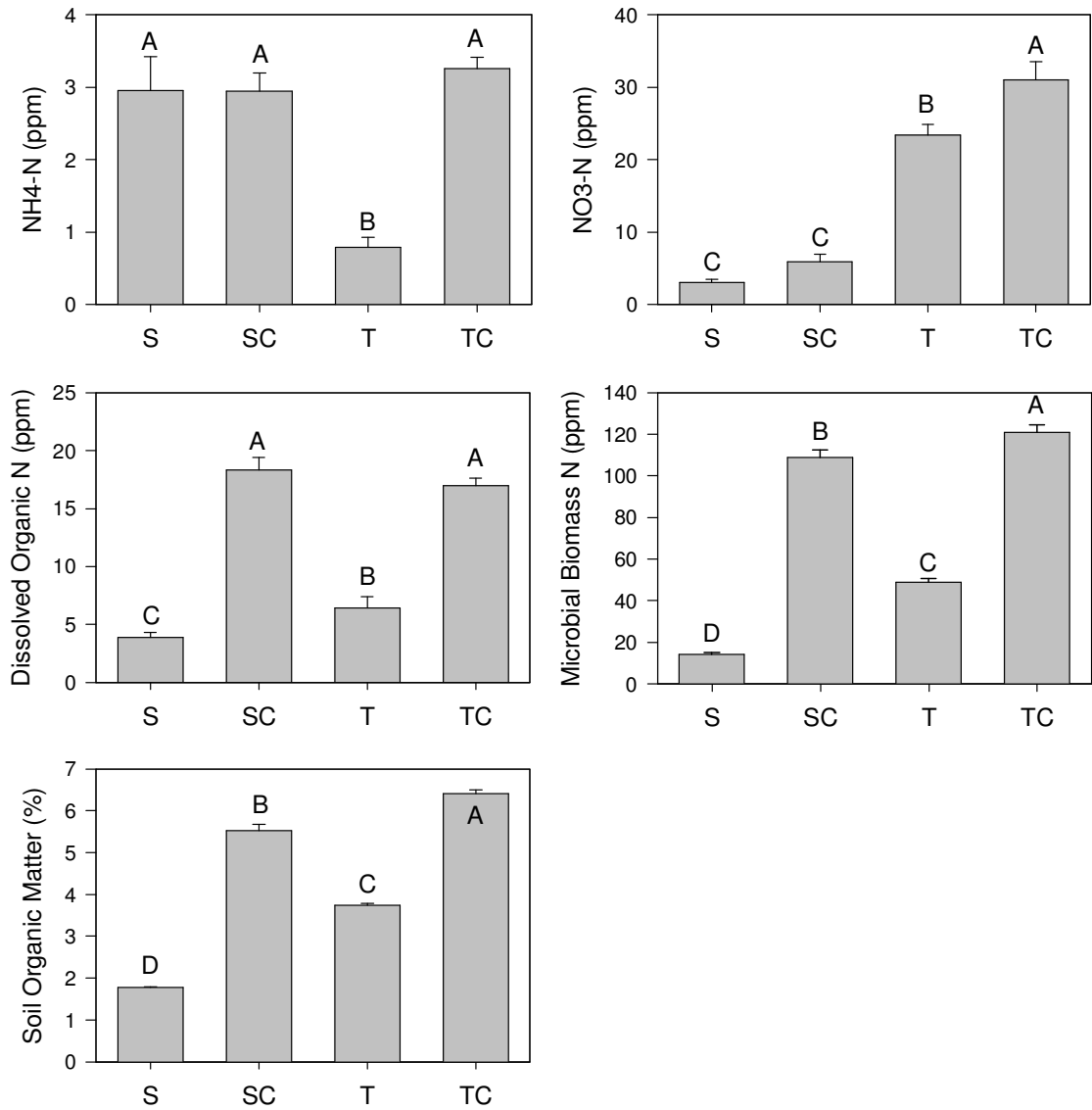


**Figure 2.1:** Effect of four main soil treatments on initial soil nutrient pools before turfgrass establishment (first sampling at May 2006). Data are Mean + SE. S=Subsoil; SC=Subsoil+Compost; T=Topsoil; TC=Topsoil+Compost.

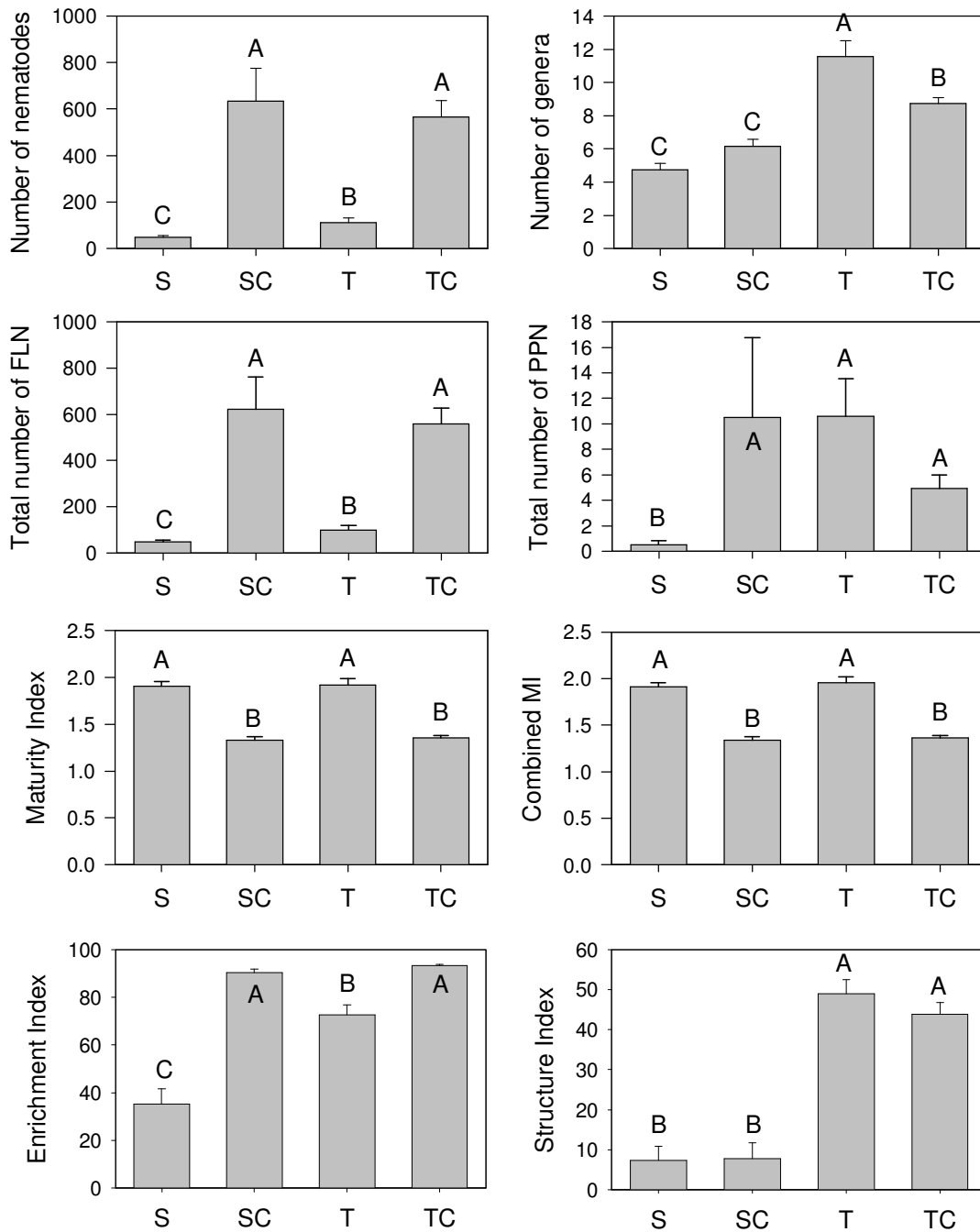


**Figure 2.2:** Effect of four main soil treatments on initial soil nematode abundance and genus number before turfgrass establishment (first sampling at May 2006). Data are Mean + SE. S=Subsoil; SC=Subsoil+Compost; T=Topsoil; TC=Topsoil+Compost.





**Figure 2.3:** Effect of four main soil treatments on soil nitrogen pools, microbial biomass N, and SOM after turfgrass establishment, but before fertilization (second sampling at July 2006). Data are Mean + SE. S=Subsoil; SC=Subsoil+Compost; T=Topsoil; TC=Topsoil+Compost.



**Figure 2.4:** Effect of four main soil treatments on soil nematode abundance and community indices after turfgrass establishment, but before fertilization (second sampling at July 2006). Data are Mean + SE. S=Subsoil; SC=Subsoil+Compost; T=Topsoil; TC=Topsoil+Compost.



Subsoil



Subsoil+Compost

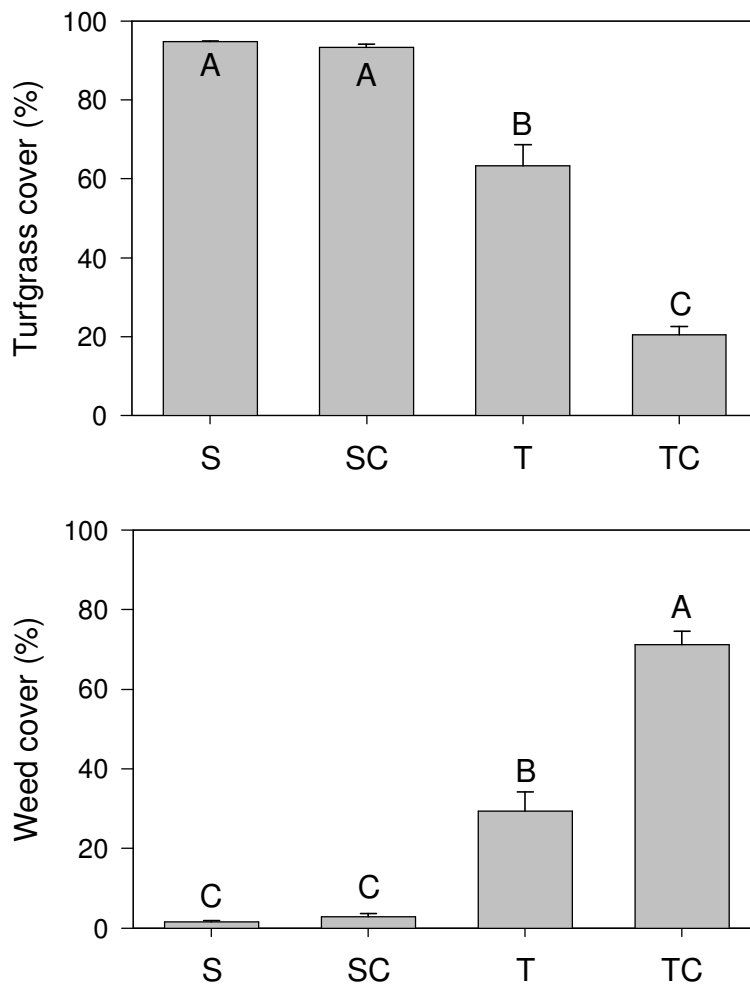


Topsoil

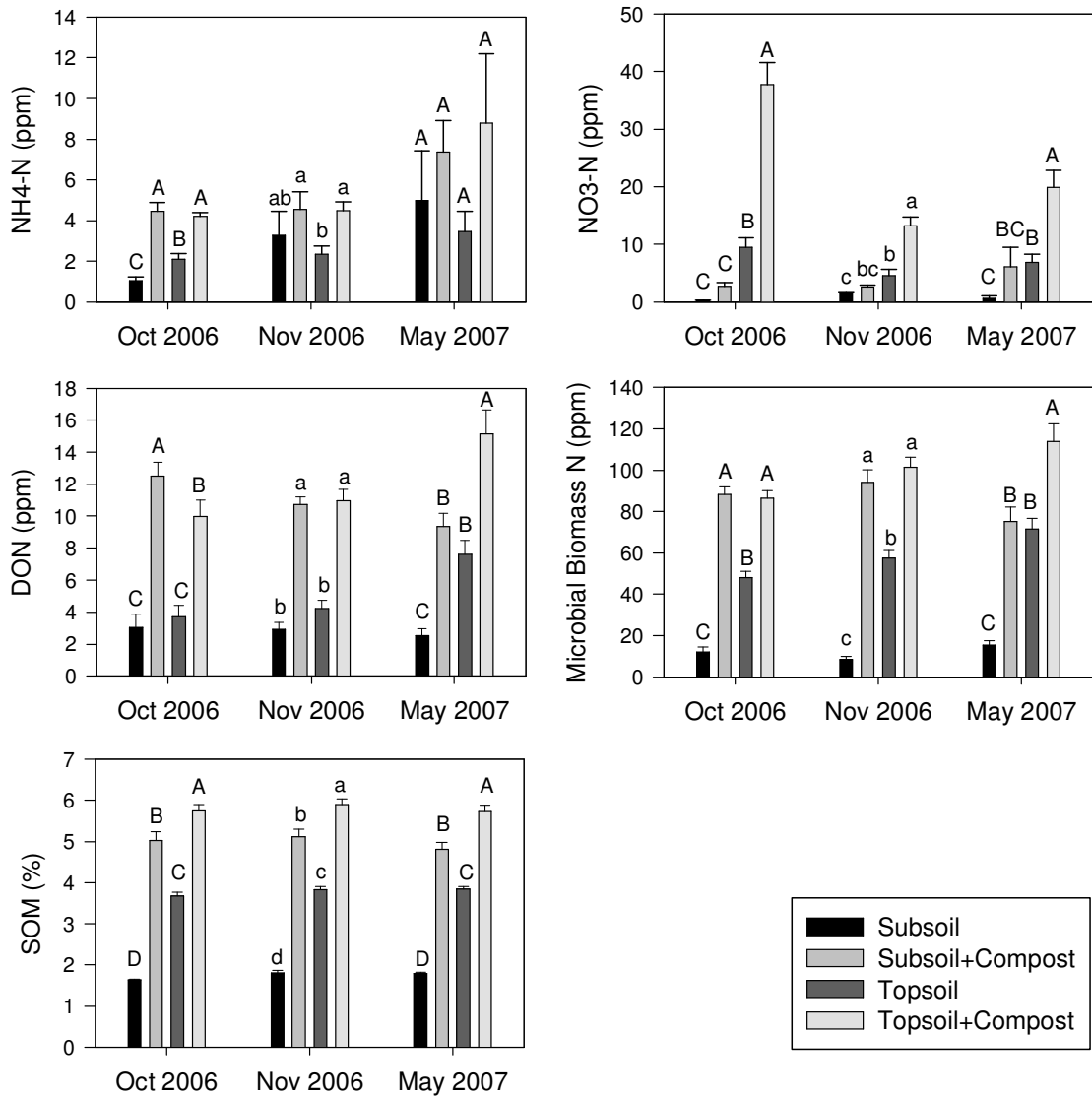


Topsoil+Compost

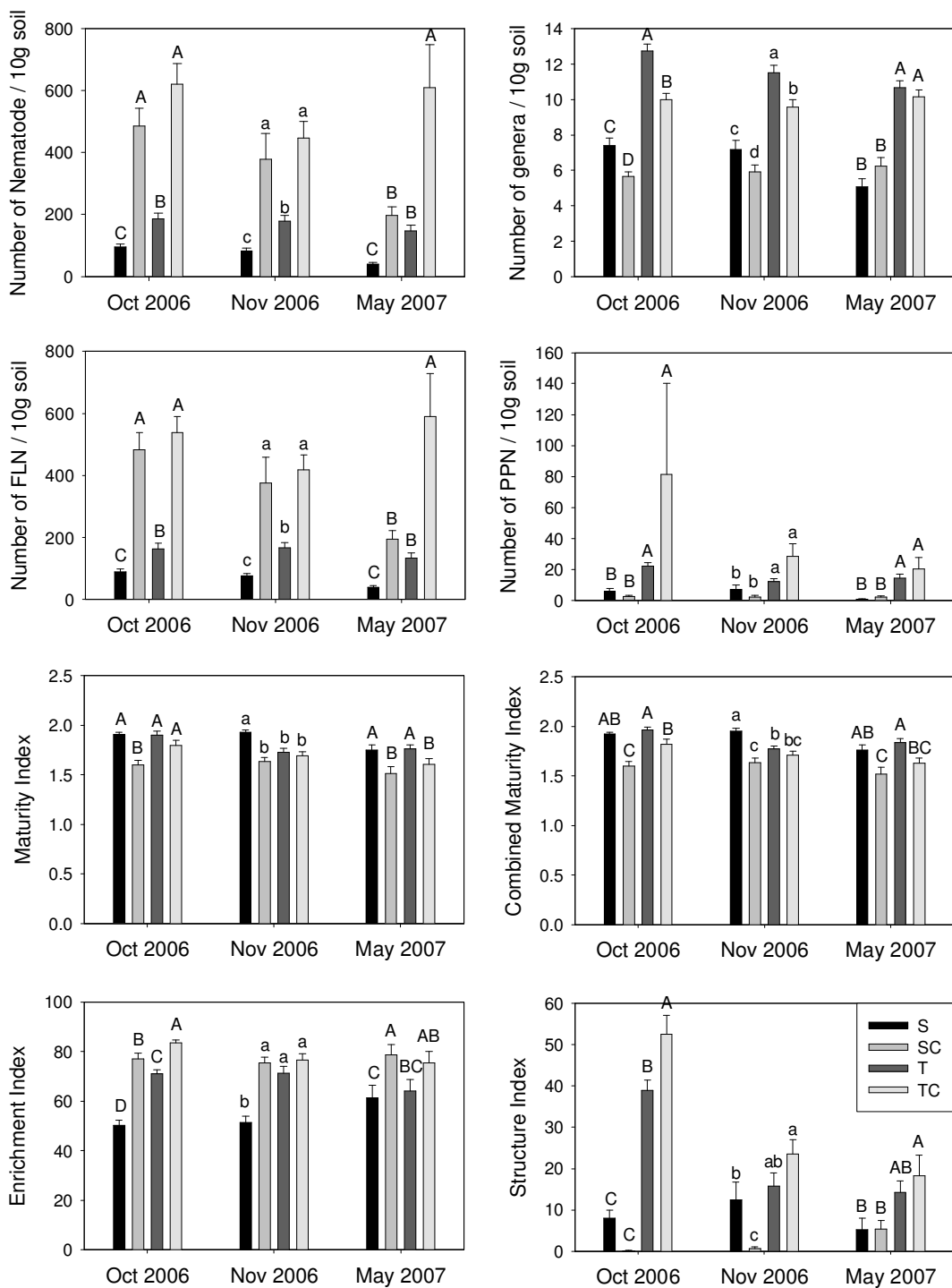
**Figure 2.5:** Comparison of turfgrass germination under four main soil treatments. Photos were taken two weeks after seeding.



