EFFECT OF CLIPPING DISPOSAL, FERTILIZER RATE AND MOWING FREQUENCY ON COOL-SEASON TURFGRASS GROWTH TO DETERMINE IMPACTS ON WASTE DISPOSAL

by

Heather Platford

A Practicum
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ABSTRACT

Two studies were established to determine the slow growth and low maintenance potential of select turfgrasses and maintenance regimes. One study focused on the effects of two different clipping disposal and fertilizer rate on five cool-season turfgrass species, and the other study examined the effects of mowing frequency on seven commercially available turfgrass mixtures.

The clipping disposal and fertilizer rate study consisted of a two-year field study which examined the effects of turfgrass mixture composition (ten mixtures composed of combinations of Kentucky bluegrass, Canada bluegrass, creeping red fescue, sheeps fescue and perennial ryegrass); clipping disposal (clippings left on plots (grasscycling) and clippings removed); and fertilizer rates (0.5 and 1 lb. of N/1000 ft^2/twice a year) on the clipping yield, height, colour, percent nitrogen in tissue, and composition of these turfgrasses. Turfgrass mixtures and fertilizer rates produced significant differences ($p<0.05$) in clipping yield and the percent nitrogen in the grasses for both treatment years. The plots treated with the high fertilizer rate produced, on average, 62.56 g/m^2 more dry weight yield throughout the combined 1995 and 1996 growing seasons than the plots treated with the low fertilizer rate (87.38 g/m^2). The grasscycling treatment resulted in a significant difference ($p<0.0500$) in the clipping yield in the 1995 field season clippings, but not in 1996. Plots imposed with grasscycling treatment produced on average 2.70 g/m^2 more total dry weight yields over the plots where clipping were removed (34.30 g/m^2). Turfgrass height, colour and plot cover also differed with the different turfgrass mixtures and fertilizer rates.

The mowing frequency study examined the effects of turfgrass mixture composition (seven commercially available mixtures), mowing frequency (once a week, and biweekly) on clipping yield, height and colour of the select turfgrasses. A significant difference ($p<0.0500$) was found in the dry weight yield between turfgrass mixtures.

The clipping disposal and fertilizer rate study found mixtures eight (Canada bluegrass, sheeps fescue, and perennial ryegrass) and six (Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass) to be the slowest growing polystands, and Kentucky bluegrass to be the slowest growing monostand. Grasscycling is the best clipping disposal method and use of slow-release fertilizers at low application rates are recommended.

Clipping yield from the mowing frequency study indicates that mixture four (OSECO's Blue Chip Low Maintenance/Reclamation Mixture composed of equal parts of Canada bluegrass, hard fescue, chewings fescue, red fescue, and perennial ryegrass) and mixture three (Pickseed's Envirogreen composed of 20% Kentucky bluegrass, 40% creeping red fescue, 25% hard fescue and 15% perennial ryegrass) be recommended for slow growth and low maintenance. It is also recommended, to reduce lawn maintenance, that biweekly mowing should be implemented in most situations.

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CHAPTER ONE

INTRODUCTION

Turfgrass is a dominant feature of urban landscapes. It is the predominant vegetation used for boulevards, road rights-of-way, sports fields, golf courses, parks, and lawns. It has many functional, recreational and aesthetic benefits, which include: protection of soil from water and wind erosion; reduction of runoff; provision of an effective groundcover; increased water retention in soils; increased soil organic matter; dissipation of heat in urban areas; reduction of noise pollution; increased visibility along rights-of-way; provision of wildlife habitat; a site to play a multitude of outdoor sports; reduced injuries due to cushioning; stress release; enhancement of the urban environments; and, increased overall well-being of people (Beard and Green, 1994).

To enable turfgrass to provide these benefits it must be managed. Management of turfgrass systems often consists of mowing, fertilizing, herbicide use, irrigating and clipping disposal. All of these management activities have environmental impacts. In an attempt to determine if the environmental impacts of turfgrass maintenance can be reduced, there is renewed interest in how different species of grasses are affected by mowing frequency, fertilizer rates, and clipping disposal methods.

ISSUE

The most commonly used turfgrass in Manitoba is Kentucky bluegrass, *Poa pratensis* L. (Cattani, 1994), it is also considered the most important and widely utilized cool-season turfgrass species in North America (Beard, 1973). Kentucky bluegrass requires large amounts of irrigated water and fertilizer to remain green throughout the summer months, continual maintenance, and grass clippings which contribute to yard waste are often disposed of in landfill sites. In order to reduce the strain on the City of Winnipeg's water source, to decrease the amount of chemical fertilizer used for lawn maintenance, to minimize the amount of time put into lawn care and to reduce the amount of grass clippings disposed of in landfill sites, cool-season turfgrasses were assessed for their slow growth, and low maintenance potential.

PURPOSE

The purpose of this study was to identify suitable turfgrass species for the City of Winnipeg, and once selected to determine their slow growth and low maintenance potential in order to recommend a turfgrass mixture and management regime that meets the criteria of slow growth and low maintenance.

RESEARCH OBJECTIVES

The objectives of this project were:

1) to review literature related to turfgrass maintenance;

2) to select slow growth turfgrass species suitable for the City of Winnipeg;

3) to determine the effects of clipping disposal method, fertilizer rate, and mowing frequency on the turfgrass mixtures chosen;

4) to make recommendations, based on the collected observations and measurements, on the slow growth/low maintenance potential of the turfgrasses to city planners, golf courses, contractors and home-owners.

HYPOTHESIS

The hypothesis for this study is:

H_0: Turfgrass mixture, clipping disposal method, fertilizer rate, or mowing frequency do not have an effect on the growth and maintenance of established turfgrass plots.

H_a: Turfgrass mixture, clipping disposal method, fertilizer rate, or mowing frequency have an effect on the growth and maintenance of established turfgrass plots.

METHODS

For this practicum two studies were completed. The first study was designed to evaluate the effects of clipping disposal and fertilizer rate on ten cool-season turfgrass mixtures. The second study was a continuation of the research started by Carriere and Mcleod (1994), seeded in 1994, and it was designed to determine the effects of mowing frequency on seven cool-season commercially available turfgrass mixtures. Detailed methods can be found in Chapter three.

ORGANIZATION

This practicum is organized into five chapters. Following the Introductory Chapter, Chapter Two presents a review of the literature pertaining to turfgrass. It contains turfgrass ecology, selection characteristics of turfgrass species, turfgrass management, turfgrass evaluation methods and some environmental impacts of turfgrass management. Chapter Three describes the chosen methods for both the clipping disposal and fertilizer rate study, and the mowing frequency study. Chapter

Four includes the results and discussion for the clipping disposal and fertilizer rate study. Chapter Five contains the results and discussion for the mowing frequency study. Chapter Six includes the conclusions, and recommendations portion of the practicum.

CHAPTER TWO

TURFGRASS: CHARACTERISTICS AND ISSUES

The study of turfgrass is a multidisciplinary field including agronomy, soil science, entomology, and plant pathology. This literature review addresses the ecological aspects of turfgrass, turfgrass selection criteria, turfgrass management and the environmental impacts of turfgrass management.

2.1 Turfgrass Ecology

To fully understand the turfgrass system, all aspects that influence the growth and survival of turfgrass must be considered. These include the following:

2.1.1 Turfgrass Growth

Energy required for turfgrass growth, like all other plant, is obtained through the conversion of light energy into chemical energy through the process of photosynthesis. Most plants are grouped into one of two categories based on their photosynthetic pathway, either as cool-season (C_3) plants or warm-season (C_4) plants. Cool-season grasses fix CO_2 using the Calvin Cycle with the first stable metabolite being 3-phosphoglyceric acid (3-PGA), a 3-carbon product. Warm season grasses fix CO_2 using the dicarboxylic acid pathway, with the initial CO_2 fixation product being malic and aspartic acids, 4-carbon products (Salisbury & Ross, 1985).

Once converted, energy is stored in the leaves, stems and roots of grasses, in the form of non-structural carbohydrates, such as, sucrose, starch and/or fructans (Hull, 1992). This stored energy can then be broken down and utilized for grass maintenance and growth.

2.1.2 Soil Properties

Increased stress on soils resulting from human cultivation activities has led researchers to study how soils can be managed in a sustainable manner. Understanding soil properties is critical when planning turfgrass studies that include fertilization and cutting regimes to ensure both plant and soil health are maintained. Soil by definition is a substrate, formed by the weathering of parent rock and comprised of organic and inorganic matter, that can support biological activity (Troeh & Thompson, 1993). Soil studies focus on chemical, physical and biological properties, each of which must be considered.

Chemical Properties

Chemical properties of soil that may influence turfgrass growth include: nutrient availability, pH, cation exchange, and salinity (Donahue et al., 1983).

Nutrients: Soil fertility or nutrient availability refers to the inorganic elements accessible to plants for metabolism and growth. On average, 40 to 60% of the total volume of soil is composed of inorganic compounds (Winegardner, 1996). The seventeen essential inorganic nutrients that plants need are carbon, hydrogen, oxygen, nitrogen, potassium, phosphorus, calcium, magnesium, sulphur, iron, manganese, zinc, copper, boron, molybdenum, cobalt, and chlorine (Salisbury & Ross, 1985; Raven et al., 1986). Turfgrasses require more available nitrogen than any of the other seventeen essential plant nutrients, with the exception of C, H and O (Turner & Hummel, 1992). Inorganic nutrient availability depends on the ability of the plant to extract nutrients from the soil, the quantity and type of nutrient sinks, soil pH, soil porosity and pore sizes and the persisting environmental state (i.e. climate) (Donahue et al., 1983).

Competitive ability and nutrient requirements of turfgrass is different for each species. For example, turfgrasses with deep roots are able to absorb nutrients from more soil horizons than can grasses with shallow roots (Donahue et al., 1983). Soils may be deficient in plant nutrients, especially nitrogen, as a result of vegetation removal, leaching, immobilization, denitrification, and volatilization. To replace the nitrogen and other nutrients that are lost during these processes, fertilizers are used. In natural systems fertilizers are not needed because dead vegetation is left in the system where it decomposes, and re-fertilizes the soil.

Cool-season turfgrasses vary in the amount of nitrogen they require for growth. Based on Beard's (1973) nitrogen requirements, the turfgrasses are ranked from high nitrogen requirements to low nitrogen requirements: timothy grass (0.5-1.0 lbs. of nitrogen/ 1000 ft^2/growing month) > tall fescue = perennial ryegrass (0.4-1.0 lbs. of nitrogen/ 1000 ft^2/growing month) > Kentucky bluegrass (0.4-0.7 lbs. of nitrogen/ 1000 ft^2/growing month) > creeping red fescue = chewings fescue (0.2-0.4 lbs. of nitrogen/ 1000 ft^2/growing month).

Soil pH: Soil pH is another important chemical property of soil. pH is a measure of the acidity or basicity of the soil. The pH scale ranges from 0 (highly acidic) to 14 (highly basic), with 7 being neutral. The pH range of soils used to grow turfgrasses is most often between 4.5 and 7.5 (Beard, 1973).

Soil pH influences the solubility of minerals, the type of vegetation, and plant growth. Basic soils tend to reduce the availability of manganese, phosphorus and iron to plants. Acidic soils tend to decrease the solubility of phosphorous, but increase the solubility of potentially toxic metals like aluminum. Plants in turn can also change soil pH. In order to maintain charge balance, plants release hydrogen (H^+) ions into the soil when ammonium (NH_4^+) is the nitrogen source, thereby decreasing soil pH. However, if the nitrogen the root takes up is in the form of nitrate (NO_3^-), the root releases bicarbonate and hydroxyl ions into the soil, increasing the soil pH (Killham, 1994).

The optimal soil pH for most grasses is 6.5, when nutrient availability is tends to be highest (Beard, 1973). Turfgrasses, however, vary in their tolerance to pH. Some grow best in a soil with a pH of 4.5 to 5.5, whereas others grow best in soils with a more basic pH of 6.5 to 7.5. Sheeps fescue grows best in very acidic soils with a pH of 4.5 to 5.5. Canada bluegrass and creeping red fescue grow optimally in soils with a pH ranging between 5.5 to 6.5 (moderately acidic). Both Kentucky bluegrass and perennial ryegrass grow best in slightly acidic to neutral soils with a pH of 6.0 to 7.0 (Beard, 1973).

Cation exchange: Cation exchange is another chemical property of soils. Cation exchange is the replacement of one positively charged ion (cation) with another cation. This type of exchange occurs on the surface of roots, clay, and humus colloids. It is an important reaction in soil fertility, fertilizer applications, nutrient uptake, and environmental quality (Tan, 1994). Cation exchange is pH dependent. In acidic soils there are fewer cation exchange sites, which often results in lower fertility. To increase soil fertility, acidic soils are limed, resulting in the replacement of H^+ ions with Ca^{2+} ions which therefore increases the cation exchange capacity of that soil (Tan, 1994). Organic matter can also influence the cation exchange capacity. Organic matter increases the cation exchange capacity of soil by providing sites for nutrients to adhere to (Miller & Donahue, 1995).

Salinity: Saline soils have high concentrations of soluble salts, such as: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) (Harivandi et al., 1992). Soil salinity tends to have an inverse effect on the growth of turfgrasses due to decreased osmotic potential of the plant. The decline in osmotic potential makes it more difficult for the roots of the turfgrass plants to absorb water (Rowell, 1994).

Soils are considered non-saline if they have an electrical conductivity (EC), on average, of 0-2.0 dS m^{-1}; slightly saline if they have an EC, on average, of 2.0-4.0 dS m^{-1}; and severely saline if they have an EC, on average, of 16.1 dS m^{-1}, or more (Plaster, 1997). Estimated salt tolerance of cool-season turfgrasses are ranked from most tolerant to least tolerant: perennial ryegrass = tall fescue (tolerates 6-10 dS m^{-1}) >

creeping red fescue = chewings fescue = hard fescue (tolerates 3-6 dS m^{-1}) > Kentucky bluegrass (tolerates < 3 dS m^{-1}) (Harivandi et al., 1992).

Soil organic matter: "The organic matter content influences many soil properties, including (i) the capacity of a soil to supply N, P, S, and trace metals to plants; (ii) infiltration and retention of water; (iii) degree of aggregation and overall structure that affect air and water relationships; (iv) cation exchange capacity; (v) soil colour, which in turn affects temperature relationships; and (vi) adsorption or deactivation (or both) of agricultural chemicals." Organic matter is important in supplying plants with available nitrogen (Nelson & Sommers, 1982).

Soil temperature: Temperature is another important soil property. Indirectly it influences soil physiology and turfgrass growth. Soil temperature is controlled by a number of factors including diurnal and seasonal changes, vegetation type and cover, moisture, and soil depth.

One of the greatest effects of temperature on soil properties is its role in regulating microbial activity and uptake of water and minerals by plants. A rise of 10^0C when the soil temperature is between 0^0C and 35^0C, doubles the amount of plant growth, plant enzyme activity (Leopold & Kriedemann, 1975) and microbial activity in the soil (Killham, 1994). Cool-season turfgrasses have optimal root growth at soil temperatures between 10 to 18^0C (Beard, 1973).

Physical properties

Physical properties of soil include pore size, soil stability, texture, structure, consistency and hardness or cementation of layers. The physical properties of soil critical to turfgrass research are pore space and size, and soil texture.

One particular concern to park and golf course managers is the extent of soil compaction. Soil compaction is defined as "the pressing together of soil particles, resulting in a more dense soil mass with less pore space" (Carrow and Petrovic, 1992). Soil compaction is often caused by foot or vehicular (lawn mowers and golf carts) traffic. Compaction affects soils by decreasing porosity and pore size, increasing bulk density, increasing the soils water holding capacity and impeding the movement of water within the soil. All of these impacts can effect turfgrass growth (Carrow and Petrovic, 1992).

Porosity: The total volume of soil consists of: pore spaces (porosity), which comprise 1/3 to 1/2 of the soil volume, and solid minerals and organic compounds, which comprise one half to two thirds of the overall soil volume (Winegardner, 1996). Pore spaces are the spaces between adjacent soil particles occupied by water or air. Porosity varies between soils, and is dependent on the degree of compaction, texture, and the concentration of soil organic matter present. Soils with high concentrations of clay and silt tend to have more, but smaller, pore spaces than soils with a high content of sand.

Pore space and size decrease with increasing compaction, resulting in declined turf cover (Carrow, 1980). Clay and silts, the soil textures which have higher porosities but smaller pore sizes, are the two soils that are highly affected by compaction. Soil compaction affects both the root and shoot growth of turfgrass. Under moderate compaction in a turfgrass system there is an increase in shallow, surface, root growth and a reduction in the deep root growth. Carrow and Petrovic (1992) link this altered root growth to the decline in soil aeration. Plant roots require well aerated soils for aerobic respiration and growth. Pore size distribution in soils is more important than the soil porosity, for determining the soil aeration.

Soil pores with diameters of 30 micrometres or greater allow sufficient amounts of oxygen to reach the roots. Large pores when filled with rain or irrigation water, rich in dissolved oxygen, are quickly drained of this water, but retain the rich oxygen supply. The principle way the soil oxygen concentration is increased is due to gravitational forces within these large pores. Smaller pores play a less important role in replenishing oxygen concentrations in soils.

Bulk density: Bulk density is another physical property of soil that changes with soil compaction. Bulk density is the mass of air dry soil per unit volume, which includes solids and pore spaces (Waddington, 1969). Consequently, soils with large proportions of clays and silts (highly porous soils) will have lower bulk densities compared to more compact soils with high quantities of sand (Troeh & Thompson, 1993).

Soil compaction causes an increase in bulk density. Rosenburg (1964) found that increased soil compaction led to reduced clipping yield and shoot density in turfgrass. If soil compaction becomes a problem for turfgrass managers there are a number of ways that it can be remedied, resulting in healthier turfgrass. Some ways of reducing soil compaction include: limiting the amount of traffic in an area; adding soil amendments, such as sand, to the soil prior to seeding; and coring or aerating established turf systems.

2.2 Turfgrass Selection

When choosing a turfgrass, selection should be based on the following criteria: climatic conditions; current turfgrass use; environmental stresses the turfgrasses must face; the environmental tolerances it possesses; and the intended maintenance regimes that will be employed, which, where possible, should include low maintenance, low waste regimes (Watschke & Schmidt, 1992).

2.2.1 Climatic conditions

"Turfgrasses are classified into four categories based on their adaptation to a specific climatic condition. The four categories are: grasses that are adapted to the cool humid zone; warm humid zone; cool arid zone; and warm arid zone" (Ward, 1969). Grasses that are best suited for Manitoba's cold semi-arid climate are all cool-season grasses from the genuses Agrostis, Poa, Festuca and Lolium (Watschke & Schmidt, 1992). Cool-season turfgrasses grow best at temperatures betweem 15 and 24^{0}C (Beard, 1973). They go dormant during the hot summer heat and resist freezing stress in the cold winter months by cell dehydration (Levitt, 1980). Cool-season turfgrasses that are most resistant to freezing stress, in order, are: Kentucky bluegrass, Canada bluegrass > creeping red fescue, tall fescue and sheeps fescue > perennial ryegrass (Gusta et al., 1980).

2.2.2 Turfgrass use

Turfgrass is the predominant vegetation used for boulevards and rights-of-way, sports fields, golf courses, parks, and lawns in most major Canadian cities. The City of Winnipeg, for example, has a number of different turfgrass blends that are used for a multitude of purposes (see Grass seed mixtures for use in the City of Winnipeg in 1992, Appendix A for details). Over 2300 hectares of turfgrass in Winnipeg are found within parks and boulevards and are maintained by the city's Parks and Recreation Department (The City of Winnipeg, Parks and Recreation Dept., 1997); 718 hectares of turfgrass are found within the Winnipeg International Airport's land and are maintained by the airport (Canadian Forces Base-Winnipeg, 1994); 243 hectares of turfgrass are found within the city-run golf courses and are maintained by the City of Winnipeg's Parks and Recreation Department (Shane, 1997); and approximately 5200 hectares of turfgrass are found within residential yards (Tomlinson, 1997).

2.2.3 Appearance

Turfgrass appearance is a personal preference, with a uniform, dense, evenly textured, dark green lawn being preferred by the majority of people.

2.2.4 Drought tolerance

Water use and conservation is a central concern for turfgrass managers. Water conservation is necessary to reduce the amount of treated drinking water used by home-owners for lawn care. On average only a few centimetres (1 in.) of water are needed per week to ensure the grass receives enough water for growth (Cattani, 1994; Beard, 1973). Yet, the population of Winnipeg, comprising 623 000 people, is using on average 16.7 million litres of water/day (Ml/d) from April to October for outdoor water use (Water and Waste Department, The City of Winnipeg, 1995). This water is being used primarily used for watering home lawns, vegetable and flower gardens (Water and Waste Department, The City of Winnipeg, 1995). The amount of water used per capita per day for outdoor use comes out to an average of 26 litres of water (Water and Waste Department, The City of Winnipeg, 1995). By utilizing turfgrasses that are drought tolerant the amount of treated water needed for outdoor lawn irrigation would be reduced.

It is well known that certain turfgrasses are able to withstand and survive drought conditions better than others. Drought tolerance is defined as the ability of a plant to regrow after being faced with drought conditions, where there is deficit plant and/or soil water conditions (Beard, 1973; Minner & Butler, 1985).

Wilson & Livingston (1932) used a ranking system (H=high, M=moderate, L=low, VL=very low), and ranked the wilt resistance of Kentucky bluegrass (*Poa pratensis*), Canada bluegrass (*Poa compressa*), and perennial ryegrass (*Lolium perenne*) as moderate, and both creeping red fescue (*Festuca rubra*) and sheeps fescue

(*Festuca ovina*) as very low. Research conducted by Minner and Butler (1985), where 55 varieties of Kentucky bluegrass, 34 varieties of perennial ryegrass, and 42 varieties of fine fescues, showed there were a number of varieties that were more drought tolerant than other varieties. Varieties of Kentucky bluegrass that are very drought tolerant include: 'A-20-6', 'H-7', 'Columbia', 'Haga', and 'Majestic'. Out of the 34 perennial ryegrass varieties, they observed that most of them had an acceptable level of drought tolerance, but the five most drought tolerant varieties were 'Bellatrix', 'Citation', 'Pennant', 'Sportiva', and 'Yorktown'. Of the red fescue varieties 'Waldorf, and 'Jamestown' were the most drought tolerant. Overall, Minner & Butler (1985) found perennial ryegrass to be more drought tolerant than Kentucky bluegrass, which in turn was more tolerant than the fine fescues. Yet, drought avoidance and drought induced dormancy was highest in Kentucky bluegrass.

2.2.5 Shade tolerance

Shade tolerance is another important turfgrass characteristic that must be considered when selecting a turfgrass mixture, because approximately 40% of all turfgrass covered areas are shaded (Beard, 1973). Shade results in reduced and potentially limited sunlight for the grass which causes numerous physiological and morphological effects. Such as reduced root and shoot growth; tillering; shoot density; and plot cover.

The overall physiological effects of shade on turfgrass can include reduced tolerance to environmental stresses (i.e., heat, cold, drought, and wear), disease, and insects, and reduced carbohydrate reserves (Beard, 1973).

Studies, i.e., Wilson (1962); Beard, (1965), show that creeping red fescue appears to be the most shade tolerant cool-season turfgrass. Tall fescue and some ryegrasses are adapted to shade when grown in an environment where they are not threatened by winterkill (Beard, 1965).

2.2.6 Competition/mixtures

It has been found to be undesirable to seed a lawn with only one grass species, due to its lower resistance to disease and insect infestations, i.e., if a lawn composed of only one grass species is infested it is likely the whole lawn will be susceptible to disease and insect injury. Grass mixtures allow the uninfected grasses to fill in the gaps left by the infected grass.

When choosing a turfgrass mixture it should include no more than three to four grass species. Turfgrass mixtures with five or more grass species commonly end up with only two to three grass species surviving (Sunset Editorial Staff, 1965). The grass species that survive are: the grasses that are better adapted to the soil, light and moisture conditions of that specific turf, resulting in them out-competing the grasses less adapted to the growing conditions; or those grasses that establish faster and crowd out the slower, but possibly more persistent grasses.

2.3 Turfgrass Management

The commonly desired lawn is dense, weed free, and dark green in colour. To achieve this aesthetic quality lawn maintenance is required. There are a number of maintenance regimes that must be considered when managing a turfgrass community, such as: mowing height, mowing frequency, weed control, fertilizers and fertilizer rates, clipping disposal, and irrigation. By utilizing a slow growing turfgrass less maintenance is required and environmental impacts of turfgrass management are reduced.

2.3.1 Mowing height

Like most green plants, the major site of photosynthesis in grasses is in the leaves. Every time grasses are mowed they lose leaf surface area, resulting in a reduction in photosynthetic area and therefore a reduction in food production. By mowing too close to the ground the grasses can be overly stressed due to the removal of such a large proportion of leaf area. It is recommended that the mowing height be 3.80 cm (1.5 inches) for fine fescues and ryegrass and 6.35 cm (2.5 inches) for bluegrasses (Schultz, 1989). Beard (1973, Table 12.1, p.386), summarized the clipping heights in a table format , that included:

Relative Cutting Height	Actual Cutting Height	Turfgrass Species
Very close	0.5-1.3 cm (0.2-0.5 inches)	Creeping bentgrass
Medium	2.5-5 cm (1-2 inches)	Red fescue
		Kentucky bluegrass
		Perennial ryegrass
High	3.8-7.6 cm (1.5-3 inches)	Tall fescue
Very high	7.6-10 cm (3-4 inches)	Canada bluegrass

2.3.2 Mowing frequency

It has been found (i.e., Madison 1962b; Lush, 1990) that increasing the interval between mowings results in a lawn with a decreased shoot density . This reduction in shoot density is caused by competition between larger grass plants and smaller plants. When mowing frequency is decreased the more vigorous plants are able to shade out the smaller plants and density therefore decreases. In an attempt to reduce lawn maintenance some turfgrass managers decrease the frequency of mowing. But, because the grass density is affected by mowing frequency, these growers are actually sacrificing the aesthetic quality of their lawn. It is recommended that the frequency of mowing should be such that no more than 1/3 of the leaf area is removed during any one cutting (Cattani, 1994). The removal of more than 1/3 of the turfgrass leaf blade can result in reduced carbohydrate reserves.

Not only is the aesthetic quality of the lawn reduced by decreased mowing frequency but the amount of maintenance and yard waste may actually be increased. When home owners decrease the mowing frequency of their lawn in an attempt to reduce lawn maintenance the result is an increase in the amount of clippings produced (Madison, 1960; Madison, 1962a). This increased yield of clippings may alter the clipping disposal method used. If there is a large yield in clippings, it is recommended that the clippings be removed from the lawn. Removal is recommended because large amounts of clippings left on the lawn may result in increased turfgrass shading. Turfgrass shading is caused by the clippings lying near the top of the turf canopy, and results in a decreased shoot density (Soper et al., 1988). To prevent a decline in turf density and the reduction of carbohydrate reserves mowing frequency should be moderate. Mowing too frequently causes a decline in rooting capability and a drop in storage of carbohydrates (Turgeon, 1980). Decreasing the frequency of mowing, and ensuring no more than 30% of the leaf blade is removed allows grasses to increase their carbohydrate reserves which improves the winter hardiness of turfgrass species.

2.3.3 Fertilizers and fertilizer rates

Plants require certain concentrations of inorganic nutrients for growth. These nutrients are broken into two groups, macronutrients and micronutrients. Since macronutrients are required in large amounts, and typically the limiting element for plant growth, they are the focus of this study. There are nine macronutrients, of which most packaged fertilizers contain only three: nitrogen, phosphorus, and potassium. Deficiency of any of these three macronutrients is the most common soil deficiency problem.

Nitrogen is a vital constituent of the chlorophyll molecule, amino acids, proteins, nucleic acids, enzymes, and vitamins (Epstein, 1972). Nitrogen is essential for root development and the dark green colour of turfgrass species. Turfgrass grown in nitrogen deficient soils has poor root development and light-green to yellowish leaf blades. Excessive nitrogen can also be detrimental to turfgrass growth. Overfeeding the lawn with nitrogen fertilizer slows down the soil microorganisms ability to decompose dead grass to nutrients which results in increased thatch build-up (Schultz, 1989).

Phosphorus is the second element in fertilizer's N-P-K ratio, it is required for photosynthesis, interconversion of carbohydrates, fat metabolism, oxidation reactions, energy relations (Adenosine triphosphate (ATP), and Adenosine diphosphate (ADP)), and as a component of genetic material (Turner & Hummel, 1992). Phosphorus helps seeds germinate and establish root systems. Sufficient phosphorus in the soil results in faster grass establishment and more hardy turfgrass plants (Salisbury & Ross, 1985).

Potassium, also an essential element, is necessary for numerous plant functions, such as photosynthesis, carbohydrate and protein formation, water relationships, and enzymatic activity" (Turner & Hummel, 1992). Potassium makes grasses more resistant to stresses such as heat, drought, cold and disease (Turner & Hummel, 1992).

Fertilizers occur in many forms. Some commonly used fertilizers include chemical fertilizers, manures, sewage sludge, composts and organic residues.
The most commonly used fertilizers are water soluble (quick-release), and quite often the nitrogen (N) amounts are in excess of what the turfgrasses can assimilate.

Basic fertilizers have three key elements, one of more of which are often limiting in soils, nitrogen (N) in the form of total nitrogen, phosphorus (P) as available P_2O_5, and potassium (K) as water soluble K_2O. Once a basic fertilizer containing N, P and K is added to the soil, plants on average are only able to efficiently use 30-70% of the added nitrogen, 50-80% of the added potassium, and as little as 20-30% of the added phosphorus (Donahue et al., 1983).

Fertilizer rates are also important to turfgrass maintenance, especially if the overall desire is a low maintenance turfgrass. For example, too much nitrogen applied to the lawn actually increases the maintenance required by increasing shoot density, and yield (Madison, 1962b). The overall result may be increased mowing frequency or an altered clipping disposal method (Ledeboer & Skogley, 1963). The efficiency of nutrient uptake by plants varies with the type of plant, the soil properties, and method of fertilizer application. To increase the plants ability to take up nutrients, it is recommended that the fertilizer be applied in split applications, where the fertilizer is applied more than once in smaller quantities, rather than one large application (Donahue et al., 1983).

Fertilizer application dates are the third factor that must be considered when applying fertilizer. Fertilizer can be applied at anytime throughout the growing season, depending on the turf manager's reason for fertilizing. It is often recommended that fertilizers be applied in split-applications (more than one application), and that the best time to apply fertilizer is when grasses are actively growing. For cool-season turfgrasses the best time to apply fertilizer is in the spring and fall (Busey and Parker, 1992). Ledeboer & Skogley (1963) found that fall nitrogen applications were more effective than summer and spring applications in achieving early spring green-up and increased shoot density. It is recommended that fertilizer be applied in early fall if the desire is to retain colour in the fall, and in late fall if the desire is to achieve early spring green-up (Ledeboer & Skogley, 1963).

2.3.4 Clipping disposal

The most common technique of disposing of grass clippings from home lawns is in landfill sites. Most parks, golf courses and playing fields return the grass clippings or compost them. Grass clippings are recognized as a good source of nitrogen, phosphorus and potassium, and if left on the lawn are an important component in reducing lawn maintenance, both in dollars and time. Studies have shown that clippings can provide up to half of the nitrogen necessary for successful lawn care (Schultz, 1989). Leaving the clippings on the mowed areas not only reduces the amount of time necessary to rake them up or empty the grass catcher bag, it also reduces the amount of clippings that people bag and put in landfill sites, and may even reduce the amount of fertilizer application necessary for turfgrass maintenance.

Mowing frequency is important if the clippings are returned to the lawn. When returning clippings to the lawn (grasscycling), it is best to mow lawns more frequently, so that clippings left on the lawn are small and easily decomposed by soil microfauna, thereby reducing thatch build-up.

2.3.5 Irrigation

To maintain a lawn that has the desirable colour, shoot density, growth and regrowth capability, and overall appearance, irrigation is often necessary (Mantell & Stanhill, 1966). Yet, few home owners take the soil moisture and field capacity of the soil into account when watering their lawn (Morton et al., 1988). Most turfgrasses consume 2.5 to 7.5 mm of water per day (Beard, 1973) during peak growth periods.

When designing a turfgrass irrigation schedule, the frequency of irrigation is also an important component to take into consideration. Watering too often can be just as detrimental to the lawn as watering infrequently, therefore a balance must be found. Madison & Hagan (1962) set up a study in California with two irrigation treatments, five times/week, and once/week, with both treatments receiving a total of 2 1/2 to 3 inches of water per week. It was found that watering frequently, five times/week, resulted in fewer, shallower roots, and that watering infrequently, once/week, resulted in fewer roots in the surface eight inches of soil, but an increased number of roots in the soil below eight inches. In conclusion, the grasses watered less frequently had deeper root systems, which is thought to improve drought tolerance, and increase nutrient absorption.

Research has shown that the turfgrass species, the type of turfgrass (i.e., cool-season vs. warm-season), soil type, topography, and the turfgrass management regime employed, all play a role in the amount of water turfgrasses need. Warm-season grasses use less water than cool-season grasses (Feldhake et al., 1983). Increasing the mowing height (Madison & Hagan, 1962; Biran et al., 1981), increasing the fertility rate (Krogman, 1966), increasing the frequency of irrigation (Mantell & Stanhill, 1966), and decreasing the soil compaction (O'Neil & Carrow, 1983), all resulted in turfgrasses that used more water.

2.4 Turfgrass Assessment

Before turfgrass can be evaluated, there must be some understanding of the components that should be evaluated. There are a number of ways of evaluating turfgrass, and the evaluation method a researcher uses should be chosen based on the type of treatments being looked at.

According to Beard (1973), dry matter yieid, verdure, visual estimates, botanical composition and colour determination are some of the common evaluation methods used in turfgrass research. Dry matter yield is representative of the shoot growth, and is often measured when determining the effects of fertilizer on turfgrass growth. Botanical composition measures the competitive ability of a grass species in a turfgrass stand. Colour is another evaluation method, it is often measured to determine the effects of fertilizer and water.

2.5 Environmental Impacts of Turfgrass Management

As citizens become more aware of anthropogenic impacts on the environment, they are increasingly concerned about environmental impacts from turfgrass maintenance (Dernoeden et al., 1994). These concerns are primarily centred on the use of: soluble fertilizers, herbicides, lawn mowers (consumption of non-renewable fossil fuels and production of air pollutants), and turfgrass clippings that are disposed of in landfills, all of which are part of traditional lawn maintenance regimes.

2.5.1 Soluble fertilizers

Most commonly used fertilizers are water soluble (quick-release), often with nitrogen concentrations in excess of what turfgrasses can assimilate (Morton et al., 1988). Quick release of nutrients from such soluble fertilizers gives grass a quick boost of growth and deepens the colour, but, any excess nitrogen that is not needed by the plants is lost from the turfgrass system due to denitrification, leaching, or ammonia volatilization. Some of the factors that influence nitrogen leaching include: fertilizer regimes (rate of nitrogen applied, form of nitrogen, and application timing), soil texture and irrigation. Nitrogen leached from turfgrass in the form of nitrate-nitrogen (NO_3-N) (Starr & DeRoo, 1981; Geron et al., 1993), or high concentrations of any form of nitrogen in runoff (Tan, 1994), is a potential source of water pollution in surrounding ground water systems. Petrovic (1990) found that nitrogen lost from the turfgrass system via leaching was often less than 10% of the applied nitrogen.

2.5.2 Machinery used for turfgrass maintenance

A third concern that must be addressed in relation to turfgrass maintenance is the consumption of fossil fuels (energy) and the production of polluting emissions. Fossil fuel consumption was not a focus of this study, but is another factor that must be considered when analyzing the environmental impacts of turfgrass maintenance.

2.5.3 Landfill space

Another concern citizens have about traditional turfgrass management is that clippings are often disposed of in landfill sites. Canadians produce an estimated 1.7 kg per capita per day of municipal solid waste, making it one of the most wasteful countries in the world (Environment Canada, 1992a & 1992b). Management of this waste has become one of the major environmental challenges of this decade. To reduce the amount of waste produced by Canadians, the Canadian Council of Ministers of the Environment set a target of 50% waste reduction by the year 2000. To reach this goal, the province of Manitoba developed The Waste Reduction and Prevention Act (WRAP).

The National Round Table on the Environment and the Economy (1991) succinctly summarizes the issue:

> Public concerns over the quality of our environment and the safety of current waste disposal practices, together with preferences for less wasteful lifestyles, have created a major, grassroots political force that is pushing for local source reduction and recycling programs, and other forms of Sustainable Development. Residential source reduction and recycling, in particular, provides families and individuals with a constructive, hands-on opportunity to have a direct and positive impact on the environment (p.7).

Recycling of grass clippings within the turfgrass system (grasscycling), composting of grass clippings, and source reduction of grass clippings by using slow growth turfgrass, are all ways of reducing the amount of clippings going to landfill sites.

The average amount of solid garbage that is produced per year in the City of Winnipeg is 215 000 tonnes, of which 43 000 tonnes or 20% of the total waste produced is residential yard waste, the majority of which is grass clippings (Ross, 1997). In Winnipeg, most yard waste goes to one of the two local landfill sites, the most popular municipal waste disposal method. These sites take up large areas of space, and are relatively expensive to maintain. Tipping fees for the City of Winnipeg's landfill sites are $15.10/metric tonne for residential garbage, and this fee will increase to $25.00/metric tonne, once the upcoming City of Winnipeg's budget is announced (Ross, 1997). Taking into consideration the amount of yard waste produced annually and the current cost of waste disposal in landfill sites, the City of Winnipeg is currently paying $649 300/year in yard waste disposal, and may be paying as much as $1 075 000/year, once the new tipping fee is imposed, if reduction of yard waste disposal is not realized. The City of Winnipeg has recently adopted a program which composts leaves each fall, potentially grass clippings could be included into this program. In 1994 the Recycling Council of Manitoba Inc. contracted a consultant to determine the benefits of implementing a "Don't Bag It" Lawn Care Program. But nothing further was done with the program.

By utilizing low-maintenance grasses that are more drought tolerant, slower growing, require fewer fertilizers, by adopting the practice of grasscycling or at least composting, and by reducing the public's expectations the environmental impacts of turfgrass management may be reduced. By changing the public's expectations allows for an increased acceptance of a "lower" turfgrass quality,

Summary

In an attempt to understand how to reduce the environmental impacts of turfgrass management and to decrease the amount of management required for turfgrass maintenance, this practicum focused on turfgrass species, clipping disposal, fertilizer rate, and mowing frequency.

CHAPTER THREE

METHODS

In an attempt to meet the research objectives of this study three components of turfgrass management, fertilizer rate, clipping disposal and mowing frequency, were examined in two separate studies. The first study evaluated the effects clipping disposal and fertilizer rate had on clipping yield, height, colour, percent nitrogen in clippings, and plot cover of ten cool-season turfgrass mixtures. The second study evaluated mowing frequency, and the effect it had on the clipping yield, height, and colour on seven commercially available cool-season turfgrass mixtures.

3.1 Effects of Clipping Disposal and Fertilizer Rate on Five Cool-Season Turfgrass Species

3.1.1 Scope

The clipping disposal and fertilizer rate study was designed to evaluate the effects that clipping disposal and fertilizer rate had on the clipping yield, height, colour, percent nitrogen in clippings, and plot cover of five cool-season turfgrass species commonly used in the City of Winnipeg. The five cool-season turfgrasses were each seeded individually in monostands, and together in polystands, on May 29 and 30/1995, for a total of ten different turfgrass mixtures (as described in Appendix A (Table A2)). Trial plots for this study were located at the University of Manitoba, Fort Garry Campus in the City of Winnipeg.

3.1.2 Experimental design

The experimental design of the clipping disposal and fertilizer rate study was a split-split-plot design. In this design there were three treatment factors 1) turfgrass mixture (factor a), 2) clipping disposal (factor b), and 3) fertilizer rate (factor c). Turfgrass mixture factor (a) contained ten different mixtures denoted $_{j1}$, $_{j2}$,...$_{j10}$, where mixture one was composed of 100% Kentucky bluegrass ($_{j1}$); mixture two was composed of 100% Canada bluegrass ($_{j2}$); mixture three was composed of 100% creeping red fescue ($_{j3}$); mixture four was composed of 100% sheeps fescue ($_{j4}$); mixture five was composed of 100% perennial ryegrass ($_{j5}$); mixture six was composed of 30% Canada bluegrass, 30% sheeps fescue, 30% creeping red fescue, and 10% perennial ryegrass ($_{j6}$); mixture seven was composed of 45% Canada bluegrass, 45% creeping red fescue, and 10% perennial ryegrass ($_{j7}$); mixture eight was composed of 45% Canada bluegrass, 45% sheeps fescue, 10% perennial ryegrass ($_{j8}$); mixture nine was composed of 45% creeping red fescue, 45% sheeps fescue, 10% perennial ryegrass ($_{j9}$); and mixture ten was composed of 90% Kentucky bluegrass, and 10% perennial ryegrass ($_{j10}$).

Clipping disposal (factor b) consisted of two different methods denoted $_{k1}$ and $_{k2}$, where $_{k1}$ was grasscycling (returning the clippings to the lawn), and $_{k2}$ was clipping removal (removing the clippings from the turfgrass system). Factor c, fertilizer rate, consisted of two rates denoted $_{l1}$ and $_{l2}$, where $_{l1}$ was a low rate of 0.5 lb of N/1000 ft^2 per application, and $_{l2}$ was a high rate of 1 lb of N/1000 ft^2 per application. Each rate was applied twice per growing season to the respective plots.

Turfgrass mixture is referred to as the whole-plot factor and it was applied to the whole-plot. Clipping disposal is referred to as the split-plot factor and the experimental units to which the two clipping disposal methods were applied are the split-plots, where each whole-plot had two split-plots, as illustrated in Appendix B, Figure 1. Fertilizer rate is referred to as the split-split plot factor and the experimental units to which the two fertilizer rates were applied are called the split-split-plots, where each split-plot had two split-split-plots, one low fertilizer rate and one high fertilizer rate, and each whole-plot had four split-split plots, two low fertilizer rates and two high fertilizer rates, as illustrated in Appendix B, Figure 2.

Within the clipping disposal and fertilizer rate study there were four blocks (r), each block contained one application of each of the ten turfgrass mixtures $_{j1,j2,\ldots,j10}$ and within each of $_j$ whole-plots there was one application of each of the clipping disposal methods, $_{k1}$, and $_{k2}$, and within each of the split-plots there was one application of each of the fertilizer rates, $_{l1}$, and $_{l2}$. Each of these three factors, turfgrass mixture, clipping disposal method, and fertilizer rate, were assigned using three independent randomizations. The observation for each split-split-plot is then the observation for the treatment combination $a_jb_kc_l$ (Hinkelmann & Kempthorne, 1994).

The split-split-plot model used in this study is:

$$Y_{ijkl} = u + r_i + a_j + b_k + ab_{jk} + c_l + ac_{jl} + bc_{kl} + abc_{jkl}$$

On May 27/95, the study site was measured and marked using stakes. The site size for the clipping disposal and fertilizer rate study was 20 m long and 12 m wide, allowing for ten treatments, and four blocks. Each of the four blocks had ten whole-plots, each whole-plot measured 2 m wide by 3 m long, each of the whole-plots had two split-plots which measured 2 m wide by 1.5 m long, and each of the split-plots had two split-split-plots which measured 1 m wide by 1.5 m long, as illustrated in Appendix B, Figure 2.

3.1.3 Turfgrass selection

The selection of the turfgrass species, used in this study, was based on a number of criteria including: whether the species was commercially available in Winnipeg; the management requirements of the species; and the adaptation of the turfgrass species to environmental stresses. The five species that were chosen for this study were Kentucky bluegrass, Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass. Kentucky bluegrass was chosen because it is the most commonly used turfgrass species in Manitoba. Canada bluegrass was chosen because of its low maintenance qualities. Creeping red fescue was selected because it requires low amounts of supplemental water and nitrogen. Sheeps fescue was selected because it is commonly used as a low maintenance turf, and grows best under non-irrigated conditions where there is a low soil fertility level and no supplemental nitrogen fertilization. Perennial ryegrass was chosen to act as a nurse crop, because it is a short-lived perennial that establishes itself quickly (Beard, 1973). For further information on the five species used in the clipping disposal and fertilizer rate study see Appendix C, Characteristics of the Five Cool-Season Turfgrass Species in the

Clipping Disposal and Fertilizer Rate Study.

3.1.4 Turfgrass mixtures

Prior to seeding, the soil in the clipping disposal and fertilizer rate study plot was prepared. Preparation of the seed bed involved tilling and packing, which was done by the University of Manitoba Plant Science staff in 1994. First a roto-tiller was used to churn the soil to 4 inches deep, then a roller was used to pack the soil, and finally a piece of board was dragged across the plot, first North/South and then East/West, to level off the plot. Once level the plot was left to fallow for one year. In early May of 1995 dandelions and other obvious weeds were hand pulled. Seeding of the clipping disposal and fertilizer rate study commenced on May 29/95 and finished on May 30/95.

Seed was weighed and the weights used were in accordance with the heavier recommended rates given by Schultz (1989). Kentucky bluegrass and Canada bluegrass were seeded at 10 g/m^2, perennial ryegrass was seeded at 40 g/m^2, and sheeps fescue and creeping red fescue were seeded at 20 g/m^2. The ten mixtures used in this study are described in Appendix A, Table 2. Once weighed the seeds were placed into size #5 coin envelopes.

On May 29 whole-plots one to six of all four blocks were seeded and on May 30 whole-plots seven to ten of the four blocks were seeded. Seeding was done using a 1 m x 1 m square seeding box that was 50 cm high. The seeding box was composed of plywood with hinges on all four corners. For each square metre one envelope containing the weighed seed was evenly distributed and raked into the soil. For each of the whole-plots there were six envelopes containing the correct weight of seed. In the clipping disposal and fertilizer rate study there were ten turfgrass mixtures, each mixture was seeded in one whole-plot in each of the four blocks, for a total of four replicates of each turfgrass mixture, as illustrated in Appendix B, Figure 3. On June 1/95, after seeding, a heavy roller full of water was used to pack the soil and seed.

To reduce competition between grass species the ten mixtures seeded in 1995 contained no more than four species each. Perennial ryegrass was seeded with all of the polystands as a nurse crop because it germinates and establishes well in the first year. As a nurse crop it reduces weed establishment and in so doing reduces the competition for limited resources thereby allowing desirable slower growing turfgrass species to establish. Turfgrass mixtures used in the clipping disposal and fertilizer rate study consisted of both monostands and polystands, allowing the researcher to monitor the clipping yield, nitrogen content, height, colour, and establishment of all the species with and without interspecific competition.

3.1.5 Clippings disposal

In the clipping disposal and fertilizer rate study each of the whole-plots had two split-plots, in one of the split-plots grasscycling was practiced and in the other split-plot the clippings were removed, as illustrated in Appendix B, Figure 4.

The grasses were mowed for the first time on June 22/95, at a height of 5.5 cm. This initial time lag was due to broad-leaf weeds and the herbicide used to control the weeds. The first grasscycling and clipping and removal treatments were applied on August 2/95, before then all clippings were collected and removed. Each week, once a week thereafter, the grasscycling and clipping and removal treatments were applied. Grasscycling was applied to determine if the nitrogen from the returned clippings had an effect on the growth of the turfgrasses.

3.1.6 Soil analysis

Soil samples were analyzed to determine the nutrient concentration of the soil and other characteristics. On May 17, 1995, prior to seeding, ten soil samples were taken randomly at a depth of 0-15 centimetres (0-6 inches) using a soil auger. The ten samples were mixed together, and one 500 ml soil sample was analyzed by Norwest Labs. Soil samples were taken a second time from the clipping disposal and fertilizer rate study site, on June 26 1996, prior to applying the first application of fertilizer for the 1996 growing season. The soil samples were collected from each of the split-split-plots for mixture ten, at a depth of 0-15 centimetres (0-6 inches). Mixture ten was used because it was composed of Kentucky bluegrass and perennial ryegrass. Kentucky bluegrass is the most common turfgrass seed mixture used in Manitoba, and was therefore considered the control in this study.

Norwest Labs completed a soil analyses, for both the 1995 and 1996 soil samples. Soil analyses included the amount of available phosphorus, potassium, nitrogen, and sulphur in the soil, and soil pH and salinity. Knowing the nutrient content of the soil enabled an estimate to be made on the amount of fertilizer required to satisfy the nutrient requirements of the grass mixtures. Norwest labs also determined the texture, soil organic matter and carbon/nitrogen ratio of the soil collected in 1996. The soil texture was determined by particle size analysis with the use of a hydrometer. The organic carbon, total nitrogen and percent organic matter were all measured using a Leco analyzer.

Bulk density and percent pore space of the soil collected from the clipping disposal and fertilizer rate study were also determined. Bulk density and percent pore space were measured using the methods described in the *Soil Science: Methods and Applications* (Rowell, 1994).

3.1.7 Fertilizer application

The 1995 soil analysis from the clipping disposal and fertilizer rate study suggested that 3.2 lbs. of nitrogen/1000 ft^2 should be applied in two to three applications to ensure nitrogen concentrations are adequate for turfgrass growth. Following the soil analysis recommendation, prior to seeding, a quick-release chemical fertilizer with a ratio of 46(N)-0(P)-0(K) was applied May 26/95 using a calibrated broadcast spreader, at a maintenance level of 0.75 lb of N/1000 ft^2. A quick-release fertilizer was re-applied to the clipping disposal and fertilizer rate study June 22/95. This time the fertilizer had a ratio of 17-17-17 and it was applied at 0.5 lb of N/1000 ft^2 to ensure the grass had sufficient nutrients to establish.

Once the turfgrass in the clipping disposal and fertilizer rate study was established the fertilizer treatments of 0.5 lb of N/1000 ft^2 and 1 lb of N/1000 ft^2 were applied, using a calibrated drop spreader, on July 19/95 and again on August 23/95 (as illustrated in Appendix B, Figure 5) and the same amounts were applied the second year on June 27/96 and Sept. 9/96 (as illustrated in Appendix B, Figure 6). There were four split-split plots where the fertilizer rates were different in 1995 compared to 1996. This difference was due to an application error. The purpose of the two fertilizer rates was to determine how a low and a high level of fertilizer would affect the growth of the ten different turfgrass mixtures.

Low and high rates of fertilizer were used because it was taken into consideration that most homeowners apply at least a small amount of fertilizer to their lawns. Therefore, the low fertilizer rate was considered the control. The fertilizer used for these applications was a slow-release chemical fertilizer, which had a N-P-K ratio of 24-4-12. The ratio indicates that the total nitrogen content was 24%, of which 1.6% was derived from ammoniacal nitrogen, 11.6% was urea nitrogen, and 10.8% was water insoluble nitrogen (Vigoro Industries, Inc., 1995). Nitrogen in the form of isobutylidene diurea (IBDU) was used in the clipping disposal and fertilizer rate study because it was a slow-release fertilizer resulting in less of the nitrogen applied to the turfgrass system leaching from the soil. This allowed for more efficient use and continuous supply of nitrogen by the grasses, which in turn reduced the need for frequent of fertilizer applications.

IBDU releases nitrogen, in the form of urea, as a result of hydrolysis. Nitrogen from urea decomposes slowly to ammonia, which is absorbed by grasses. IBDU releases nitrogen independent of microbial activity; nitrogen release is influenced by moisture, temperature, soil pH, and fertilizer particle size (Lunt and Clark, 1969; Turner & Hummel, 1992). Therefore it was important that the irrigation dates and quantities, and climate records for the summers of 1995 and 1996 be recorded.

3.1.8 Watering

Water is also essential for grass growth and survival. To prevent desiccation the trial plots in the clipping disposal and fertilizer rate study received water twice a day for 30 minutes (5.14 mm/day) for the first three weeks after seeding, as suggested by turfgrass managers. After the first three weeks the trial plots in the clipping disposal and fertilizer rate study received one hour (10.27 mm) of water every other day up until July 19/95, the day the fertilizer treatment was applied. After July 18/95 the amount of water used was logged because of the increased solubility of IBDU in water. To determine the amount of water that was being applied once the fertilizer treatment was applied, the sprinklers were calibrated using numerous straight sided containers placed in a number of different areas within the study site. The sprinklers were determined to dispense an average of 10.27 mm of water/hr on the turfgrass plots.

3.1.9 Grass clippings

One purpose of the clipping disposal and fertilizer rate study was to determine which of the ten grass mixtures produced the shortest grass height, and the lightest clipping weight. On August 16/95 the clippings from all of the split-split-plots (1.5 m x 1 m) in blocks one, two, and three were collected using a blade height of 3.5 cm. Because of bad weather, clippings from block four were not collected until August 21/95. Clippings were also collected September 14/95, October 9/95, and in the second year they were collected June 8, July 27, September 14 and October 5/96. When collecting clippings from the split-split-plots, 12.5 cm on each of the four sides of the plots were not mowed to reduce edge effect, therefore, the clippings were collected from a 1.25 x 0.75 m area, with the total area being 0.94 m^2 per split-split-plot. Once the collection of the clippings had been completed the grasscycling and clipping and removal treatments were applied to the edges that were not mowed.

The grass was cut using a John Deere B-series 5.0 hp 4-cycle engine lawn mower (model number L15-150-7) outfitted with a mulching blade. When grasscycling was imposed a mulching plug was used, and when the clippings were collected a rear clipping collection bag was used.

Once collected, the clippings were weighed to determine wet weight, then dried in a drying oven at 65^{0}C until the dry weight was constant, and reweighed to determine dry weight. From this information, percent moisture of the clippings was calculated using the formula: (wet weight-dry weight)/wet weight.

Wet weight and dry weight measurements were used to compare the growth rate of the different grass mixtures. The weight of the clippings was also an indicator of the potential amount of clippings that could be disposed of in landfill sites.

3.1.10 Nitrogen content in the clippings

Once dried and weighed, the collected grass clippings were analyzed for nitrogen content. The content of nitrogen in the grass clippings was an indication of the amount of nitrogen that was being absorbed by each grass mixture. It also was used to determine if the two clipping disposal regimes and fertilizer rates had an impact on the amount of nitrogen present in the grasses.

The following procedures were used to determine percent nitrogen in the clippings. Clippings were collected, and dried at 65°C until they maintained a constant dry weight. Once dry, the clippings for turfgrass mixtures one to five were set aside for analysis. Once dried, the clippings from each split-split-plot, for turfgrass mixtures one to five, for all four blocks, were then separately ground to a mesh size of 2 mm. Once ground, the clippings were taken to the University of Manitoba, Department of Plant Science, for nitrogen determination using the combustion method on a Leco FP 428 machine (Leco Corporation, St. Joseph, MI, U.S.A.). The results of the combustion method of nitrogen determination were in protein content values for each of the analyzed split-split-plot's clippings. Using the following formula:

$$\frac{\text{protein content}}{6.25} = \%\ \text{nitrogen},$$

the protein content values were converted to percent nitrogen values (Acker, 1983).

The five monostands were the only treatments looked at because of budget constraints. Data from mixtures one to five can be used to infer what likely happened within the other five mixtures based on species composition.

3.1.11 Turf characteristics (height and colour)

One of the purposes of turf is to be aesthetically pleasing. To ensure aesthetics were taken into account when recommending a slow growing/low maintenance turfgrass both turfgrass height and colour were measured. Turfgrass height was measured with the use of a ruler. Ten or more readings were taken at random, from the base of the grass stem to the tip of the average leaf blade, and averaged. Height measurements were taken for each of the split-split-plots throughout the growing season.

Turfgrass colour was another characteristic to be considered when considering appropriate low maintenance grasses. Colour was measured subjectively. There are a number of ways of determining turfgrass colour, including: visual rating, leaf chlorophyll content, and light reflection. The method used in this study was the visual rating from a scale of 1-10. Where 1 was poor quality, brown turfgrass, and 10 was high quality, dark green turfgrass. It has been documented (Birth, and McVey, 1968) that there is a high correlation between visual ratings and light reflectance, supporting the use of visual ratings for turfgrass colour.

3.1.12 Speciating the vegetation

In the clipping disposal and fertilizer rate study, speciation of the vegetation was conducted to determine the plot cover of the grasses and to look at intraspecific and interspecific competition. Speciation of the vegetation was carried out in the fall of 1995, using a 0.125 m^2 point quadrat. Each of the split-split-plots in blocks one, two and three were speciated. The quadrat location was randomly chosen within each of the 120 split-split-plots speciated. The species information collected from the quadrats was used to determine species composition in percentages for each treatment. Using the percentages of grass species in the grass mixes and the percentages in the established plots, competition between grass species in each treatment could be measured.

3.1.13 Weather data monitoring

Weather data collected in 1995 and 1996 included: soil temperature, air temperature, and precipitation in the study area. The data was used to evaluate the hardiness of the grass mixtures and was used to evaluate trends in the data; for example: an increase in clipping weights may be correlated to a rainy period.

3.1.14 Data analysis

A statistical advisor at the University of Manitoba was consulted for experimental design (as described in section 3.1.2), and statistical analysis methods. The advisor suggested the use of the Statistical Analysis System (SAS) to perform Analysis of Variances on the collected data. Analysis of Variance (ANOVA) were used to compare the results of the clipping yield and nitrogen content in the clippings obtained from each of the split-split-plots in the clipping disposal and fertilizer rate study, for both 1995 and 1996. To determine which treatments produced significant differences, a Least Significant Difference test was done on the four main variables:

blocks, mixtures, clipping disposal methods, and fertilizer rates at the 0.05 alpha level.

3.2 Effects of Mowing Frequency on Seven Cool-Season Turfgrass Mixtures

3.2.1 Scope

The mowing frequency study was a continuation of the project started by Henri Carriere and Calvin McLeod (1994) titled "Establishing Whether Slower Growing Lawns are Suitable for the City of Winnipeg". In this study aimed at evaluating the slow growth and low maintenance potential of seven cool-season turfgrass mixtures. These mixtures included four commercial slow growing, low maintenance cool-season turfgrass mixtures; a monostand of Sheeps Fescue; a low maintenance grass mixture; and an average lawn seed mixture. The composition of the seven mixtures are described in Appendix A, Table A3. These mixtures were seeded on May 30 and 31/1994. The trial plots for this study were located at the University of Manitoba, Fort Garry Campus in the City of Winnipeg. In the summer of 1995, there were some additional methods added to the study to increase the comprehension of how much maintenance was necessary to ensure aesthetically pleasing turf. The methods for this study are listed below.

3.2.2 Experimental design

The experimental design for the mowing frequency study, set up by Carriere and McLeod (1994), was a pseudo split-plot design. In a split-plot design there are two randomized complete block designs superimposed on each other. In a randomized complete block design there are matched sets of experimental units, called blocks, each block contains every combination of treatments, and the treatments are assigned randomly (McClave & Dietrich, 1988).

The mowing frequency study was a pseudo split-plot design because treatments were not all randomly assigned. The mowing frequency study had two blocks, each containing one application of each of the seven turfgrass mixtures. The seven turfgrass mixtures were assigned randomly in block one, but not in block two. Block two treatments were assigned using the same order of turfgrass mixtures in block one, but in reverse, such that in block one, treatment one was the first plot (plot one), and treatment one was the last plot (plot 14) in block two, as illustrated in Appendix B, Figure 7.

The two factors in the mowing frequency study were: 1) turfgrass mixture (factor a) and 2) mowing frequency (factor b). The turfgrass mixture, factor a, had seven different mixtures denoted $_{j1}$, $_{j2}$,...$_{j7}$, where: mixture one (Dawson Seed Co.'s Bighorn Sheeps Fescue) was composed of 100% sheeps fescue, and was considered a monostand, because it consisted of only one grass species ($_{j1}$); mixture two (Pickseed's Cottage N' Country) was composed of 10% Canada bluegrass, 20% Mustang tall fescue, 25% creeping red fescue, 5% white clover, 20% timothy, and 20% annual ryegrass ($_{j2}$); mixture three (Pickseed's Envirogreen) was composed of 20% Banff Kentucky bluegrass, 40% Jasper creeping red fescue, 25% Spartan hard fescue, and 15% lowgrow perennial ryegrass ($_{j3}$); mixture four (OSECO's Blue Chip Low Maintenance/Reclamation Mixture) was composed of 20% Certified Canada bluegrass, 20% Certified hard fescue, 20% Certified chewings fescue, 20% Certified red fescue, and 20% Certified turf-type perennial ryegrass ($_{j4}$); mixture five (Bishop's Low Maintenance Mixture) was composed of 10% Serra hard fescue, 10% MX-86 sheeps fescue, 10% Park Kentucky bluegrass, 25% Koket chewings fescue, 30% creeping red fescue, and 15% Omega II perennial ryegrass ($_{j5}$); mixture six (Pickseed's Town and Country) was composed of 50% creeping red fescue, 40% Kentucky bluegrass, and 10% Fiesta II perennial ryegrass ($_{j6}$); and mixture seven (Dawson Seed Co.'s Enviro Turf) was composed of 15% Shade Master creeping red fescue, 20% Longfellow chewings fescue, 25% Serra hard fescue, 25% Aurora hard fescue, and 15% Seville perennial ryegrass ($_{j7}$).

There were two mowing frequencies, factor b, which were: mowing every week ($_{k1}$), and mowing every other week ($_{k2}$).

Turfgrass mixture was referred to as the whole-plot factor and it was applied to the whole-plot. Each whole-plot measured 1 m wide x 10 m long. Mowing frequency was referred to as the split-plot factor and the experimental units to which the two mowing frequencies were applied to were the split-plots, each split-plot measured 1 m wide x 5 m long. Each whole-plot had two split-plots, as illustrated in Appendix B, Figure 8.

Within the mowing frequency study there were two blocks (r), each block contained one application of each of the seven turfgrass mixtures $_{j1,j2,\ldots,j7}$ and within each of the seven whole-plots there was one application of each of the mowing frequencies, $_{k1}$, and $_{k2}$. The observation for each split-plot was the observation for the treatment combination $a_j b_k$ (Hinkelmann & Kempthorne, 1994).

The split-plot model used in this study is:

$Y_{ijkl} = u + r_i + a_j + b_k + ab_{jk}$

3.2.3 Turfgrass mixtures

In the mowing frequency study there were seven turfgrass mixtures, each mixture was seeded in one whole-plot in each of the two blocks (for a total of two replicates of each turfgrass mixture). Each whole-plot measured 1 m wide x 10 m long.

Prior to seeding the soil was prepared. Preparation of the seed bed involved tilling and packing, which was done by the University of Manitoba Plant Science staff in 1993. First a roto-tiller was used to churn the soil to 4 inches deep, then a roller was used to pack the soil, and finally a piece of board was dragged across the plot first North/South and then East/West, to level off the plot. Once level, the plot was left to fallow for one year. In early spring of 1994 dandelions and other obvious weeds were removed. Seeding of the mowing frequency study commenced on May 30/94 and finished on May 31/94. The seven turfgrass mixtures are described in Appendix A, Table A3. The layout of the turfgrass mixtures in the mowing frequency study is shown in Appendix B, Figure 7. See Appendix C, Characteristics of the Cool-Season Turfgrass Species in the Mowing Frequency Study for a brief description of the turfgrass species used.

3.2.4 Mowing frequency

Mowing frequency was another variable examined in an attempt to reduce turfgrass maintenance. In the mowing frequency study each of the whole-plots had two split-plots, in one split-plot the grass was mowed once a week, and in the second split-plot the grass was mowed every other week (once every two weeks), as illustrated in Appendix B, Figure 9.

Treatments were seeded May 30 and 31/94, but it was not until June 29/94 that the grass was mowed for the first time once it reached a height of 6.5 cm from the soil (Carriere and McLeod, 1994). The mowing frequencies were first applied on June 29/95, a year after the first mowing. Before June 29/95 all of the clippings were collected and removed every week, in both 1994 and 1995.

3.2.5 Grass clippings

To reduce the edge effect, the size of the mowed area per split-plot was 9 metres x 0.53 metres, leaving a 28 cm edge on each side and a 25 cm edge on each end. The plots were mowed using a John Deere B-series 5.0 hp 4-cycle engine, gas powered lawn mower (model number L15-150-7). Once mowed and collected in the rear catcher on the mower, the clippings from each whole-plot were placed in a black garbage bag and sealed immediately after each plot was cut. In 1994 (Carriere and McLeod) the clippings were only weighed to determine wet weight. In 1995, the clippings once collected and bagged, were weighed to determine wet weight, then placed in a drying oven and reweighed to determine dry weight. From the two weights the percent moisture of each of the different mixtures was determined. This was done for each of the whole-plots until June 29/95. From June 29/95 until September 25/95 (the end of the growing season) the two different mowing frequencies were applied to each of the whole-plots, and the clippings were collected in each of the split-plots making the mowed area per split-plot equal to 4.5 m x 0.53 m.