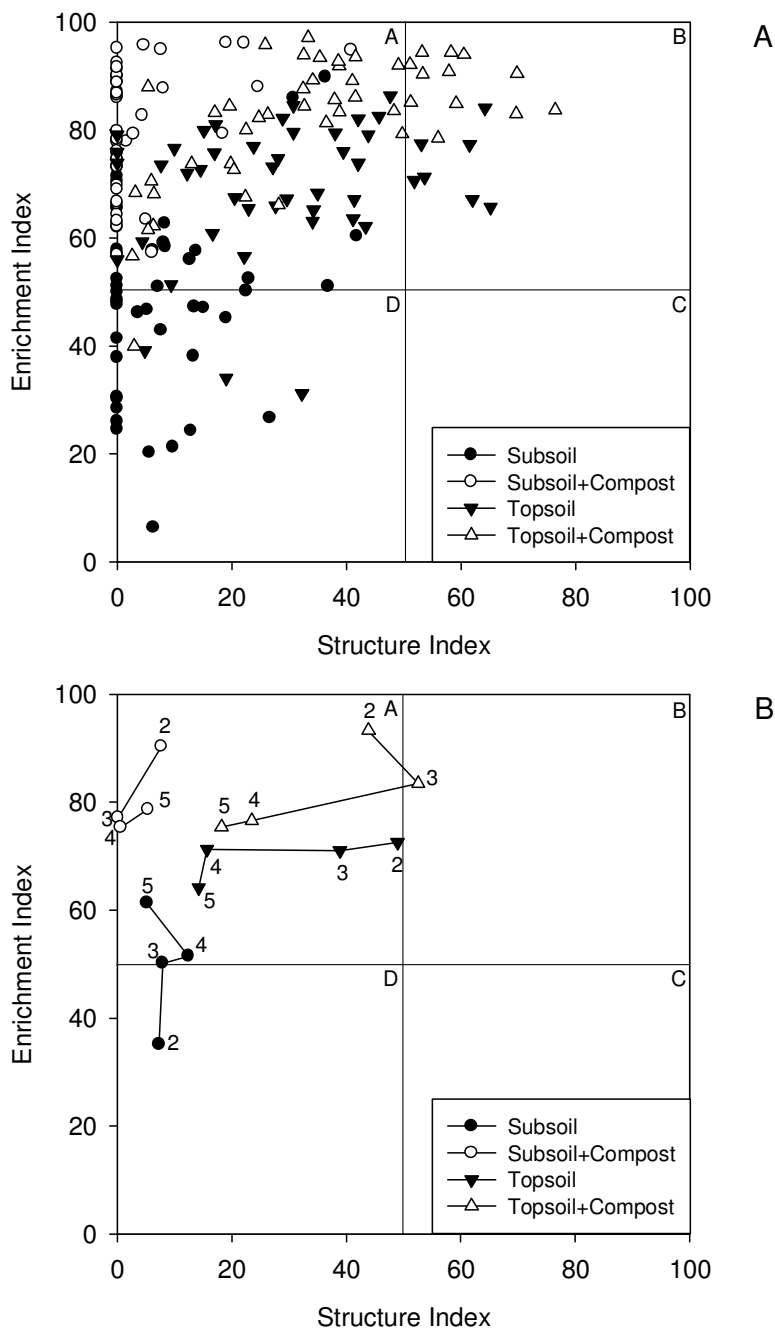
**Figure 2.6:** Percentage + SE turfgrass and weed cover under four main soil treatments two months after seeding. S=Subsoil; SC=Subsoil+Compost; T=Topsoil; TC=Topsoil+Compost.



**Figure 2.7:** Effect of four main soil treatments on soil nitrogen pools, microbial biomass N, and SOM during turfgrass maintenance. Data are Mean + SE.



**Figure 2.8:** Effect of four main soil treatments on soil nematode abundance and community indices during turfgrass maintenance. Data are Mean + SE. S=Subsoil; SC=Subsoil+Compost; T=Topsoil; TC=Topsoil+Compost.



**Figure 2.9:** A) Nematode food web enrichment and structure deduced from faunal analysis under four main soil treatments. Each point represents the EI and SI scores for an experimental plot at one of the last four sampling times; B) Temporal progression of the nematode food web under four main soil treatments. Each point represents the EI and SI scores for a soil treatment at one of the last four sampling times (numbers 2-5). Last four sampling times: July 2006, October 2006, November 2006, May 2007.

## CHAPTER 3

### EFFECTS OF LONG-TERM TURFGRASS MANAGEMENT PRACTICES ON SOIL NITROGEN POOLS, MICROBIAL BIOMASS, ORGANIC MATTER, AND NEMATODE COMMUNITY

#### Abstract

The impact of long-term turf management practices on soil nematode abundance, community structure and soil nutrient pools were studied in replicated Kentucky bluegrass (*Poa pratensis*) plots maintained under nine different organic- and mineral-fertilizer management regimes for 15 years in Delaware, Ohio. Soil samples were collected in September 2003, July 2004 and October 2004. All free-living and plant-parasitic nematodes were identified to genus level and counted. Total nematode abundance, free-living nematode (FLN) abundance, plant-parasitic nematode (PPN) abundance, genus diversity, richness, evenness, maturity index (MI), plant-parasitic index (PPI), and combined maturity index (CMI) were calculated. In addition, soil nematode faunal profile analysis was conducted to determine soil food web condition by using enrichment index and structure index.  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , dissolved organic nitrogen (DON), microbial biomass nitrogen (MBN), and soil organic matter (SOM) were measured to describe soil status. Results from repeated



measures analysis of variance showed that in general, nematode abundance and food web indices were not differently affected by the 9 management regimes. However, nematode community indices, MI and CMI, were generally lower and Enrichment Index was generally higher under high and medium N-input compared to low N-input management. Herbicide, insecticide, or fungicide applications had no significant negative effect on nematode community in turfgrass soil ecosystem. Overall, the soil food webs were highly enriched but poorly to moderately structured in all management regimes. In addition, organic-fertilizer based turf management resulted in higher soil microbial biomass in general compared to mineral-fertilizer management or the control. But herbicide, insecticide, or fungicide applications had no significant negative effect on soil microbial biomass and soil organic matter.

### **3.1. Introduction**

Turfgrass lawns have become a central part of urban and suburban landscapes throughout North America. Milesi et al. (2005) estimated that the total turfgrass area, including residential, commercial, and institutional lawns, golf courses, and parks, occupied 163,800 km<sup>2</sup> ( $\pm$  35,850 km<sup>2</sup>) in the U.S., and this area is expanding because of rapid urbanization (Robbins and Birkenholtz, 2003). Currently, turfgrass occupies about 20 million ha in the USA (Qian and Follett, 2002) and is expanding because of rapid urbanization (Robbins and Birkenholtz, 2003). With dense shoots above ground, well-developed root system and large amounts of biomass underground, turfgrass provides many environmental benefits, including

soil erosion protection, water runoff and leaching control, contributing to carbon sequestration, moderating temperature, reducing noise, glare, and visual pollution (Beard and Green, 1994). Consumer demands for improved lawn quality and control of pests that may impair its quality can be exasperated by lawns planted to poorly adapted cultivars and/or improper cultural inputs. Consequently, lawns increasingly have become chemical input intensive systems with repeated, often routine, applications of water-soluble fertilizers, herbicides, and insecticides. For example, in Ohio, a 2001 survey of commercial pesticide applicators indicated that nearly 65% of the respondents applied pesticides to turfgrass, with an average amount of 4.72 kg of active ingredient per ha (Young et al., 2003). These inputs are expensive, and are often perceived as a significant source of environmental contamination, which may impair natural ecological processes in the lawn ecosystem and threaten nearby water bodies (Overmyer et al., 2005). Unlike other grass ecosystems, turf lawn ecosystems are very rich in organic matter due to extensive root growth and the continuous addition of clippings following mowing (Strom et al., 1992). Thus, turf ecosystems have high potential for microbial activity (Horst et al., 1996) that can rapidly degrade chemical pesticide inputs (Starrett et al., 1994; Gan et al., 2003). Therefore, the net effect of management practices on lawn soil ecosystems may be negligible. Thus, we hypothesized that proper applications of herbicides, insecticides, and fungicides to turfgrass will not negatively affect soil microbial biomass or food web condition, especially in the long run.

Besides several key ecological indicators (various N pools, microbial biomass, soil organic matter) in turfgrass soil ecosystems, nematode community is studied for an in-depth understanding of soil food webs. Nematodes are the most abundant metazoa on the earth (Ferris et al., 2001) and they play an essential role in the soil and sediment ecosystems, appearing at almost every trophic level such as bacterivores, fungivores, plant parasites, predators, and omnivores (Yeates et al., 1993). Since nematodes depend on the continuity of soil water films for movement, their activities are largely controlled by soil physical and biological conditions (Yeates and Bongers, 1999). Also, nematodes are in direct contact with dissolved chemicals in the soil solution through their permeable cuticle and can react rapidly to disturbances and contaminants. Thus, nematodes can provide a good indication of the condition of soil food web, environmental disturbance, and pollution. In addition, compared to soil microbial groups, representative samples of soil nematode communities are easy to obtain and they are relatively easy to identify and count (Ritz and Trudgill, 1999). Therefore, nematodes are used as indicators for assessing the conditions of soil environment (Ritz and Trudgill, 1999; Neher, 2001; Somasekhar et al., 2002; Nahar et al., 2006). However, studies of nematode community in turfgrass soil ecosystem are few, and most of them deal only with plant-parasitic nematodes.

Ferris et al. (2001) established a new faunal profile analysis matrix that relates soil nematode community to soil food web health. This model integrates nematode feeding groups (Yeates et al., 1993) and the *colonizer-persister* scale (cp scale) into a

matrix classification of functional guilds. The cp scale is composed of five levels (1-5). The colonizers whose reproduction rates are high receive a low value; while the persisters, which reproduce slowly, are placed in high cp categories. According to this model, from basal conditions, indicated by the dominance of Ba<sub>2</sub> and Fu<sub>2</sub> guilds (bacterivores and fungivores which are in cp-2 categories), there are two developing trajectories for the soil food web, one of which is enrichment trajectory, and the other is structure trajectory. Opportunistic non-herbivorous guilds, Ba<sub>1</sub> and Fu<sub>2</sub>, are considered as indicators for enriched food web. While large-bodied high cp guilds (cp 3-5) are indicators for structured food web, which has more complex trophic correlations and where recovery from stress is occurring. Therefore, we hypothesized that the amount of nitrogen fertilizer input will affect soil nematode community and food web health in the long term. Specifically, higher amount of N input will increase the relative abundance of low c-p value nematodes.

Due to the concerns of potential negative impacts of chemical fertilizers and pesticides, organic lawn management practices are becoming attractive. Major objectives of organic lawn care approach are to substantially reduce the addition of synthetic fertilizers and pesticides, improve turf quality and density, enhance resistance to pests and diseases, and improve soil quality and nutrient availability (Northeast Organic Farming Association, 2004). However, it is not clear whether turfgrass soil food webs differ under organic management compared with conventional lawn management, especially in the long term. Hence, this study determined the impacts of varied long-term turf management practices, both organic

and inorganic, on turf soil ecosystem conditions in experimental turfgrass plots. Here, we hypothesized that organic-fertilizer management improves turf soil ecosystem conditions over the mineral-fertilizer input management.

## **3.2. Materials and Methods**

### *3.2.1. Management regimes and experimental design*

The field experiment was conducted on Kentucky bluegrass (*Poa pratensis*) turf established at TruGreen Technical Center in Delaware, Ohio in autumn of 1983. The soil type is Blount Clay / Silt Loam and this area was used as farmland before the Technical Center was established. The mean temperature at the site is 15°C in spring and 21°C in summer. The mean precipitation is 98 mm in spring and 90 mm in summer. Turfgrass was mowed weekly at 5 cm height up to the year 2000 and 6.25 cm thereafter. Clippings were returned to the turf.

In spring 1989, a long-term study was initiated to examine differences in turfgrass response to varying input regimes. The study plots were maintained annually from 1989 to 2003 for a total of 15 years. A total of 9 management regimes were evaluated (Table 3.1). They can be broadly categorized into Control, Organic-fertilizer management, and Mineral-fertilizer management. They can also be grouped based on four levels of N application rate (considering the control). The details are as follows: 1) Untreated Control, 2) Organic a (Oa): with four bi-monthly granular organic fertilizer applications, high N input, 3) Organic b (Ob): with four bi-monthly organic fertilizer applications and once each spring a

post-emergent herbicide applied to control broadleaf weeds, high N input, 4) Mineral High-N a (MHNa): with five granular urea-N mineral fertilizer applications, 5) Mineral Low-N (MLN) with liquid urea-N fertilizer and post-emergent herbicide applied each spring and fall, 6) Mineral High-N b (MHNb): with monthly applications of either liquid urea-N mineral fertilizer with spring-applied pre-emergent herbicide and post-emergent herbicide applied spring and autumn, or a fungicide application in late spring and granular blend of Sulfur Coated Urea (SCU) and urea-N fertilizer in summer and late fall, 7) Mineral High-N c (MHNc): with five applications every six weeks of liquid urea-N mineral fertilizer, pre-emergent herbicide in spring, and post-emergent weed control each spring and autumn, 8) Mineral High-N d (MHNd): with five applications every six weeks of granular urea-N mineral fertilizer, impregnated with pre-emergent herbicide in spring, and a sequential liquid spray of post-emergent herbicide annually in spring and autumn, and 9) Mineral Medium-N (MMN): with four semi-monthly applications of a consumer-formulated granular urea-N mineral fertilizer alone or impregnated with pre-emergent herbicide, post-emergent herbicide, or surface insecticide.

Treatments were arranged in a randomized complete block design with four replications. Each plot was 2.4 m by 1.2 m. Oa, Ob, and MM were established in 1990 and all other regimes were established in 1989. Beginning August 2003, all managements were discontinued except for mowing.

### *3.2.1.a Fertilizer Treatments*

Oa and Ob used RichLawn commercial organic fertilizer (Richlawn Turf, Platteville,

CO) for the first 9 years and Ringer commercial organic fertilizer (Woodstream Corporation, Lititz, PA) thereafter. All other fertilizer treatments contained urea, sulfur coated urea, ammonium phosphates, and potassium chloride. The regimes differed in N-P-K composition and application rate, where MLN received lowest N input ( $98 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ) compared to other regimes that received medium and high N input ( $171\text{-}245 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ). The Control was not fertilized.

#### *3.2.1.b. Pesticide Treatments*

Pesticide applications were applied annually as follows: the pre-emergent herbicide pendimethalin was applied each spring to regimes 5-9; broadleaf herbicide containing MCPA + mecoprop + Dicamba was applied to regimes 3 and 5-8, while a mixture of 2,4-D + mecoprop+Dicamba was applied to regime 9; the insecticide diazinon was applied to regime 9; and the fungicide triadimefon was applied to regime 6.