Dry weight measurements were used to compare the two mowing frequencies for the different grass mixtures. This comparison was used to determine if mowing frequency altered the amount of clippings produced, and if so, does one of the frequencies allow for a reduction in the amount of maintenance required.

3.2.6 Watering

The mowing frequency study was watered from June 16/95 to June 21/95, twice a day for thirty minutes per watering. Originally the plan was not to water the mowing frequency study but because of the dry, hot conditions of the summer of 1995 the grass was watered for this six day period so it would green up.

3.2.7 Soil analysis

Soil analysis was completed to determine if the soil the turf was growing in required fertilizer at the beginning of the growing season to promote growth. On May 17/95 fourteen soil samples were taken within the mowing frequency study, one soil sample randomly from within each of the whole-plots, at a depth of 0-15 centimetres

(0-6 inches). Once collected all of the fourteen samples were mixed together, and one 500 ml soil sample was analyzed by Norwest Labs. Norwest Labs completed a soil analysis which determined the amounts of phosphorus, potassium, nitrogen, and sulphur available, as well as the pH and salinity of the soil, see Table 4.5. The nutrient content of the soil enabled an inference to be made on the nutrient requirements for the mowing frequency study, which in turn enabled an estimate to be made on the fertilizer requirements of the mowing frequency study.

3.2.8 Fertilizer application

Once the amount of nutrients in the soil was determined and appropriate fertilizer rates calculated, a quick-release chemical fertilizer with the ratio of 32(N)-3(P)-10(K) was applied on May 26/95, using a calibrated broadcast spreader, at a level of 1.0 lbs. of N/1000 ft^2. Norwest labs recommended that 3.9 lbs of nitrogen/1000 ft^2, be applied in two to three applications, and 0.2 lbs of sulphur/1000 ft^2 also be applied. The actual amount of nitrogen added to the study plots (1 lbs./1000 ft^2) was much less than recommended by Norwest labs, because the study was directed to measure the response of the turfgrass mixtures to low maintenance conditions.

3.2.9 Aesthetic quality

The quality of the seeded turfgrasses used in this study was determined in an attempt to assess turf aesthetics qualitatively. The measurements that were looked at to determine aesthetic quality were turfgrass height and colour, and are described in section 3.1.10.

3.2.10 Data analysis

A statistical advisor at the University of Manitoba was consulted for statistical analysis methods, and suggested the use of the Statistical Analysis System (SAS) to perform Analysis of Variances on the collected data. Analysis of Variance (ANOVA) were used to compare the results, of the dry weight clipping yield, obtained from each of the split-plots in the mowing frequency study for 1995. To determine which treatment produced significant differences a Least Significant Difference test was done on the two main effect variables: blocks, and mixtures at the 0.05 alpha level.

CHAPTER FOUR

THE EFFECTS OF CLIPPING DISPOSAL AND FERTILIZER RATE ON COOL-SEASON TURFGRASSES

The results of the clipping disposal and fertilizer rate study are outlined first, followed by the discussion. The results of the study include the weather conditions, soil parameters, and vegetation parameters measured during the 1995 and 1996 growing seasons.

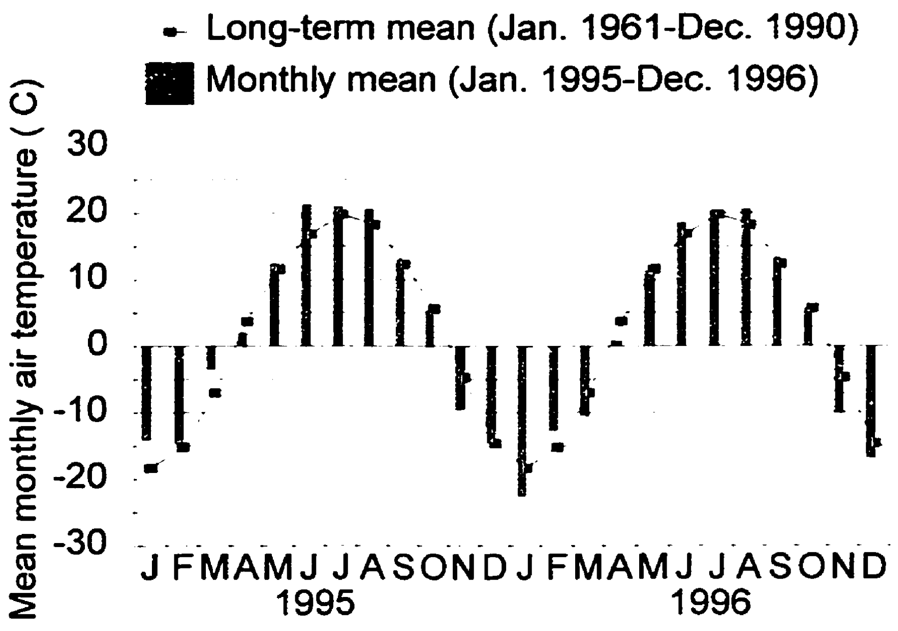
4.1 Results of the Clipping Disposal and Fertilizer Rate Study

4.1.1 Weather conditions

1995 Weather Conditions: In 1995, soil temperature, air temperature and precipitation data were collected to determine the effect these parameters had on turfgrass growth throughout the growing season. The weather data for 1995 can be found in Appendix D, Table D1.

The mean monthly temperature from January to May 1995 resembled that of the long-term average (Figure 4.1a). The total monthly precipitation, collected at the Winnipeg International Airport (Environment Canada, 1993), during this period was only 50% of the long-term average (Figure 4.1b). During the 1995 growing season (May to September) the plots only received 78% of the normal precipitation. The temperature during the 1995 growing season averaged 1.8 ^{0}C above normal, June's average temperature was 4.3 ^{0}C higher than the long-term average. Average soil temperature from January to April 1995 was +0.3891^{0}C, during the 1995 growing season (May to September) it was +18.94^{0}C, and in the fall (Oct and November) it

(a)



(b)

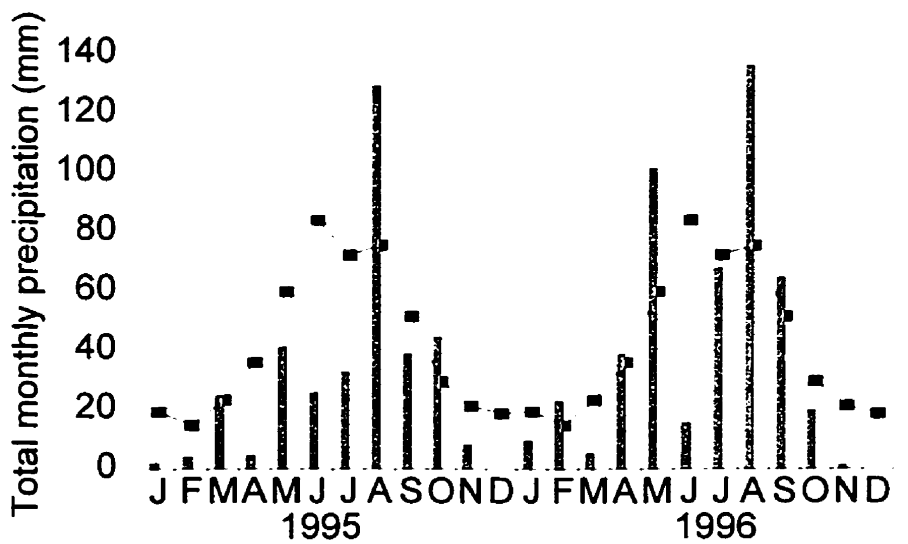


Figure 4.1: Mean monthly air temperature and total monthly precipitation from 1961 - 1990 (line) and during 1995 and 1996 (shaded bars). (a) Mean monthly air temperature (C). (b) Total monthly precipitation (mm).

averaged +4.10^{0}C (Figure 4.2).

The optimal soil temperature for root growth is between 10 and 18^{0}C (Beard, 1973), and the dates in the 1995 growing season where the soil temperature fell within this range were noted. In 1995, the soil temperature was in the optimal temperature range from May 2-May 10, May 16-May 27, Sept. 5-17, and again between September 23 and October 11/95.

The optimal temperature for shoot growth is when the air temperature falls between 15^{0}C and 24^{0}C (Beard, 1973). In the 1995 growing season, the air temperature was in the optimal temperature range for shoot growth from May 1 until May 27, and again from September 5 until September 30/95. The air temperature was above 24^{0}C from May 28 until September 4/95. The rate of photosynthesis is directly related with temperature when air temperatures are greater than 10^{0}C, up to a maximum of 30^{0}C (Leopold & Kriedemann, 1975). In 1995, from May 5 to 10, May 16 to Sept 16, and again from September 23 to September 30, the air temperature was conducive for optimal photosynthesis. In turfgrass systems, freezing stress occurs at or below soil temperatures of 0^{0}C (DiPaola & Beard, 1992). In 1995, the soils remained at or below 0^{0}C between January 1 and April 8, and again between November 25 and December 31/95.

In early 1995, prior to seeding, the soil in the study plot was dry having only received 50% of the average precipitation between the months of January and May 1995. Throughout the 1995 growing season the plots only received 78% of the average precipitation. To supplement the rainfall, irrigation was implemented. In

(a)

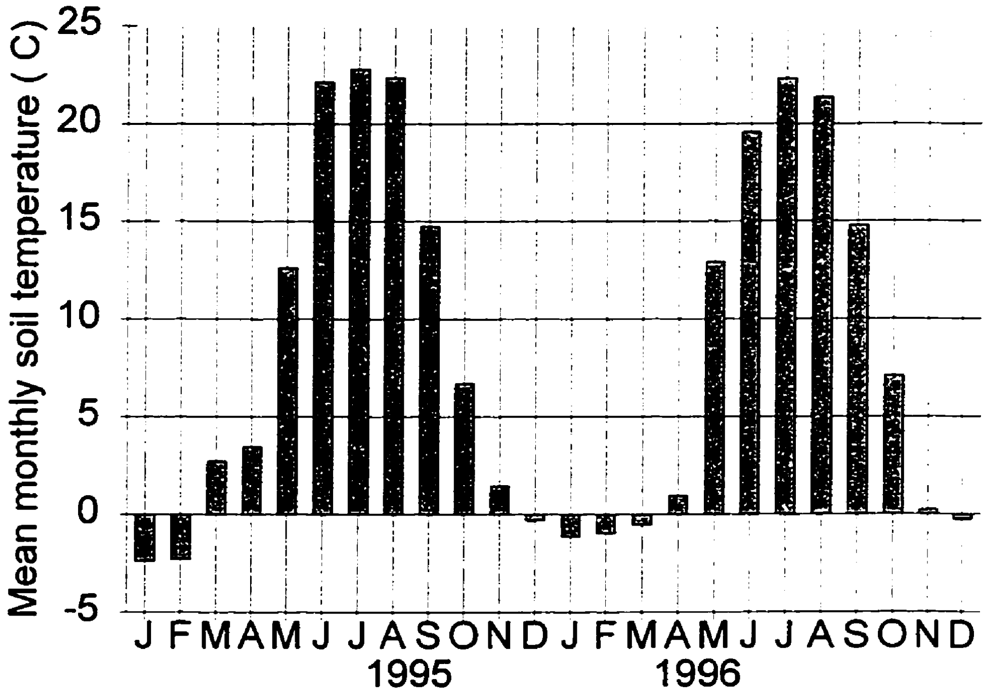


Figure 4.2: Mean monthly soil temperature during 1995 and 1996 (shaded bars).

1995 the amount of irrigation time was logged only after establishment, i.e., after the first fertilizer treatment application (July 18/95). During the 1995 growing season, 184.81 mm of supplemental irrigation was applied to the plots in the clipping disposal and fertilizer rate study at a rate of 10.27 mm of water/hr.

1996 Weather Conditions: In 1996, soil temperature, air temperature and precipitation data were collected to determine the effect these parameters had on turfgrass growth throughout the growing season. The weather data for 1996 can be found in Appendix D, Table D2.

Temperature and precipitation for the 1996 growing season (May to September) was above average (Figure 4.1). Soil temperature between January and April 1996 averaged -0.42^{0}C, for the 1996 growing season (May-September) the average temperature was +18.20^{0}C, and in the fall (October and November) of 1996 soil temperature averaged +3.67^{0}C (Figure 4.2). The soil temperature was above 18^{0}C between May 28 and September 4. The soil temperature was at the optimal temperature range for root growth from May 4-7, May 12-June 6, June 20-June 24, Sept. 9-27 and off and on until mid-October. The soil temperature was above 18^{0}C from June 7-June 19 and from June 25-September 8.

In 1996, the optimum temperature for shoot growth occurred between May 25 and June 5, on June 18 and June 25, and again between September 9 and September 24/96. The air temperature was above 24^{0}C between June 6 and June 18, June 26 and August 3, and again between August 9 and September 8/96. From May 12 to

September 24, the temperature was optimal for photosynthesis.

The study plots received eight times more precipitation in April 1996 compared to the amount of precipitation received in April 1995. The plots received 169% and 180% above normal precipitation for the months of in May and August 1996, respectively. The plots received close to two times as much precipitation during May, July, and September/96 compared to the same months in 1995. In August the study plots received approximately equal precipitation to that received in 1995. The plots only received 18% of the normal precipitation in June 1996. The study plots received 1.5 times more rain in June 1995, than they did in June 1996.

Because the plots received, on average, a large amount of rainfall during the 1996 growing season only 20.55 mm of supplemental irrigation was applied to the plots in the clipping disposal and fertilizer rate study. This supplemental water was applied twice during the growing season, each time for one hour after the fertilizer applications, at a rate of 10.27 mm/hr.

4.1.2 Soil parameters

1995 Soil Sample: A representative soil sample analysis conducted on the soil collected, prior to seeding, from the clipping disposal and fertilizer rate study plot found that the soil contained: 44 lbs./acre of estimated available nitrate-N; 102 lbs./acre of estimated available phosphate; 924 lbs./acre of estimated available potassium; and 32 lbs./acre of estimated available sulphate-S. The soil had a pH of 7.5 (mildly alkaline) and an electrical conductivity of 0.6 (Table 4.1).

Table 4.1: 1995 Soil Sample Analysis for the Clipping Disposal and Fertilizer Rate Study.

SAMPLE DEPTH	NUTRIENT ANALYSIS (P.P.M)				
	Ammonium-N	Nitrate-N	Phosphate	Potassium	Sulphate-S
0-6"		11	51	462	8
Total lbs/acre		22	102	924	16
Estimated Available lbs./acre		44	102	924	32
Quantity		Deficient	Optimum	Slightly excessive	Optimum

SAMPLE DEPTH	SOIL QUALITY	
	pH (acidity)	E.C. (Salinity)
0-6"	7.5 (normal)	0.6

1996 Soil Sample: Soil samples collected in 1996 from mixture ten treatment C1F1 (low fertilizer rate and clippings removed) showed that the soil contained, on average: 44 lbs./acre of estimated available nitrate-N; 110 lbs./acre of estimated available phosphate; 854 lbs./acre of estimated available potassium; and 48 lbs./acre of estimated available sulphate-S. The pH of this soil sample was 7.7, and the electrical conductivity was 0.6. There was 0.04% total organic carbon, 0.07% organic matter, 0.31% total nitrogen and a carbon to nitrogen (C:N) ratio of 0.13 (Table 4.2, 4.3, and 4.4) in this soil sample.

The soil sample collected in 1996 from mixture ten treatment C1F2 (low fertilizer rate and grasscylcing) contained: 60 lbs./acre of estimated available nitrate-N; 112 lbs./acre of estimated available phosphate; 906 lbs./acre of estimated available potassium; and 52 lbs./acre of estimated available sulphate-S. Soil pH was 7.6, and the electrical conductivity was 0.8. The soil sample contained 4.14% total organic carbon, 7.37% organic matter, 0.30% total nitrogen, and had a C:N ratio of 13.8 (Table 4.2, 4.3, and 4.4).

Soil samples collected in 1996 from mixture ten treatment C2F1 (high fertilizer rate and clippings removed) contained: 76 lbs./acre of estimated available nitrate-N; 108 lbs./acre of estimated available phosphate; 846 lbs./acre of estimated available potassium; and 52 lbs./acre of estimated available sulphate-S. Soil pH was 7.6 and the electrical conductivity was 0.8. There was 4.00% total organic carbon, 7.12% organic matter, 0.31% total nitrogen, and a C:N ratio of 12.9 (Table 4.2, 4.3, and 4.4) in the soil sample.

Table 4.2: 1996 Soil Sample Analysis for the Clipping Disposal and Fertilizer Rate Study (Mixture Ten).

SAMPLE DEPTH		NUTRIENT ANALYSIS (P.P.M)				
	Treatment	Ammonium-N	Nitrate-N	Phosphate	Potassium	Sulphate-S
0-6"	C1F1		11	55	427	12
	C1F2		15	56	453	13
	C2F1		19	54	423	13
	C2F2		>80	48	451	14
Total lbs./acre	C1F1		22	110	854	24
	C1F2		30	112	906	26
	C2F1		38	108	846	26
	C2F2		>160	96	902	28
Estimated Available lbs./acre	C1F1		44	110	854	48
	C1F2		60	112	906	52
	C2F1		76	108	846	52
	C2F2		320	96	902	56
Quantity	C1F1		Deficient	Optimum	Optimum	Optimum
	C1F2		Marginal	Excess	Optimum	Optimum
	C2F1		Marginal	Optimum	Optimum	Optimum
	C2F2		Excess	Optimum	Optimum	Optimum

SAMPLE DEPTH		SOIL QUALITY	
	Treatment	pH (acidity)	E.C. (Salinity)
0-6"	C1F1	7.7	0.6
	C1F2	7.6	0.8
	C2F1	7.6	0.8
	C2F2	7.2	2.1

C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate.

Table 4.3: Total Organic Carbon, Percent Organic Matter, Total Nitrogen, and C:N Ratio for Soil Samples Collected in 1996 from Mixture Ten, in the Clipping Disposal and Fertilizer Rate Study.

SAMPLE DEPTH	Treatment	Total organic carbon	% organic matter	Total Nitrogen	C:N ratio
0-6"	C1F1	0.04	0.07	0.31	0.13
	C1F2	4.14	7.37	0.30	13.8
	C2F1	4.00	7.12	0.31	12.9
	C2F2	3.94	7.01	0.34	11.6

C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate.

Table 4.4: Physical Analysis of the Soil Samples Collected in the 1996 Growing Season from the Clipping Disposal and Fertilizer Rate Study.

SAMPLE DEPTH	Particle Size	Actual distribution
0-6"	% Sand	16
	% Silt	35
	% Clay	49

The soil samples collected in 1996 from mixture ten, treatment C2F2 (high fertilizer rate and grasscycling) contained: 320 lbs./acre of estimated available nitrate-N; 96 lbs./ acre of estimated available phosphate; 902 lbs./acre of estimated available potassium; and 56 lbs./acre of estimated available sulphate-S. The pH of the soil was 7.2 and the electrical conductivity was 2.1. Total organic carbon of the soil sample was 3.94%, organic matter was 7.01%, total nitrogen was 0.34%, and it had a C:N ratio of 11.6 (Table 4.2, 4.3, and 4.4).

Ranking the treatments from highest to lowest in available nitrogen content, the following trend resulted: grasscycling and high fertilizer rate (320 p.p.m. of available nitrogen) > grasscycling and low fertilizer rate (76 p.p.m. of available nitrogen) > clipping removal and high fertilizer rate (60 p.p.m. of available nitrogen) > clipping removal and low fertilizer rate (44 p.p.m. of available nitrogen).

The soil samples collected from mixture ten had different nitrogen, and potassium concentrations, from for each of the four different treatments (C1F1, C2F1, C1F2, C2F2). Sulphate and phosphate concentrations for the four treatments were not very different. The grasscycling and high fertilizer plots (C2F2) had the lowest amount of estimated available phosphate, at only 96 p.p.m., while the other three treatments had phosphate concentrations of 110 p.p.m. ± 2 p.p.m. The available nitrogen concentrations of the soil, for the four treatments was very different. The soil in the plots where clipping removal and low fertilizer rates (C1F1) were applied had the lowest available nitrogen concentration, of 44 p.p.m., the soil from the plots where grasscycling and high fertilizer rates (C2F2) were applied had the highest available nitrogen concentration, of 320 p.p.m. From the nitrogen levels in the soil samples, it appears that when grasscycling and high fertilizer rates were imposed in combination, nitrogen concentrations increased in the soil compared to any of the other three treatments.

The particle density of the soil, collected from the clipping disposal and fertilizer rate study plot, was determined to be 2.214, 2.002, and 2.103 mg/m^3, with an average of 2.106 mg/m^3. The bulk density of this soil was 1.085, 1.102, and 1.084 mg/m^3, with an average of 1.09 mg/m^3. Porosity was calculated, using the averages for particle density (2.106 mg/m^3) and bulk density (1.090 mg/m^3) and the following formula: % pore space = 1 - (bulk density/particle density) (Rowell, 1994) to be 48.20%. Percent pore space using the method described in *Soil Science: Methods and Applications* (Rowell, 1994), was determined to be 50%. The calculated porosity result of 48.2% and the second porosity value determined to be 50%, varied slightly. This variance was likely due to an error in the procedure described in *Soil Science: Methods and Applications* (Rowell, 1994) to determine porosity, resulting in air pockets affecting the results. The $CaCO_3$ content of the soil was 10%.

4.1.3 Vegetation parameters

In this study, dry weight yield, and wet weight yield data were collected seven times, three in 1995 and four in 1996; turfgrass height and colour prior to mowing were monitored in the 1995 and 1996 growing seasons; and percent nitrogen in select turfgrass clippings, and interspecific and intraspecific competition were also quantitatively measured.

4.1.3.1 Results of dry weight yields

1995 Dry Weight Yields: In 1995, turfgrass clippings were collected and dried on three dates, August 16, September 14, and October 9, to determine if the amount of dry weight yield produced differed due to fertilizer regime, clipping disposal method, and/or mixture composition. Results of the dry weight yield data for 1995 were analyzed separately for each of the three clipping dates and summed together for the overall 1995 growing season results.

Dry weight yields collected on August 16/95, were significant different from each other in plots due to blocks, mixture composition, clipping disposal, and fertilizer rate (Figure 4.3a). There was a significant difference ($p<0.0003$) in dry weight clipping yield between blocks. Using a Least Significant Difference Test, the block means were considered significantly different if there was a difference of 1.76 g/m^2 or more between the means. Ranking the means, the following trend resulted: block four (13.24 g/m^2) > block three (11.82 g/m^2) > block two (11.33 g/m^2) > block one (9.35 g/m^2).

There was also a significant difference ($p<0.0001$) in dry weight clipping yield between mixtures if the means differed by at least 2.81 g/m^2. The average dry weight clipping yield was highest for mixture five, a monostand of perennial ryegrass, and lowest for mixture one, a monostand of Kentucky bluegrass. Mixture five produced

(a)

(b)

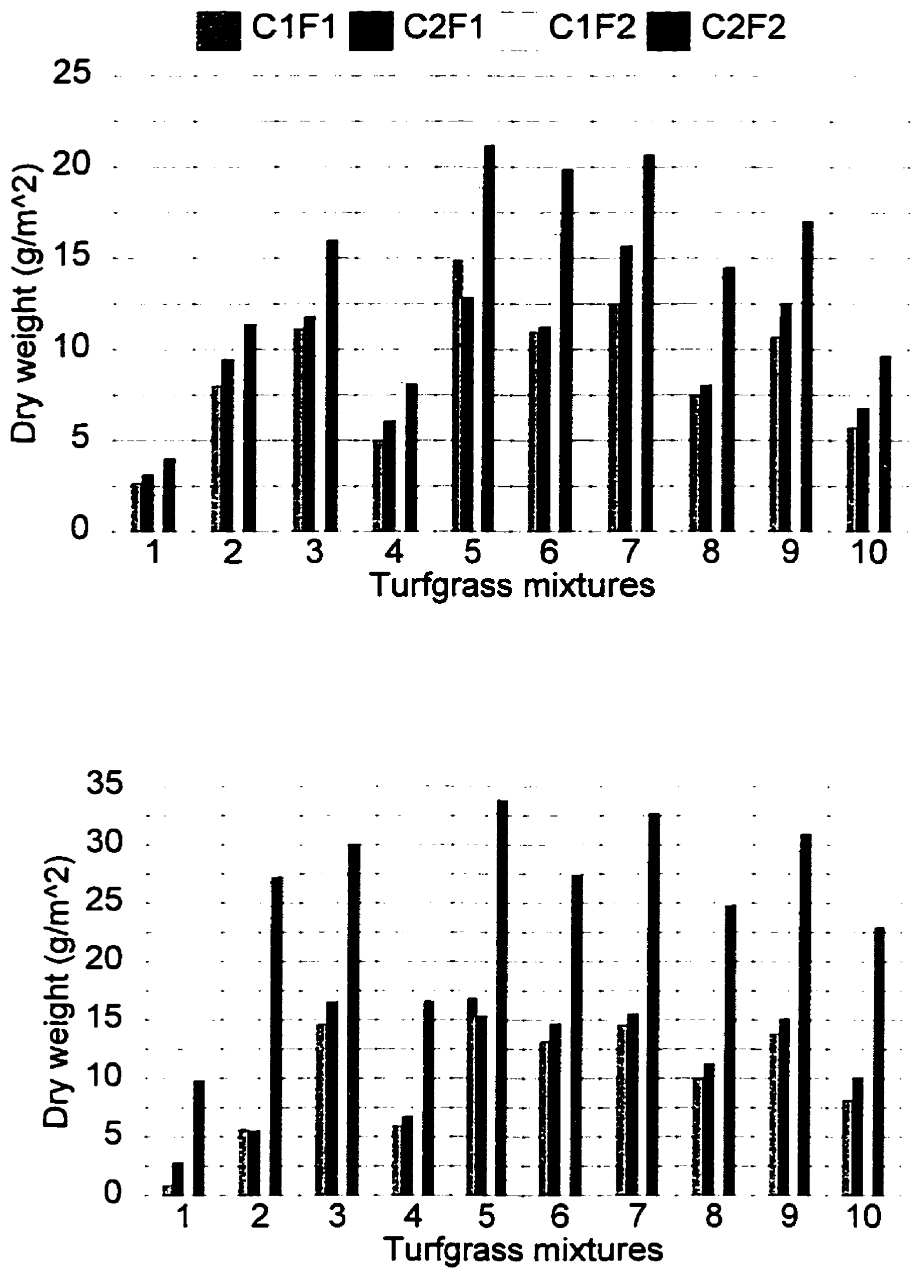


Figure 4.3: Dry weight clipping yield for the ten mixtures collected on (a) August 16, 1995 and (b) September 14, 1995.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

on average a dry weight yield of 17 g/m^2, 14 g/m^2 more than mixture one.

The dry weight yields for the ten mixtures ranked as follows, from heaviest to lightest: mixture five (16.93 g/m^2) > mixture seven (16.80 g/m^2) > mixture six (14.61 g/m^2) > mixture three (13.25 g/m^2) > mixture nine (13.19 g/m^2) > mixture eight (10.99 g/m^2) > mixture two (10.15 g/m^2) > mixture ten (7.65 g/m^2) > mixture four (6.82 g/m^2) > mixture one (2.97 g/m^2).

Fertilizer rate also had a significant effect on the dry weight clipping yield. The plots treated with the high fertilizer rate produced significantly ($p<0.0001$) heavier dried clipping values than did the plots treated with the low fertilizer rate. The plots treated with the high fertilizer rate, averaged across all ten mixtures, produced on average a dry weight yield of 13.50 g/m^2, whereas the plots treated with the low fertilizer rate only produced, on average, 9.26 g/m^2.

Clippings collected on August 16, 1995 also showed a significant difference ($p<0.0392$) in dry weight clipping yield between the two clipping disposal regimes. The practice of grasscycling resulted in mixtures producing on average 12.01 g/m^2 of dried clippings, 1.28 g/m^2 more than the plots where clippings were removed.

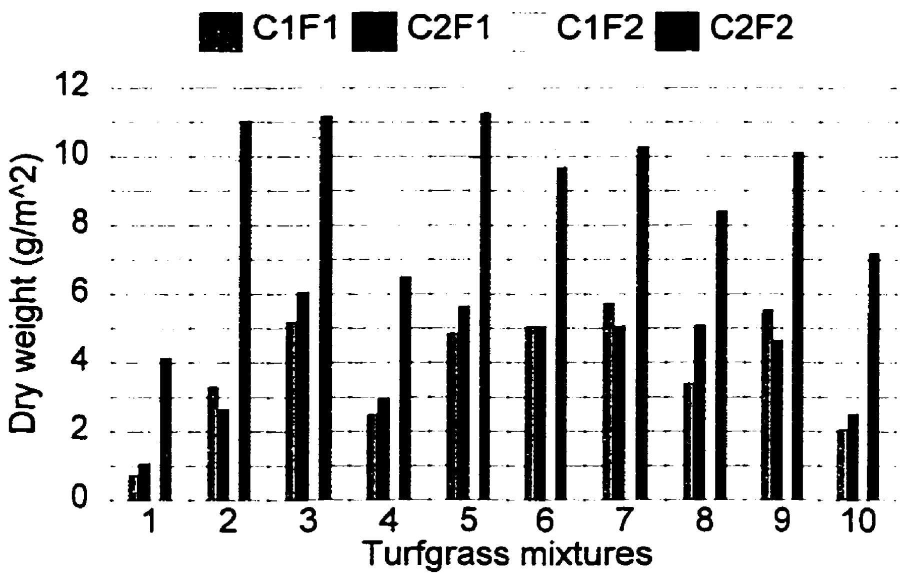
Clippings collected on September 14/95 had significant differences between dry weight yields due to blocks, and mixtures*fertilizer rate interaction (Figure 4.3b). There was a significant difference ($p<0.0001$) in dry weight yield between blocks. By completing a Least Significant Difference test on the block factor, the blocks were significantly different if their means were 1.64 g/m^2 or more different. Plots in block four produced the heaviest average amount of dried clippings (22.10 g/m^2), followed by block three (17.98 g/m^2), then block two (17.45 g/m^2), and block one produced the lightest dried weight clipping yield (14.92 g/m^2).

There was also one significant interaction betweem mixtures*fertilizer rate ($p<0.0002$). In general, the plots treated with the high fertilizer rate produced a heavier dry weight clipping yield than the plots treated with the low fertilizer rate. However, plots seeded with mixture one and treated with the high fertilizer rate produced a much lower clipping yield than all of the other mixtures treated with the high fertilizer rate. Plots seeded with mixture one where the high fertilizer rate was applied even produced lighter clipping yield than some of the other mixtures treated with the low fertilizer rate.

Clippings collected on October 9, 1995 showed significant differences between blocks, mixtures and fertilizer rate (Figure 4.4a). The results of a least significant difference test found that blocks were significantly different ($p<0.0001$) if the difference between the means was 0.98 g/m^2 or more. The dry weight yield for block one (7.53 g/m^2) > block two (6.36 g/m^2) > block three (5.99 g/m^2) > block four (5.09 g/m^2).

The difference in dry weight yield between mixtures was also found to be significant ($p<0.0001$). Mixture three, produced, on average, the heaviest weight, 8.25 g/m^2, of dried clippings and mixture one produced, on average, the lightest weight, 2.22 g/m^2, of dried clippings. Using a least significant difference test on the data the

(a)



(b)

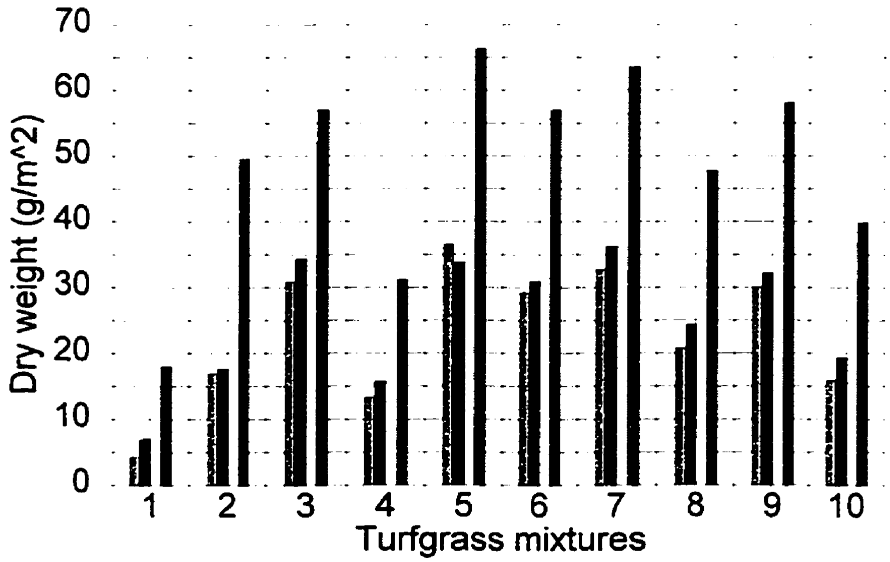


Figure 4.4: Dry weight clipping yield for the ten mixtures collected on (a) October 9, 1995 and (b) Sum of Aug., Sept., and Oct. 1995.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

results showed that the mixtures were significantly different if the difference between the means was 1.54 g/m^2 or more . The average dry weight yield for mixture three (8.24 g/m^2) > mixture five (7.94 g/m^2) > mixture seven (7.64 g/m^2) > mixture six (7.51 g/m^2) > mixture nine (6.87 g/m^2) > mixture two (6.72 g/m^2) > mixture eight (6.12 g/m^2) > mixture four (4.87 g/m^2) > mixture ten (4.30 g/m^2) > mixture one (2.22 g/m^2).