#### *3.2.2. Soil sampling*

Soil samples were collected in September 2003, July 2004 and October 2004 to take into account the seasonal variation associated with nematode populations. Soil samples were taken from each plot with a 3 cm diameter soil probe to a depth of 15 cm. A linear transect was set across each plot and one soil core was collected from each of the four sampling points evenly spaced along the transect. All 4 soil cores from each plot were mixed to make one composite sample in order to reduce the variance with aggregated spatial patterns of nematodes in soil (Barker and Campbell, 1981). Soil samples were placed in polyethylene bags to prevent water loss and

were kept in a cooler while in transit to the laboratory and during handling.

Samples were stored at 4 °C before analysis to minimize changes in nematode populations and biochemical reactions (Barker et al., 1969).

### 3.2.3. *Extraction and identification of nematodes*

Nematodes were isolated from soil samples following the Baermann funnel technique (Flegg and Hooper, 1970). Ten grams of soil from each composite sample was placed on each funnel. After 72 hours, nematodes in the water were collected in plastic vials through a rubber tube attached beneath each funnel.

Nematodes were allowed to settle for at least 12 h at 4 °C and then the upper layer of water was discarded carefully without disturbing the nematodes until about 5 ml of suspension remained. The nematodes were killed and fixed using 5 ml boiling TAF solution (70 ml formaldehyde + 20 ml triethanolamine + 910 ml distilled water) in a fume hood (Shepherd, 1970). Finally, nematodes were identified and counted using a stereomicroscope. All nematodes were identified to at least the genus level using published keys (Goodey, 1963; Mai and Lyon, 1975). They were then assigned to a trophic group (plant parasites, fungivores, bacterivores, omnivores or predators) according to Yeates et al. (1993) and a colonizer-persister (c-p) value was assigned according to Bongers (1990). Two replications were conducted for each soil sample and these two data were combined for nematode community analysis.

Nematode numbers were not corrected for extraction efficiency which is about 85% for the method we used (Grewal, 1991).



#### 3.2.4. Nematode community and food web indices

Two different aspects of community structure contribute to species/genus diversity, i.e., species/genus richness and species/genus evenness. Diversity index incorporates both richness and evenness components and can provide heterogeneity information for vegetation and wildlife studies. In this study, nematode genus richness, diversity, and evenness were calculated using the following formulae:

Richness Index (*Margalef*) =  $(G-1)/\ln(n)$ , where  $G$  is the total number of genera and  $n$  is the total number of individuals in a community; Diversity Index

(*Shannon-Weiner Index*)  $H' = -\sum P_i(\ln P_i)$ , where  $P_i$  is the proportion of genus  $n_i$  in the nematode community  $n$ ; and Evenness Index (*Pielous index*)  $J' = H'/\ln(G)$  where  $G$  is the number of genera in the community (Pielou, 1977).

Maturity Index (MI), considering free-living nematodes only, was calculated using the formula  $MI = (\sum v_i f_i)/n$ , where  $v_i$  is the c-p value assigned to nematode genus  $i$ ,  $f_i$  is the frequency of nematode genus  $i$ , and  $n$  is the total number of individuals in the soil sample (Bongers, 1990). Plant parasitic index (PPI) was calculated based only on plant parasitic nematodes as  $PPI = (\sum v_i f_i)/n$  where  $v_i$  is the c-p value for the plant-parasitic nematode genus  $i$ , and  $f_i$  is the frequency of plant-parasitic nematode genus  $i$ , and  $n$  is the total number of individuals in the soil sample (Bongers, 1990). The combined maturity index (CMI) included both plant parasitic and free-living nematode genera and was calculated as  $CMI = (\sum v_i f_i)/n$ , where  $v_i$  is the c-p value of nematode genus  $i$ ; and  $f_i$  is the frequency of nematode genus  $i$  and  $n$  is the total number of individuals in the soil sample.

The enrichment index (EI) and structure index (SI) provide information for the enrichment and structure of the soil food web and were calculated according to Ferris et al. (2001). First, basal components ( $b$ ) of the food web (fungal and bacterial feeders in the c-p 2 guild) were calculated as  $b = \sum k_b n_b$  where  $k_b$  is the weighted constant for the guild, and  $n$  is the number of individuals in that guild. Then enrichment ( $e$ ) and structure ( $s$ ) components were calculated, using nematode guilds indicative of enrichment (bacterivores in c-p 1, and fungivores of c-p 2), and structure (bacterivores in c-p 3-5, fungivores c-p 3-5, omnivores of c-p 3-5, and predatory nematodes of c-p 2-5). Finally the EI was calculated as  $100 * e/(e + b)$ , and the SI as  $100 * s/(s + b)$ .

### *3.2.5. Soil N pools, microbial biomass, and organic matter analysis*

Soil sand, silt, and clay content were analyzed using a method described by Kettler et al. (2001) with some modifications. Soil organic matter (SOM) was measured by calculating the weight loss during ignition (Storer, 1984).  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , and dissolved organic nitrogen (DON) were extracted from soil by adding 0.5 M  $\text{K}_2\text{SO}_4$  solution, and were digested by alkaline persulfate oxidation (Cabrera and Beare, 1993). They were then determined using a modification of the indophenol blue technique in microtiter plates (Sims et al., 1995). The concentration of DON in filtrates is calculated as the difference between total nitrogen and mineral nitrogen. Microbial biomass nitrogen (MBN) is determined using a modification of the chloroform fumigation method described by Brookes et al. (1985). A 10 g of coarsely screened soil is fumigated with ethanol-free chloroform in the dark for 48 hours and

extracted again with 0.5 M K<sub>2</sub>SO<sub>4</sub> solution. The extract is filtered and digested by alkaline persulfate oxidation (Cabrera and Beare 1993) and the concentration of total nitrogen in the digested filtrate is determined using the modified indophenol blue technique (Sims et al., 1995). MBN is calculated as the difference between total extractable nitrogen from unfumigated and fumigated soil samples, assuming extraction efficiency for MBN of 0.45 (Jenkinson, 1988). The concentration of each of the nitrogen pools is expressed as ppm.

### *3.2.6. Statistical analysis*

Repeated measures analysis of variance (PROC GLM, SAS Release 9.1, SAS Institute, Cary, NC) was performed to obtain *p*-values for the block experimental design using the appropriate error terms in the model, to take into account time and management\*time interaction. Soil nematode community indices and nutrient pools were compared among all nine regimes. In addition, in order to detect clear impacts from the rather complicated nine regimes, they were categorized into different management groups to perform repeated measures analysis of variance using the same statistical package. These group analyses were: A) control, low-N input (regime 5), medium-N input (regime 9), and high-N input (regimes 2-4 and 6-8); B) control, organic-fertilizer management (regimes 2 and 3) and mineral-fertilizer management (regimes 4-9); C) no-input control and inputs (all other regimes); D) management without herbicides (regimes 2 and 4) and with herbicides (regimes 3 and 5-9); E) management with insecticides (regimes 9) and without insecticide (regimes 2-8); and F) management with fungicides (regimes 6)

and without fungicide (regimes 2-5, 7-9). Fisher LSD was used for mean comparisons within each sampling season. Nematode population data were transformed as  $\ln(x+1)$  prior to statistical analysis to normalize the variance. An alpha level  $\leq 0.05$  was considered significant. In addition, analysis of variance based on P and K rate were performed separately and no significant differences were found (data not presented in this chapter).

### **3.3. Results**

#### *3.3.1. Nematode abundance*

Nematode genera identified in all nine management regimes are summarized in Table 3.2. Among the most abundant genera were *Rhabditis*, *Cephalobus*, *Acrobeloides*, *Aphelenchus*, *Dorylaimus*, *Pratylenchus*, and *Tylenchus*. Total number of nematode genera did not differ among the nine management regimes, but ranged from 6 to 22 per plot. Table 3.3 provides details of mean value  $\pm$  SE for nematode population and community indices measured under all 9 regimes. The number of total nematodes, free-living nematodes (FLN), and plant-parasitic nematodes (PPN) were not significantly different among the 9 regimes (Table 3.4). In addition, nematode abundance was not affected by insecticide, fungicide or herbicide applications (Table 3.4).

#### *3.3.2. Nematode community structure*

Maturity Index (MI) and Combined Maturity Index (CMI) were not significantly different among the 9 management regimes (Table 3.4). But group analysis of

variance suggested that MI and CMI were significantly different under managements with different N input overall (Table 3.4), where the trend was that they were higher under low N input compared to medium and high N input managements. This trend was significant in October 2004 samples (Figure 3.1 A, B). No significant differences were noted in Plant Parasitic Index (PPI), nematode species diversity (*Shannon-Weiner Index H'*), richness (*Margalef index*) and evenness (*Pielous Index J'*) indices under the 9 regimes (Table 3.4). Again, nematode community indices were not affected by insecticide, fungicide and herbicide applications (Table 3.4).

### 3.3.3. Food web condition

There was no significant difference for either Enrichment Index (EI) or Structure Index (SI) among the 9 management regimes overall (Table 3.4), but both were affected by time of sampling (EI:  $p < 0.0001$ ; SI:  $p < 0.0001$ ). However according to group analysis of variance, EI was significantly different under managements with different N input overall (Table 3.4), where the trend was that EI was lower under low N input compared to medium and high N input managements. This trend was significant in October 2004 samples (Figure 3.1 C). In addition, EI was marginally significantly higher in management with inputs than the control ( $p = 0.0578$ , Table 3.4). The soil nematode food web conditions described by EI and SI showed that most food webs were highly enriched and poorly to moderately structured (Figure 3.2).

### 3.3.4. Soil N pools, microbial biomass, and organic matter analysis

Average soil sand, silt, and clay contents were 18%, 75%, and 7%, respectively

in these plots. During the two-year sampling period, NH<sub>4</sub>-N ranged from 1.0 to 3.2 ppm; NO<sub>3</sub>-N from 0.7 to 38.8 ppm; DON from 0 to 22.7 ppm; MBN from 70.4 to 192.2 ppm; and SOM from 3.5% to 6.2% in all plots under 9 regimes. Table 3.5 provides details of mean value  $\pm$  SE for all nutrient pools measured under all 9 regimes. MBN and SOM differed significantly among the 9 regimes overall (Table 3.4), where Ob had the highest MBN. These were consistent with the result of group analysis (B) to detect the effect of fertilizer type (Table 3.4 and Figure 3.3 A, B). Organic-fertilizer regimes also resulted in significantly higher MBN and SOM compared to the control, while mineral-fertilizer regimes did not (Figure 3.3 A, B). In addition, MBN and SOM under no input management (the control) showed a trend to be lower than under management with inputs (Table 3.4 and Figure 3.3 C, D). However, MBN and SOM were not negatively affected by herbicide, fungicide, and insecticide application.

### **3.4. Discussion**

In this study, we found no significant differences in nematode abundance, free-living nematode (FLN) abundance, and plant-parasitic nematode (PPN) abundance among the 9 turfgrass management regimes. Soil nematodes, especially free-living nematodes, are generally favored by N input. But in this study FLN abundance did not differ significantly with the level of N input. Dunn and Diesburg (2004) suggest that without the addition of N and herbicides (the control, in this study), turfgrass systems are easier to be colonized by opportunistic weeds,

some of which are leguminous. In fact, white clover (*Trifolium repens*), a leguminous plant, did show significantly higher cover in the Control and Organic-fertilizer management compared to mineral-fertilizer management without weed control (Richmond and Grewal, 2003. unpublished data). Therefore, through their N fixation, weeds can enhance N availability in the absence of fertilizer input (Bormann et al., 1993). This could explain why nematode abundance in the control was not lower than that under management regimes receiving N inputs. We also did not detect any significant impact of insecticide, fungicide, and herbicide applications on total nematode abundance, FLN abundance, and PPN abundance. In addition, no significant differences were noted among the 9 regimes in terms of diversity (*Shannon-Weiner Index H'*), richness (*Margalef Index*) and evenness (*Pielous Index J'*) indices of the nematode community. This is consistent with other studies (Neher, 1999; Porazinska *et al.*, 1999; Bulluck *et al.*, 2002), where no significant differences were detected for nematode diversity, richness and evenness between chemical and organic inputs on agricultural farms. Starrett et al. (1994) found that pesticides including pendimethalin, MCPP, 2,4-D, dicamba, isozophos, chlorpyrifos, and metalaxyl degraded faster under turfgrass systems than some agronomic cropping systems. Another study comparing the effect of 4 different planting covers (turfgrass, ground cover, mulch, and tree) on herbicide persistence in landscape soils showed that in both surface and subsurface soils, the most rapid 2,4-D degradation occurred in the turfgrass soil (Gan et al., 2003). Therefore, it is suggested that turfgrass ecosystems are buffered against negative impacts of

chemical pesticides perhaps due to the high organic matter content (3.5% to 6.2% in this study) and high microbial activity associated with a turf soil ecosystem (Horst et al., 1996).

Although MI and CMI showed no significant differences among the original 9 regimes, we found they were generally lower under high and medium N input management compared to the low-N input management. Although this trend was only significant in October 2004 samples, the same trend was found in September 2003 and July 2004 samples as well. This is consistent with Bongers et al. (1997) who found a decrease in MI under the influence of N-fertilization. MI offers possibilities to measure changes in the functioning of the soil ecosystem as a result of disturbance and subsequent recovery (Bongers and Bongers, 1998). Higher maturity in the system is an indicator of higher c-p value nematodes and stable ecosystem (Bongers, 1990; Bongers and Bongers, 1998). Thus, our results suggested that the long-term higher rate of N input disturbed turf soil ecosystem functioning compared to low rate of N input. Similarly, when evaluating nematode food web conditions, EI was found to be generally lower under low N compared to high and medium N input management. This trend was only significant in October 2004 samples, but the same trend could be found in September 2003 and July 2004 samples as well, due to the fact that EI was also affected by time of sampling. High EI represents an enriched food web, where disturbance occurs and resources become available because of organism mortality, turnover, or favorable shifts in the environment (Odum, 1985). Therefore, high EI again suggests that higher rate of N



input caused greater disturbance to turf soil food web. In fact, lawn care inputs, in general, can stimulate EI increase as we found in this study. SI was not significantly affected by the application of insecticides, fungicides, and herbicides in this study. This result is consistent with the finding of Biswas and Mishra (1987) who showed no adverse effect of various herbicides, including tetrapion, butachlor, nitrofen, alachlor and atrazine, on some predatory and free-living nematodes.

Soil nutrient analysis revealed that significant difference for MBN and SOM existed among the 9 regimes, where organic-fertilizer regimes (Oa and Ob) resulted in higher MBN and SOM compared to mineral-fertilizer management and the control. SOM in organic-fertilizer management was not significantly higher than in mineral-fertilizer management, but it was higher than the control. These findings suggest that organic-fertilizer management could further promote soil microbial biomass and thus probably microbial activity in turfgrass ecosystem. These findings are consistent with other studies where positive, long-term effects on soil properties were documented for organic treatments compared to conventional inorganic treatment in farming systems (van Bruggen, 1995; Poudel et al., 2001; Nahar et al., 2006). In addition, microbial biomass and soil organic matter pools in turf soil ecosystems were generally improved by inputs as the control resulted in lower MBN and SOM than all other regimes overall. Again, microbial biomass and SOM were not negatively affected by herbicide, insecticide, and fungicide applications.

Faunal profile analysis indicated that most food webs in turfgrass soil were highly enriched but poorly to moderately structured, with variations due to sampling time. Soil food webs in undisturbed natural grasslands and forest systems are mainly fueled by high cellulosic and lignified organic matter and usually exhibit fungal dominated decomposition pathways which favor fungivorous nematodes belonging to Fu<sub>2</sub>, Fu<sub>3</sub>, and Fu<sub>4</sub> guilds (Ferris et al., 2001). Fu<sub>3</sub> and Fu<sub>4</sub> are important contributors to the Structure Index, and soil food webs in natural grasslands and forest systems are usually highly structured and poorly to moderately enriched (Quadrat C in the model) (De Goede and Bongers, 1998; Ferris *et al.*, 2001). However, in turfgrass soil, enrichment opportunistic nematodes of low c-p values dominated, while nematodes of high c-p values did not. Therefore, the food webs in managed turfgrass soil indicated a disturbed food web compared to natural grasslands and forest ecosystems.

By using soil nematode community as a bio-indicator, results from this study suggest that turfgrass systems are relatively resistant to the disturbance impacts from application of insecticides, fungicides, and herbicides, which may be due to the high organic matter and high microbial activity in the system. Nitrogen fertilizer input levels showed impacts on turf soil nematode food web conditions, reducing Maturity Index and Combined Maturity Index, and increasing Enrichment Index in this study. Our results also showed that organic-fertilizer management could further promote soil microbial biomass and SOM in turfgrass systems, although it had no significant effect on the nematode community. Overall, food webs in managed turfgrass soil

systems are evaluated to be highly enriched and poorly to moderately structured compared to the natural grasslands and forest ecosystems which usually have poorly to moderately enriched but highly structured food webs.