There was also a significant difference ($p<0.0001$) in dry weight yield due to fertilizer rates. Plots treated with the high fertilizer rate produced on average 4.57 g/m^2 more dried clippings than the plots treated with the low fertilizer rate.

Total dry weight collected from the three sampling dates in the 1995 growing season showed significant differences in dry weight clipping yield between blocks, clipping disposal, and mixtures*fertilizer rates (Figure 4.4b). Total dry weight yield was significantly different ($p<0.0001$) between blocks when the values differed by 3.61 g/m^2 or more. The total dry weight yields, averaged across mixtures, for the four blocks ranked as follows: block four (42.87 g/m^2) > block three (36.86 g/m^2) > block two (34.77 g/m^2) > block one (29.37 g/m^2).

The clipping disposal treatment, grasscycling and removing the clippings, showed a significant difference ($p<0.0382$) in total dry weights for the 1995 season. The average dry weight yield produced in plots where the grasscycling regime was 37.07 g/m^2, 2.70 g/m^2 more than clippings than that produced by the plots where the clippings were removed.

There was a significant interaction between mixture*fertilizer rate

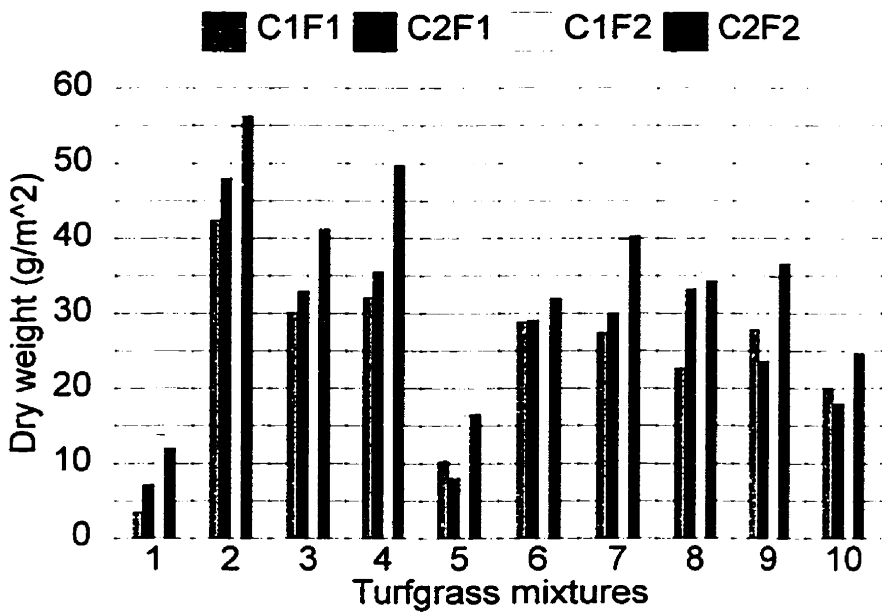
($p<0.0163$). In general, the plots treated with the high fertilizer rate produced a heavier dry weight clipping yield than the plots treated with the low fertilizer rate. However, the plots of mixture one with the high fertilizer rate had a much lower clipping yield than all of the other mixtures treated with the high fertilizer rate. Plots seeded with mixture one where the high fertilizer rate was applied even produced lighter clipping yield than some of the other mixtures treated with the low fertilizer rate.

1996 Dry Weight Yields: In 1996, turfgrass clippings were collected and dried on four dates, June 8, July 27, September 14, and October 5, to determine if the amount of dry weight yield produced per mixture differed due to fertilizer regime, clipping disposal method, and mixture composition. When determining the results of the dry weight yield data for 1996, the yields were analyzed separately for each of the four clipping dates and summed together for the total dry weight yield in 1996.

Clippings collected on June 8/96 were significant differences in dry weight yield between blocks, mixtures, and fertilizer rate (Figure 4.5a). A significant difference ($p<0.0001$) in dry weight yield resulted between blocks if the mean dry weight yield was 3.50 g/m^2 or more different. Plots in block four produced 37.03 g/m^2 of dried clippings, block three produced 30.10 g/m^2, block two produced 28.92 g/m^2, and block one produced 26.34 g/m^2.

Dry weight yield was also significantly different ($p<0.0001$) between mixtures

(a)



(b)

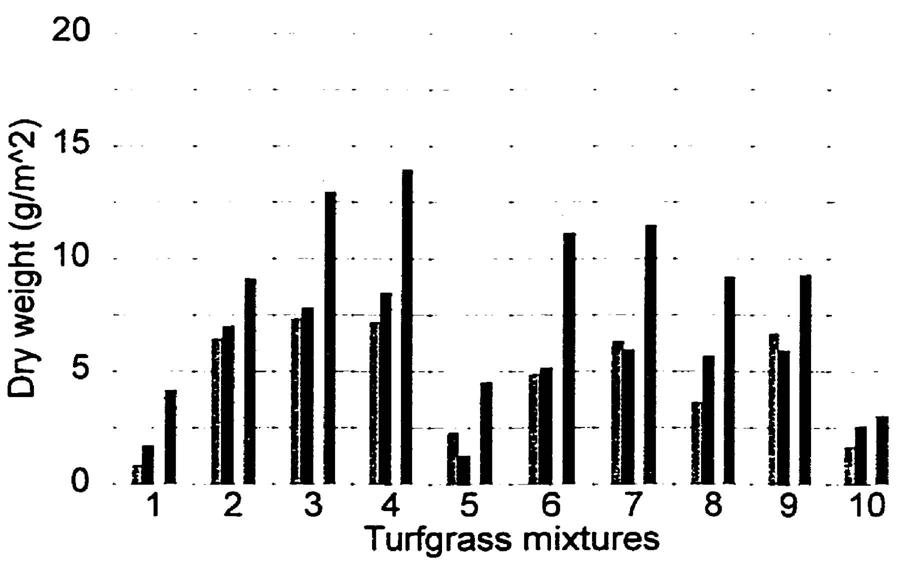


Figure 4.5: Dry weight clipping yield for the ten mixtures collected on (a) June 8, 1996 and (b) July 27, 1996.

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

if the mean clipping yields differ by 5.58 g/m^2. Plots seeded with mixture two produced the heaviest amount of dried clippings (50.42 g/m^2), and plots seeded with mixture one produced the lightest (9.11 g/m^2). Using a least significant difference test on the data the following trend resulted: The dry weight yield for mixture two (50.42 g/m^2) > mixture four (42.94 g/m^2) > mixture three (37.34 g/m^2) > mixture seven (34.37 g/m^2) > mixture six (32.88 g/m^2) > mixture eight (31.44 g/m^2) > mixture nine (30.69 g/m^2) > mixture ten (22.01 g/m^2) > mixture five (12.83 g/m^2) > mixture one (9.11 g/m^2) (Figure 4.5a).

Dry weight yield was also significantly different ($p<0.0001$) between fertilizer rates. Plots treated with the high fertilizer rate produced, on average, 9.44 g/m^2 more dried clippings than the plots treated with the low fertilizer rate.

Clippings collected July 27/96 showed significant differences in average dry weight yield between mixtures and fertilizer rates (Figure 4.5b). A significant difference ($p<0.0001$) in dry weight yield was present between mixtures when the mixtures differed by 2.38 g/m^2 or more. Mixture four produced the heaviest amount of dried clippings (11.51 g/m^2), and mixture ten produced the lightest amount of dried clippings (2.57 g/m^2). Using the Least Significant Difference Test, the overall ranking of the average dried clipping yield per mixture is: mixture four (11.51 g/m^2) > mixture three (10.40 g/m^2) > mixture six (8.28 g/m^2) > mixture seven (8.23 g/m^2) > mixture nine (8.00 g/m^2) > mixture two (7.98 g/m^2) > mixture eight (6.63 g/m^2) > mixture five (2.92 g/m^2) > mixture one (2.64 g/m^2) > mixture ten (2.57 g/m^2) (Figure 4.5b).

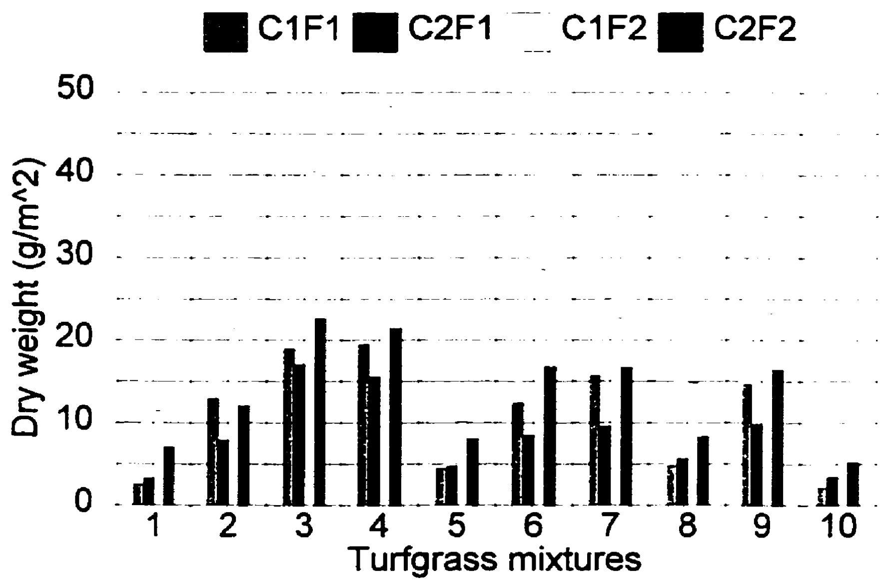
There was also a significant difference ($p<0.0001$) in dry weight yield between fertilizer rates. The high fertilizer rate produced on average 3.95 g/m^2 more dried clippings than the low fertilizer rate.

Clippings collected on September 14/96 had significant differences in dry weight yield between blocks, fertilizer rates, and mixtures*clipping disposal (Figure 4.6a). A significant difference ($p<0.0001$) in dry weight yield was found between blocks when the difference between the means was 3.09 g/m^2 or more. Plots in block four produced, on average, 7.80 g/m^2 more dried clippings than plots in block three, which produced, on average, 0.62 g/m^2 more clippings than plots in block two, which in turn produced, on average, 0.93 g/m^2 more clippings than plots in block one.

Fertilizer rates, on average, produced a significant difference ($p<0.0001$) in dry weight yield. Plots treated with the high fertilizer rate produced, on average, 17.75 g/m^2 of dried clippings, 7.96 g/m^2 more dried clippings than plots treated with the low fertilizer rate.

The interaction between clipping disposal*fertilizer rates also produced a significant difference ($p<0.0021$). In general the plots where the clippings were removed produced a heavier clipping yield than the plots where the clippings were returned (grasscycling), with the exception of mixture ten. Plots seeded with mixture ten produced equal clipping weights for both the grasscycling and the clipping removal treatments.

(a)



(b)

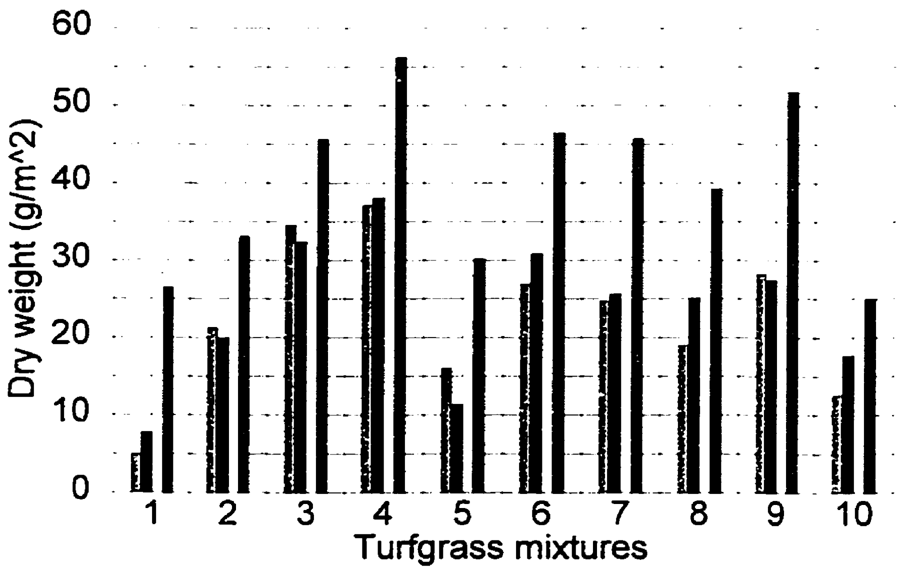


Figure 4.6: Dry weight clipping yield for the ten mixtures collected on (a) September 14, 1996 and (b) October 5, 1996.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

Clippings collected on October 5/96 had significant differences in dry weight yield between blocks, mixtures, and fertilizer rates (Figure 4.6b). A significant difference ($p<0.0001$) in dry weight yield between blocks was found if the means were 4.03 g/m^2 or more different. The average dry weight clipping yield for plots in block four was 41.34 g/m^2, which was 9.00 g/m^2 more than the average clipping weight collected from plots in block three, 14.40 g/m^2 more than the average yield collected from plots in block two, and 16.24 g/m^2 more than the average dried clipping yield produced in plots in block one.

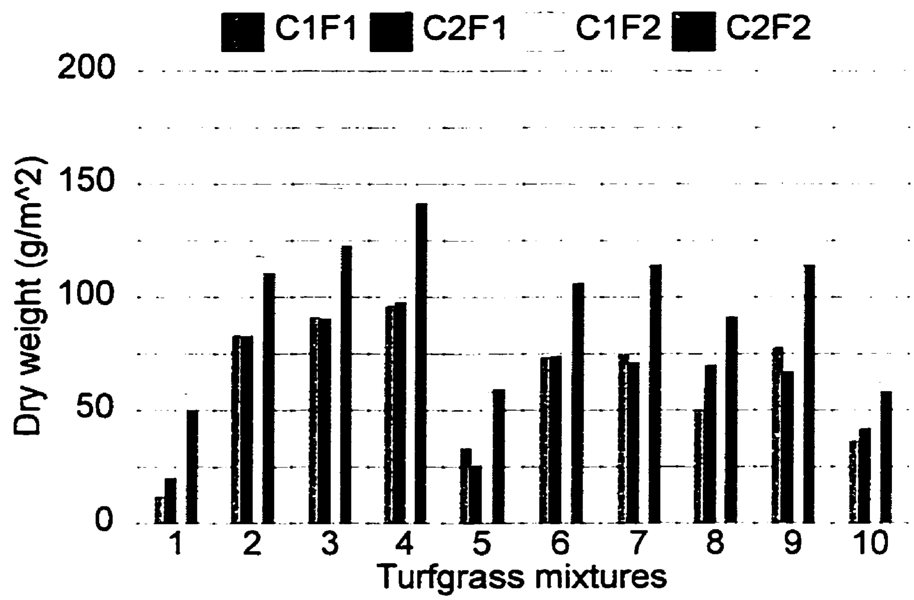
There was also a significant difference ($p<0.0001$) in dried clipping yield between mixtures. The highest producer of dried clippings were plots seeded with mixture four which produced, on average, 46.59 g/m^2, 6.11 g/m^2 more than the second highest producer of dried clippings, mixture three, and an average of 29.71 g/m^2 more than the lowest producer, mixture one. Using a Least Significant Difference test on the data, the means were significantly different if they were by 6.38 g/m^2 or more different. By ranking the mixtures according to dry weight yield, the following trend resulted: the dry weight yield for mixture four (46.59 g/m^2) > mixture three (40.48 g/m^2) > mixture nine (38.39 g/m^2) > mixture six (37.81 g/m^2) > mixture seven (34.43 g/m^2) > mixture eight (30.90 g/m^2) > mixture two (26.66 g/m^2) > mixture five (21.43 g/m^2) > mixture ten (20.78 g/m^2) > mixture one (16.85 g/m^2).

The two fertilizer rates also produced a significant difference ($p<0.0001$) in dry weight clipping yield. Significantly more dry weight yield was obtained from the plots receiving the high fertilizer rate compared to plots treated with the low fertilizer rate. The plots receiving the high fertilizer rate produced on average 16.66 g/m^2 more dried clippings than the plots that received the low fertilizer rate.

The total dry weight yield for the 1996 growing season showed that there were significant differences in dry weight yield between blocks, mixtures, and fertilizer rates (Figure 4.7a). The total dry weight showed significant differences ($p<0.0001$) between blocks. The Least Significant Difference test found that the dry weight clipping yield was significantly different between blocks if there was a difference of 10.19 g/m^2 or more. The total dry weight produced in plots in block four, averaged across mixtures, was 106.37 g/m^2, 25.09 g/m^2 more than the total dry weight produced in plots in block three, 32.54 g/m^2 more than the average total dry weight produced in plots in block two, and 35.89 g/m^2 more than the average total dry weight produced in plots in block one.

There was a significant difference ($p<0.0001$) in total dry weight yield between mixtures when the means were different by 16.12 g/m^2 or more. The heaviest amount of total dried clippings, averaged across blocks, was produced by plots seeded with mixture four (130.46 g/m^2) and the lightest amount of dried clippings, averaged across blocks, was produced by plots seeded with mixture one (34.55 g/m^2). The Least Significant Difference Test on total dry weight yield, averaged across blocks, for mixtures starting with the highest clipping producer, going to the lowest clipping producer is: mixture four (130.46 g/m^2) > mixture three (113.07 g/m^2) > mixture two (98.70 g/m^2) > mixture six (95.58 g/m^2) > mixture seven (93.27 g/m^2) > mixture nine

(a)



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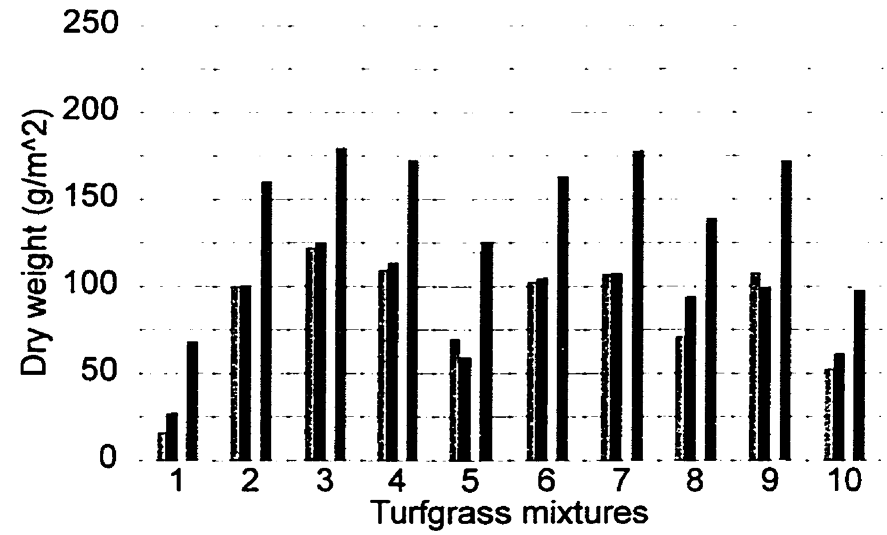


Figure 4.7: Dry weight clipping yield for the ten mixtures collected on
(a) Sum of June, July, Sept. and Oct. 1996
(b) Total dry wt. yield for 1995 and 1996 summed.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

(93.19 g/m^2) > mixture eight (77.40 g/m^2) > mixture ten (49.65 g/m^2) > mixture five (44.04 g/m^2) > mixture one (34.55 g/m^2).

There was also a significant difference ($p<0.0001$) in total dry weight yield between fertilizer rates. The plots treated with the high fertilizer rate produced on average a total dry weight yield of 102.72 g/m^2, 39.45 g/m^2 more than the total clippings produced by plots treated with the low fertilizer regime.

Summary of Dry Weight Yields for 1995 and 1996: Overall, the total dry weight yield of clippings for all seven collection dates, three in 1995 and four in 1996, showed that there were significant differences in dry weight yield between blocks, mixtures, and fertilizer rates (Figure 4.7b). The total dry weight yield showed a significant difference ($p<0.0001$) between blocks, consistent with the results from the 1995 and 1996 growing seasons. The Least Significant Difference Test calculated that the average dry weight clipping yield for a block was significantly different than another if there was a difference of 12.88 g/m^2 or more between them. Plots in block four produced 149.24 g/m^2 of total dried clippings, 32.10 g/m^2 more than plots in block three, 40.64 g/m^2 more than plots in block two, and 49.39 g/m^2 more than plots in block one.

There was a significant difference ($p<0.0001$) in total dry weight yield between mixtures. In the 1995 growing season plots seeded with mixture five produced the heaviest amount of clippings, and plots seeded with mixture one produced the lightest. In the 1996 growing season, plots seeded with mixture four produced the heaviest dried clippings, and plots seeded with mixture one once again produced the lightest. The total dry weight yield of the clippings collected in the 1995 and 1996 growing seasons combined found plots seeded with mixture three to produce the heaviest yield of dry weight yield, 156.73 g/m^2, and plots seeded with mixture one produced the lightest amount of dry weight yield, 45.10 g/m^2. The dry weight clipping yield for the mixtures are significantly if they differ by 20.70 g/m^2 or more. The final ranking, using the Least Significant Difference Test, of all the total dried clippings collected in both the 1995 and 1996 growing seasons showed the dry weight yield of plots seeded with mixture three produced (156.73 g/m^2) > mixture four (154.23 g/m^2) > mixture seven (140.57 g/m^2) > mixture six (138.88 g/m^2) > mixture nine (135.62 g/m^2) > mixture two (131.90 g/m^2) > mixture eight (112.61 g/m^2) > mixture five (93.89 g/m^2) > mixture ten (77.57 g/m^2) > mixture one (45.10 g/m^2). There was also a significant difference ($p<0.0001$) in dry weight yield between fertilizer rates, consistent with all of the seven dates the clippings were collected. For the seven clipping dates combined, the high fertilizer rate produced on average 149.99 g/m^2 dried clippings, 62.56 g/m^2 more than the low fertilizer rate.

4.1.3.2 Results of wet weight yield

The wet weight trends were identical to dry weight trends, for each date and the overall 1995 and 1996 results. On average the wet weight for all of the clippings combined was 65% more than the dry weight values.

4.1.3.3 Results of height and colour data

Height and Colour Results for 1995: The overall trend in turfgrass heights for all mixtures in the 1995 growing season show similar trends to the dry and wet weight clipping yield results (Figures 4.8 and 4.9). All of the mixtures' heights appear to be declining from a peak between July 25 and August 1, 1995. The mixtures all increased in height beginning August 15, 1995, some reached their peak height on September 5, while others continued to increase in height until September 13, 1995.

The plots which received the higher fertilizer rate had consistently taller turfgrass than the plots that received the low fertilizer rate, for mixtures one, two, three, four, five, six, nine, and ten. Mixture seven and eight did not conform to this trend. Grass in plots seeded with mixture seven treated with grasscycling, regardless of fertilizer rate, was taller than in plots where clippings were removed. For mixture eight, the plots where grasscycling and the low fertilizer were imposed produced the tallest turfgrass for all sampling dates in the 1995 growing season, except on the September 5 sampling date when the plots seeded with mixture eight and treated with the high fertilizer rate had taller grass.

Statistics were not done on height measurements, but there was a measurable difference in height between mixtures. In 1995 plots seeded with mixture seven had the tallest shoot growth, followed my mixture three. Plots seeded with mixture one had the shortest shoot growth, and plots seeded with mixture four had the second shortest shoot height. The results of ranking the overall height for the ten mixtures in the 1995 growing season, regardless of fertilizer and clipping disposal regime, from

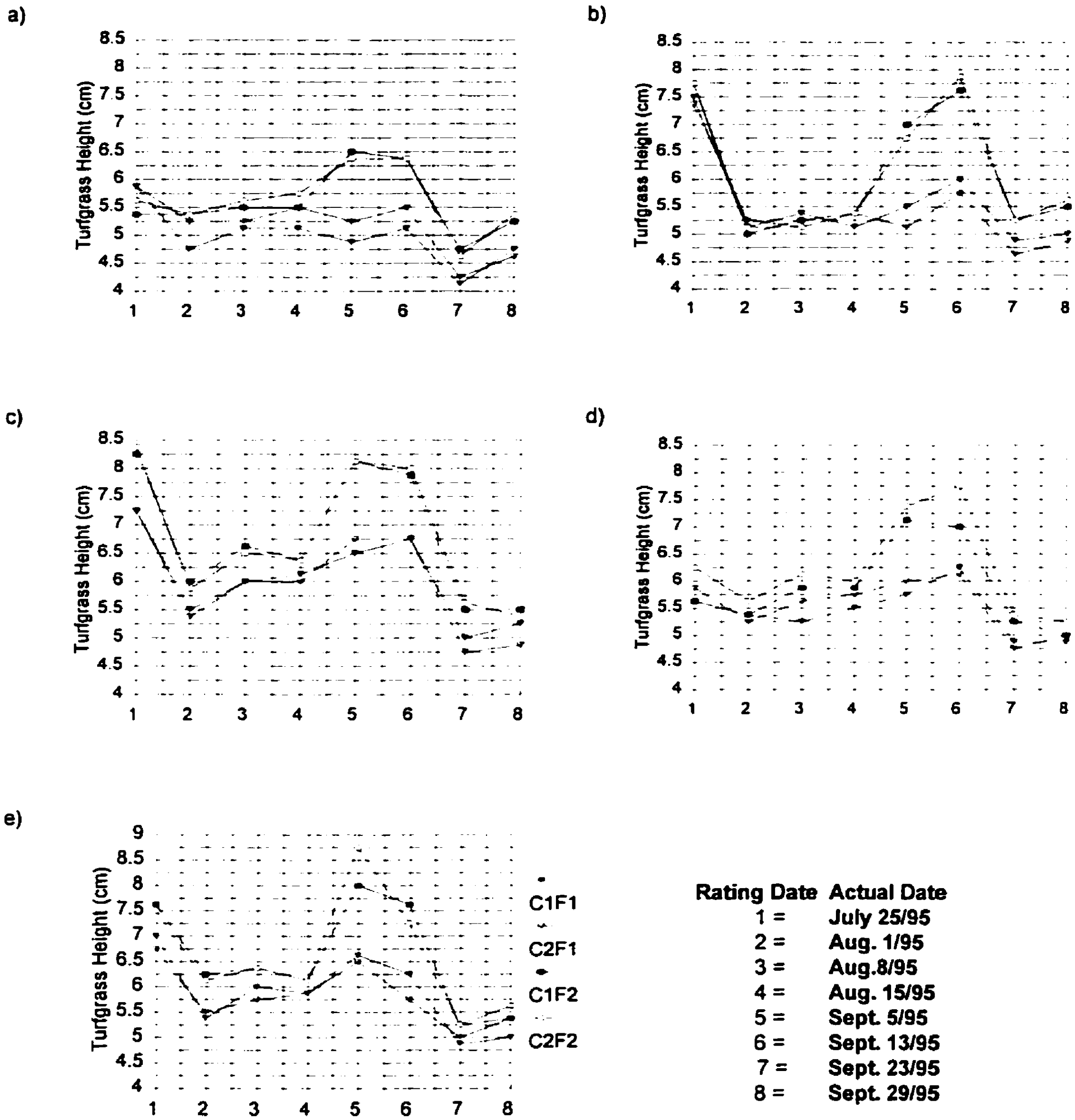
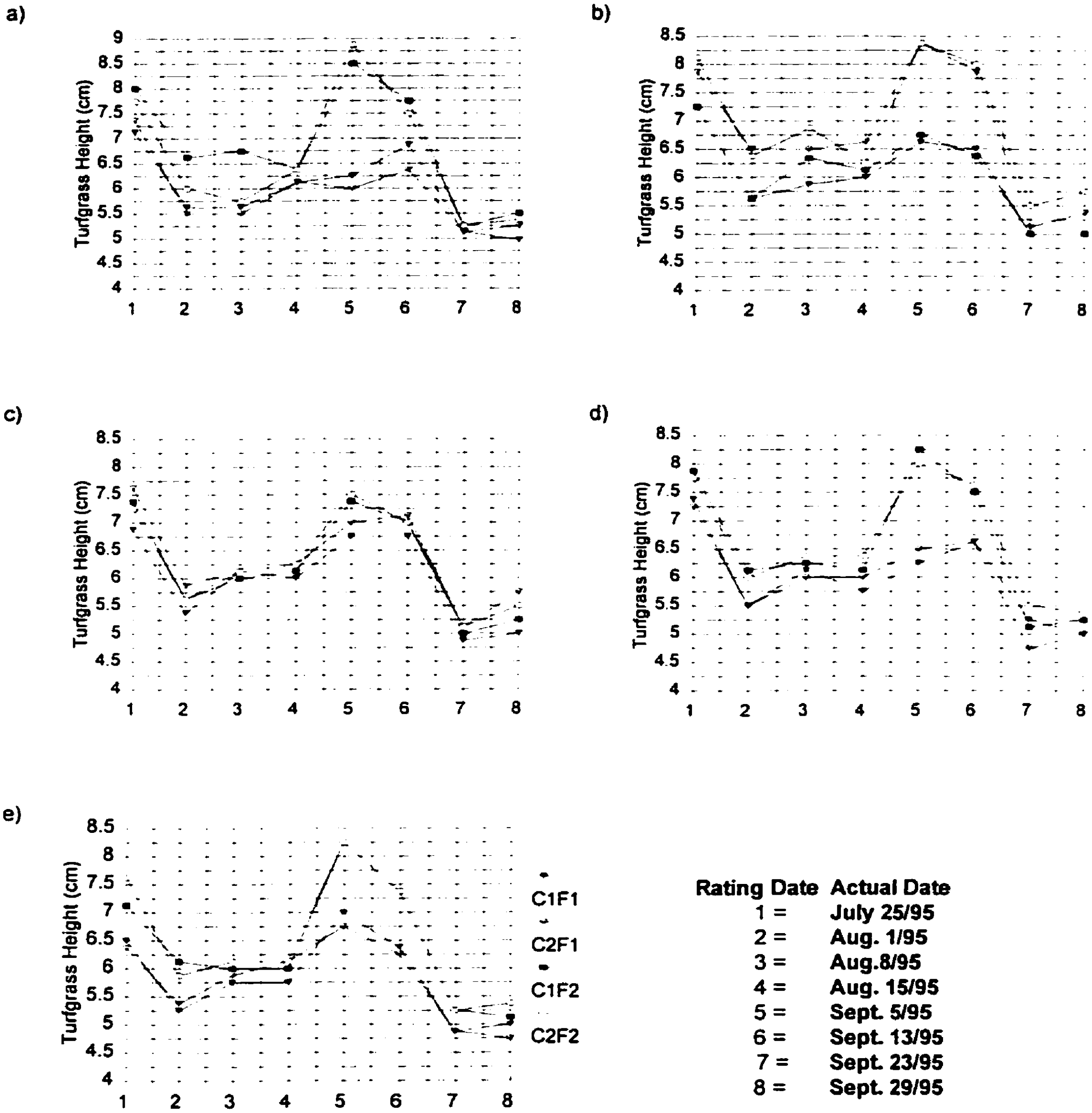


Figure 4.8: Mean turfgrass height for mixtures one to five, for eight sampling dates in the 1995 growing season. (a) Mean turfgrass height for mixture one. (b) Mean turfgrass height for mixture two. (c) Mean turfgrass height for mixture three. (d) Mean turfgrass height for mixture four. (e) Mean turfgrass height for mixture five.