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**Table 3.1:** Annual application schedule of fertilizers, herbicides, fungicides and insecticides to Kentucky bluegrass plots maintained under different turfgrass management regimes.



Target application date	Control	Oa	Ob	MHNa	MLN	MHNb	MHNc	MHNd	MMN
April 19	–	48-10-29†	48-10-29 Tri-Power ‡	49-0-0	49-6-14 Pre-M § Tri-Power	36-4-13 Pre-M	48-5-17 Pre-M Tri-Power	49-0-0 Pre-M Tri-Power	46-4-14 Pre-M
May 8	–	–	–	–	–	25-3-7 Tri-Power	–	–	–
May 31	–	36-7-22	36-7-22	36-4-7	–	25-3-7	37-4-11	36-4-7	39-5-4 2, 4-D 3 Way #
June 23	–	–	–	–	–	25-3-7 Bayleton ¶	–	–	–
July 19	–	36-7-22	36-7-22	36-4-7	–	24-2-5	37-4-11	36-4-7	42-9-6 † Diazinon ††
August 11	–	–	–	–	–	24-2-5	–	–	–
September 4	–	48-10-29	48-10-29 Tri-Power	49-0-0	49-6-14 Tri-Power	25-3-7 Tri-Power	50-6-14 Tri-Power	49-0-0 Tri-Power	44-4-13
September 25	–	–	–	–	–	37-4-11	–	–	–
October 16	–	48-10-29	48-10-29	49-0-0	–	24-0-0	49-0-0	49-0-0	–
Total per year	–	216-44-131	216-44-131	219-8-14	98-12-28	245-24-62	221-19-53	219-8-14	171-22-37

**Table 3.1 (continued)**

† N-P-K	kg ha <sup>-1</sup> yr <sup>-1</sup>
‡ Three way broadleaf herbicide	3.5 l ha <sup>-1</sup> yr <sup>-1</sup> , comprises of 2-Methyl-4-Chlorophenoxy-acetic acid, (+)-R-2-(2-Methyl-4-Chlorophenoxy) propionic acid, and 3,6-Dichloro-o-Anisic acid
§ Pre-emergent herbicide	1.7 kg ha <sup>-1</sup> yr <sup>-1</sup> , Pendimethalin, N-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine
¶ Fungicide	0.15 l ha <sup>-1</sup> yr <sup>-1</sup> , 1-(4-chlorophenoxy)-3,3-dimethyl-1-(1,2,4-triazol-1-yl)-butan-2-one
# Broadleaf Herbicide	1.7 kg ha <sup>-1</sup> yr <sup>-1</sup> , 2,4-dichlorophenoxyacetic acid
†† Insecticide	5.6 kg ha <sup>-1</sup> yr <sup>-1</sup> , O,O-Diethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl) thiophosphoric acid
Abbreviations	Organic a (Oa), Organic b (Ob), Mineral High-N a (MHNa), Mineral Low-N (MLN), Mineral High-N b (MHNb), Mineral High-N c (MHNc), Mineral High-N d (MHNd), Mineral Medium-N (MMN).

<b>Bacterivores</b>	<b>Fungivores</b>	<b>Predators</b>	<b>Omnivores</b>	<b>Plant parasites</b>
<i>Acrobeles</i> (2)	<i>Aphelenchoides</i> (2)	<i>Mononchus</i> (4)	<i>Dorylaimus</i> (4)	<i>Criconemoides</i> (3)
<i>Acrobeloides</i> (2)	<i>Aphelenchus</i> (2)		<i>Eudorylaimus</i> (4)	<i>Filenchus</i> (2)
<i>Alaimus</i> (4)			<i>Mesodorylaimus</i> (4)	<i>Helicotylenchus</i> (3)
<i>Cephalobus</i> (2)			<i>Pungentus</i> (4)	<i>Heterodera</i> (3)
<i>Eucephalobus</i> (2)				<i>Hoplolaimus</i> (3)
<i>Mesorhabditis</i> (1)				<i>Longidorus</i> (5)
<i>Monhystera</i> (1)				<i>Paratylenchus</i> (2)
<i>Panagrolaimus</i> (2)				<i>Pratylenchus</i> (3)
<i>Pelodera</i> (1)				<i>Psilenchus</i> (2)
<i>Plectus</i> (2)				<i>Rotylenchus</i> (3)
<i>Rhabditis</i> (1)				<i>Telotylenchus</i> (2)
<i>Turbatrix</i> (1)				<i>Tylenchorhynchus</i> (3)
<i>Wilsonema</i> (2)				<i>Tylenchus</i> (2)
				<i>Xiphinema</i> (5)

**Table 3.2.** List of nematode genera identified and colonizer-persister scale values (numbers in brackets) assigned in all nine management regimes.

**Table 3.3:** Long-term effect of 9 turf management regimes applied for 15 years on soil nematode abundance and community indices. Values presented are Mean  $\pm$  Standard Error.

	<i>Regimes</i>	<i>Total nematodes / 20g soil</i>	<i>Free-living nematodes / 20g soil</i>	<i>Plant parasites / 20g soil</i>	<i>Maturity Index (MI)</i>	<i>Plant-parasitic Index</i>	<i>Combined MI</i>	<i>Enrichment Index</i>	<i>Structure Index</i>
Sept. 2003	Control	110±38	78±27	33±11	1.82±0.09	2.49±0.04	2.02±0.07	79.4±6.42	52.2±6.62
	Oa	53±15	41±11	13±5	1.67±0.13	2.58±0.12	1.85±0.13	86.2±2.85	50.9±6.73
	Ob	93±47	69±34	25±13	1.79±0.15	2.27±0.18	1.92±0.06	76.2±4.72	38.9±5.56
	MHNa	41±5	32±2	10±3	1.83±0.09	2.37±0.04	1.95±0.08	78.5±2.74	45.7±7.02
	MLN	66±21	46±16	21±7	1.85±0.14	2.37±0.02	2.03±0.09	81.5±3.45	56.3±4.05
	MHNb	86±19	66±15	22±4	1.78±0.05	2.41±0.05	1.94±0.05	78.3±0.82	40.0±5.74
	MHNd	54±21	39±15	16±7	1.82±0.18	2.62±0.19	2.00±0.16	76.6±7.96	47.6±6.25
	MMN	72±18	55±12	18±6	1.68±0.06	2.55±0.11	1.88±0.10	82.0±2.36	37.5±10.7
July 2004	Control	294±64	96±14	198±50	1.81±0.11	2.51±0.06	2.28±0.01	69.9±6.17	23.4±5.59
	Oa	198±41	94±16	103±26	1.86±0.11	2.54±0.04	2.20±0.06	72.7±3.87	33.0±12.3
	Ob	212±47	76±5	135±50	1.90±0.23	2.36±0.00	2.21±0.04	75.2±7.86	46.2±7.69
	MHNa	273±74	108±35	165±41	1.66±0.09	2.45±0.04	2.14±0.07	76.4±3.89	16.0±1.49
	MLN	253±43	88±14	166±32	1.92±0.09	2.58±0.03	2.34±0.03	65.6±4.87	30.5±4.95
	MHNb	226±21	78±10	145±16	1.84±0.06	2.43±0.05	2.22±0.05	71.9±3.43	29.6±6.34
	MHNd	253±45	114±30	138±26	1.79±0.11	2.55±0.06	2.19±0.07	72.0±4.83	26.9±5.06
	MMN	296±114	122±38	174±75	1.69±0.07	2.45±0.10	2.12±0.13	77.2±4.44	26.6±1.06
Oct. 2004	Control	356±52	136±51	220±16	2.00±0.06	2.54±0.06	2.34±0.08	51.5±3.74	20.1±5.13
	Oa	457±114	164±35	291±86	1.87±0.02	2.53±0.12	2.27±0.10	61.3±1.18	13.2±3.91
	Ob	300±10	123±30	178±40	1.90±0.03	2.60±0.04	2.31±0.12	59.8±2.03	14.8±3.01
	MHNa	460±61	189±6	271±60	1.75±0.05	2.65±0.07	2.27±0.02	68.0±3.79	10.1±2.33
	MLN	310±42	83±20	226±31	2.07±0.04	2.55±0.08	2.42±0.07	55.0±1.74	32.1±4.98
	MHNb	461±106	192±61	267±47	1.86±0.12	2.57±0.06	2.27±0.08	62.6±8.78	20.4±6.29
	MHNd	462±8	141±20	320±25	1.89±0.02	2.56±0.06	2.35±0.01	64.0±1.29	19.7±5.38
	MMN	344±90	116±40	225±47	1.87±0.13	2.60±0.07	2.36±0.11	66.0±8.40	28.3±4.67
	MMN	302±39	112±12	191±39	1.84±0.05	2.49±0.10	2.23±0.05	64.6±5.23	14.3±4.18

<i>Parameter</i>	<i>9 regimes</i>	<i>A) control, low-N, medium-N, high-N</i>	<i>B) control, organic, mineral</i>	<i>C) no input (control), with inputs</i>	<i>D) no herbicides, with herbicides</i>	<i>E) no insecticide, with insecticides</i>	<i>F) no fungicide, with fungicides</i>
Total nematodes	0.80 †	0.36	0.58	0.33	0.98	0.26	0.18
Total genera	0.91	0.53	0.71	0.47	0.64	0.19	0.44
Free-living nematodes (FLN)	0.61	0.10	0.60	0.57	0.39	0.62	0.24
Plant-parasitic nematodes (PPN)	0.58	0.28	0.45	0.20	0.47	0.14	0.21
Richness Index (Margalef)	0.93	0.52	0.99	0.95	0.58	0.80	0.71
Diversity Index (H')	0.95	0.53	0.51	0.64	0.34	0.58	0.85
Evenness Index (Pielous J')	0.96	0.70	0.88	1.00	0.31	0.90	0.64
Maturity Index	0.29	<b>0.04</b>	0.59	0.30	0.35	0.32	0.88
Plant-parasitic Index	0.63	0.96	0.92	0.68	0.50	0.75	0.40
Combined Maturity Index	0.20	<b>0.01</b>	0.44	0.22	0.45	0.19	0.84
Enrichment Index	0.12	<b>0.01</b>	0.16	0.06	0.30	0.16	0.59
Structure Index	0.56	0.23	0.93	0.86	0.25	0.75	0.57
NH <sub>4</sub> -N	0.77	0.61	0.694	0.60	0.60	0.37	0.10
NO <sub>3</sub> -N	0.60	0.16	0.46	0.49	0.34	0.43	0.05
Dissolved organic N	0.49	0.06	0.71	0.42	0.63	0.19	0.83
Microbial biomass N	<b>0.00</b>	0.21	<b>&lt;.0001</b>	0.08	0.59	0.51	0.17
Soil organic matter	<b>0.03</b>	<b>0.02</b>	<b>0.00</b>	<b>0.02</b>	0.37	0.63	0.53

**Table 3.4:** P values obtained from repeated measures analysis of variance showing the overall long-term impact of turfgrass management regime groups on nematode community, nitrogen pools, microbial biomass N, and soil organic matter.

**Table 3.5:** Long-term effect of 9 turf management regimes applied for 15 years on soil nitrogen pools and organic matter.

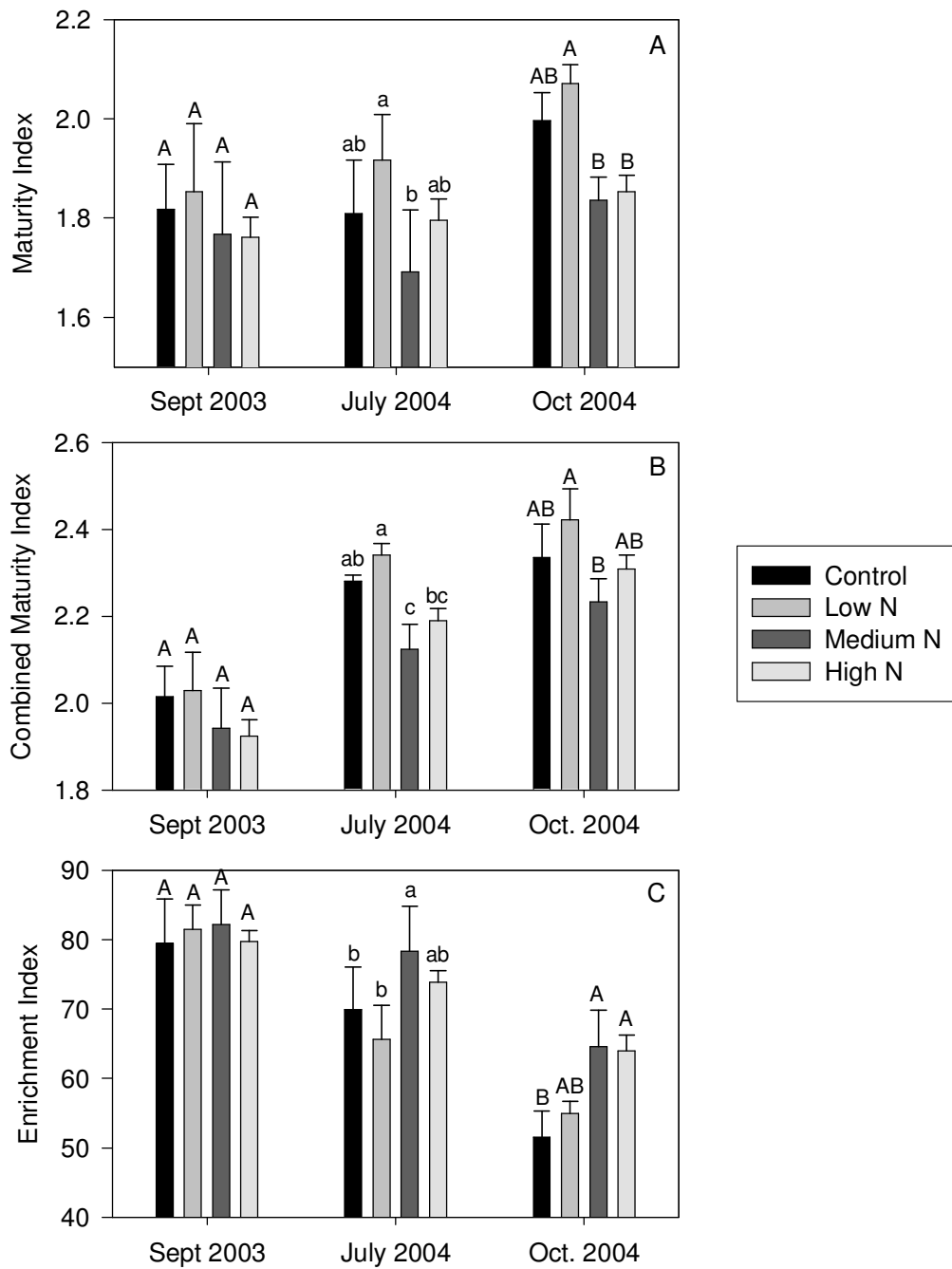
<i>Sampling Time</i>	<i>Regimes</i>	<i>NH<sub>4</sub>-N (ppm)</i>	<i>NO<sub>3</sub>-N (ppm)</i>	<i>Dissolved organic N (ppm)</i>	<i>Microbial biomass N (ppm)</i>	<i>Soil organic matter (%)</i>
Sept. 2003	Control	1.37±0.00 †	1.38±0.12	10.5±1.46	109.4±3.86 b ‡	3.91±0.15 c
	Oa	1.83±0.06	2.67±0.80	14.4±0.09	135.4±11.6 ab	5.06±0.38 ab
	Ob	2.43±0.41	3.42±1.14	17.7±0.96	168.4±17.5 a	5.24±0.19 a
	MHNa	1.95±0.55	3.68±0.53	13.2±2.62	100.9±3.96 b	4.26±0.19 bc
	MLN	1.39±0.02	2.09±0.74	12.0±0.27	115.5±10.5 b	4.23±0.41 bc
	MHNb	2.03±0.18	4.10±0.29	17.6±0.99	115.1±4.92 b	4.85±0.28 abc
	MHNc	2.22±0.46	4.23±0.24	17.1±2.72	134.4±13.9 ab	5.09±0.16 ab
	MHNd	1.94±0.18	3.49±0.35	15.2±2.14	131.1±19.2 b	5.15±0.27 ab
	MMN	2.27±0.43	3.51±0.81	17.6±2.19	113.3±9.85 b	4.79±0.32 abc
July 2004	Control	2.28±0.25	7.55±2.71	6.63±0.85	87.7±8.76 D	4.63±0.28 E
	Oa	2.02±0.25	10.4±1.69	9.18±1.49	110.1±2.99 ABC	5.46±0.12 BC
	Ob	1.94±0.08	5.07±0.37	7.50±0.48	126.1±0.46 A	6.11±0.12 A
	MHNa	1.98±0.19	8.15±1.62	9.00±1.86	113.4±7.77 AB	5.68±0.15 AB
	MLN	2.38±0.30	8.34±1.82	5.42±0.59	110.3±4.54 ABC	5.08±0.11 CDE
	MHNb	3.34±1.34	8.99±0.93	5.52±0.97	92.1±5.16 D	4.84±0.10 DE
	MHNc	2.14±0.26	7.66±1.16	7.34±2.27	96.7±9.84 CD	5.36±0.42 BCD
	MHNd	1.72±0.41	7.74±1.74	5.99±1.38	102.2±14.5 BCD	4.93±0.39 DE
	MMN	2.07±0.27	6.95±1.13	7.48±0.93	109.3±3.00 BC	4.98±0.12 CDE
Oct. 2004	Control	1.82±0.26	16.3±11.3	6.49±3.83	104.2±3.53 c	4.51±0.23 b
	Oa	1.89±0.21	11.5±0.96	3.78±1.20	133.8±2.59 a	4.95±0.20 a
	Ob	1.40±0.21	11.2±5.66	1.67±0.03	127.7±10.3 ab	4.55±0.12 b
	MHNa	1.77±0.27	9.58±1.33	7.07±2.03	106.3±10.3 c	4.44±0.19 b
	MLN	1.60±0.14	6.03±1.01	4.36±1.77	100.3±5.80 c	4.37±0.02 b
	MHNb	1.58±0.15	12.7±4.15	4.30±1.44	109.5±9.43 c	4.63±0.19 b
	MHNc	1.46±0.23	10.5±3.93	4.79±2.42	105.6±7.93 c	4.68±0.12 ab
	MHNd	1.74±0.14	11.1±2.09	4.15±1.37	112.2±7.30 bc	4.52±0.20 b
	MMN	2.16±0.38	9.30±2.18	4.84±1.32	106.7±3.86 c	4.63±0.10 b



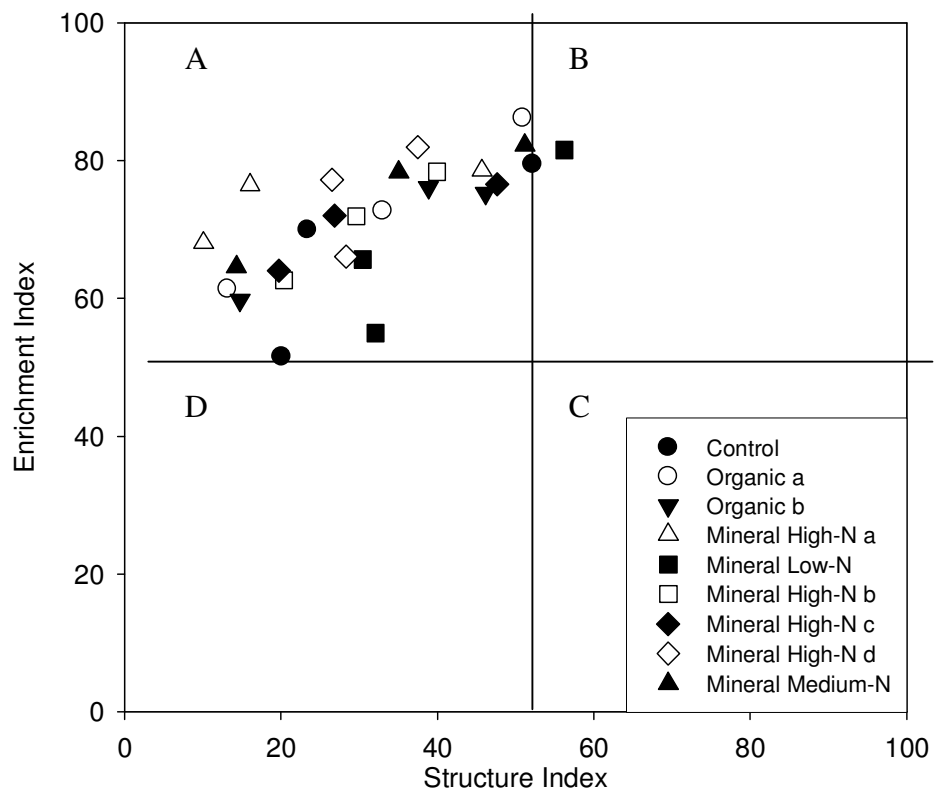
**Table 3.5 (continued):**

† Values are Mean  $\pm$  Standard Error

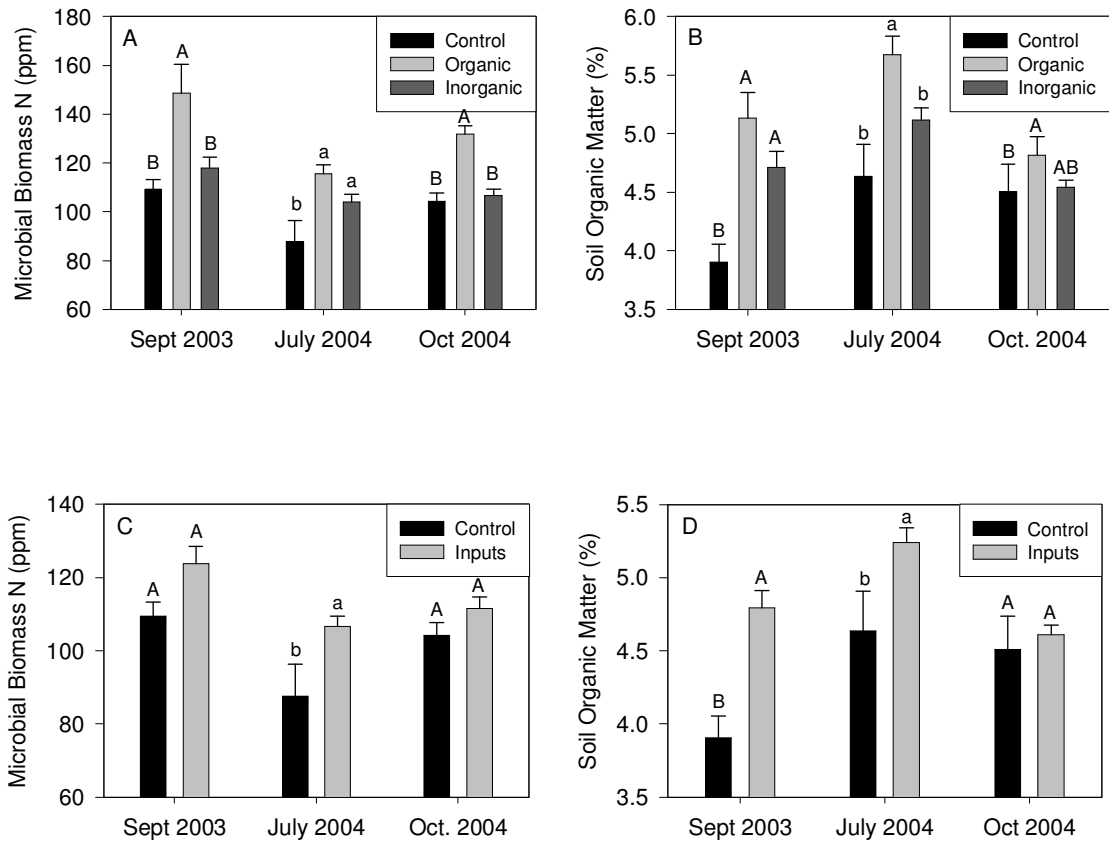
‡ Means comparison within each sampling time using fishers LSD test;  $p \leq 0.05$



**Figure 3.1:** Effects of N input level on nematode community indices Maturity Index, Combined Maturity Index and Enrichment Index. Data are Mean + SE.



**Figure 3.2:** Nematode food web conditions deduced from faunal analysis under 9 different turfgrass management regimes.



**Figure 3.3:** Effects of management groups on microbial biomass nitrogen and soil organic matter. Management groups presented were: 1) control, organic-fertilizer management, mineral-fertilizer management (A, B); 2) control (no input), with inputs (C, D). Data are Mean + SE.

## CHAPTER 4

### AN ASSESSMENT OF THE ECOLOGY OF URBAN LAWNS: COMPARISON OF HOME LAWN MANAGEMENT PROGRAMS

#### **Abstract**

Turfgrass lawns are a central part of urban and suburban landscapes throughout North America. However, homeowner quest for a “perfect” lawn has resulted in the evolution of lawn care programs that rely on repeated applications of chemical fertilizers and pesticides. These inputs are expensive and are perceived to have negative impact on ecological processes in lawns and nearby aquatic systems. Therefore, we evaluated the effectiveness and influence of three most common lawn care programs on ecological characteristics of turfgrass lawns. Twenty-eight home lawns in Wayne and Holmes Counties in Ohio, separated into 3 categories based on the lawn care program (professional, do-it-yourself (DIY), and no-input) used, were studied. Data on turf quality, weed and insect infestation, and diseases incidence were collected in September 2003 and July 2004. Soil samples were collected in September 2003, July 2004 and October 2004 to analyze nematode community,  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , dissolved organic nitrogen (DON), microbial biomass nitrogen (MBN), and soil organic matter (SOM) as ecological indicators in the lawn ecosystem. Results indicated that professionally managed lawns had better turfgrass quality than the other two programs, but DIY lawns did not differ from the no-input lawns. Professionally managed lawns also had lower intensity of major weeds found in the

study, compared to the DIY and no-input lawns. No significant differences in total soil nematode population and nematode community indices across lawn care programs were found, indicating no differences in net ecosystem productivity. Soil nematode food webs were highly enriched but moderately structured in all lawn care programs, indicating a relatively disturbed food web compared to natural grasslands and forest ecosystems. Levels of soil  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$  and DON were the same in all lawn care programs, but soil MBN and SOM were found to be generally higher under no-input management than the other two programs. We conclude that homeowners relying on typical DIY programs are unable to achieve the desired levels of turf quality and weed control, and chemical input intensive management negatively affects MBN and SOM contents in lawns. Overall, the soil food web in turfgrass lawns represents a disturbed food web due to excessive N availability in the system irrespective of the lawn care program used.

#### **4.1. Introduction**

Turfgrass lawns are now a central part of urbanized landscapes throughout North America. It is estimated that the total turfgrass area, including residential, commercial, and institutional lawns, golf courses, and parks, occupied  $163,800 \text{ km}^2$  ( $\pm 35,850 \text{ km}^2$ ) in the U.S. (Milesi et al., 2005), and this area is expanding because of rapid urbanization (Robbins and Birkenholtz, 2003). In Ohio, there was nearly 0.97 million ha of turf in 1989 (Sporeleder et al., 1991). With highly-developed root system and dense shoots above ground, turfgrass provides many environmental benefits, including soil erosion control, water runoff and leaching reduction, contributing to carbon sequestration, moderating temperature, reducing noise, glare, and visual pollution (Beard and Green, 1994). However, during the past few decades,

homeowner quest for a “perfect” lawn has resulted in a lawn care system that relies on repeated, often calendar-based applications of water-soluble fertilizers and pesticides. A 2001 Ohio survey of professional pesticide applicators indicated that about 65% of the respondents applied pesticides to turfgrass, with an average amount of 472 kg of active ingredient per km<sup>2</sup> (Young et al., 2003). These inputs are expensive, and are usually perceived as a source of environmental contamination, which may impair natural ecological processes in the lawns and even threaten water quality due to runoff and leaching (Overmyer et al., 2005).

Urban lawns in North America are typically managed using one of the three lawn care programs: 1) A professional program in which a lawn care company is hired by the homeowner to manage the lawn; 2) A do-it-yourself (DIY) program in which the homeowner applies retail turf management products on a calendar basis following a 4, 5, or 6-step program; and 3) A no chemical input approach in which homeowner maintains the lawn without the application of any chemical fertilizers and pesticides. In Ohio, about 22% of homeowners employ a lawn care company, about 39% use the chemically based DIY program, and the remaining use a no-chemical input approach (Blaine et al, 2004, unpublished data). In the professional and DIY programs, the application of fertilizers are targeted to enhance the aesthetic quality of lawns by providing three major macronutrients, nitrogen (N), phosphorus (P), and potassium (K). The pesticides applied to the lawns include a variety of herbicides to control broadleaf and annual grassy weeds and insecticides to control surface, stem, and root feeding insects that directly or indirectly affect turf quality. According to the National Turfgrass Evaluation Program (NTEP), turfgrass quality is a visual assessment of combination of color, density, uniformity, texture, and diseases or environmental stress. In this study our first goal was to compare the effectiveness of the three

commonly used lawn care programs (professional, DIY, and no-input) in maintaining turf quality, and controlling the weed, insect, and disease problems. We hypothesized that the professional lawn care program will produce better aesthetic quality lawns compared to the DIY and no-input programs.

As the application of fertilizers and pesticides have the potential to impair the natural ecological processes in lawns, we also assessed the impacts of the three lawn care programs on several key ecological indicators in urban lawns. Specifically, we quantified the amount of soil organic matter (a key indicator of overall soil quality),  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  (two major forms of N utilized by the plants), dissolved organic nitrogen (important N reservoir), and microbial biomass (a key indicator of the microbial activity and nutrient cycling efficiency). Our hypothesis is that the professional and DIY managed lawns will have lower soil organic matter and microbial biomass but higher  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  compared to the no-input lawns.

To gain additional insights into the condition of the soil food web, we used nematode community as an environmental bioindicator. Nematodes are the most abundant metazoa on the earth (Ferris et al., 2001) and occupy central positions in soil food web and sediment ecosystems, appearing at multiple trophic levels, such as bacterivores, fungivores, plant parasites, predators, and omnivores (Yeates et al., 1993). Since nematodes depend on the continuity of soil water films for movement, their activities are largely controlled by soil physical, chemical, and biological conditions (Yeates and Bongers, 1999). Also, nematodes are in direct contact with dissolved chemicals in the soil solution through their permeable cuticle and can react rapidly to disturbances and contaminants. Thus, nematodes have the potential to provide meaningful insights into the condition of soil food web, environmental disturbance and pollution.



We used a new faunal profile analysis matrix that relates soil nematode community to soil food web health status (Ferris et al., 2001) by integrating nematode feeding groups and the *colonizer-persister* scale (cp scale) into a matrix classification of functional guilds (Figure 4.1). The cp scale is composed of five levels (1-5). The colonizers whose reproduction rates are high and body sizes are usually small receive a low value; while the persisters, which reproduce slowly but are larger in size, are placed in high cp categories. According to this model, from basal conditions, indicated by the dominance of Ba<sub>2</sub> and Fu<sub>2</sub> guilds (bacterivores and fungivores which are in cp-2 categories), there are two developing trajectories for the soil food web to recover from a disturbance event, one of which is enrichment trajectory, and the other is structure trajectory. Opportunistic non-herbivorous guilds, Ba<sub>1</sub> and Fu<sub>2</sub>, are considered as indicators for enriched food web. High cp guilds (cp 3-5) are indicators for structured food web, which has more complex trophic correlations and where recovery from stress is occurring. We hypothesized that the professional and DIY programs will negatively affect the soil food web compared to the no-input program.

Our overall goal was to determine the influence of three different lawn care programs on turfgrass quality and soil food web structure and function by surveying home lawns in Wayne and Holmes Counties in Ohio, representing typical urban and suburban communities in the Midwestern United States. The specific objectives were to: 1) assess the impacts of the three commonly used lawn care programs (professional, DIY, and no-input) on turf quality, weed, insect, and disease control; 2) determine the differential impacts of professional, DIY, and no-input lawn care programs on soil N pools, organic matter and microbial biomass; and 3) compare the soil food webs (using nematode community as the indicator) under the three lawn care programs.

## **4.2. Materials and Methods**

### *4.2.1. Survey approach*

Twenty-eight home lawns in Wayne and Holmes Counties in Ohio were included in this study for obtaining samples. We sent a brief survey email to homeowners to participate in this study. The following questions were asked: Who manages your lawn (yourself or lawn-care company)? How often is fertilizer applied? How often is herbicide applied? How often is insecticide applied? and How old is the lawn, and what is the previous land use? Based on the information provided by homeowners, all lawns were separated into three management categories: professional (6 lawns), DIY (11 lawns), and no-input (11 lawns) management lawns. These three management categories were defined as: 1) professional: home owners hired a professional lawn-care company to maintain their lawns, with routine applications of fertilizers and pesticides; 2) DIY: home owners maintained their lawns themselves, applying both fertilizers, herbicides and/or insecticides; 3) no-input: home owners maintained their lawns themselves, without applying any fertilizers or pesticides. Mowing was performed by the homeowners in majority of the cases in all three lawn care programs.

### *4.2.2. Lawn quality, weed, insect and disease infestation assessments*

In September 2003 and July 2004, we conducted onsite lawn evaluations. Overall turfgrass quality was evaluated using a relative scale of 0 to 3 with 0 indicating very poor and 3 indicating very good quality, considering color, density, uniformity, texture, weeds, insect damage and diseases. A transect, which varied in length according to the size of each lawn, was established across each lawn and data on weed and insect infestations and disease occurrence were taken along this transect. Weed infestation levels were assessed by surveying a one meter wide area along the

entire length of each side of the transect, recording all weed species present and rating the severity of infestation of each individual species on a relative scale of 0 to 3 with 0 indicating absence and 3 indicating a severe infestation of a particular species. Insect presence and damage were assessed by examining the same area from which the weed assessment was made. Any sign of insect damage was followed by close inspection of the affected area sufficient to determine which species was responsible. Damage resulting from each insect species was rated on a relative scale from 0 to 3 with 0 indicating no damage and 3 indicating a severe damage directly attributed to a particular insect species. Disease infestation was also ranked according to the same 0-3 scale.