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).



Rating Date	Actual Date
1 =	July 25/95
2 =	Aug. 1/95
3 =	Aug.8/95
4 =	Aug. 15/95
5 =	Sept. 5/95
6 =	Sept. 13/95
7 =	Sept. 23/95
8 =	Sept. 29/95

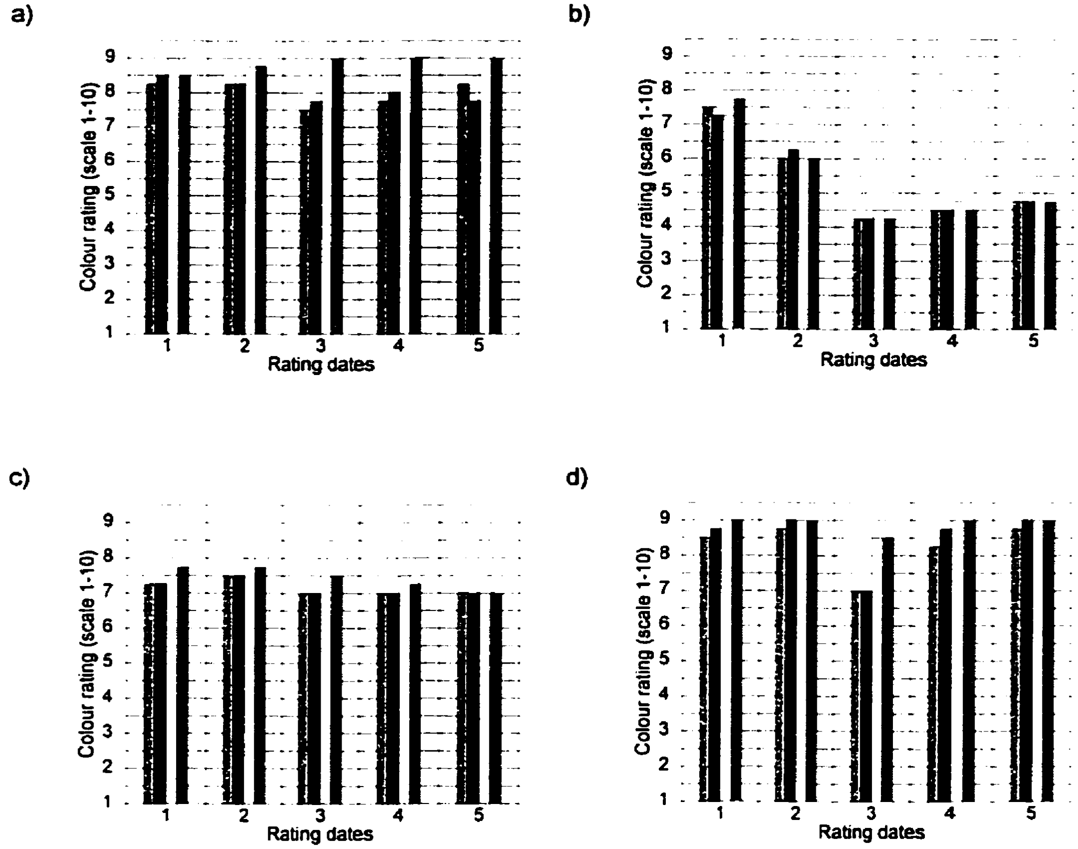
Figure 4.9: Mean turfgrass height for mixtures six to ten, for eight sampling dates in the 1995 growing season. (a) Mean turfgrass height for mixture six. (b) Mean turfgrass height for mixture seven. (c) Mean turfgrass height for mixture eight. (d) Mean turfgrass height for mixture nine. (e) Mean turfgrass height for mixture ten.

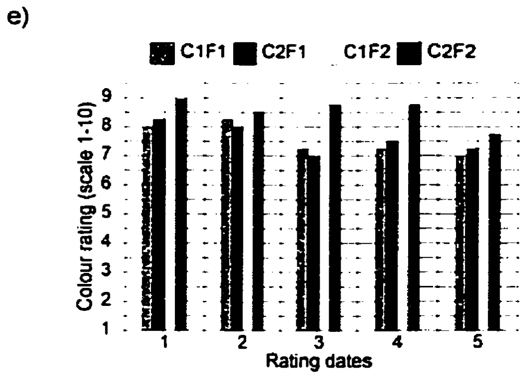
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

tallest to shortest, was as follows: mixture seven (6.43 cm) > mixture three (6.85 cm) > mixture six (6.33 cm) > mixture nine (6.28 cm) > mixture five (6.22 cm) > mixture eight (6.21 cm) > mixture ten (6.13 cm) > mixture two (5.80) > mixture four (5.77 cm) > mixture one (5.34 cm).

Turfgrass colour varied with mixture (Figures 4.10 and 4.11). Plots seeded with mixture two were the only plots that had unacceptable turfgrass colour any time during the growing season. Turfgrass colour was unacceptable if it was ranked less than 6. The majority of turfgrass mixtures had an average ranking of 8 for turfgrass colour, except for mixture two which had a much lower colour ranking average. The overall colour for the ten mixtures in the 1995 growing season was ranked as follows: mixture four (8.64) > mixture one (8.46) > mixture eight (8.35) > mixture ten (8.34) > mixture seven (8.29) > mixture six (8.15) > mixture nine (8.10) > mixture five (8.04) > mixture three (7.31) > mixture two (5.44). Although not statistically tested, the turfgrass colour ranking was higher for the plots treated with the high fertilizer rate, compared to those treated with the low fertilizer rate.

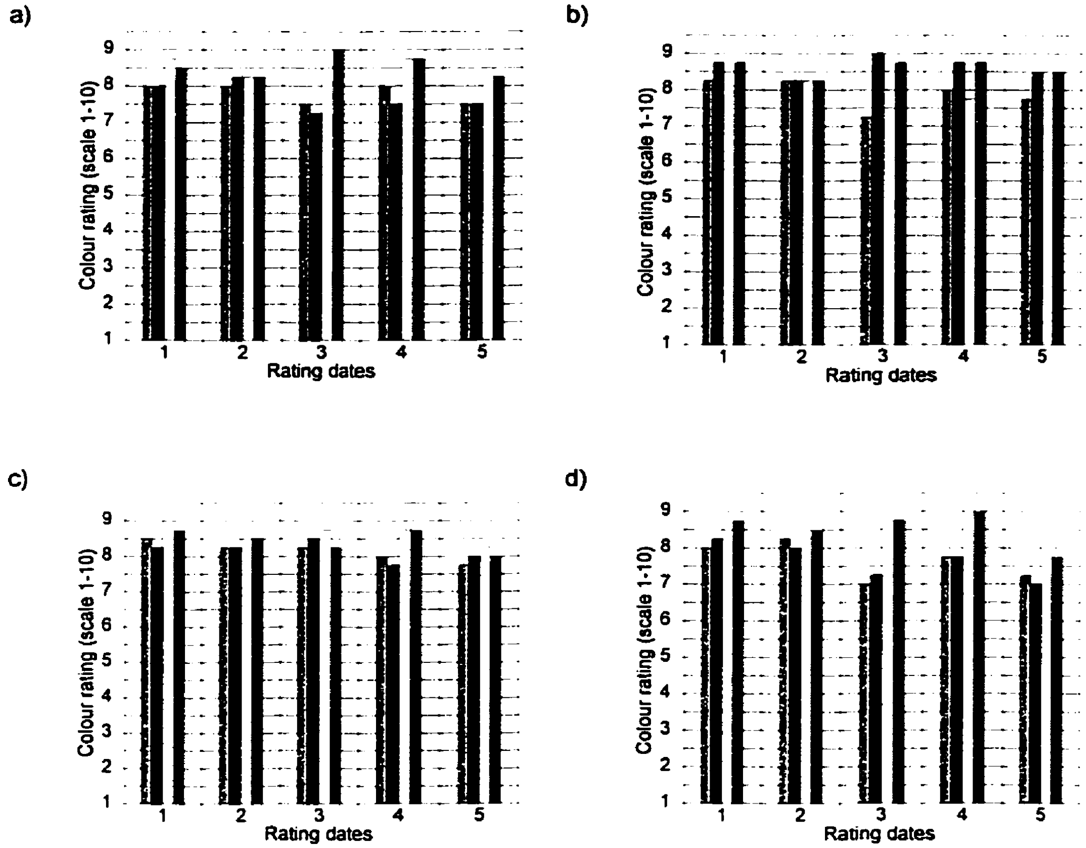
Height and Colour Results for 1996: Turfgrass peaked in height between June 2 and June 8/96, for all mixtures (Figures 4.12 and 4.13). Grass height for all mixtures declined from this peak, to a height of 4 to 4.5 cm by the June 24, 1996 sampling date. Turfgrass height increased after June 24 to a second peak in height which occurred for all mixtures on July 27, 1996. Height declined a second time, after July 27/96, with the exception of mixtures one, five and ten. Ranking of the average

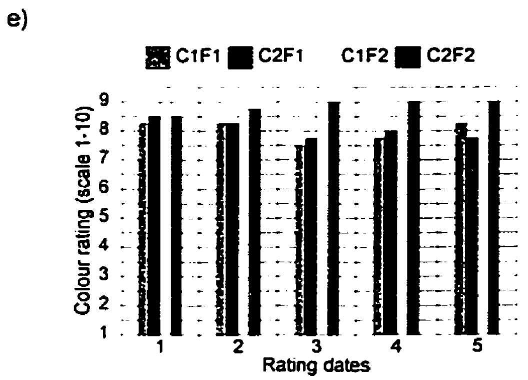




Rating Date	Actual Date
1 =	Aug.8/95
2 =	Aug. 15/95
3 =	Sept. 5/95
4 =	Sept. 13/95
5 =	Sept. 29/95

Figure 4.10: Mean turfgrass colour for mixtures one to five, for five sampling dates in the 1995 growing season. (a) Mean turfgrass colour for mixture one. (b) Mean turfgrass col for mixture two. (c) Mean turfgrass colour for mixture three. (d) Mean turfgrass colour for mixture four. (e) Mean turfgrass colour for mixture five.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; C2F2 = grasscycling and high fertilizer rate).

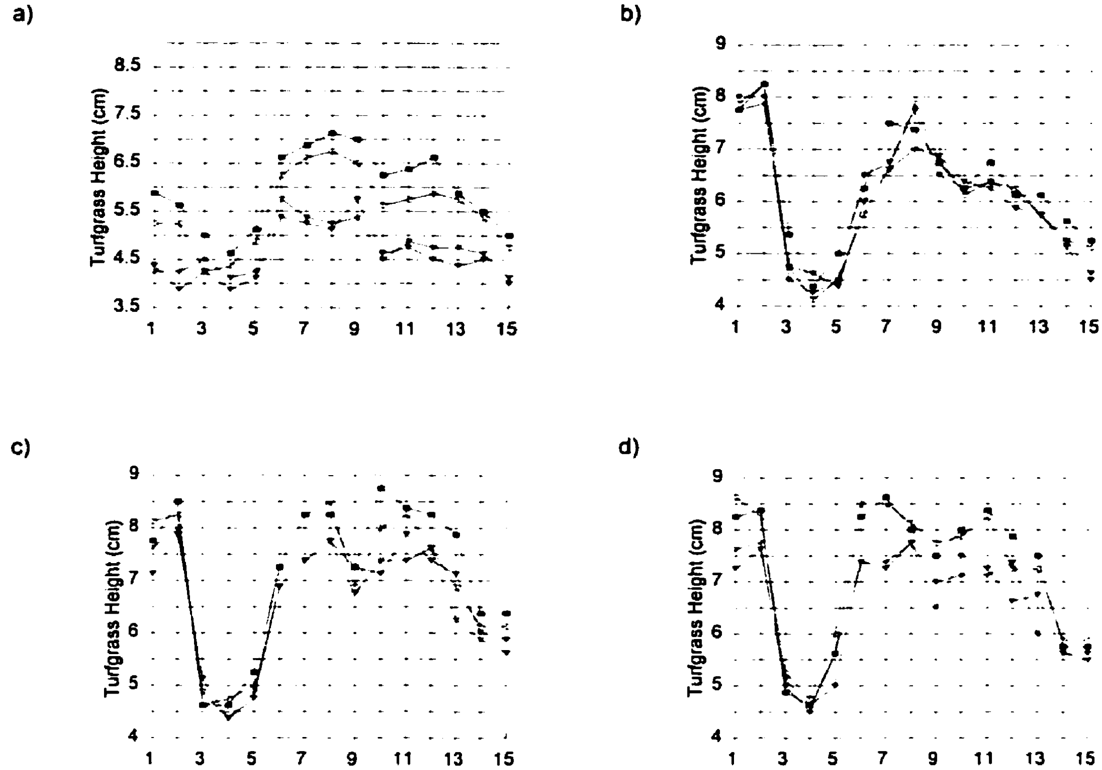


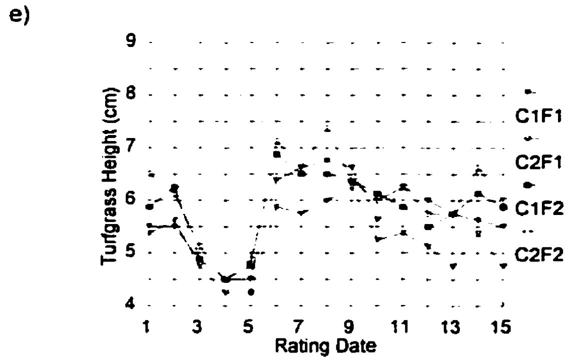


Rating Date	Actual Date
1 =	Aug.8/95
2 =	Aug. 15/95
3 =	Sept. 5/95
4 =	Sept. 13/95
5 =	Sept. 29/95

Figure 4.11: Mean turfgrass colour for mixtures six to ten, for five sampling dates in the 1995 growing season. (a) Mean turfgrass colour for mixture six. (b) Mean turfgrass colo for mixture seven. (c) Mean turfgrass colour for mixture eight. (d) Mean turfgrass colour mixture nine. (e) Mean turfgrass colour for mixture ten.

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; C2F2 = grasscycling and high fertilizer rate).

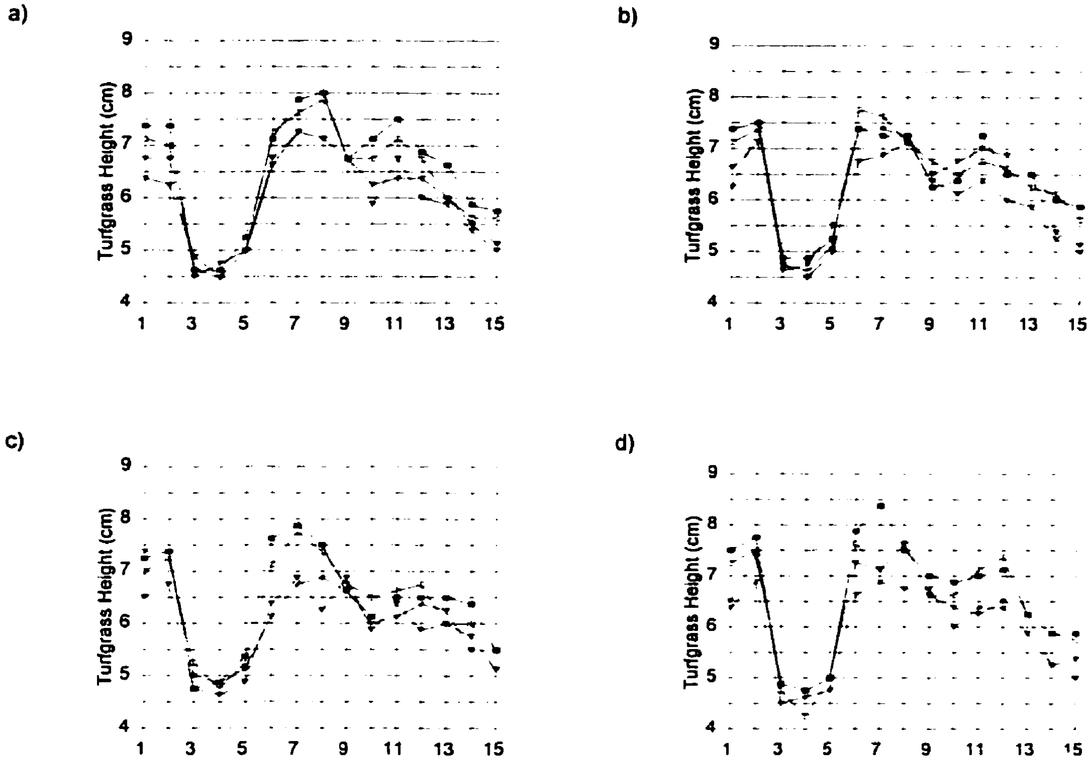


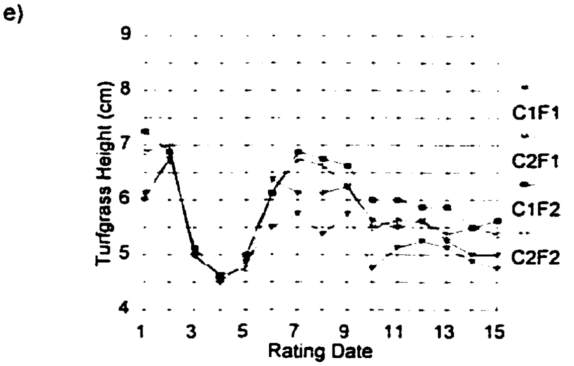


Rating Date	Actual Date
1 =	June 2/96
2 =	June 8/96
3 =	June 16/96
4 =	June 24/96
5 =	July 1/96
6 =	July 9/96
7 =	July 22/96
8 =	July 27/96
9 =	Aug. 5/96
10 =	Aug. 26/96
11 =	Sept. 2/96
12 =	Sept. 8/96
13 =	Sept. 14/96
14 =	Sept. 28/96
15 =	Oct. 10/96

Figure 4.12: Mean turfgrass height for mixtures one to five, for fifteen sampling dates in the 1996 growing season. (a) Mean turfgrass height for mixture one. (b) Mean turfgrass height for mixture two. (c) Mean turfgrass height for mixture three. (d) Mean turfgrass height for mixture four. (e) Mean turfgrass height for mixture five.

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).





Rating Date	Actual Date
1 =	June 2/96
2 =	June 8/96
3 =	June 16/96
4 =	June 24/96
5 =	July 1/96
6 =	July 9/96
7 =	July 22/96
8 =	July 27/96
9 =	Aug. 5/96
10 =	Aug. 26/96
11 =	Sept. 2/96
12 =	Sept. 8/96
13 =	Sept. 14/96
14 =	Sept. 28/96
15 =	Oct. 10/96

Figure 4.13: Mean turfgrass height for mixtures six to ten, for fifteen sampling dates in the 1996 growing season. (a) Mean turfgrass height for mixture six. (b) Mean turfgrass height for mixture seven. (c) Mean turfgrass height for mixture eight. (d) Mean turfgrass height for mixture nine. (e) Mean turfgrass height for mixture ten.

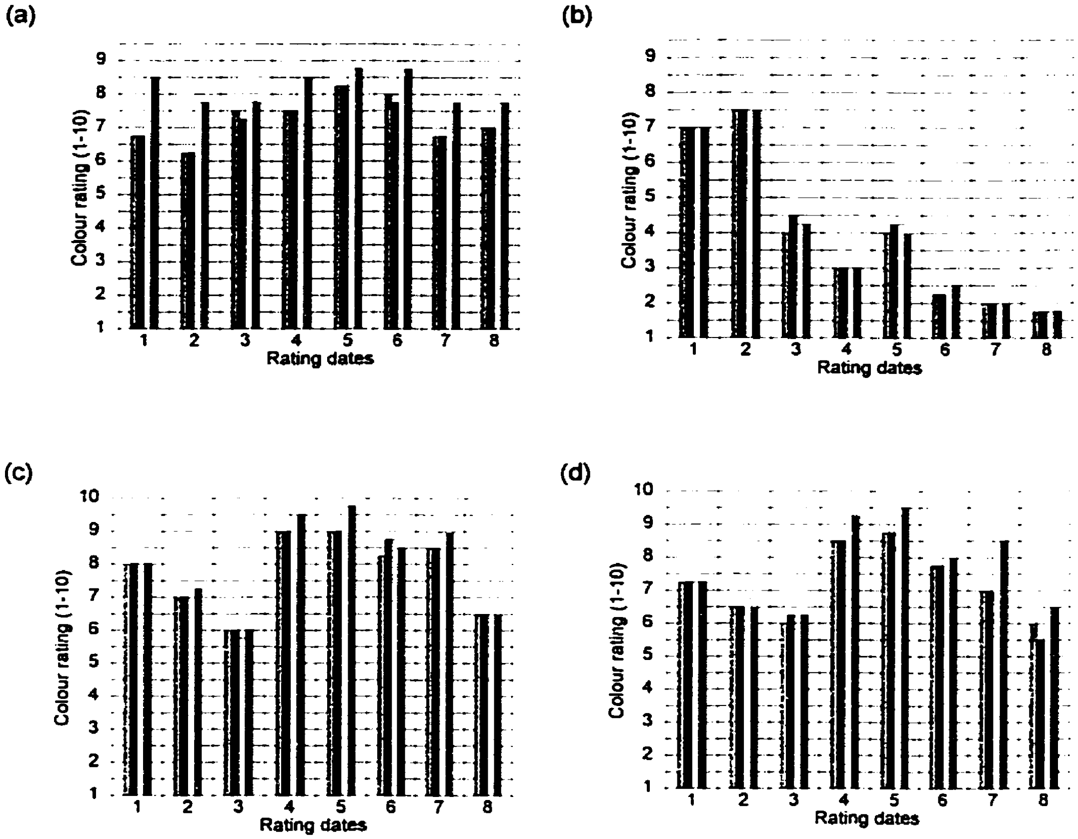
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

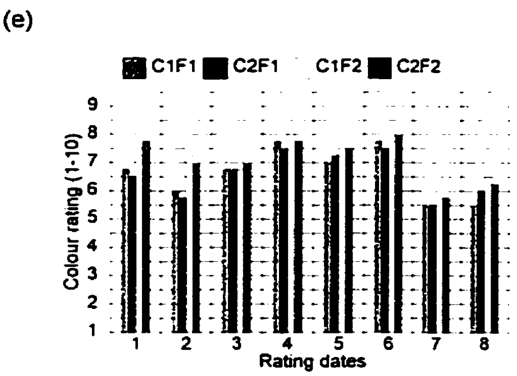
height for the ten mixtures in the 1996 growing season, regardless of fertilizer and clipping disposal regime, from tallest to shortest, was as follows: mixture four (6.87 cm) > mixture three (6.85 cm) > mixture seven (6.35 cm) > mixture nine (6.31 cm) > mixture six (6.35 cm) > mixture two (6.12 cm) > mixture eight (5.93 cm) > mixture five (5.73 cm) > mixture ten (5.68 cm) > mixture one (5.20 cm).

Turfgrass colour varied with mixture (Figure 4.14 and 4.15). Mixtures two, five and ten were the only three mixtures that had an unacceptable light green colour (ranked lower than 6) at any time during the growing season. Mixture two only had acceptable turfgrass colour on two sampling dates, June 2 and June 8. Mixture five only had unacceptable turfgrass colour on August 26. Mixture ten had acceptable colour on the first five of eight sampling dates. The average colour ratings for the 1996 growing season are as follows: mixture three (7.93) > mixture one (7.70) > mixture four (7.45) > mixture seven (7.34) > mixture six (7.31) > mixture nine (7.20) > mixture eight (7.00) > mixture five (6.86) > mixture ten (6.41) > mixture two (4.00). The overall trend, although not statistically tested, appeared to be that the turfgrass colour was ranked higher for the plots treated with the high fertilizer rate. Clipping disposal did not appear to make a difference in turfgrass colour.

4.1.3.4 Results of nitrogen data

1995 Percent Nitrogen in Clippings: Results of percent nitrogen will be presented separately for each of the three clipping dates, and summed together for the overall 1995 growing season results.

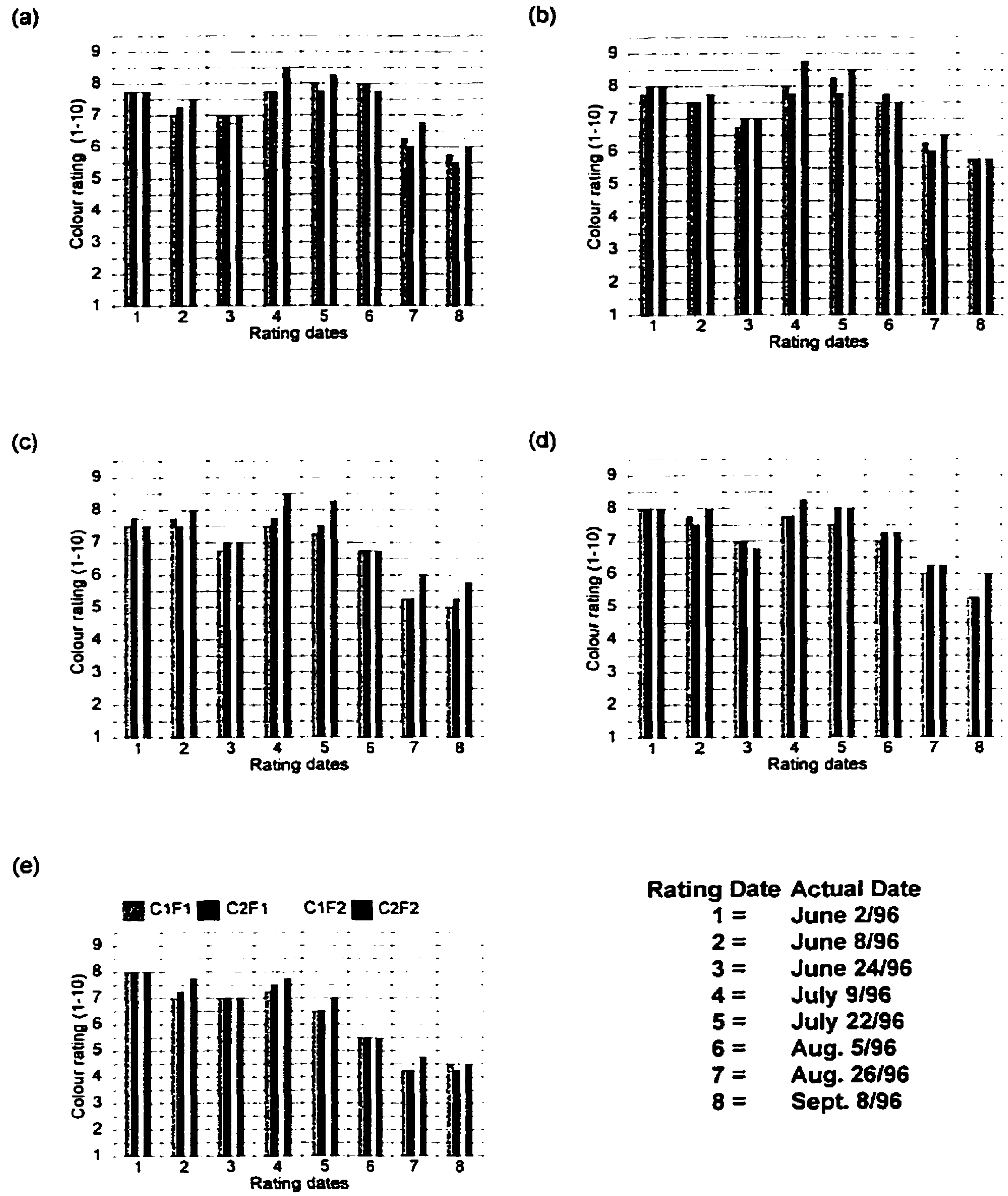




Rating Date	Actual Date
1 =	June 2/96
2 =	June 8/96
3 =	June 24/96
4 =	July 9/96
5 =	July 22/96
6 =	Aug. 5/96
7 =	Aug. 26/96
8 =	Sept. 8/96

Figure 4.14: Mean turfgrass colour for mixtures one to five, for the eight sampling dates i the 1996 growing season. (a) Mean turfgrass colour for mixture one. (b) Mean turfgrass colour for mixture two. (c) Mean turfgrass colour for mixture three. (d) Mean turfgrass co for mixture four. (e) Mean turfgrass colour for mixture five.

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).



Rating Date	Actual Date
1 =	June 2/96
2 =	June 8/96
3 =	June 24/96
4 =	July 9/96
5 =	July 22/96
6 =	Aug. 5/96
7 =	Aug. 26/96
8 =	Sept. 8/96

Figure 4.15: Mean turfgrass colour for mixtures six to ten, for the eight sampling dates in t 1996 growing season. (a) Mean turfgrass colour for mixture six. (b) Mean turfgrass colo for mixture seven. (c) Mean turfgrass colour for mixture eight. (d) Mean turfgrass colour f mixture nine. (e) Mean turfgrass colour for mixture ten.

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

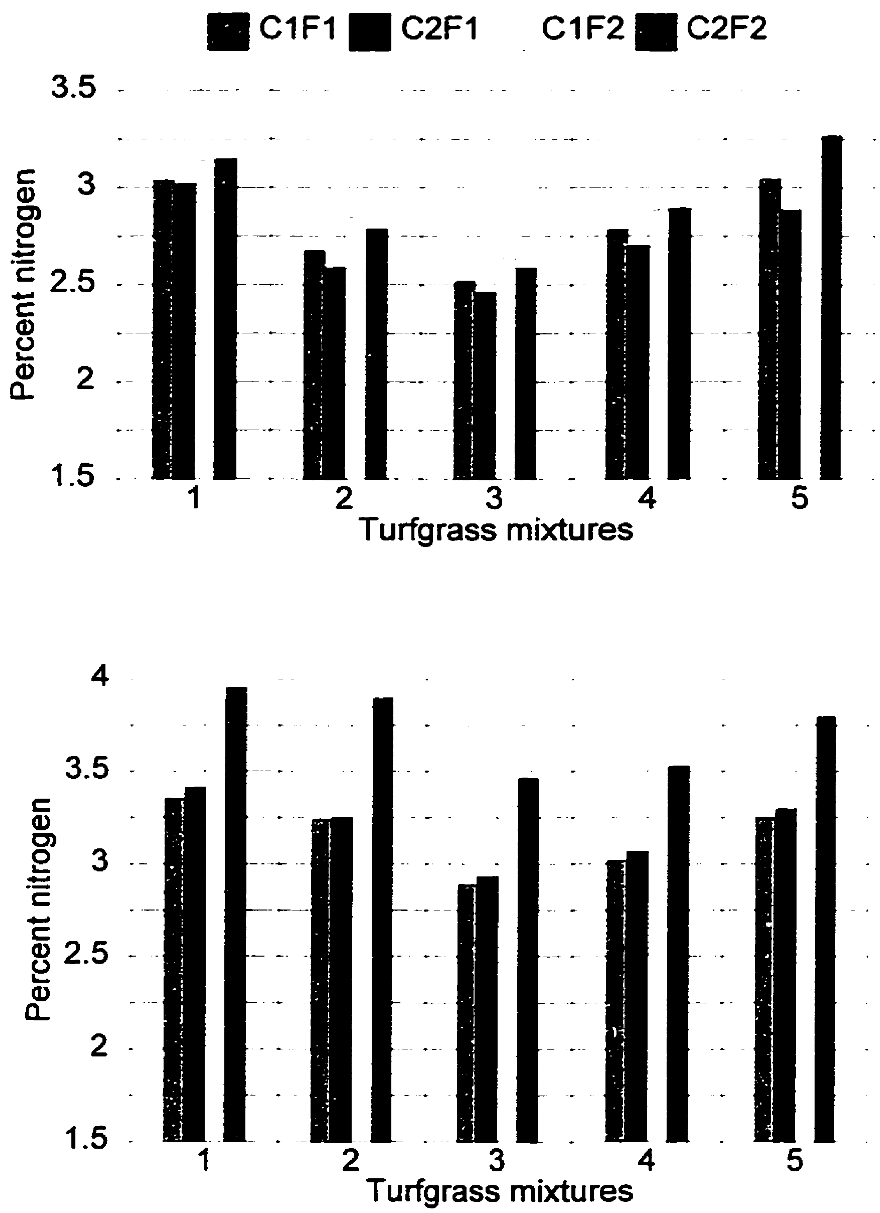
Clippings collected on August 16/95 showed significant differences in percent nitrogen between blocks, mixtures, and fertilizer rate (Figure 4.16a). The percent nitrogen in the clippings collected on August 16, 1995 were significantly different ($p<0.0001$) between blocks. On average clippings collected from block three contained the most nitrogen (2.98%). Clippings from blocks two, four and one contained 2.89%, 2.86% and 2.67% nitrogen, respectively. Average nitrogen of the clippings collected from the blocks were significantly different if the mean percent nitrogen differed by 0.10% or more.