#### *4.2.3. Soil sampling*

Soil samples were collected in September 2003, July 2004 and October 2004. Soil samples were taken from each lawn with a 3 cm diameter soil probe to a depth of 15 cm. A linear transect was set at least 10 feet away from the house and one soil core was collected from each of the six sampling points evenly spaced along the transect. All 6 soil cores from each lawn were mixed to make one composite sample in order to reduce the variance with aggregated spatial patterns of nematodes in soil (Barker and Campbell, 1981). Soil samples were placed in polyethylene bags to prevent water loss and were kept in a cooler while in transit to the laboratory and during handling. Samples were stored at 4°C before analysis to minimize changes in nematode populations and biochemical reactions (Barker et al., 1969).

#### *4.2.4. Extraction and identification of nematodes*

Nematodes were isolated from soil samples following the Baermann funnel technique (Flegg and Hooper, 1970). Ten grams of soil from each composite sample was placed on each funnel. After 72 hours, nematodes in the water were collected in

plastic vials through a rubber tube attached beneath each funnel. Nematodes were allowed to settle for at least 12 h at 4 °C and then the upper layer of water was discarded carefully without disturbing the nematodes until about 5 ml of suspension remained. The nematodes were killed and fixed using 5 ml boiling TAF solution (70 ml formaldehyde + 20 ml triethanolamine + 910 ml distilled water) in a fume hood (Shepherd, 1970). Finally, nematodes were identified and counted using a stereomicroscope. All nematodes were identified to at least the genus level using published keys (Goodey, 1963; Mai and Lyon, 1975). They were then assigned to a trophic group (plant parasites, fungivores, bacterivores, omnivores or predators) according to Yeates et al. (1993) and a colonizer-persister (c-p) value was assigned according to Bongers (1990). Two technical replications were conducted for each soil sample and these two data were combined for nematode community analysis.

Nematode numbers were not corrected for extraction efficiency which is about 85% for the method we used (Grewal, 1991).

#### *4.2.5. Soil N, microbial biomass, and organic matter analysis*

Soil sand, silt, and clay content were analyzed using a method described by Kettler et al. (2001) with some modifications. Soil organic matter (SOM), expressed as a percentage, was measured by calculating the weight loss during ignition (Storer, 1984).  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ , and dissolved organic nitrogen (DON) were extracted from soil by adding 0.5 M  $\text{K}_2\text{SO}_4$  solution, and were digested by alkaline persulfate oxidation (Cabrera and Beare, 1993). They were then determined using a modification of the indophenol blue technique in microtiter plates (Sims et al., 1995). The concentration of DON in filtrates is calculated as the difference between total nitrogen and mineral nitrogen. Microbial biomass nitrogen (MBN) is determined using a modification of the chloroform fumigation method described by Brookes et al. (1985). A 10 g of coarsely

screened soil is fumigated with chloroform in the dark for 48 hours and extracted again with 0.5 M K<sub>2</sub>SO<sub>4</sub> solution. The extract is filtered and digested by alkaline persulfate oxidation (Cabrera and Beare 1993) and the concentration of total nitrogen in the digested filtrate is determined using the modified indophenol blue technique (Sims et al., 1995). MBN is calculated as the difference between total extractable nitrogen from unfumigated and fumigated soil samples, assuming extraction efficiency for MBN of 0.45 (Jenkinson, 1988). The concentration of each of the nitrogen pools is expressed as ppm.

#### *4.2.6. Statistical analysis*

Non-parametric Kruskal-Wallis analysis followed by Dunn's Test (Sigmastat 3.5, Systat Software, Inc., San Jose, CA) was performed on turf quality, weed and insect infestations, and disease occurrence data from July 2003 and September 2004 onsite evaluations separately. Repeated measures analysis of variance (PROC GLM, SAS Release 9.1, SAS Institute, Cary, NC) was performed on soil nematode community indices and soil pools to obtain *p*-values using the appropriate error terms in the model, to take into account seasonal variations and management\*time interaction. Soil nematode community indices and nutrient pools were compared among all three lawn care programs. In addition, Fisher LSD was used for mean comparisons within each sampling time for all soil and nematode community data. Nematode population data were transformed as  $\ln(x+1)$  prior to statistical analysis to normalize the variance. An alpha level  $\leq 0.05$  was considered significant. Correlations between lawn age (only partial information was available from homeowners) and nematode community and soil pools were determined using Minitab Version 14 (Minitab, Inc., State College, PA). Soil nematode community indices were calculated as below.

Two different aspects of community structure contribute to species/genus diversity, i.e., species/genus richness and species/genus evenness. Diversity index incorporates both richness and evenness components and can provide heterogeneity information for vegetation and wildlife studies. In this study, nematode genus richness, diversity, and evenness were calculated using the following formulae: Richness Index (*Margalef*)  $= (G-1)/\ln(n)$ , where  $G$  is the total number of genera and  $n$  is the total number of individuals in a community; Diversity Index (*Shannon-Weiner Index*)  $H' = -\sum P_i(\ln P_i)$ , where  $P_i$  is the proportion of genus  $n_i$  in the nematode community  $n$ ; and Evenness Index (*Pielous index*)  $J' = H'/\ln(G)$  where  $G$  is the number of genera in the community (Pielou, 1977).

Maturity Index (MI), considering free-living nematodes only, was calculated using the formula  $MI = (\sum v_i f_i)/n$ , where  $v_i$  is the c-p value assigned to nematode genus  $i$ ,  $f_i$  is the frequency of nematode genus  $i$ , and  $n$  is the total number of individuals in the soil sample (Bongers, 1990). Plant parasitic index (PPI) was calculated based only on plant parasitic nematodes as  $PPI = (\sum v_i f_i)/n$  where  $v_i$  is the c-p value for the plant-parasitic nematode genus  $i$ , and  $f_i$  is the frequency of plant-parasitic nematode genus  $i$ , and  $n$  is the total number of individuals in the soil sample (Bongers, 1990).

The enrichment index (EI) and structure index (SI) provide information for the enrichment and structure of the soil food web and were calculated according to Ferris et al. (2001). First of all, basal components ( $b$ ) of the food web (fungal and bacterial feeders in the c-p 2 guild) were calculated as  $b = \sum k_b n_b$  where  $k_b$  is the weighted constant for the guild, and  $n$  is the number of individuals in that guild. Then enrichment ( $e$ ) and structure ( $s$ ) components were calculated, using nematode guilds indicative of enrichment (bacterivores in c-p 1, and fungivores of c-p 2), and

structure (bacterivores in c-p 3-5, fungivores c-p 3-5, omnivores of c-p 3-5, and predatory nematodes of c-p 2-5). Finally the EI was calculated as  $100 * e/(e + b)$ , and the SI as  $100 * s/(s + b)$ .

### 4.3. Results

#### 4.3.1. Lawn quality and weed, insect and disease infestations

In both years, overall turfgrass quality was significantly higher in professionally managed lawns compared to the no-input lawns. The professional program resulted in a near perfect turf quality with a median of 3.0 in both September 2003 and July 2004 out of 3.0 (Figure 4.2). The DIY program did not result in higher lawn quality compared to the no-input program.

A total of 40 weed species were identified, of which dandelion (*Taraxacum officinale*), white clover (*Trifolium repens*), ground-ivy (*Glechoma hederacea*), broadleaf plantain (*Plantago major*), and buckhorn plantain (*Plantago lanceolata*) were most common. Dandelion infestation did not differ among the three programs in July 2004 evaluations, but was significantly lower in the professional program compared to the no-input program in September 2003 evaluation (Figure 4.3). In both years, ground ivy infestation was lower in the professional program compared to the no-input program, but it did not differ significantly between the DIY and no-input program (Figure 4.3). Similar trend was noted for white clover and broad-leaf plantain infestations, although the trend was only marginally significant ( $0.05 < P < 0.1$ ) (Figure 4.3).

Only billbug (*Sphenophorus parvulus*) and white grub (scarabaeid larvae) infestations were noticed in the lawns but the numbers were too few to draw any conclusions. Rust infestation was only found in September 2003 evaluations, where

no-input program showed lower infestation compared to the professional and DIY programs (Figure 4.4).

#### 4.3.2. Nematode abundance

Nematode genera identified in soil samples from the home lawns across the three lawn care programs are listed in Table 4.1. Among the most abundant genera were *Rhabditis*, *Cephalobus*, *Eucephalobus*, *Acrobeloides*, *Plectus*, *Monhystera*, *Aphelenchoides*, *Pratylenchus*, *Tylenchus*, *Filenchus*, and *Hoplolaimus*. Total number of nematode genera did not differ among the lawn care programs, but ranged from 12 to 24 per lawn. Table 4.2 provides the mean  $\pm$  SE for total number of nematodes and nematode community indices measured. The numbers of total nematodes, free-living (FLN), and plant-parasitic (PPN) nematodes were not significantly different among the 3 lawn care programs during the 2-year sampling period (Table 4.3).

#### 4.3.3. Nematode community structure and food web condition

Maturity Index (MI) and Plant parasitic index (PPI) were not significantly different among the lawn care programs during the 3 samplings times overall (Table 4.3). No significant differences were noted in nematode genus diversity (*Shannon-Weiner Index H'*), richness (*Margalef index*) and evenness (*Pielous Index J'*) indices among the 3 lawn care programs (Table 4.3). There was also no significant difference for either Enrichment Index (EI) or Structure Index (SI) among the lawn care programs (Table 4.3). The soil nematode food web conditions described by EI and SI showed that most food webs were highly enriched but moderately structured (Figure 4.5).



#### *4.3.4. Soil N, microbial biomass, and organic matter analysis*

Average sand, silt, and clay contents were 27%, 61%, and 12%, respectively in the soil. During the two-year sampling period, NH<sub>4</sub>-N ranged from 1.22 to 9.37 ppm; NO<sub>3</sub>-N from 2.44 to 50.37 ppm; DON from 0 to 29.34 ppm; MBN from 19.75 to 134.74 ppm; and SOM from 2.06% to 5.98% in all home lawns under all three lawn care programs (Table 4.4). According to the repeated measurement analysis, MBN and SOM differed significantly among the 3 lawn care programs overall (Table 4.3), where the trend was that no-input management had higher MBN and SOM compared to the professional and DIY lawn care programs. This trend was significant in September 2003 samples (Figure 4.6). Significant correlation between lawn age and SOM was found in July 2004 ( $p=0.002$ ) and October 2004 samples ( $p=0.004$ ).

#### **4.4. Discussion**

The on-site lawn evaluations yielded several interesting results. First, the professional program produced the best turf quality, but the DIY program did not differ from the no-input program. Similarly, among the most common weeds found, white clover, ground-ivy, and broadleaf plantain infestations tended to be the lowest in the professional program, but they did not differ significantly between the DIY and no-input programs. One reason for these findings is probably related to inappropriate application of herbicide products by the homeowner. More granular herbicides than liquid herbicides are sold to homeowners. For granular herbicides, ensuring a wet leaf surface during application is critical for efficacy compared to liquid herbicides applied by professional lawn care companies. Also the lawn care company technicians are formally trained in lawn management techniques, while homeowners

usually are not. These factors, coupled with the need for proper equipment calibration, could explain the relatively high weed infestation levels and poor turf quality in DIY lawns compared to the professional program. We also found that the professional and DIY lawns had higher levels of rust infestation than no-input lawns. Although rust is usually considered to be associated with poor nutrition, our soil analysis indicated that no-input lawns had higher microbial biomass and SOM, and had the same level of N pools compared to professional and DIY lawns. Therefore, it is possible that higher soil microbial biomass and SOM may contribute to reduced disease severity in no-input lawns.

The total nematode abundance can be used to indicate the net productivity of ecosystem (Ritz and Trudgill, 1999). Therefore, the lack of significant differences in total nematode abundance, free-living nematode (FLN) abundance, and plant-parasitic nematode (PPN) abundance over the 2-year sampling period indicates no difference in the net ecosystem productivity among the three lawn care programs. Due to their high N content (Kopp and Guillard, 2002; Strom et al., 1992), grass clippings following mowing can maintain high nitrogen availability in turfgrass lawns. Also, Dunn and Diesburg (2004) suggested that without the addition of nitrogen and herbicides, turfgrass systems are rapidly colonized by opportunistic weeds, some of which are leguminous. In fact, white clover, a leguminous plant, did show the tendency of higher ground cover in no-input lawns compared to lawns under professional program with intensive inputs, as discussed above. Through their N fixation, clover can contribute up to 80% of the total N requirement of the grass (Broadbent, Nakashima & Chang 1982; Boller & Nösberger 1987; Ledgard 1991). Therefore, such weeds can maintain high N availability in the absence of fertilizer

inputs (Bormann et al., 1993). In deed, the N pools were not different among the three lawn care programs whether fertilizers were applied or not.

Maturity Index (MI) offers possibilities to measure changes in the functioning of the soil ecosystem as a result of disturbance, both chemical and physical, and subsequent recovery. By measuring the relative proportion of colonizers and persisters in the soil, the MI assesses the impact of disturbance in a habitat (Bongers, 1990; Bongers and Bongers, 1998; Neher, 1999). High maturity in the system is an indicator of higher abundance and diversity of high c-p value nematodes and a stable ecosystem (Bongers, 1990; Bongers and Bongers, 1998). Differences in MI can be found when comparisons are made among agroecosystems, turfgrass, shrublands, and forest ecosystems (Briar et al., 2007 in press; Yeates and Bongers, 1999; de Goede and Dekker, 1993; Neher et al., 2005 ). The lack of differences in MI among the three lawn care programs (MIs are all below 2) in the current study may be due to the fact that all soil food webs are under continuous physical disturbance caused by soil compaction due to mowing activities, and chemical disturbance caused by fertilization and clippings returns. Probably due to the same reason, no significant differences were noted in nematode diversity (*Shannon-Weiner Index H'*), richness (*Margalef index*) and evenness (*Pielous Index J'*) indices among the three lawn care programs.

Faunal profile analysis combining Enrichment Index (EI) and Structure Index (SI) indicated that food webs in turfgrass soils are highly enriched and moderately structured across all management intensities (Quadrats A and B in the model, Figure 4.1). High EI represents the availability of new resources due to organism mortality, turnover, or favorable shifts in the environment (Odum, 1985). Therefore, the high EI in turfgrass soils is probably maintained by continuous disturbance imposed by routine fertilizer applications and the return of grass clippings. No differences in EI

among the different lawn care programs suggest that there are enough disturbance and enormous available nutrients in lawns to support the soil food web even in the absence of external fertilizer inputs. Structure index, which represents the diversity of trophic links (or food web connectance, sensu Ferris et al., 2001) in a nematode food web, was also not significantly different among the three lawn care programs. This suggests that chemical inputs in turfgrass did not impose significant additional constraints on soil nematode community, compared to the no-input lawn care program. Furthermore, the low SI scores across all lawn care programs also suggest that the food webs may be compromised in turfgrass soils. In fact, the soil food webs in undisturbed natural grasslands and forest ecosystems are usually poorly to moderately enriched but highly structured due to the relative dominance of high c-p value nematodes (Quadrat C in the model, Figure 4.1) (De Goede and Bongers, 1998; Ferris et al., 2001). But in turfgrass soils, enrichment opportunistic nematodes (i.e. low c-p value nematodes) dominated, while high c-p value nematodes did not (also see Briar et al., 2007 in press; Chapter 3). Therefore, we conclude that the soil food web in home lawns indicates a relatively disturbed food web with high enrichment but poor structure compared to the natural grasslands and forest ecosystems.

Our analysis revealed significant differences in MBN and SOM among the three lawn care programs. The no-input lawn care program resulted in higher MBN and SOM compared to the input-intensive professional and DIY programs. Although the difference was only significant in September 2003, the trend was similar for July and October 2004 as well. These findings suggest that lawn care inputs could have negative impact on turfgrass ecosystem, in terms of microbial biomass and soil organic matter build up. However, opposite finding was noted in a study conducted on experimental plots comparing nine different turfgrass management regimes

(Chapter 3). We suspect that the difference between the experimental plots and home lawns could be due to the fact that the controlled experimental plots were properly established on agricultural field soils, where initial soil biota, nutrient pools, and SOM were probably very abundant, while some home lawns were probably established on subsoil, which may lack in SOM and other essential nutrients. The relative lack of SOM could reduce the capacity of the soil to act as an environmental buffer by absorbing or transforming chemicals (Marquez et al., 1999), thus the disturbance impacts from lawn care inputs could be more easily reflected in home lawns. In addition, we found that SOM was generally correlated with lawn age, which is in agreement with previous finding by Petrovic (1990). This raised another possibility from the social perspective that home owners who used professional or DIY programs were probably in higher salary-earning class and lived in newer homes where the soil had been recently disturbed yielding lower SOM. Consistent with the nematode community analysis results, the level of  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$  and DON were also not different among the three lawn care programs, suggesting that even no-input lawn care program provides enough available and usable nitrogen to support the grass and the soil food web. The continuous addition of grass clippings results in continuous disturbance and organic matter accumulation in turfgrass soils (Strom et al., 1992), and thus high microbial activity is maintained (Horst et al., 1996). Therefore, based on soil microbial biomass, SOM, and nitrogen availability data, our results suggest that the addition of external chemical fertilizers to lawns is probably not necessary for maintaining high N availability.