Nitrogen content of the clippings were also significantly different ($p<0.0001$) between grass mixtures if they differed by at least 0.11%. On average, clippings from plots seeded with mixture five had the highest nitrogen content (3.09%), and clippings collected from plots seeded with mixture three contained the lowest nitrogen content (2.55%). The percent nitrogen in the clippings, ranked from highest to lowest was: mixture five (3.09%) = mixture one (3.09%) > mixture four (2.82%) > mixture two (2.72%) > mixture three (2.55%).

The fertilizer rate also resulted in a significant difference ($p<0.0001$) in percent nitrogen of clippings. Plots treated with the high fertilizer rate produced clippings with an average percent nitrogen content of 2.93%, plots treated with the low fertilizer rate produced clippings containing on average 2.77% nitrogen.

Clippings collected September 14/95 showed significant differences in percent nitrogen between blocks, mixtures, and fertilizer rate (Figure 4.16b). Percent nitrogen

(a)



(b)

Figure 4.16: Percent nitrogent content in clippings for five select turfgrass mixtures collected on (a) August 16, 1995 and (b) September 14, 1995.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

of clippings were significantly different ($p<0.0001$) between blocks. On average, clippings collected in block one contained 3.59% nitrogen, and clippings in blocks two, three and four contained 3.41%, 3.40% and 3.35% nitrogen, respectively. Percent nitrogen values were significantly different between blocks if they differed by at least 0.09 %.

Nitrogen content in clippings were also significantly different ($p<0.0001$) between mixtures. On average, clippings collected from plots seeded with mixture one contained the highest nitrogen content (3.65%), and clippings collected from plots seeded with mixture three contained the lowest nitrogen content (3.15%). The percent nitrogen in the clippings for mixture one (3.65%) > mixture two (3.56%) > mixture five (3.52%) > mixture four (3.31%) > mixture three (3.15%). Percent nitrogen values of were significantly different between mixtures if they differed by 0.10% or more.

Fertilizer rate also resulted in a significant difference ($p<0.0001$) in percent nitrogen in clippings. Plots treated with the high fertilizer rate produced clippings with an average percent nitrogen content of 3.70%, compared to 3.17% nitrogen content in plots treated with the low fertilizer rate.

Clippings collected October 9/95 were significantly different in percent nitrogen between blocks, mixtures, and fertilizer rate (Figure 4.17a). The content of nitrogen in the clippings showed significant differences ($p<0.0002$) between blocks if the nitrogen values differed by 0.09% or more. Clippings collected from block four (3.05%) > block three (3.01%) > block two (2.93%) > block one (2.85%).

(a)

(b)

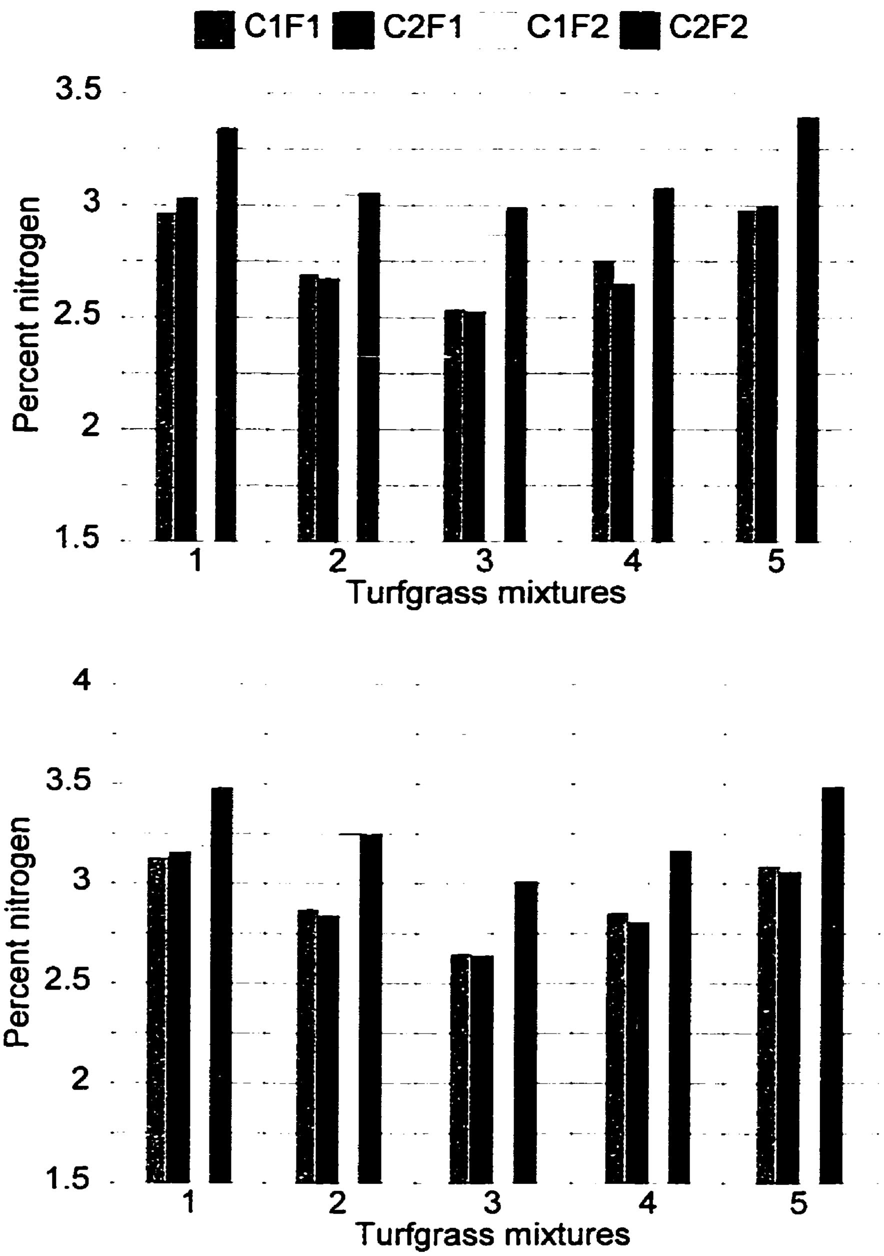


Figure 4.17: Percent nitrogent content in clippings for five select turfgrass mixtures collected on (a) October 9, 1995 and (b) Avg. of Aug., Sept., and Oct., 1995. (C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

Percent nitrogen content in the clippings showed significant differences ($p<0.0001$) between mixtures if the nitrogen values differed by at least 0.10%. Clippings collected from plots seeded with mixture five contained on average, 3.18% nitrogen, compared to plots seeded with mixture three where the clippings only contained on average, 2.73% nitrogen. The percent nitrogen in the clippings for mixture five (3.18%) > mixture one (3.16%) > mixture four (2.88%) > mixture two (2.87%) > mixture three (2.73%).

There was also a significant difference ($p<0.0001$) in percent nitrogen in clippings due to fertilizer rates. Plots treated with the high fertilizer rate produced clippings with an average percent nitrogen content of 3.15%, where as, plots treated with the low fertilizer rate produced clippings containing only 2.78% nitrogen.

When nitrogen contents from all dates in the 1995 growing season were pooled together for a total average percent nitrogen content, there were significant differences in percent nitrogen between mixtures and fertilizer rates (Figure 4.17b). There was a significant difference ($p<0.0001$) in percent nitrogen from clippings between mixtures if the nitrogen values differed by at least 0.14%. Clippings collected from plots seeded with mixture five had, on average, the highest nitrogen content (3.26%), and clippings collected from plots seeded with mixture three had, on average, the lowest nitrogen content (2.81%). The percent nitrogen in mixture five (3.26%) > mixture one (3.24%) > mixture two (3.05%) > mixture four (3.00%) > mixture three (2.81%).

Clippings collected in 1995 also had significantly different ($p<0.0001$) percent nitrogen between fertilizer rates. The clippings collected from the plots treated with the high fertilizer rate had, on average, 3.24% nitrogen, and clippings collected from the plots treated with the low fertilizer rate had, on average, 2.88% nitrogen.

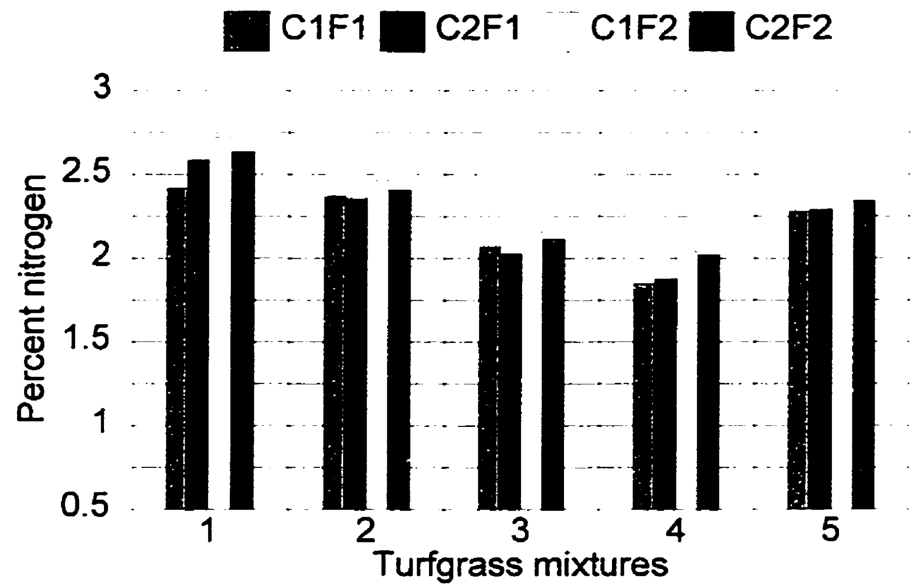
1996 percent nitrogen in clippings: Results of percent nitrogen for dried clippings collected in 1996 will be presented separately for each of the three clipping dates, and then summed together for an overall 1996 estimate.

Clippings collected June 8/96 were significantly different in percent nitrogen between mixtures and fertilizer rate (Figure 4.18a). Nitrogen content in clippings were significantly different ($p<0.0001$) between mixtures if they differed by 0.07% or more. Clippings collected from plots treated with mixture one contained the highest content of nitrogen, and clippings collected from plots seeded with mixture four contained the lowest content of nitrogen. The percent nitrogen in the clippings for mixture one (2.59%) > mixture two (2.40%) > mixture five (2.31%) > mixture three (2.09%) > mixture four (1.95%).

A significant difference ($p<0.0001$) was also found in clippings with different fertilizer rates. Plots treated with the high fertilizer rate produced clippings with an average percent nitrogen content of 2.32%, whereas plots treated with the low fertilizer rate produced clippings containing only 2.21% nitrogen.

Clippings collected on July 27/96 had a significant difference in percent

(a)



(b)

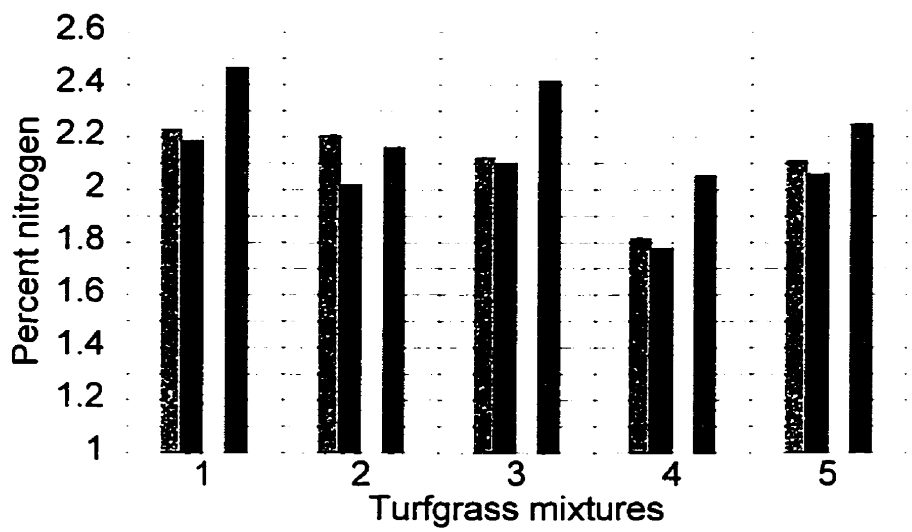


Figure 4.18: Percent nitrogent content in clippings for five select turfgrass mixtures collected on (a) June 8, 1996 and (b) July 27, 1996.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

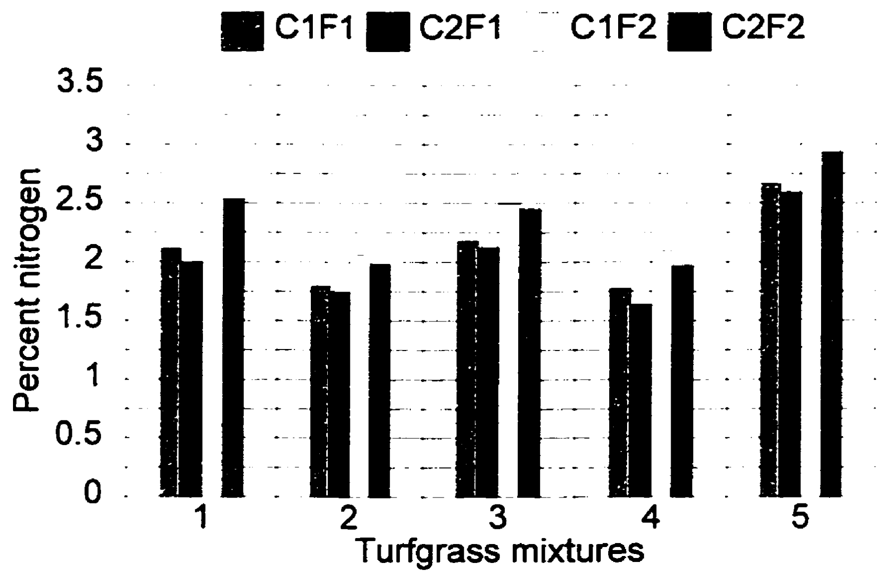
nitrogen between blocks, mixtures, and fertilizer rates (Figure 4.18b). Percent nitrogen of the clippings were significantly different ($p<0.0169$) if they differed by 0.16% or more. Ranking the percent nitrogen in the clippings, collected from the blocks, resulted in this trend: block one (2.27%) > block two (2.26%) > block three (2.09%) > block four (2.08%).

Percent nitrogen of the clippings collected showed significant differences ($p<0.0007$) between mixtures if they differed by at least 0.18%. On average clippings collected from plots seeded with mixture one contained the highest content of nitrogen, and clippings collected from plots seeded with mixture four contained the lowest content of nitrogen. The percent nitrogen in the clippings for mixture one (2.34%) > mixture three (2.28%) > mixture five (2.17%) > mixture two (2.13%) > mixture four (1.97%).

Fertilizer rate also resulted in a significant difference ($p<0.0001$) in percent nitrogen of clippings. Plots with high fertilizer rate produced clippings with an average percent nitrogen content of 2.29%, whereas, the plots treated with the low fertilizer rate produced clippings containing only 2.06% nitrogen.

Clippings collected on September 14/96 were significantly different in percent nitrogen between mixtures and fertilizer rate (Figure 4.19a). The content of nitrogen in the clippings showed significant differences ($p<0.0001$) between mixtures if they differed by 0.20% or more. On average, clippings collected from plots seeded with mixture five contained the highest content of nitrogen, and clippings collected from

(a)



(b)

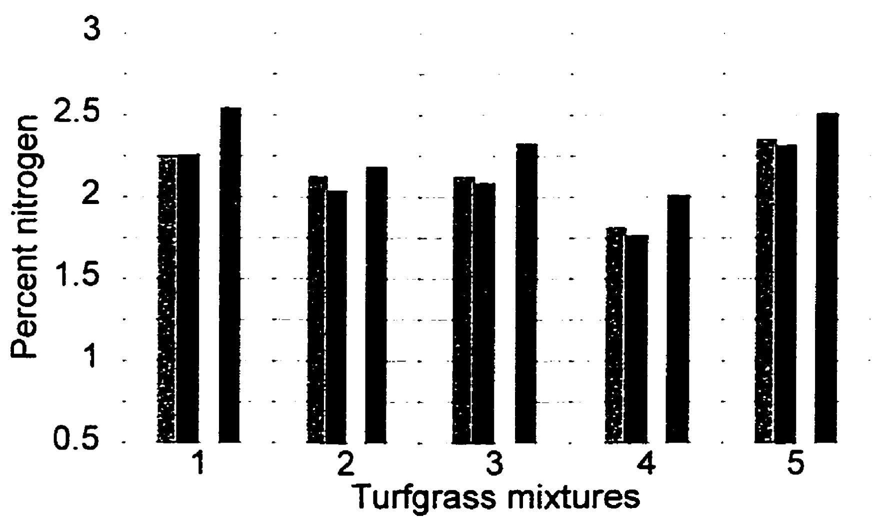


Figure 4.19: Percent nitrogent content in clippings for five select turfgrass mixtures collected on (a) September 14, 1996 and (b) Avg. June, July, and September, 1996

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

plots seeded with mixture four contained the lowest content of nitrogen. The percent nitrogen in the clippings for mixture five (2.80%) > mixture one (2.32%) > mixture three (2.31%) > mixture two (1.89%) > mixture four (1.87%).

Fertilizer rate also resulted in a significant difference ($p<0.0001$) in percent nitrogen in clippings. Clippings from plots treated with the high fertilizer rate had an average percent nitrogen content of 2.42%, whereas, plots treated with the low fertilizer rate produced clippings containing 2.06% nitrogen.

When data from all dates in 1996 were pooled, there were significant differences in percent nitrogen between mixtures and fertilizer (Figure 4.19b). There was a significant difference ($p<0.0001$) in percent nitrogen between mixtures when the difference in nitrogen values was 0.12% or more. Clippings collected from plots seeded with mixture one had, on average, the highest nitrogen content, and clippings collected from plots seeded with mixture four had, on average, the lowest nitrogen content. The percent nitrogen in mixture five (2.43%) > mixture one (2.42%) > mixture three (2.23%) > mixture two (2.14%) > mixture four (1.93%).

Clippings collected in 1996 also had significant differences ($p<0.0001$) in percent nitrogen between fertilizer rates. Clippings collected from the plots treated with the high fertilizer rate had, on average, 2.34% nitrogen, whereas, clippings collected from the plots treated with the low fertilizer rate had on average 2.11% nitrogen.

Summary of Clipping Nitrogen Content, 1995 and 1996: The combined average percent nitrogen for clippings from all six collection dates analyzed via the combustion method of nitrogen determination, three in 1995 and three in 1996, were significantly different in nitrogen content between mixtures and fertilizer rates (Figure 4.20). The average percent nitrogen over the six collection dates showed a significant difference ($p<0.0001$) between mixtures if they differed by 0.10% or more. In 1995 the clippings collected from plots seeded with mixture five contained the highest percent nitrogen, and clippings collected from plots seeded with mixture three, contained the least. In 1996, clippings from plots seeded with mixture one contained the highest percent nitrogen, and clippings from plots seeded with mixture four contained the least amount of nitrogen. Overall, clippings from 1995 and 1996 combined, had the highest content of nitrogen when collected from plots seeded with mixture five and the lowest content of nitrogen when collected from plots seeded with mixture four. The final ranking of percent nitrogen within the clippings collected in 1995 and 1996 showed that the percent nitrogen in mixture five (2.85%) > mixture one (2.83%) > mixture two (2.60%) > mixture three (2.52%) > mixture four (2.46%). There was also a significant difference ($p<0.0001$) in clipping nitrogen content between fertilizer rates, consistent with all of the dates the clippings were collected. The high fertilizer rate produced on average 2.79% nitrogen, the low fertilizer rate produced on average clippings with 2.51% nitrogen.

(a)

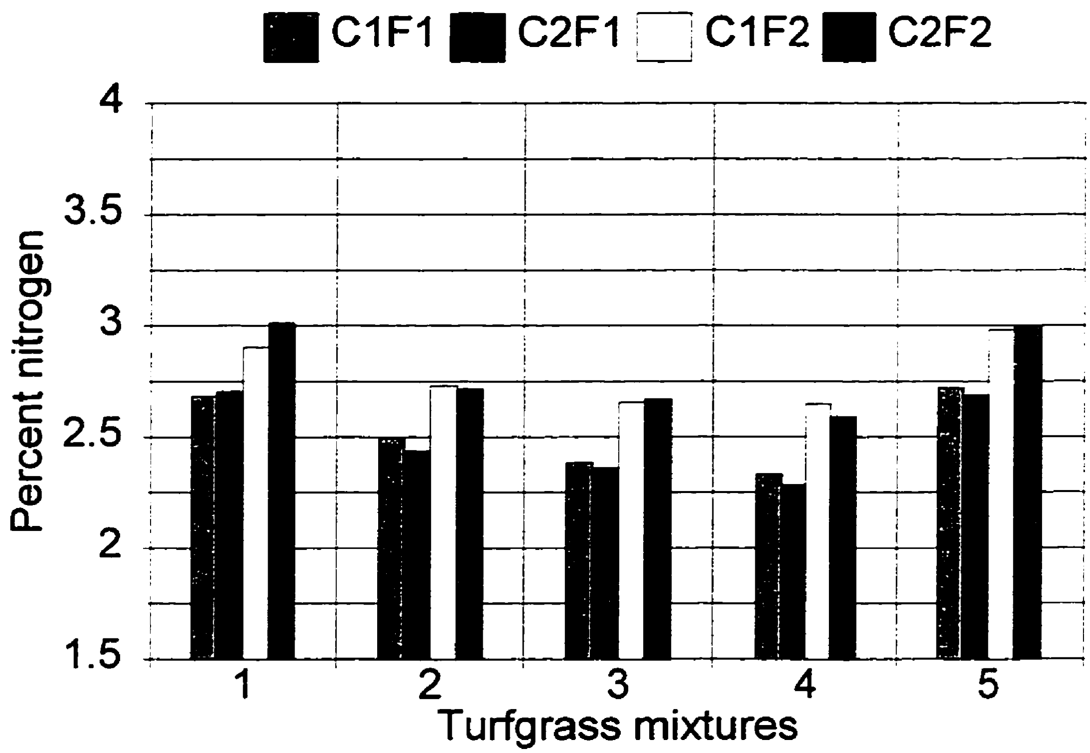


Figure 4.20: Percent nitrogent content in clippings for five select turfgrass mixtures
(a) Avg. of 1995 and 1996.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

4.1.3.5 Species composition and competition

The clipping disposal and fertilizer rate study contained ten different turfgrass mixtures. Five of the ten mixtures were monostands and five were polystands as described in Appendix A (Table A2). Percent cover of each of the mixtures was collected in the fall of 1995. The percent cover measured can be used as an indicator of the competitive abilities of each of the species, in the ten mixtures. The intraspecific competition and interspecific competition will be discussed for Kentucky bluegrass, Canada bluegrass, perennial ryegrass, and the fine fescues will be lumped together.

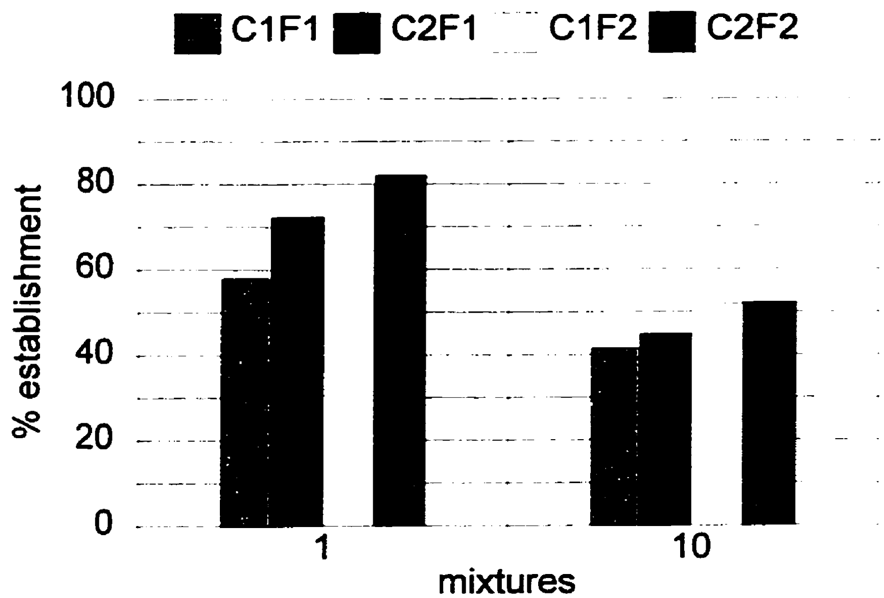
Intraspecific Competition: Intraspecific competition is the competition of the same species for the available resources.

Mixture one was seeded with 100% Kentucky bluegrass, the actual number of Kentucky bluegrass culms counted ranged from an average of 58% plot cover in the low fertilizer, clipping removal regime to 82% plot cover in the high fertilizer, grasscycling regime (Figure 4.21a).

Mixture two was seeded with 100% Canada bluegrass, the plot cover ranged from an average of 74% in the low fertilizer, clipping removal regime to 87% in the high fertilizer, clipping removal regime. The plot cover for the high fertilizer, grasscycling regime was, 84%, a 3% lower plot cover than the high fertilizer, clipping removal regime (Figure 4.21b).

Mixture three was seeded with 100% creeping red fescue, the average percent

(a)



(b)

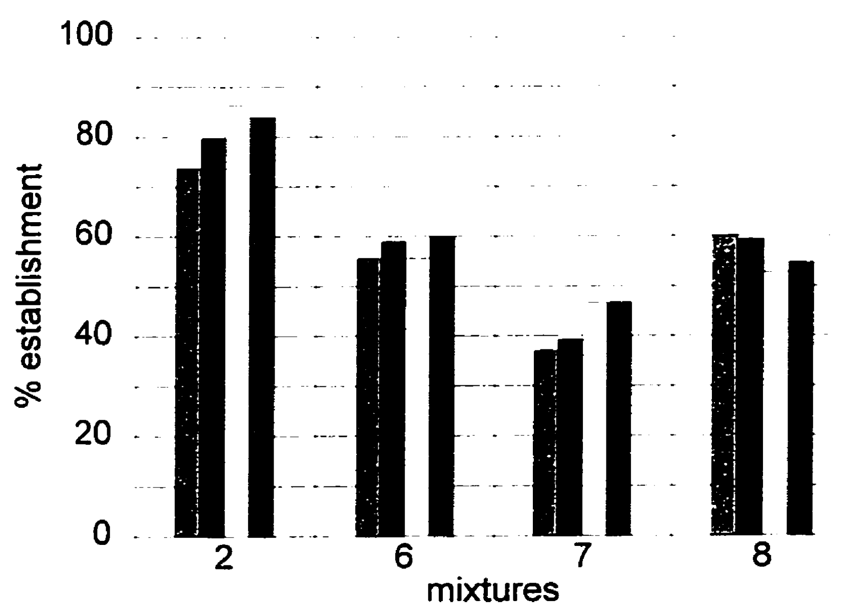


Figure 4.21: Fall 1995 establishment rate of turfgrass species seeded in 1995 (a) Kentucky bluegrass and (b) Canada bluegrass.
(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = Grasscycling and high fertilizer rate).

plot cover ranged from 68% for the low fertilizer, clipping removal regime to 80% for the high fertilizer, grasscycling regime (Figure 4.22a).

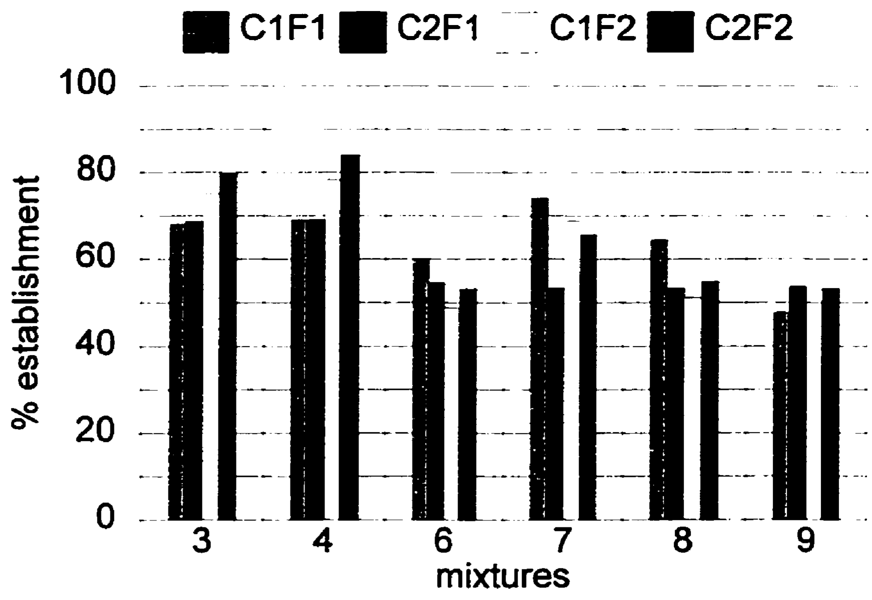
Mixture four was seeded with 100% sheeps fescue, the average percent plot cover value ranged from 69% for both of the low fertilizer rate plots, regardless of clipping disposal method, to 84% for the plots treated with the high fertilizer rate, grasscycling regime (Figure 4.22a).

Mixture five was seeded with 100% perennial ryegrass, the average percent plot cover ranged from 98% for both of the low fertilizer rate plots, regardless of clipping disposal method, and for the high fertilizer rate, clipping removal regime to 100% for the high fertilizer rate, grasscycling regime (Figure 4.22b).

Interspecific Competition: Interspecific competition is the competition between different species for the same available resources.

Mixture six was seeded with 30% Canada bluegrass, 30% creeping red fescue, 30% sheeps fescue, and 10% perennial ryegrass. The plot cover for each species varied depending on the clipping disposal and fertilizer rate regimes used. The average plot cover for Canada bluegrass ranged from 56% for both of the plots where the clipping removal treatment was imposed, regardless of fertilizer rate, to 60% for the plots treated with the high fertilizer rate and grasscycling (Figure 4.21b). The average plot cover for the fine fescues, ranged from a low of 49% for the plots treated with the high fertilizer rate and clipping removal to a high of 60% for the plots treated with the low fertilizer rate and clipping removal regime (Figure 4.22a). Perennial

(a)



(b)

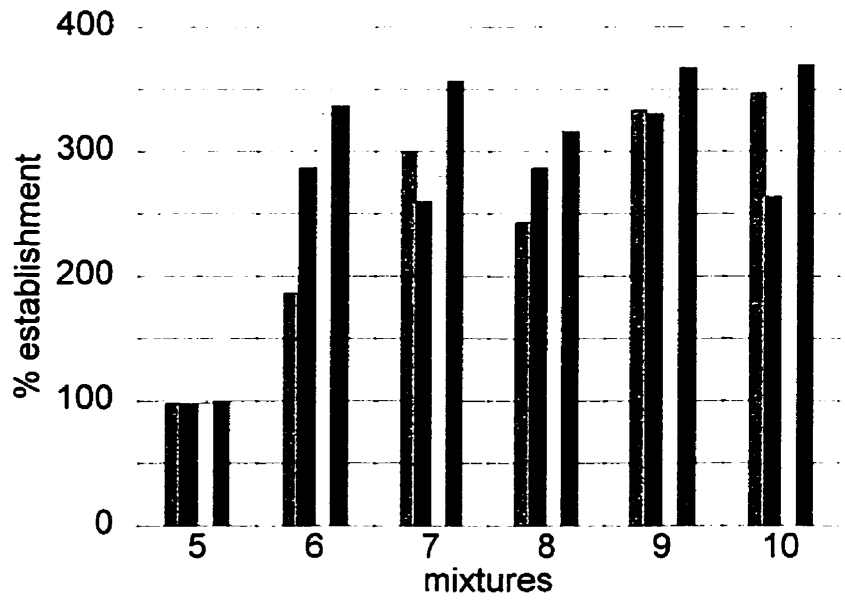


Figure 4.22: Fall 1995 establishment rate of turfgrass species seeded in 1995 (a) Fine fescues and (b) Perennial ryegrass.

(C1F1 = clipping removal and low fertilizer rate; C2F1 = grasscycling and low fertilizer rate; C1F2 = clipping removal and high fertilizer rate; and C2F2 = grasscycling and high fertilizer rate).

ryegrass had an average plot cover of 187% for the plots treated with the low fertilizer rate and clipping removal. Plots treated with the high fertilizer rate and grasscycling had an average perennial ryegrass plot cover of 337% (Figure 4.22b).

Mixture seven was seeded with 45% Canada bluegrass, 45% creeping red fescue, and 10% perennial ryegrass. The average plot cover for Canada bluegrass was only 38% for the low fertilizer rate and clipping removal regime, and as high as 47% for both of the high fertilizer rate plots, regardless of clipping disposal (Figure 4.21b). Creeping red fescue had an average plot cover ranging from 54% in the low fertilizer and grasscycling plots to 75% in the low fertilizer rate and clipping removal plots. The average plot cover values of creeping red fescue in the high fertilizer rate and grasscycling plots, and in the high fertilizer rate and clipping removal plots were 66% and 54%, respectively (Figure 4.22a). The average plot cover for perennial ryegrass ranged from 260% in the low fertilizer rate and grasscycling plots to a high of 357% in the high fertilizer rate and grasscycling plots (Figure 4.22b).

Mixture eight was seeded with 45% Canada bluegrass, 45% sheeps fescue, and 10% ryegrass. The average plot cover for Canada bluegrass was lowest, at 53%, in the plots treated with the high fertilizer rate and clipping removal, and highest, at 60%, for both of the plots imposed with the low fertilizer rate, regardless of clipping disposal (Figure 4.21b). The plot cover for sheeps fescue was lowest, on average, at 52% in the plots treated with the high fertilizer rate and clipping removal, and highest at 65% in plots treated with the low fertilizer rate and clipping removal (Figure 4.22a). Perennial ryegrass on average had a plot cover as low as 244% in the plots treated with the low fertilizer rate and clipping removal, to a high of 317% for both of the plots imposed with the high fertilizer rate, regardless of clipping disposal (Figure 4.22b).

Mixture nine was seeded with 45% creeping red fescue, 45% sheeps fescue and 10% perennial ryegrass. The fine fescues had, on average, a plot cover value as low as 48% for the plots treated with the low fertilizer and clipping removal, to a plot cover value of 54% for both of the plots imposed with the grasscycling regime, regardless of fertilizer rate (Figure 4.22a). The plot cover for perennial ryegrass on average was 330% in the plots treated with the low fertilizer rate and grasscycling regime, and 367% in the plots treated with the high fertilizer and grasscycling (Figure 4.22b).

Mixture ten was seeded with 90% Kentucky bluegrass, and 10% perennial ryegrass. The Kentucky bluegrass on average had the lowest plot cover, of 42% in the plots treated with the low fertilizer and clipping removal, and had the highest plot cover of 53% in plots treated with the high fertilizer rate and grasscycling (Figure 4.21a). Perennial ryegrass had, on average, a low plot cover of 264% in the plots treated with the low fertilizer rate and grasscycling, and a high plot cover of 370% in the plots treated with the high fertilizer rate and grasscycling (Figure 4.22b).

By comparing what the plot cover for a monostand of a particular species was to the plot cover of the same species in a mixture, one can determine the interspecific competitive ability of that species.

On average, plots seeded with mixture one, had a plot cover of 73%. When Kentucky bluegrass was seeded with perennial ryegrass, such as that seen in the composition of mixture ten, the plot cover of Kentucky bluegrass declined to 48%. Mixture two, had an average plot cover of 81%, but when Canada bluegrass was seeded in a mixture the plot cover declined. This trend can be seen in mixture six, seven and eight where the plot cover for Canada bluegrass was only 58%, 42%, and 57% respectively. Mixture three had an average plot cover of 73%. The plot cover of creeping red fescue declined to an average of 66% in mixture seven. The plot cover for mixture four was, on average, 75%. In mixture eight the plot cover of sheeps fescue was only 56%. Mixture five, on average, had a plot cover of 98%. In mixtures six to ten perennial ryegrass out competed all other species, and had a plot cover ranging from 285% to 343%.

4.2 Discussion of the Clipping Disposal and Fertilizer Rate Study

4.2.1 Weather conditions

Turfgrass growth is extremely sensitive to temperature. Temperature primarily influences enzyme activity in grass. Cool-season turfgrasses grow best at temperatures between 15 to 24^{0}C (Beard, 1973), they go dormant during the hot summer heat and resist freezing stress in the cold winter months by cell dehydration (Levitt, 1980). Freezing stress occurs when temperatures are below 0^{0}C. Cool-season grasses are known to have optimal root growth at soil temperatures between 10 to 18^{0}C (Beard, 1973), and optimal shoot growth at air temperatures of 15^{0}C to 24^{0}C. Photosynthetic rates are also affected by temperature. In most plants the photosynthetic rate is directly related to temperature it increases from a minimum at 10^{0}C up to a maximum at 30^{0}C (Leopold & Kriedemann, 1975).

The parameters that did correlate well with temperature changes include clipping yield trends for both 1995 and 1996; height values in 1995 and 1996 (especially June/96); and colour values for mixture two in 1995 and 1996.

Clipping Yield: Clipping weights were low on August 16 (Figure 4.3a), they increased on September 14 (Figure 4.3b), and then declined again on October 9/95 (Figure 4.4a). The low clipping weights on August 16/95 can be explained by the temperatures (Appendix D, Table D1). The air temperature was above the range for optimum root and shoot growth for August 16/95, and had been since late June 1995. This created sub-optimal growth conditions which lowered clipping yield. A decrease in air and soil temperatures, to within the optimal range for shoot and root growth, in late August, early September resulted in an increase in clipping yield for September 14/95. The average clipping yield for October 9/95 was 6.24 g/m^2. This decline in the weight of clippings collected correlates with the drop in air and soil temperatures below the optimum for photosynthesis.

In 1996 clipping yields were high in June/96, with an average weight of 30.40 g/m^2 (Figure 4.5a). This high clipping yield corresponds well with the temperatures for optimum root and shoot growth which were prevalent from May/96 until the end of May/96 (Appendix D, Table D1), and the large amounts of reproductive culms being produced. The average clipping yield in July decreased to 6.91 g/m^2 (Figure 4.5b). This decrease in clipping yield corresponds with temperatures above the range for optimal root and shoot growth. Average clipping yields for September 1996 increased to 13.91 g/m^2 (Figure 4.6a). This increase in clipping yield corresponds with a reduction in temperature which once again was within the optimal range for root and shoot growth. Clipping yields for October/96 increased to an average of 31.40 g/m^2 (Figure 4.6b). The clipping yield increase correlates with the optimal growing conditions, there was plenty of precipitation, and the second fertilizer treatment applied September 9/96, provided additional nitrogen to the turfgrass system.

Heights: Height measurements were used to determine shoot growth. Height measurements declined from July 25/95 to August 15/95 (Figure 4.8 & 4.9) when air and soil temperatures were above optimal (Appendix D, Table D1). Heights began to increase from August 15/95 until September 13/95, which correlates well with the decrease in temperature to optimal. Turfgrass height declines again from September 13/95 until September 23/95. This decline correlates with a number of factors including a decline in the mean air temperature below 10^{0}C (Leopold & Kriedemann, 1975), the maximum air temperature between September 17/95 and September 21/95 falls below the optimal temperature, and the first frost was September 21/95. Between September 23/95 and September 29/95 there appears to be a slight increase in turfgrass height. This height increase corresponds with an increase in the maximum air temperature from September 22/95 until September 28/95, once again, falling within the range for optimum shoot growth. The height increase was also likely influenced by an elevation in soil temperatures from September 23/95 until October 2/95 when the temperatures was within the range for optimal root growth.

One of the most obvious trends in the height data occurs between June 8/96 and June 24/96, when all of the mixtures show a decline in height (Figures 4.13 & 4.12). This height decline correlates well with the low precipitation in June 1996. The month of June 1996 only received 18% of the long term average (Appendix D, Table D2).

Colour: Turfgrass colour in 1995 and 1996 appeared to be unaffected by climatic conditions for all mixtures (Figures 4.10, 4.11, 4.14 & 4.15).

4.2.2 Soil parameters

The soil parameters measured in the clipping disposal and fertilizer rate study include bulk density, nutrients, pH, salinity, and soil organic matter. Measurements for these parameters were taken in both the 1995 and 1996 growing seasons.

Bulk Density: Bulk density is used to determine the amount of soil compaction and, in turn, the suitability of soil for plant growth. Bulk density values are affected by size and quantity of pore spaces, consequently, soils with large quantities of clays and silts, highly porous soils, will have lower bulk densities compared to more compact soils which have high quantities of sand (Plaster, 1997). Bulk densities range from 1.0 Mg/m^3 to 1.6 Mg/m^3 for clays, 1.2 Mg/m^3 to 1.8 Mg/m^3 for loams and sands (Brady, 1990). Highly compacted soils can have bulk densities as high as 2 Mg/m^3, compared to well aggregated soils that have bulk densities as low as 1 Mg/m^3. Soil from the clipping disposal and fertilizer rate study had an average bulk density of 1.09 mg/m^3. According to Brady's (1990) bulk density values, this soil was a clay with very little compaction, therefore, the soil was suitable for plant growth. The particle size analysis, completed by Norwest Labs, supports this finding. Norwest Labs found that the soil type of the clipping disposal and fertilizer rate study was a clay (Table 4.4).

Soil Nutrient Analysis: Soil samples collected from the clipping disposal and fertilizer rate study plot were deficient in available nitrogen (44 lbs. of nitrogen/acre (Table 4.1)), the recommended nitrogen application for turfgrass establishment was 139 lbs. of nitrogen/acre (Norwest Labs, 1995). .

In 1996, the soil samples collected from mixture ten had different nitrogen concentrations for each of the four different treatments (C1F1, C2F1, C1F2, C2F2). The soil samples indicate that when grasscycling (C2) was imposed, nitrogen concentrations in the soil increased. The nitrogen level in the plots treated with grasscycling and low fertilizer rate (C2F1) had 60 lbs. of available nitrogen/acre, 16 lbs. of available nitrogen/acre more than the plots treated with the clipping removal and low fertilizer rate (C1F1). Starr & Deroo's (1981) research, on the effects of grasscycling in a cool-season grass mixture over a four year period, found a 45% increase in soil nitrogen in plots where the clippings were returned, compared to soil in plots where the clippings were removed which supports the findings of this study. They also found that in plots where the clippings were returned there was four grams more soil nitrogen available per square metre compared to plots where the clippings were removed.

pH of the Soil: The soil pH in 1995, of 7.5 (Table 4.1), likely favoured Kentucky bluegrass and perennial ryegrass. which prefer pH values between 6.0-7.0. At this pH Canada bluegrass, creeping red fescue, and sheeps fescue, were not grown under optimal pH conditions. Beard (1973) found the optimal pH's for the growth and competitive abilities of these grasses to be 5.5-6.5, 5.55-6.5, and 4.5-6.5, respectively. In 1996 the pH of the soil collected from the clipping disposal and fertilizer rate study, was, on average, 7.5 (Table 4.2), the same as the soil pH in 1995. Once again the soil pH favours Kentucky bluegrass and perennial ryegrass growth.

Salinity of the Soil: Salinity was measured because high levels of salts in soil can reduce the ability of turfgrass roots to absorb water and may actually be toxic to grasses. Just like pH some turfgrass species can tolerate higher salinity levels than other grasses. Soil collected in 1995, prior to seeding, from the clipping disposal and fertilizer rate study was not saline (Table 4.1). In 1996, one plot was slightly saline (2.1 dS/m (Table 4.2)). This was the plot treated with the high fertilizer and grasscycling. The average EC for the study plot was 0.6 in 1995 and in 1996 the C1F1, C1F2, and C2F1 had ECs of 0.6, 0.8, and 0.8, respectively, therefore it appears the combination of the high fertilizer rate and grasscycling contributed to the observed high electrical conductivity value. This EC value was within the tolerance range of all the turfgrass species included in this study, and likely did not significantly affect the turfgrass growth.

Soil Organic Matter (1996): Plots treated with the combination of clipping removal and low fertilizer rate (C1F1) contained 0.07% organic matter, which was approximately 1% of the soil organic matter found in the other three clipping disposal and fertilizer rate combinations (Table 4.3). The low organic matter in this plot was because clippings were not being returned to the soil. Plots treated with low fertilizer rate and grasscycling (C2F1) contained 7.12% soil organic matter, implying that grasscycling increased the organic matter in the plots, by returning the clippings to the turfgrass system.

Soil Carbon/Nitrogen ratio (1996): The carbon/nitrogen (C/N) ratio is indicative of the amount of organic matter in the soil (Brady, 1990). The low C/N ratio of plots treated with clipping removal and low fertilizer (C1F1) support this hypothesis (Table 4.3). The C:N ratio of the C1F1 plots was 0.31 (1:3). This is approximately two orders of magnitude lower than the C/N ratios of the other three treatment combinations (C1F2, C2F1, C2F2) which averaged 12.77 ± 1.03. This means C1F2, C2F1, and C2F2 all had greater soil organic matter than C1F1.

4.2.3 Turfgrass mixtures

Five cool-season turfgrass species, Kentucky bluegrass, Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass were examined, both in monostands and polystands, with a total of ten mixtures. See Appendix A, Table A2, for the exact composition of the mixtures. This study evaluated the following parameters: clipping weight; turfgrass height; colour and plot cover; and turfgrass selection qualities, that should be considered when choosing an appropriate turfgrass mixture.

Clipping Yield: Clipping yield weights were collected to determine the response of the ten mixtures to nutritional and environmental factors applied to the test plots. Significant differences ($p<0.05$) were found in clipping yield measures between the ten mixtures used in the clipping disposal and fertilizer rate study. In the 1995 growing season, the establishment year, mixture five consistently produced the highest dry weight yield and mixture one consistently produced the lowest dry weight yield. During 1996, mixture three and four, both monostands of fine fescues, produced the two highest dry weight yields. Mixture one, once again, produced the lowest dry weight yield, and mixture five produced the second lowest dry weight yield. Mixture four was second lowest in total dry weight yield in 1995, and mixture three was third highest in 1995.

The high clipping yield of mixture five, a monostand of perennial ryegrass, during the 1995 growing season can be explained by its fast establishment rate, good plot cover, and vigourous seedling growth. Perennial ryegrass was the first species to emerge after seeding in 1995 and also had the highest plot cover of the five cool-season grass species used in the study. Perennial ryegrass is known to have a high germination rate, good seedling vigour (Chippendale, 1932), and therefore high establishment rate and plot cover. Once established perennial ryegrass tillers rapidly (Blaser et al., 1956b) which leads to a high culm density. Rogler & Haas' (1947) research findings concluded that clipping yield was highly dependent on plant density. Therefore, due to the high density of perennial ryegrass, clipping yield was correspondingly high. This theory is supported by looking at the plot cover results for mixture five. Mixture five had the highest plot cover, compared to the other nine mixtures. For low fertilizer plots the cover was 98% and for high fertilizer plots the cover was 100% for mixture five.

In 1996 the clipping yield of perennial ryegrass was the second lowest. This reduction in clipping yield was likely due to poor winter hardiness, one of the characteristics of perennial ryegrass. There were 18 days in late January and early February where the minimum temperature was below -30°C (Appendix D, Table D2). Out of the five perennial cool-season turfgrasses used in this study, perennial ryegrass has the lowest winter hardiness (Van Dersal, 1936; Gusta et al., 1980).

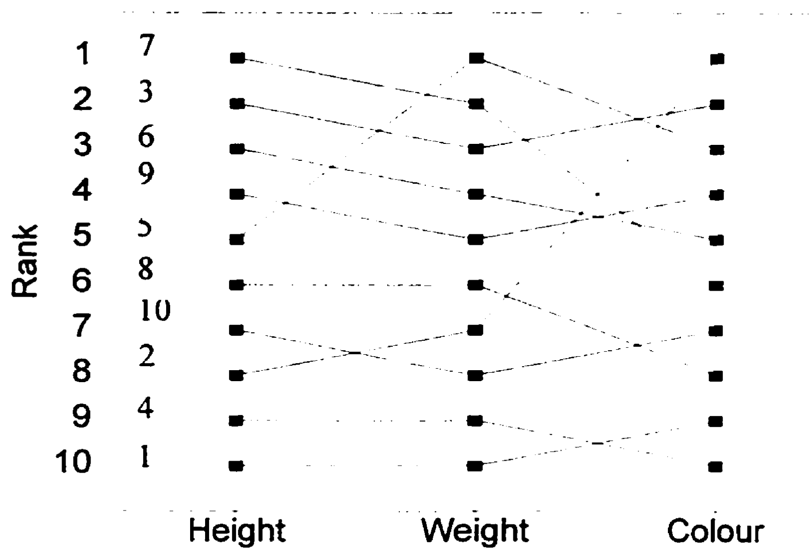
Mixture one, a monostand of Kentucky bluegrass, had the lowest clipping yield for both study years. This may be in part due to the fact that Kentucky bluegrasses are slow to germinate and have low seedling vigour (Blaser et al., 1956a), which resulted in very little above-ground growth being produced in the first few years of establishment.

Adams et al. (1974) found that compared to perennial ryegrass, Kentucky bluegrass required more nitrogen for the same amount of top growth produced. Available soil nitrogen may have been limiting for Kentucky bluegrass, and since all mixtures had the same amount of fertilizer treatments applied, this is one possible explanation for the reduced growth of Kentucky bluegrass. Another explanation could be that Kentucky bluegrass was transporting a lot of its energy, obtained from photosynthesis, into rhizome growth to establish its extensive rhizome system (Hunt & Dunn, 1993). Blaser et al. (1956a) made comparisons between seven week old ryegrass and Kentucky bluegrass seedlings and found the ryegrass seedlings produced more than 30 times more above-ground dry weight. Therefore, the light clipping yield of Kentucky bluegrass was likely a combination of its slow establishment rate and high nitrogen requirement.

Height: Another desirable low maintenance characteristic of turfgrass is a slow growing shoot. Shorter grass requires less frequent mowings and therefore cost savings in terms of time, money, and man-power, ultimately reducing yard waste. Differences in height between mixtures were measurable and visually apparent.

There were some obvious trends between height measurements and dry weight yield. To better visualize these trends, height and dry weight yield were ranked from highest (ranking one) to lowest (ranking 10), for each of the ten mixtures (Figure 4.23 (a) and (b)). In 1995 average grass height and average dry weight clipping yield appear to be directly related, with the exception of mixture five (Figure 4.23 a). Simply stated, the taller the grass was, the heavier the clipping weights. The exception, mixture five produced the heaviest dry weight yield, but it had intermediate height measurements. This trend was likely due to mixture five being a monostand of perennial ryegrass, and as discussed earlier, it has a denser growth pattern than the other mixtures. Average grass height and the average dry weight clipping yield also appear to be directly related in the 1996 growing season (Figure 4.23b). The trend was not as pronounced in 1996, but a trend was still present. In 1996 one mixture that did not conform to this trend was mixture two. Mixture two was ranked sixth in height, but was ranked third in clipping yield. The most obvious explanation for this high yield ranking was the abnormally high dry weight yield collected on June 8/96. The dry weight yield clipping yield for mixture two was 22.24 g heavier than the

(a)



(b)

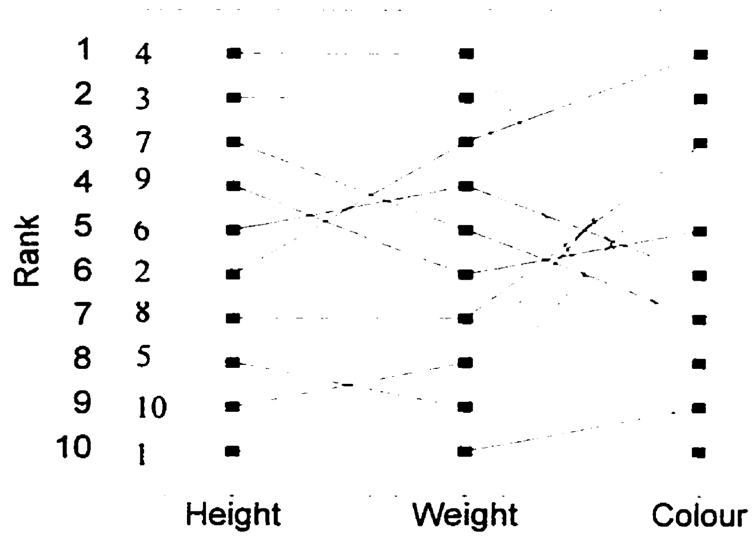


Figure 4.23: Comparison of height, dry weight, and colour ratings for each of the ten mixtures
(a) Overall rating for mixtures one to ten in the 1995 growing season.
(b) Overall rating results for mixtures one to ten in the 1996 growing season.
(The numbers within the graph pane, on the left hand side indicate the ten mixtures, they are rated from 1 (least desirable (tallest, heaviest, or lightest green)) to ten (most desriable (shortest, lightest, or darkest green))).

average dry weight yield of 28.18 g for the other nine mixtures on that date. Mixture two had a high clipping yield on this date due to uniform heading of Canada bluegrass at this time. Clippings collected on this date for mixture two skewed the results. If, however, you reduced the weight of mixture two from 50.42 g for the June 8/96 collection date to 28.18 g, the total dry weight yield for the 1996 growing season would be 76.36 g. This would rank mixture two seventh heaviest, and closer to the corresponding height ranking of sixth tallest.

The considerable differences between the heights collected from 1996 compared to those collected in 1995, emphases the importance of a second field season to measure some of the turfgrass characteristics and responses to the management regimes. Mixture four had the largest height difference between the 1995 and 1996 growing seasons. In 1995 the average height for mixture four in the growing season was 5.77 cm, and in 1996 it was 6.87 cm, an increase in average height of over 1 cm. Mixture four was a monostand of creeping red fescue, the reason for the increase in average height is because it was better established in the second growing season and the growing conditions were optimal. Creeping red fescue requires low amounts of supplemental water and nitrogen, its nitrogen requirements are 0.2 to 0.5 lb per 1000 sq ft per growing month, which is quite low compared to most cool-season turfgrass species (Beard, 1973).

Colour: Turfgrass colour was rated a number of times throughout the two growing seasons. Colour ratings were assessed to ensure the aesthetic quality was taken into consideration when making final recommendations, because clipping yields do not measure the aesthetic quality of grass, they only measure the effect nutritional and environmental factors, such as fertilizer rates, have on the grasses (Beard, 1973).

There were some obvious trends when comparing the colour values to the dry weight yield data. To better visualize these trends, colour and dry weight yield were ranked from highest (ranking one) to lowest (ranking 10), for each of the ten mixtures (Figure 4.23 (a) and (b)). During the 1995 growing season there appears to be an indirect relationship between colour and dry weight yield. Mixtures one and four are ranked lowest and second lowest, respectively, in height and dry weight, however, the colour for mixture one was ranked second highest, and highest for mixture four. The slower growing turfgrass mixtures two and four used less nutrients for growth, and had less damage due to clipping removal, therefore, these two mixtures were less stressed allowing for the darker green. This trend was seen in reverse for both mixtures five and six. Mixture five was ranked heaviest and mixture six was ranked third heaviest in dry weight yield, but the colour rankings are third lowest and second lowest respectively. In terms of low maintenance this is very interesting since the shortest and lowest yielding turfgrasses in 1995, mixtures one and four, are the ones with the greenest colour. This combination is ideal for choosing low maintenance grasses.

All mixtures received the same fertilizer rate treatments, yet mixture one and two produced low clipping yields and the clippings had relatively high nitrogen concentrations. This suggests that because both mixtures one and two had low growth rates and high nitrogen content, compared to the other mixtures in the study, that these two mixtures were not using as much nitrogen for above-ground growth, and therefore, less nitrogen was being removed when the grass was mowed allowing for an increase of nitrogen in the grass tissues in mixtures one and two in 1995. This trend can also seen for mixtures one and five in 1996.

One explanation for the dark green colour in the low growing and yielding turfgrass mixtures may be due to the slow germination of both fescues and Kentucky bluegrass (Beard, 1973) when compared to perennial ryegrass. Since only four of the ten mixtures seeded in the clipping disposal and fertilizer rate study lacked a perennial ryegrass component, and two of these mixtures were mixture one and mixture four, a slow germination rate is plausible. By having a slow germination and growth rate the grasses could have accumulated nitrogen in the tissues due to lack of nitrogen needed for growth. This is supported for mixture one in the *nitrogen content in the clippings* section.

Colour, height and dry weight yields were more directly related in 1996, with the two exceptions of mixtures one and two (Figure 4.23b). Mixture one was once again ranked lowest in height and dry weight yield, yet maintained a colour ranking of second. The high colour ratings for mixture one have already been discussed.

Mixture two was intermediate in height, third highest in weight, yet was ranked the lowest for desirable colour. One possible reason for the poor colour rating, and possibly high dry weight yield for the June 8/96 collection date, has to do with the temperature dependent growth rate of Canada bluegrass. Canada bluegrass is a cool-season grass and has suppressed growth during the summer months and increases production in the fall and spring when the temperature is cooler. Because Canada bluegrass grows better at a height of 7.6-10 cm (Beard, 1973), and has a low temperature tolerance, it makes a good rights-of-way turf, but it is undesirable for use in home lawns or high maintenance parks.

The colour of mixture eight was dark green all summer and late into the fall for the 1995 growing season, but in the 1996 growing season, the turf colour was unacceptable (ranking <6) in the fall sample dates.

Nitrogen Content in the Clippings: An interesting trend in the data shows an inverse relationship between height and percent nitrogen content in the leaves. For the 1995 growing season, as the grass height increases, the percent nitrogen decreases, with the exception of mixture five. This trend was not as obvious in 1996. One explanation for the inverse relationship of grass height and nitrogen content was that leaf growth and mowing results in nitrogen loss from the plant. Since mowing induces leaf growth (Salisbury & Ross, 1985), the taller grasses which have more leaf tissue removed during mowing would have greater nitrogen loss than the shorter grasses. Hull (1992) supports this theory by stating that nitrogen content on a leaf area basis is higher when available nitrogen is limiting. Colour and nitrogen content do not appear to be related (Figure 4.24 (a) and (b)). Duell (1960) and Dotzenko's (1961) studies also found the same trend, where the lower yielding grass species had the highest nitrogen content.

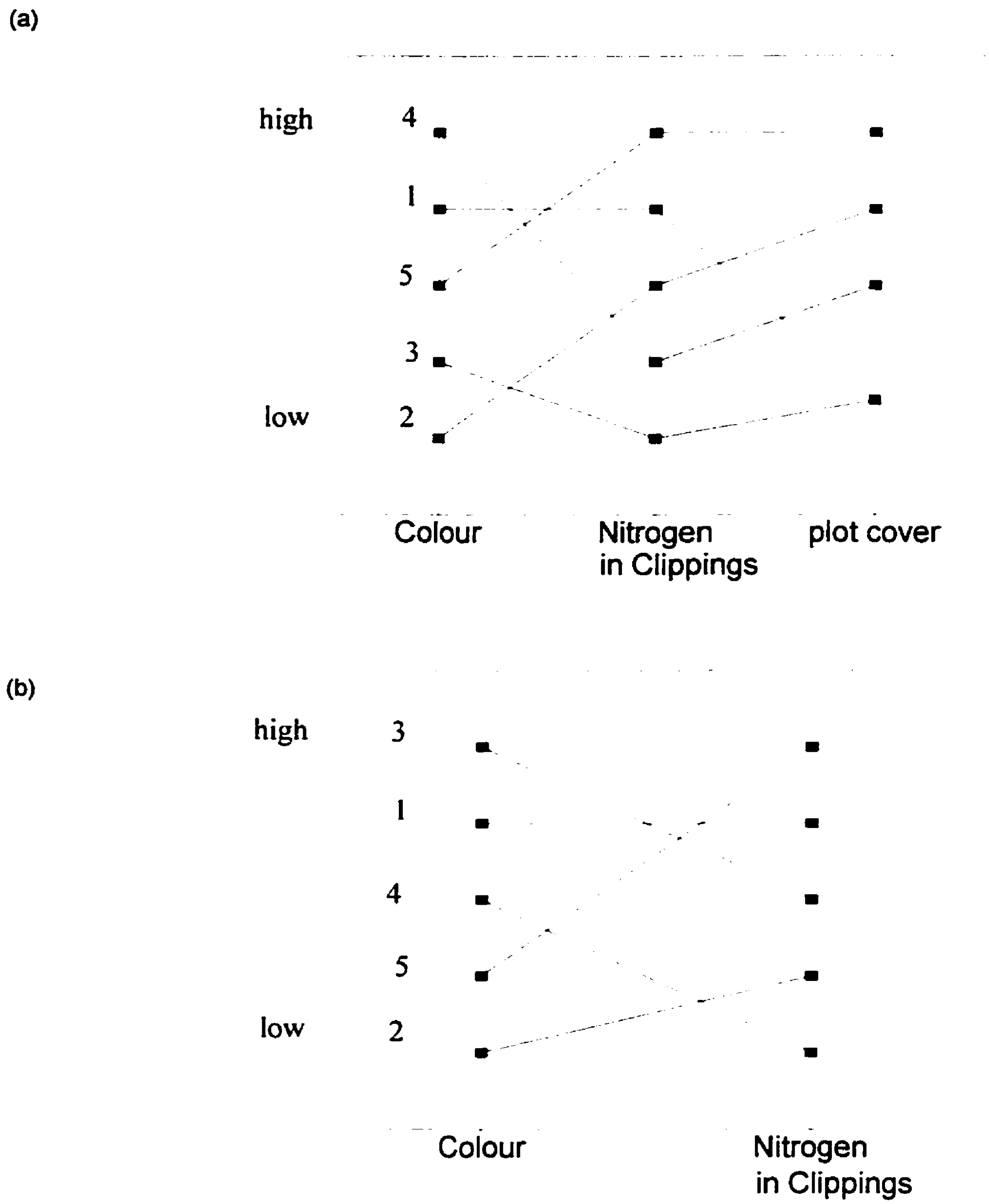


Figure 4.24: Comparison of colour, nitrogen, and plot cover rankings for each of the five monostands.

(a) Overall ranking results for mixtures one to five in the 1995 growing season.

(b) Overall ranking results for mixtures one to five in the 1996 growing season.

Note: Figure 5.2 (b) does not have establishment values, because this variable was not measured in 1996.

(The numbers within the graph pane, on the left hand side indicate the five mixtures, they are ranked from low (least desirable (light green, low nitrogen content, or low establishment)) to high (most desirable (darkest green, high nitrogen content, or high establishment)).

Plot Cover: Each grass species has a different competitive ability depending upon the moisture, light, and nutrients available. Species with a competitive advantage will be the first to establish, and therefore, have the highest percent plot cover. In 1995, turfgrass mixture five (a monostand of 100% perennial ryegrass) was the first to establish, had the heaviest dry and wet weight clipping yields, the highest percent nitrogen for all three of the collection dates, and the highest percent plot cover. Chippendale (1932) found that perennial ryegrass had a high germination rate, and good seedling vigour. Blaser et al. (1956b) noted that once established, perennial ryegrass tillered rapidly. Both of these characteristics support the high plot cover observed for turfgrass mixture five. Plots seeded with 100% Kentucky bluegrass were the slowest to establish, the average composition of mixture one had only 74% of the Kentucky bluegrass culms establish. This is supported by Watschke & Schmidt (1992) who found Kentucky bluegrass slow to germinate. Fescues are considered intermediate in establishment rate (Beard, 1973). Cover does not appear to be related to colour, but there may be a direct relationship between nitrogen content and plot cover (Figure 4.24 (a)).

Mixture Composition: Results show that the plot cover of Kentucky bluegrass declined when seeded in a polystand, compared to that of a monostand. This was also true for Canada bluegrass, creeping red fescue and sheeps fescue. The reduction in establishment due to interspecific competition was recognized as a common phenomenon, as early as 1898. Brede (1982) found that when a grass mixture was comprised of 10% or more perennial ryegrass, ryegrass was the dominant grass in that mixture. Whereas, Erdmann and Harrison (1947) found that ryegrass was the

dominant grass in a mixture comprised of 25% or more perennial ryegrass. The current study, the clipping removal and fertilizer rate study, found that when seeded at a rate of 10% of the seed mixture, perennial ryegrass, on average, comprised 31% of the plot cover in 1995. There are two explanations for these results. One explanation is that perennial ryegrass can be inhibitory to Kentucky bluegrass and fescue seedlings (Erdmann & Harrison, 1947). Grasses produce a chemical called coumarin, which can inhibit seedling germination (Salisbury & Ross, 1985). Another explanation, which is more likely, is that because perennial ryegrass was such a quick establishing grass, that it out shaded and out competed the other slower germinating bluegrasses and fescues in the mixtures.