In summary, DIY program resulted in no improvement in turfgrass quality and no reduction in weed infestation levels compared to the no-input program, but professional lawn care program produced better turfgrass quality and much lower

weed infestation. These results indicate that homeowners in this study were unable to achieve the desired results related to turfgrass quality and weed control even when they used fertilizers and herbicides. No significant differences in nematode community among the three lawn care programs were noted. Overall, food webs in turfgrass soils were found to be highly enriched but moderately structured, compared to those in natural grasslands and forest ecosystems which are usually poorly to moderately enriched but highly structured. Results from this study also indicate that microbial biomass and SOM were generally higher under no-input lawn care program than the chemical-intensive professional and DIY programs, and thus external inputs have the potential to impose negative impacts on the components of the soil food web. Therefore, in addition to the aesthetic lawn quality, homeowners should consider the health of soil food web, resource use efficiency, environmental impacts, and sustainability of the lawn ecosystem, while choosing a lawn care program.

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<b>Bacterivores</b>	<b>Fungivores</b>	<b>Predators</b>	<b>Omnivores</b>	<b>Plant parasites</b>
<i>Acrobeles</i> (2)	<i>Aphelenchoides</i> (2)	<i>Mononchus</i> (4)	<i>Aporcelaimus</i> (4)	<i>Criconemoides</i> (3)
<i>Acrobeloides</i> (2)	<i>Aphelenchus</i> (2)		<i>Dorylaimus</i> (4)	<i>Dolichodorus</i> (3)
<i>Alaimus</i> (4)			<i>Eudorylaimus</i> (4)	<i>Filenchus</i> (2)
<i>Cephalobus</i> (2)			<i>Mesodorylaimus</i> (4)	<i>Helicotylenchus</i> (3)
<i>Diplogaster</i> (1)			<i>Pungentus</i> (4)	<i>Hemicriconemoides</i> (3)
<i>Eucephalobus</i> (2)				<i>Heterodera</i> (3)
<i>Mesorhabditis</i> (1)				<i>Hoplolaimus</i> (3)
<i>Monhystera</i> (1)				<i>Longidorus</i> (5)
<i>Panagrolaimus</i> (2)				<i>Paratylenchus</i> (2)
<i>Pelodera</i> (1)				<i>Pratylenchus</i> (3)
<i>Plectus</i> (2)				<i>Psilenchus</i> (2)
<i>Rhabditis</i> (1)				<i>Rotylenchus</i> (3)
<i>Turbatrix</i> (1)				<i>Telotylenchus</i> (2)
<i>Wilsonema</i> (2)				<i>Tylenchorhynchus</i> (3)
				<i>Tylenchus</i> (2)
				<i>Xiphinema</i> (5)

**Table 4.1:** List of nematode genera identified and the assigned colonizer-persister scale values (numbers in brackets, following Bongers, 1990) from soil samples collected from home lawns across the three management programs.

	<i>Management program</i>	<i>Total nematodes / 20g soil</i>	<i>Free-living nematodes / 20g soil</i>	<i>Plant parasites / 20g soil</i>	<i>Maturity Index (MI)</i>	<i>Plant-parasitic Index</i>	<i>Enrichment Index</i>	<i>Structure Index</i>
Sept. 2003	Professional	228±36 †	150±25	78.2±14	1.90±0.0813	2.61±0.0249	81.2±2.64	53.9±4.85
	Do-it-yourself	254±39	155±24	98.5±21	1.95±0.0374	2.56±0.0351	75.5±1.99	55.3±2.51
	No-input	205±25	151±19	54.6±8	1.76±0.0675	2.52±0.0520	78.5±1.55	45.0±3.21
July 2004	Professional	283±76	191±56	91.8±23	1.75±0.127	2.52±0.0303	78.4±5.17	32.5±8.24
	Do-it-yourself	274±35	152±23	122±24	1.85±0.0514	2.45±0.0438	79.3±1.63	53.4±3.02
	No-input	318±37	199±27	119±11	1.87±0.0761	2.43±0.0310	74.3±3.77	46.9±4.5
Oct. 2004	Professional	413±151	277±126	130±32	1.65±0.173	2.51±0.0446	84.6±4.95	49.1±4.96
	Do-it-yourself	337±82	196±49	137±47	1.66±0.0931	2.30±0.0632	83.5±3.24	45.0±7.23
	No-input	405±218	308±183	91±35	1.85±0.142	2.49±0.0851	83.2±3.71	50.4±8.80

**Table 4.2:** Effect of three management programs on nematode abundance and nematode community indices in soil in urban lawns.

† Values are Mean ± Standard Error

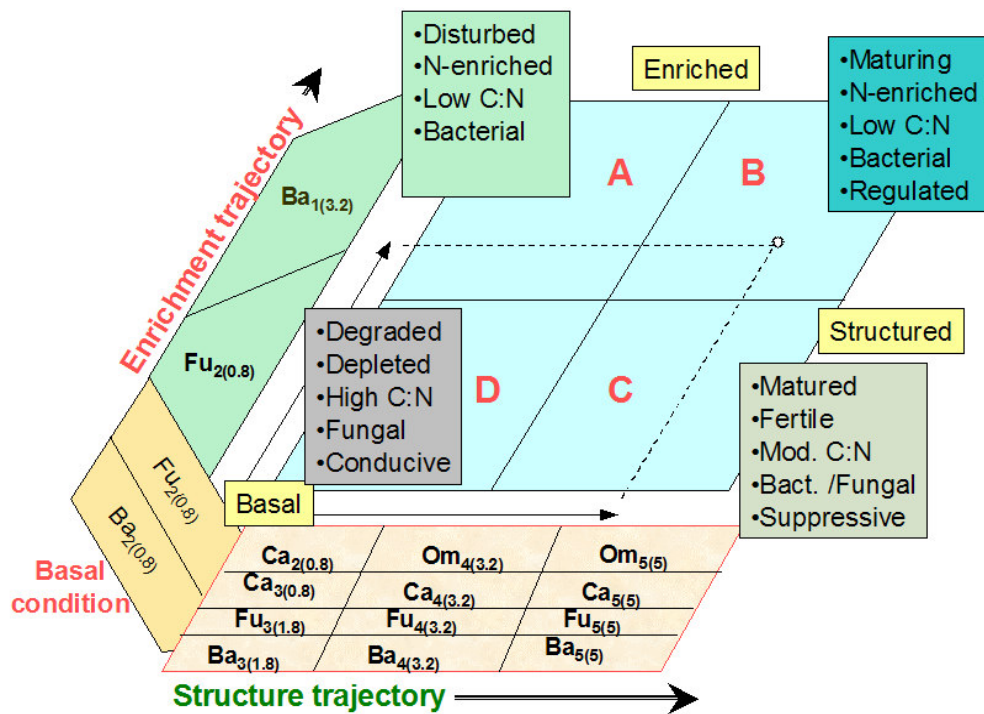
<i>Parameter</i>	<i>Management program</i>
Total number of nematodes	0.73
Total number of genera	0.70
Total number of free-living nematodes (FLN)	0.59
Total number of plant-parasitic nematodes (PPN)	0.56
Richness Index (Margalef)	0.34
Diversity Index (H')	0.51
Evenness Index (Pielous J')	0.66
Maturity Index	0.26
Plant-parasitic Index	0.16
Enrichment Index	0.40
Structure Index	0.35
NH <sub>4</sub> -N	0.81
NO <sub>3</sub> -N	0.79
Dissolved organic N	0.12
Microbial biomass N	<b>0.024</b>
Soil organic matter	<b>0.0007</b>

**Table 4.3:** P values obtained from repeated measures analysis of variance showing the overall impact of the three management programs on nematode community, nitrogen pools, microbial biomass N, and soil organic matter in urban lawns.

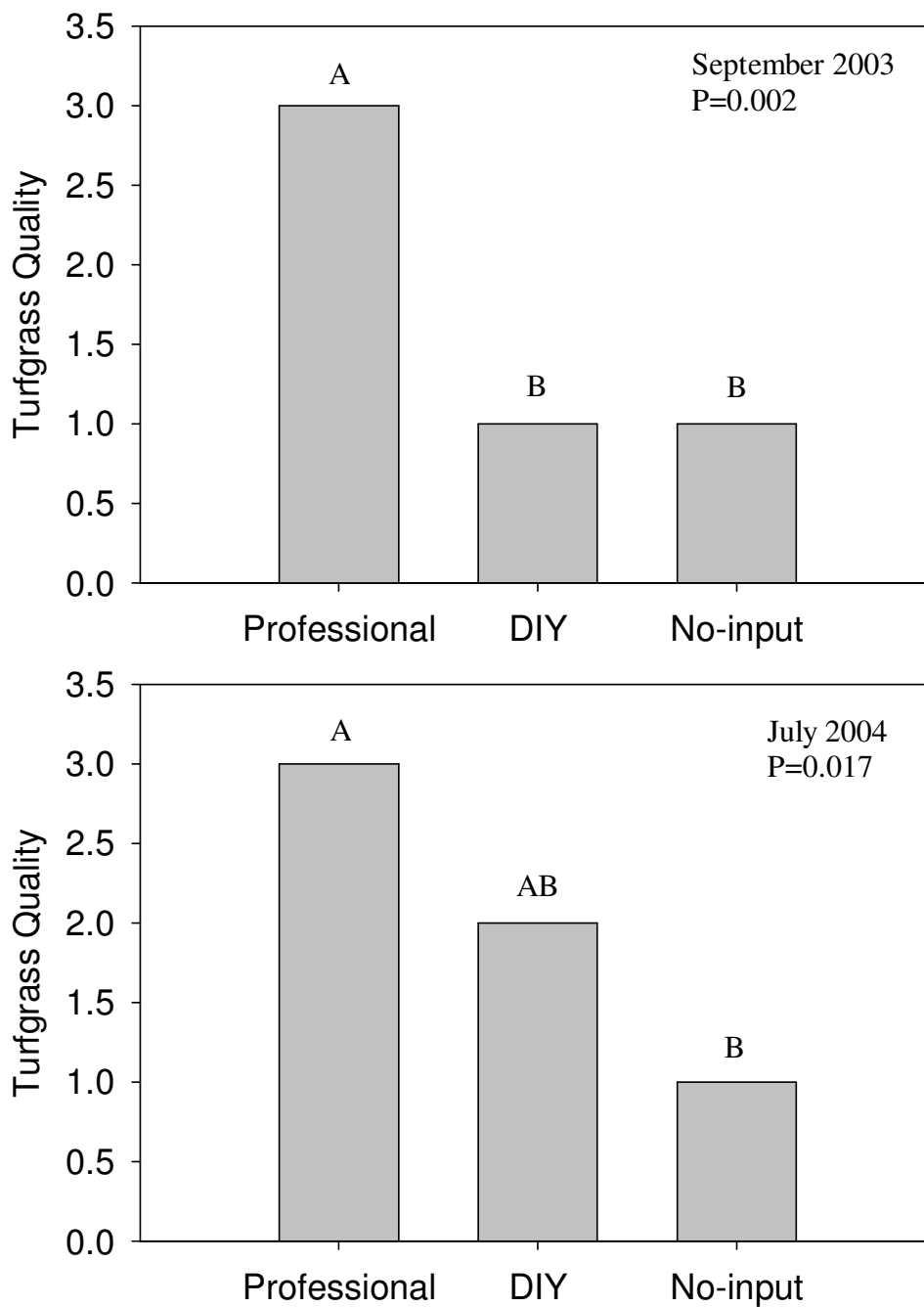
<i>Sampling Time</i>	<i>Management program</i>	<i>NH<sub>4</sub>-N (ppm)</i>	<i>NO<sub>3</sub>-N (ppm)</i>	<i>Dissolved organic N (ppm)</i>	<i>Microbial biomass N (ppm)</i>	<i>Soil organic matter (%)</i>
Sept. 2003	Professional	4.47±1.45 †	31.0±2.94	20.3±2.34	62.4±6.41	2.95±0.399
	Do-it-yourself	3.28±0.484	17.3±2.47	17.3±1.01	67.8±6.19	3.73±0.248
	No-input	3.44±0.524	22.1±2.54	17.4±1.43	97.8±10.5	4.43±0.146
July 2004	Professional	2.07±0.291	18.2±2.69	7.81±0.941	72.0±8.99	3.72±0.293
	Do-it-yourself	2.05±0.166	17.0±1.49	5.81±0.835	71.8±4.29	3.77±0.275
	No-input	2.73±0.385	16.7±2.18	7.60±1.34	81.7±4.47	4.67±0.443
Oct. 2004	Professional	2.65±0.602	21.9±4.64	6.83±1.33	51.0±8.23	3.50±0.288
	Do-it-yourself	2.96±0.722	25.9±5.04	4.56±0.774	40.0±4.84	3.65±0.233
	No-input	1.93±0.244	16.4±3.43	6.86±1.21	53.6±6.86	3.96±0.382

**Table 4.4:** Effect of three management programs on soil nitrogen pools, microbial biomass (N), and soil organic matter in urban lawns.

† Values are Mean ± Standard Error

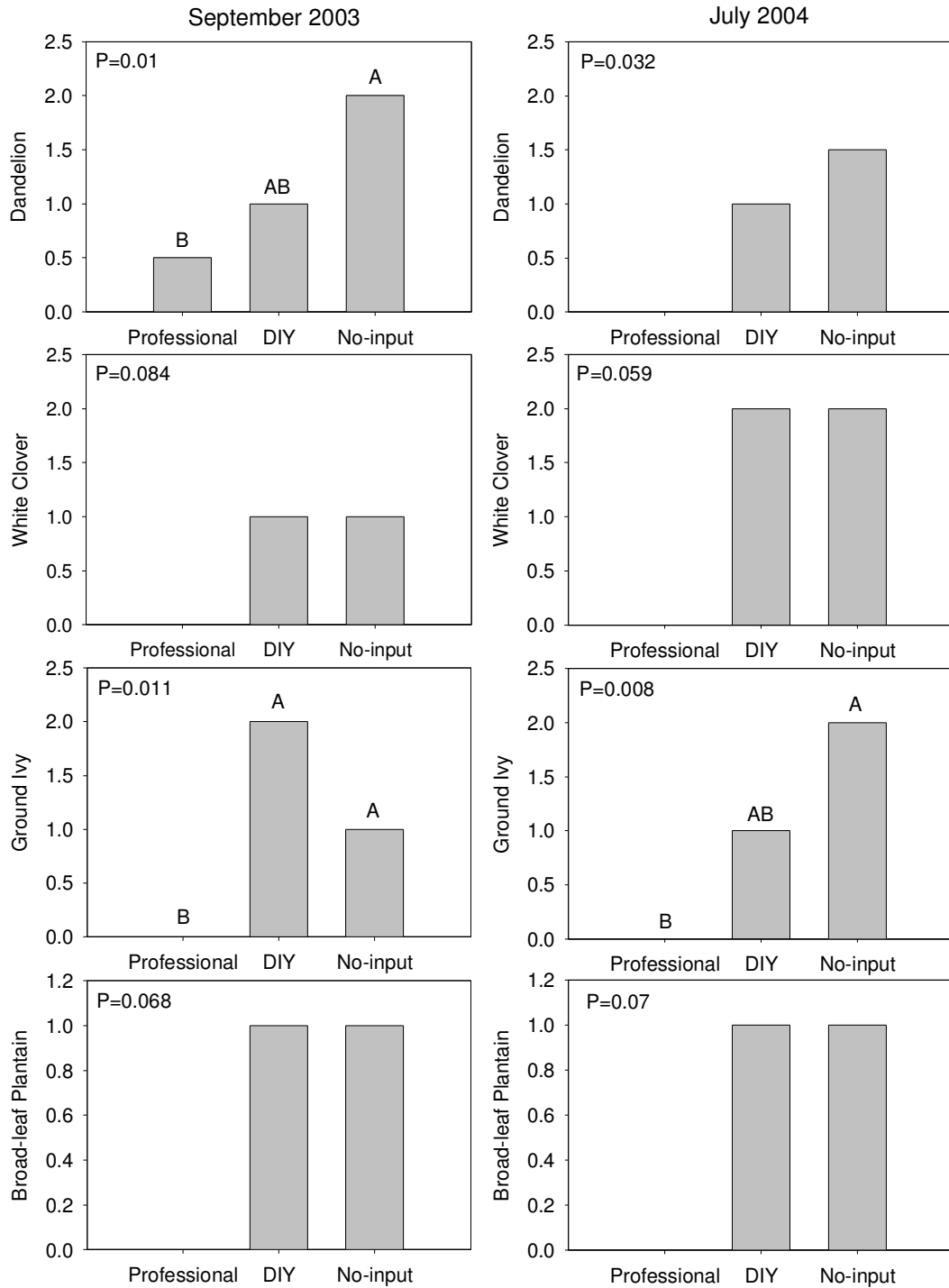


**Figure 4.1:** Graphic representation of the soil food web indicated by nematode faunal analysis (from Ferris et al., 2001).  $Ba_x$  (bacterivores),  $Fu_x$  (fungivores),  $Ca_x$  (carnivores, or predators),  $Om_x$  (omnivores) (where value of  $x = 1-5$  on the cp scale) represents various functional guilds. Indicator guilds of soil food web condition (basal, structured, enriched) are designated and weightings of the guilds along the structure and enrichment trajectories are provided, for determination of the enrichment index (EI) and structure index (SI) of the food web.

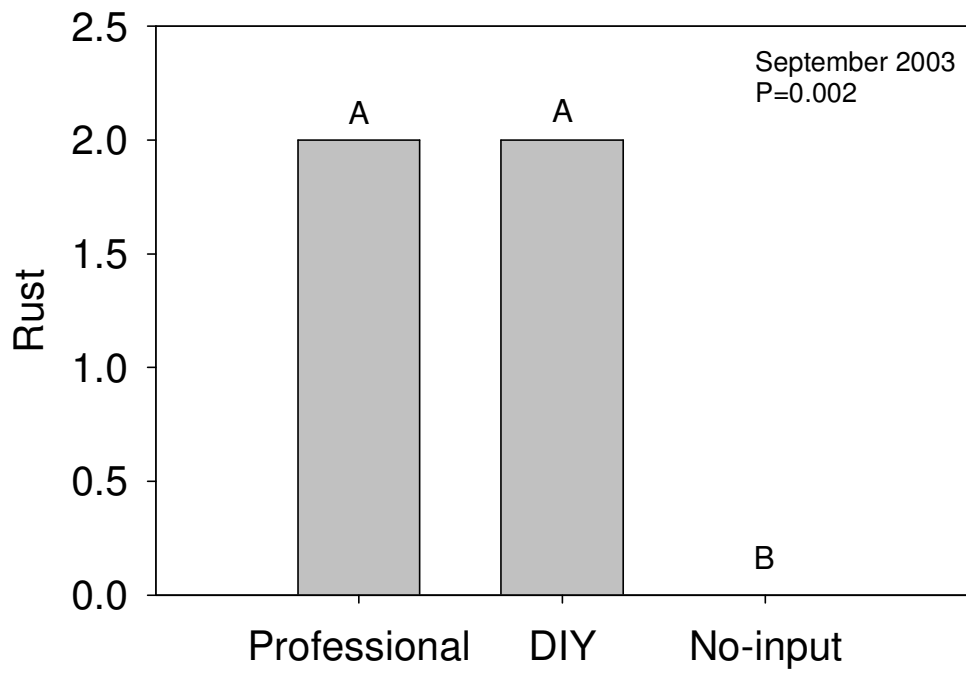


**Figure 4.2:** Median of turfgrass quality scores under three management programs in urban lawns. Turfgrass quality was assessed using a 0-3 scale with 0 indicating very poor and 3 indicating very good quality. DIY = Do-it-yourself management program.

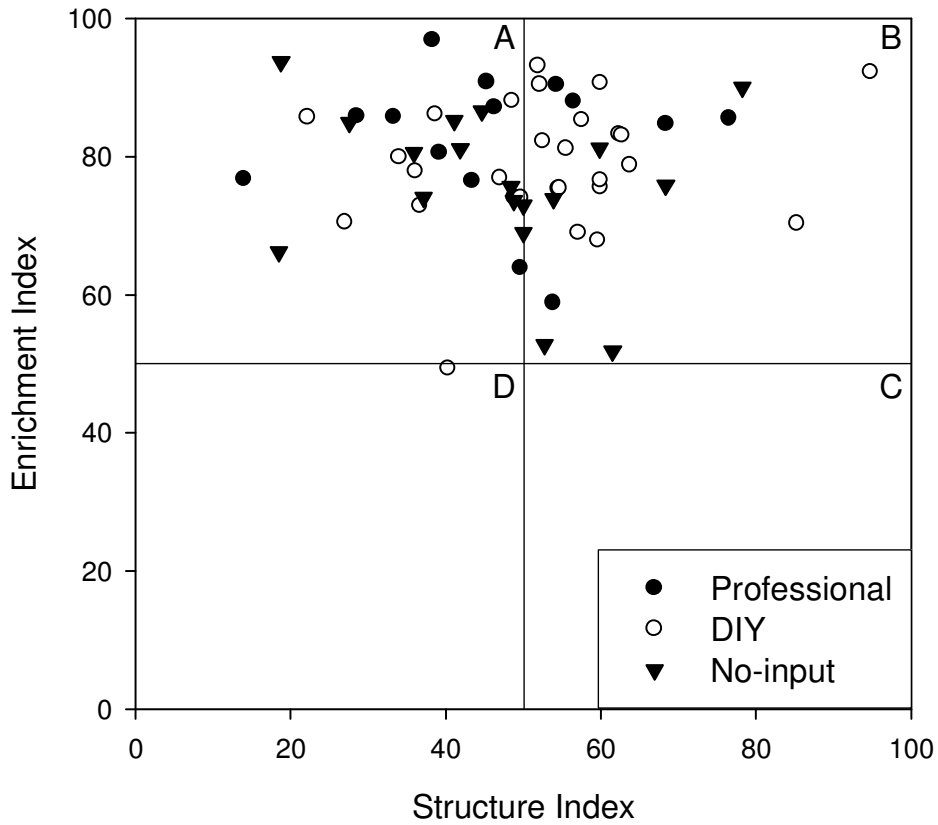




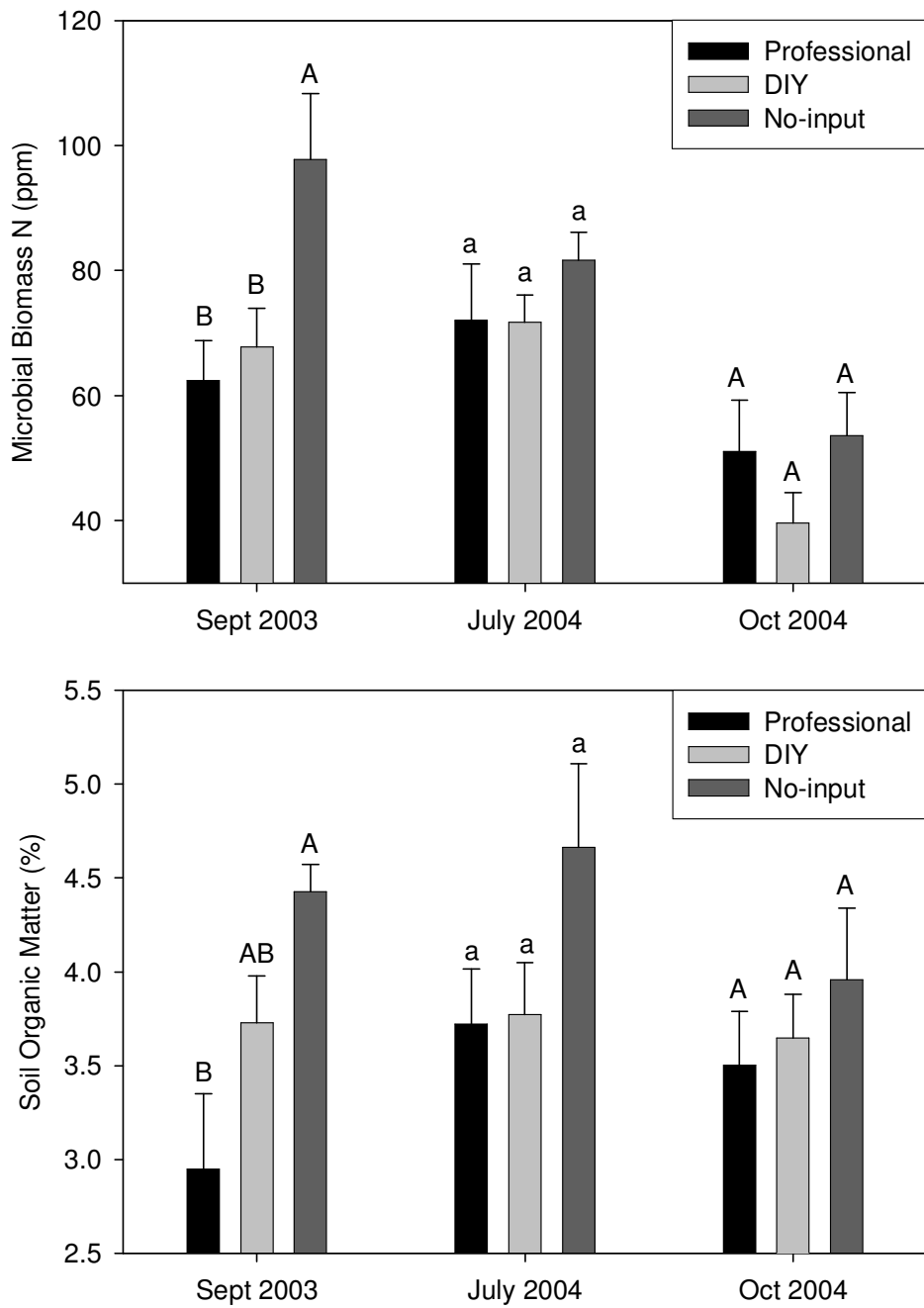
**Figure 4.3:** Median of infestation levels of major weeds under three management programs in urban lawns. Infestation was measured using a 0-3 scale for each species with 0 indicating absence and 3 indicating a severe infestation of a particular species. DIY = Do-it-yourself management program.



**Figure 4.4:** Median of rust severity ratings under three management programs in urban lawns. Rust severity was rated using a 0-3 scale with 0 indicating no damage and 3 indicating a severe damage caused by a disease. DIY = Do-it-yourself management program.



**Figure 4.5:** Nematode food web enrichment and structure conditions deduced from faunal analysis under three management programs in urban lawns. Each point represents the EI and SI scores for a home lawn at one of the three sampling times. DIY = Do-it-yourself management program.



**Figure 4.6:** Effects of the three management programs on microbial biomass N (ppm) and soil organic matter (%) in urban lawns. Data are mean + SE. DIY = Do-it-yourself management program.

## CHAPTER 5

### CONCLUSIONS AND FUTURE DIRECTIONS

In this study, we assessed the impact of a variety of lawn establishment and management practices on turfgrass soil ecosystem using several key ecological indicators, including soil nitrogen pools ( $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$ , and dissolved organic nitrogen), soil organic matter (SOM) content, microbial biomass, and nematode community.

In Chapter 2, we assessed the differences among the four soil preparations practiced in urban lawn establishment (subsoil, subsoil with compost amendment, topsoil, and topsoil with compost amendment). We found that topsoil had higher nitrogen pools, microbial biomass, SOM, nematode abundance and genus numbers compared to the subsoil. In addition, compost amendment resulted in higher levels of soil nutrient pools compared to the subsoil, which were maintained during the course of the one-year study period. An interesting finding was that during turfgrass germination and establishment, topsoil plots were invaded rapidly by weeds. These results emphasize the importance of weed control during the early stage of turfgrass establishment on topsoil.

We found that long-term organic-fertilizer based turf management resulted in higher soil microbial biomass in general compared to mineral-fertilizer management or the control (Chapter 3). One interesting finding is that long-term application of herbicides, insecticides, and fungicides did not impose significant negative impacts on

soil microbial biomass, SOM content, and nematode community (Chapter 3). Therefore, it is suggested that turfgrass ecosystems are buffered against negative impacts of chemical pesticides perhaps due to the high microbial activity associated with a turfgrass soil ecosystem. However, we did detect significant long-term effect of N application on soil nematode food web, where maturity index (MI) and combined MI (CMI) were generally lower and enrichment index was generally higher under high and medium N-input compared to low N-input (Chapter 3). In contrast, in newly established turfgrass plots, no such effect was noticed (Chapter 2). We suspect that the difference in the initial soil nutrient pools in the two studies could play a role for these different findings. In addition, the N application could impose long-term (after 15-year continuous management in the study discussed in Chapter 3) cumulative effect on nematode food web rather than short-term (45 days after each fertilizer application in Chapter 2) impact. The long-term effect may reflect a relatively stable shift in nematode food web rather than a temporary change.

Results in Chapter 4 suggested that homeowners relying on typical do-it-yourself programs are unable to achieve the desired levels of turf quality and weed control. Soil N pools were not different among the three lawn care programs whether fertilizers were applied or not, suggesting that the addition of external chemical fertilizers to lawns might not be necessary for maintaining high N availability. However, chemical input intensive management could impose negative impacts on turfgrass soil ecosystem in terms of microbial biomass and SOM. Therefore, in addition to the aesthetic lawn quality, homeowners should consider the health of soil food web, resource use efficiency, environmental impacts, and sustainability of the lawn ecosystem, while choosing a lawn care program.

Turfgrass soil nematode food web was found to be highly enriched but poorly to moderately structured, irrespective of the management practices involved (Chapters 2, 3, and 4). In contrast, soil food webs in natural grasslands and forest ecosystems are usually poorly to moderately enriched but highly structured (De Goede and Bongers, 1998; Ferris et al., 2001). We suspect that the continuous physical disturbance caused by soil compaction due to mowing activities, and chemical disturbance caused by fertilization and clippings returns contribute to this finding. In addition, this suggests a possible homogenizing force of turfgrass on the soil food web, which could be an evidence of bottom-up control. In deed, the temporal progression of nematode food web detected in Chapter 2 showed that soil food webs tended to move towards each other during the course of turfgrass establishment and maintenance. Overall, nematodes can be regarded as an effective bio-indicator complementary to direct soil analysis and provide an overall picture of the soil food web from a different angle. However, as the nematode food web model was originally based on agricultural soil systems, there are some relatively subjective assumptions. First of all, one root of this model, c-p value allocation of nematodes is a tentative one and is subject to modification (Bongers, 1999). Second, the guild weightings assigned are based on several simple (but usually acceptable) assumptions (Ferris et al., 2001). In addition, all plant-parasitic nematodes are excluded from this model. Therefore, in order to efficiently apply this model in turfgrass soil systems, some modifications are probably needed, such as modifications of guild weightings according to specific turfgrass soil ecosystems, and inclusion of some most important plant-parasitic nematodes presented in turfgrass soil ecosystems.

As raised in Chapter 2, an immediate further question is how long does it take for nematode community in subsoil to develop abundance and trophic diversity similar to that in topsoil, under the influence of turfgrass growth and various maintenance practices. To the best of our knowledge, there is no such study reported to date. Therefore, such study can fill some major gaps in our knowledge of nematode food web development and succession in turfgrass soil ecosystems.

Urban runoff has become an important environmental concern in recent years. According to the U.S. Environmental Protection Agency (1995), urban runoff in U.S. ranks as the third most common source of water pollution for rivers, and the second most common source for lakes and estuaries, affecting about 28% of the lake area that does not meet water quality standards. One major problem caused by urbanization is that many impervious surfaces such as roads, parking lots, and pavements are created, which prevent the infiltration of water into the soil (Arnold et al., 1996), resulting in increased volume and velocity of surface runoff. However with urbanization, huge amount of turfgrass areas are established. With dense biomass aboveground and root system below ground, turfgrass offers an excellent cover to protect soil and acts to reduce chemical particle movement and filter pollutants from water. The leaves over the soil surface intercept and absorb raindrop impact and provide resistance to water runoff (Krenitsky et al., 1998). In addition, the high microbial activity in turf soil has the potential to degrade chemicals relatively rapidly, thus improving the runoff water quality. Studies have been done where turfgrass lawns are found more effective than other land uses and ground covers in terms of runoff volume control and runoff water quality improvement (Atlavinyte et al., 1974; Broadbelt, 2000; Gan et al., 2003).

However, it is now a common practice for builders to scrape the ground of its organic rich topsoil and build the new lawns on subsoil. In addition to low nutrient



levels, the subsoil usually has poor water infiltration ability, which results in compaction and anaerobic conditions. These conditions not only lead to challenges in growing the turfgrass on subsoil, but also could reduce the runoff control ability of turfgrass lawns. Yet, the comparison in the effectiveness of runoff control ability between turfgrass lawns established on subsoil and topsoil has not been conducted. As mentioned in Chapter 2, our new plots were established with a 4-degree cross-angle slope defined by wood frames to conduct such a runoff study.

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