Turfgrass selection qualities: Some of the advantages of using Kentucky bluegrass include its ability to withstand cold temperatures, its fall colour retention, and its good regrowth capacity. Alternatively, some of the undesirable characteristics of Kentucky bluegrass include its slow establishment rate, its need for medium levels of maintenance and it requires high levels of nitrogen (Schultz, 1989; Beard, 1973).

Canada Bluegrass is considered undesirable for home lawns because of high cutting height requirements, slow regrowth, and low aesthetic colour quality. It is a good turfgrass for low maintenance areas along roadsides with virtually no management inputs, i.e., fertilizers, watering or mowing.

Creeping red fescue was another turfgrass that was evaluated. It was found to have a slower plot cover than perennial ryegrass, but once established produced a dense dark green turf. Some other advantages of creeping red fescue include its low fertilizer requirement, and its superior shade tolerance (Beard, 1973).

Sheeps fescue was the second fine fescue used in this study. It was similar to creeping red fescue in plot cover, but unlike creeping red fescue because it required higher inputs of water and fertilizer to keep it at a desirable colour.

The final turfgrass species used in this study was perennial ryegrass. Perennial ryegrass established well the first year, producing a dense, dark green turf. Some of the undesirable characteristics of perennial ryegrass includes its very competitive nature, out competing all the other turfgrass species, and its low winter hardiness. Perennial ryegrass had a high quality turf in the establishment year, but in this study did not overwinter well, resulting in a low aesthetically quality turf the second year.

4.2.4 Clipping disposal

Two clipping disposal methods were utilized in this study. The clipping disposal methods were grasscycling and clipping removal. As outlined in Chapter Three, by returning the clippings to the turfgrass system, grasscycling can actually add nitrogen back into the system. Grass clippings provide high concentrations of nitrogen and potassium (Starr & DeRoo, 1981; Donahue et al., 1983).

Clipping Yield: Clipping disposal methods did not result in significantly different clipping weight yields. Yields collected from plots with grasscycling were not statistically different from plots with clipping removal, with the exception of August 16/95, the very first clipping collection date. One explanation for this result was that the clippings collected on August 16 likely responded to the grasscycling due to deficient nitrogen in the soil. The clippings that were being returned may have had enough nitrogen content to return a sufficient amount of nitrogen to the soil thus creating a significant increase in clipping yield, on August 16/95. The increase in clipping yield from plots where grasscycling was practiced was significantly greater ($p<0.05$) than in the plots where the clippings were removed.

The clippings collected in September of the 1996 growing season from plots where grasscycling was imposed, had statistically significant ($p<0.05$) lower clipping yields compared to the plots with the same fertilizer rate, but where the clippings were removed. The other three collection dates appeared to have a similar trend, although the clipping yield data did not differ statistically. This may be due to thatch build-up or shading, causing a reduction in grass production, or nitrogen immobilization. Thatch was not measured in this study, but, it has been reported (Soper et al., 1988) that nitrogen fertilization and grasscycling can increase thatch build-up. Thatch accumulation can result in the shading of turf, reduced tiller density, and ultimately decreased clipping yield (Soper et al., 1988). Not only can thatch cause shading, it can also result in increased nitrogen leaching from the turfgrass system (Nelson et al., 1980). Nitrogen can also be tied up in the biodegradation of the clippings, resulting in less nitrogen being returned to the soil for turfgrass growth (Miller & Donahue, 1995). Both thatch build-up and nitrogen immobilization would result in reduced nitrogen to the grass, ultimately resulting in reduced growth.

Height: Clipping disposal treatments, grasscycling and clipping removal, did not appear to have an effect on the height of the grasses in either 1995 or 1996. Plots seeded with mixture eight, where grasscycling was practiced, regardless of fertilizer rate, were taller for all sampling dates.

Colour: Clipping disposal treatments, grasscycling and clipping removal, did not have an obvious effect on the visual ratings of the mixtures in either 1995 or 1996. Therefore, grasscycling did not reduce the aesthetic quality of the turfgrass mixtures.

Nitrogen Content in the Clippings: The percent nitrogen in the clippings was not directly correlated to the clipping yield. There were no significant differences in the nitrogen content of the clippings between grasscycling and clipping removal for either the 1995 or 1996 collection dates. Grass clippings can provide high concentrations of nitrogen and potassium (Donahue et al., 1983).

Plot Cover: At the low fertilizer rate the clipping disposal method did not appear to alter the average plot cover of perennial ryegrass, but at the high fertilizer rate, grasscycling increased the plot cover. The plot covers for the other cool-season turfgrass species, used in this study, were unaffected by the clipping disposal methods.

4.2.5 Fertilizer rate

Since nitrogen is most often the growth limiting nutrient in soils (Salisbury & Ross, 1985) nitrogen addition is thought of as the most important component in fertilizers. Therefore, when referring to fertilizer rate, nitrogen rate is usually what is being discussed. Available soil nitrogen levels are often insufficient to support aesthetically desirable turfgrass growth, therefore, additional nitrogen must be added to the turfgrass system to maintain quality (Turner & Hummel, 1992). The study utilized two fertilizer rates, which included: a low rate, consisting of 0.5 lb of N/1000 ft^2 (0.23 kg of N/92.903 m^2) per application, and a high rate, consisting of 1.0 lb of N/1000 ft^2 (0.45 kg of N/92.903 m^2) per application. Each fertilizer rate was applied twice to the prescribed plots, during the 1995 growing season, on July 19 and Aug 23, and twice during the 1996 growing season, on June 27 and Sept. 9.

Nitrogen can affect a number of turfgrass characteristics, including colour, density, shoot growth, root growth, susceptibility to diseases and environmental stress, composition of the turfgrass stand, and regrowth ability (Turner & Hummel, 1992). To determine the effect nitrogen had on the turfgrass mixtures, clipping yield, height, colour, percent nitrogen in clippings, plot cover and mixture composition were measured, and are summarized below.

Clipping Yield: The mean dry weight and wet weight yields for all mixtures treated with the high fertilizer rate were significantly greater than the yields obtained from the plots treated with the low fertilizer rate. These results are consistent with reported findings (Madison, 1962c; Waddington et al., 1964; Goss & Law, 1967).

Although root yields were not measured in this experiment, Madison (1962c), and Goss & Law (1967) found that the root yields decrease with increasing nitrogen fertilizer rates, with a corresponding increase in shoot growth. This increase in shoot growth is due to decreased transportation of carbohydrates to the roots (Miflin, 1980). Deeper and more fibrous root systems will have more sources of nutrients and water which the plant can use for growth. By reducing the amount of root growth, increased nitrogen fertilizer rates may actually decrease drought tolerance (Beard, 1973). Therefore, excessive use of nitrogen fertilizer can be wasteful in terms of fertilizer production, but it may also result in increased maintenance in terms of irrigation requirements due to decreased drought tolerance and an increased cutting requirement if energy is used for shoot growth.

Height: Grass from plots treated with the high fertilizer rate were consistently taller in height. This is consistent with previous research findings (Madison, 1962c: Yust et al., 1984). Both articles (Madison, 1962c; Yust et al., 1984) found that applying nitrogen to turfgrass increased the growth rate of the turfgrass. Nitrogen fertilizer levels are directly related to grass growth, the greater the nitrogen rate, the greater the growth (Goss & Law, 1967). Grass growth consists of root, shoot and leaf growth.

Colour: Turfgrass colour was darker green (ranked higher) in the plots where the high fertilizer rate was applied. This dark green colour is considered more desirable from an aesthetic view point. Research carried out by Yust et al. (1984) and Madison (1962c) reported the same findings as the current research, turfgrass colour increases when nitrogen is applied.

Nitrogen Content in the Clippings: On average, turfgrasses contain, on a dry matter basis, between 3 to 5% nitrogen, unless the available nitrogen is limiting (Davis, 1962; Turgeon, 1980). Using 3 to 5% nitrogen as a reference, the clippings in 1995, for both the low and high fertilizer rate had close to 3% nitrogen, therefore, the nitrogen was adequate for turfgrass growth. Contrary to 1995, the clippings in 1996 had on average 2.2% nitrogen, suggesting that the nitrogen may have been present in limiting concentrations.

On average, there was a significant difference in percent nitrogen in the clippings between fertilizer rates, for both 1995 and 1996. The plots treated with the high fertilizer rate produced clippings with higher percent nitrogen values than did the plots treated with the low fertilizer rate. This is supported by Beard (1973) who found nitrogen content of grasses to be higher when fertilized with higher nitrogen levels.

Plot Cover: Tiller establishment is directly proportional to nitrogen, i.e., as the rate of nitrogen fertilization increases so do the number of established tillers (Madison, 1962c). The average number of shoots for plots treated with the low fertilizer rate, regardless of clipping disposal and turfgrass species, was 77 culms per 100 points sampled. The plots treated with the high fertilizer rate, regardless of clipping disposal and turfgrass species, had an average shoot density of 84 culms per 100 points sampled. Mixtures one, two, three and four all had higher plot covers when the high fertilizer rate was applied, regardless of clipping disposal regime.

Mixture Composition: Composition of turfgrass mixtures is often influenced by nitrogen-fertility levels. In polystands containing fescue, with the exception of mixture nine, both creeping red fescue and sheeps fescue consistently had more tillers in plots where the low fertilizer rate was applied and clippings were removed. Juska et al. (1955) found a similar trend in Kentucky bluegrass-red fescue mixtures, where red fescue was dominant at lower nitrogen rates.

4.2.6 Elements of error

Block Effect: There was a significant difference ($p<0.05$) between dry weight clipping yield between blocks. The significant differences between the four blocks was likely because the blocks had different growing conditions. Block four was situated in a sunny site, at the bottom of a very slight slope. Therefore, it likely had a high photosynthetic potential, and slightly moister soil. Block one, on the other hand, was the closest block to the fence where large willow trees were growing, and it was at the top of the slight slope. Grasses in block one had less light and potentially less water due to the willows. Therefore, there may have been reduced photosynthesis in block one and ultimately lower clipping yields.

Weekly Clipping Yield for an Average Home Lawn

Based on this study, clipping weight was converted to a standard home lawn size. This conversion was done to estimate the amount of clippings home lawns produce and dispose of in landfill sites weekly, depending on the fertilizer rate used, for each of the ten mixtures.

The average size lot is 50 ft. x 100 ft.(15.24 m x 30.48 m), the average house size is 1000 ft^2, and there are 160 000 residential lots in the City of Winnipeg (Tomlinson, 1997). Therefore, the average lot size, subtract the house, is 4000 ft^2, minus 500 ft^2 for garage, driveway, and/or garden, making the average lawn size 3500 ft^2 (325 m^2). Using the average lawn size of 325 m^2, the average weekly wet weight clipping yields, for low and high fertilizer rates, were calculated for each of the ten cool-season turfgrass mixtures (see Table 4.5). The values are based on the average value of clippings collected from the respective plots in the 1996 growing season. On average, the grasses grown in the high fertilizer rate plots produced 1.9 times more clippings than the grasses grown in the low fertilizer rate plots. Plots seeded with Kentucky bluegrass had the greatest difference in wet weight clipping yield between fertilizer rates. Kentucky bluegrass plots fertilized with the high fertilizer rate (1 lb N/1000 ft^2) produced five times more clippings than did the plots seeded with the low fertilizer rate (0.5 lb N/1000 ft^2).

Using the weights calculated in Table 4.5, and the tipping fee for the City of

Table 4.5: Average Weight of Clippings Collected, Per Collection Date, from the Turfgrass Mixtures Seeded in the Clipping Disposal and Fertilizer Rate Study, Based on the Size of an Average Home Lawn.

Mixture	Description	Wet weight (kg/325 m^2)	
		C1F1	C1F2
1	100% Kentucky Bluegrass	1.75	9.15
2	100% Canada Bluerass	12.78	23.00
3	100% Creeping Red Fescue	16.25	28.62
4	100% Sheeps Fescue	12.27	26.72
5	100% Perennial Ryegrass	11.20	20.65
6	30% Canada Bluegrass 30% Sheeps Fescue 30% Creeping Red Fescue 10% Perennial Ryegrass	15.00	29.35
7	45% Canada Bluegrass 45% Creeping Red Fescue 10% Perennial Ryegrass	15.73	27.12
8	45% Canada Bluegrass 45% Sheeps Fescue 10% Perennial Ryegrass	9.75	21.84
9	45% Creeping Red Fescue 45% Sheeps Fescue 10% Perennial Ryegrass	16.02	23.86
10	90% Kentucky Bluegrass 10% Perennial Ryegrass	7.43	15.87

C1F1= clipping removal and low fertilzer rate
C1F2= clipping removal and high fertilzer rate

Winnipeg's landfill sites of $15.10/metric tonne, the cost of disposing one homeowner's weekly clippings in the landfill was calculated (Table 4.6). Using the values from Table 4.6, multiplied by a factor of sixteen, multiplied by a factor of 160 000, divide by a factor of two, the cost of disposing of the home lawn generated turfgrass clippings in Winnipeg per year can be figured out. The factor of sixteen is the average number of times a home lawn is mowed per year, if the mowing begins in mid-May and stops mid-September. The factor of 160 000 is the number of residential lots in the city of Winnipeg. The factor of two is to allow for the assumption that only 50% of the people in Winnipeg are disposing of their turfgrass clippings in the landfill. For example, using mixture ten the control, the cost of disposing of all of the residential turfgrass clippings for one growing season, assuming all turfgrass mixtures are composed of mixture ten, would be $140 800 for the low fertilizer rate and $307 200 for the high fertilizer rate.

Table 4.6: Cost of Clippings Disposed of in Landfill Sites Based on the Average Weight of Clippings Collected, Per Collection Date, from the Turfgrass Mixtures Seeded in the Clipping Disposal and Fertilizer Rate Study, Based on the Size of an Average Home Lawn.

Mixture	Description	Wet weight (kg/325 m^2)	
		C1F1	C1F2
1	100% Kentucky Bluegrass	$0.03	$0.14
2	100% Canada Bluerass	$0.19	$0.35
3	100% Creeping Red Fescue	$0.25	$0.43
4	100% Sheeps Fescue	$0.19	$0.40
5	100% Perennial Ryegrass	$0.17	$0.31
6	30% Canada Bluegrass 30% Sheeps Fescue 30% Creeping Red Fescue 10% Perennial Ryegrass	$0.23	$0.44
7	45% Canada Bluegrass 45% Creeping Red Fescue 10% Perennial Ryegrass	$0.24	$0.41
8	45% Canada Bluegrass 45% Sheeps Fescue 10% Perennial Ryegrass	$0.15	$0.33
9	45% Creeping Red Fescue 45% Sheeps Fescue 10% Perennial Ryegrass	$0.24	$0.36
10	90% Kentucky Bluegrass 10% Perennial Ryegrass	$0.11	$0.24

C1F1= clipping removal and low fertilzer rate
C1F2= clipping removal and high fertilzer rate

CHAPTER FIVE

THE EFFECTS OF MOWING FREQUENCY ON COOL-SEASON TURFGRASSES

5.1 Results of the Mowing Frequency Study

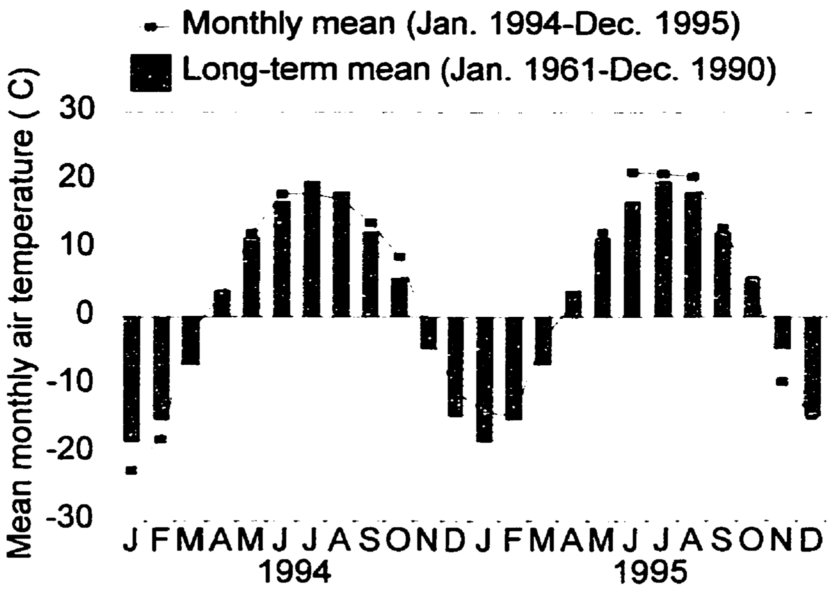
5.1.1 Weather conditions

1994 Weather Conditions: In 1994, air temperature and precipitation data were collected to determine the effects these parameters have on turfgrass growth throughout the growing season. The weather data for 1995 can be found in Appendix D, Table D1.

The mean monthly weather for January to May 1994 resembled that of the long-term average. The air temperature during the 1994 growing season (May to September) resembled the long-term average (Figure 5.1a). Total precipitation during this time was 25 mm less than the long-term average collected at the Winnipeg International Airport (Environment Canada, 1993) (Figure 5.1b). The study plot in the 1994 growing season received 125 mm more precipitation that normal. August 1994 had a total of 121 mm of rain, 45.7 mm more than the long-term average for that month.

1995 Weather Conditions: In 1995, soil temperature, air temperature and precipitation data were collected to determine the indirect effect these parameters have on turfgrass growth throughout the growing season.

(a)



(b)

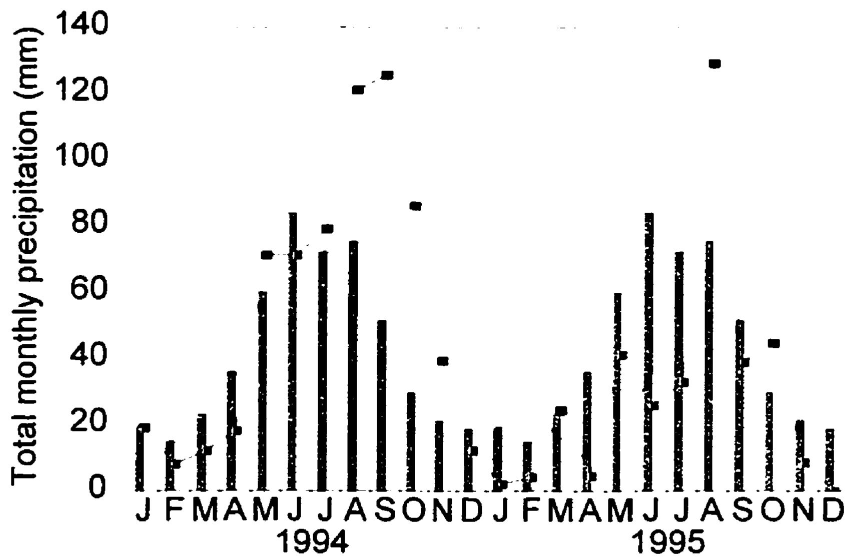


Figure 5.1: Mean monthly temperature and total monthly precipitation from 1961-1990 (shaded bars) and during 1994 and 1995 (line).
(a) Mean monthly temperature (C). (b) Total monthly precipitation (mm).

The mean monthly temperature from January to May 1995 resembled that of the long-term average (Figure 5.1a) and the total monthly precipitation during this period was only 50% of the long-term average collected at the Winnipeg International Airport (Environment Canada, 1993) (Figure 5.1b). During the 1995 growing season (May to September) there was only 78% of the normal precipitation. The temperature during the 1995 growing season averaged 1.8 ^{0}C above normal, June's average temperature was 4.3 ^{0}C higher than the long-term average.

Since the optimal soil temperature for root growth is between 10 and 18^{0}C (Beard, 1973), the dates in 1995 where the soil temperature fell within this range were noted. In 1995, the soil temperature was in the optimal temperature range from May 2-May 10, May 16-May 27, Sept. 5-17, and again from September 23-October 11/95. The optimal temperature for shoot growth is when the air temperature falls between 15^{0}C and 24^{0}C (Beard, 1973). In the 1995 growing season, the air temperature was in the optimal temperature range for shoot growth from May 1 until May 27/96. The air temperature was above 24^{0}C from May 28 until September 4/95. The rate of photosynthesis is directly related with temperature when air temperatures are greater than 10^{0}C, up to a maximum of 30^{0}C (Leopold & Kriedemann, 1975). In 1995, from May 5 to 10, May 16 to Sept 16, and again from September 23 to September 30, the air temperature was conducive for photosynthesis. In turfgrass systems, freezing stress occurs at or below soil temperatures of 0^{0}C (DiPaola & Beard, 1992). In 1995, the soils remained below 0^{0}C from January 1 until April 8, and again from November 25 until December 31/95.

5.1.2 Soil parameters

Soil temperatures were unavailable for the 1994 growing season due to a malfunction in the computerized weather station at the Agriculture Point, University of Manitoba. The average soil temperature from January to April 1995 was +0.3891°C; from May to September was +18.94°C; and the fall (oct & Nov) of 1995 had an average soil temperature of +4.10°C.

Fourteen soil samples were taken within the study plot on May 17, 1995. The soil was analyzed at Norwest Labs. Soil samples were taken from a depth of six inches and were found to have an estimated available Nitrate-N of 12 lbs./ acre, an estimated available Phosphate of 90 lbs./ acre, an estimated available potassium of 840 lbs./ acre, and an estimated available Sulphate-S of 32 lbs./ acre. The soil had a pH value of 7.7, and the electrical conductivity was 0.6 (Table 5.1).

5.1.3 Vegetation parameters

In this study, dry weight yield data of plots mowed every week and plots mowed every other week were compared on six different dates in 1995. Turfgrass height and colour measurement were also collected, prior to mowing, in the 1994 and 1995 growing seasons.

5.1.3.1 Results of wet weight yield

1994 Wet Weight Yield: Data from Henri Carriere and Calvin McLeod's report (1994) is referenced here only as the total wet weight clipping yields. During the 1994 tABLE 5.1

growing season the grass was clipped seven times. Because the clipping intervals were irregularly spaced the only data that could be directly compared was the total wet weight yield for the mixtures. The total wet weights were as follows: mixture two (1092.45 g/m^2) > mixture six (767.30 g/m^2) > mixture three (631.13 g/m^2) > mixture five (626.73 g/m^2) > mixture seven (512.68 g/m^2) > mixture four (496.23 g/m^2) > mixture one (264.15 g/m^2).

1995 Wet Weight Yield: To allow for comparisons of growth between the 1994 and 1995 growing seasons, the total wet weight yield for all of the mixtures was determined for 1995. The grass was clipped fifteen times during the 1995 growing season. The time interval between clipping dates was consistently one week. Each time the grass was mowed the wet weight yield was recorded. The total wet weight measurements for the 1995 growing season were as follows: mixture one (2173.77 g/m^2) > mixture six (1461.06 g/m^2) > mixture seven (1348.62 g/m^2) > mixture two (1302.05 g/m^2) > mixture five (1223.43 g/m^2) > mixture three (1068.23 g/m^2) > mixture four (931.50 g/m^2).

1995 Dry Weight Yield: In 1995, turfgrass clippings for both mowing frequencies were collected and dried on six dates, July 7, July 20, August 4, August 25, September 5, and September 25. To determine if the amount of dry weight yield produced per mixture differed due to fertilizer regime, clipping disposal method, mixture composition, and/or intermediate effects, Analysis of Variances (ANOVAs) were conducted on the data. When determining the results of the dry weight yield data for 1995, the yields were analyzed separately for each of the six clipping dates and summed together for the overall 1995 growing season results.

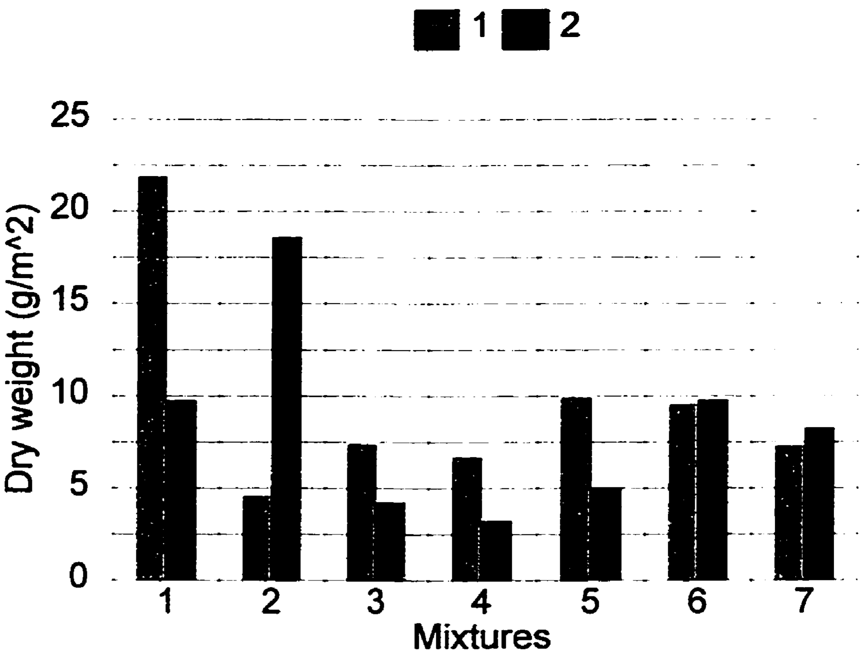
5.1.3.2 Results of dry weight yield

The clippings collected on July 7/95 showed a significant mixture*frequency interaction ($p<0.0246$) (Figure 5.2a). In general, plots produced equal clippings weights, regardless of mowing frequency, with the exception of mixtures one, two, and five. Plots seeded with mixtures one and five produced heavier clipping yields when mowed every week, compared to every other week. Mixture two produced a heavier clipping yield when the plots were mowed every other week compared to every week.

The clippings collected on July 20/95 showed a significant mixture*frequency interaction ($p<0.0452$) (Figure 5.2b). In general, plots mowed every week produced heavier clippings than plots mowed every other week, with the exception of mixtures two, six and seven. Mixture two produced a heavier clipping yield when the plots were mowed every other week compared to every week, and both mixtures six and seven appeared to produce equal clipping weights, regardless of mowing frequency

The clippings collected on August 4/95 showed a significant mixture*frequency interaction ($p<0.0452$) (Figure 5.3a). In general, plots produced equal dry weight clipping yields, regardless of mowing frequency, with the exception of mixtures one, two. Mixture one produced more clippings when the plots were mowed every

(a)



(b)

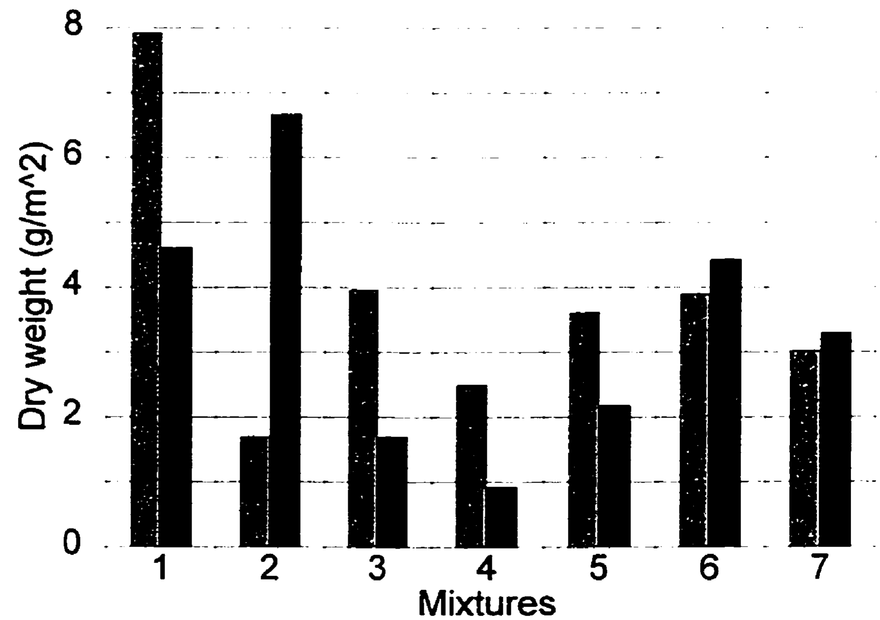
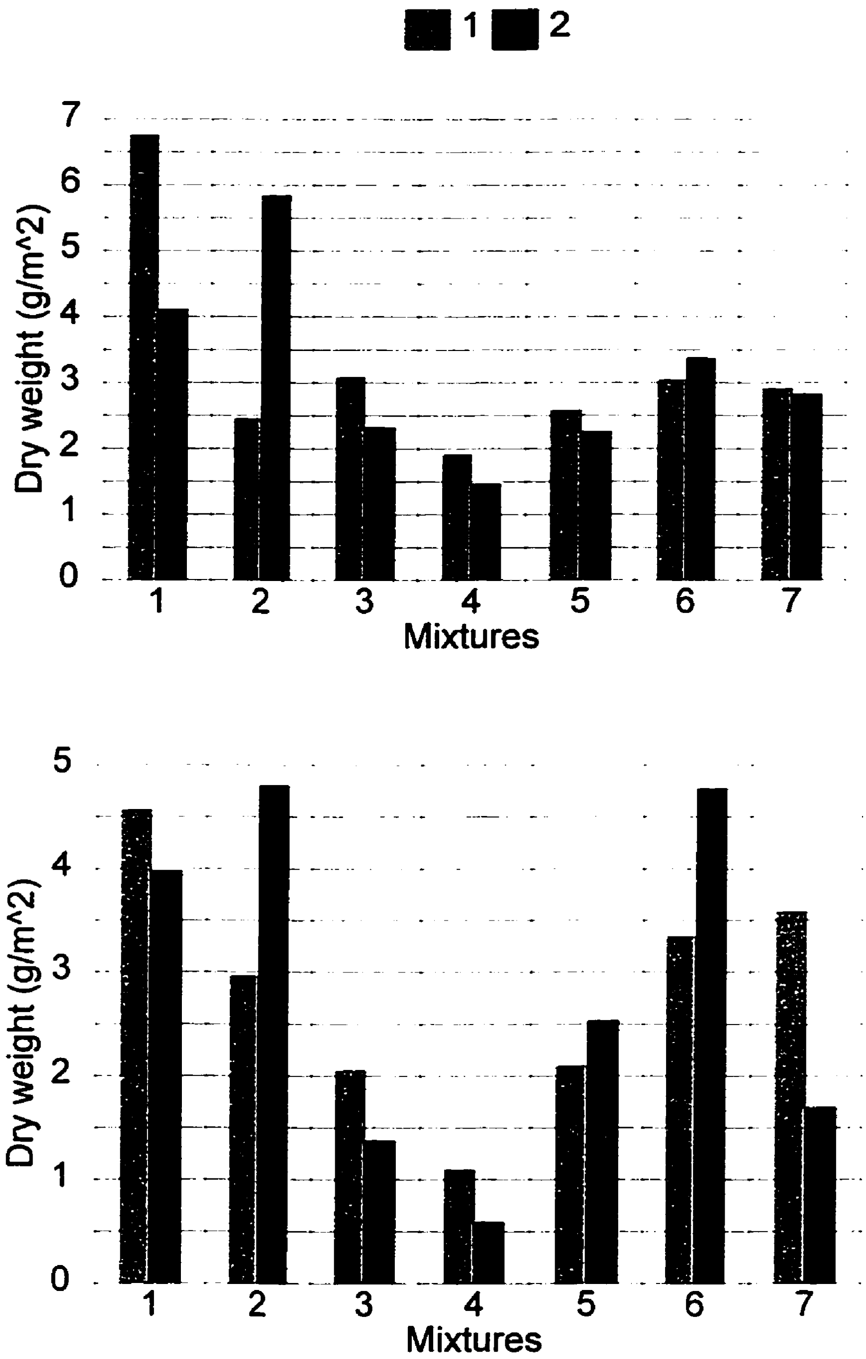


Figure 5.2: Dry weight clipping yield for the seven mixtures collected on (a) July 7, 1995 and (b) July 20, 1995.
(1 = Mow every week; and 2 = Mow every other week).

(a)



(b)

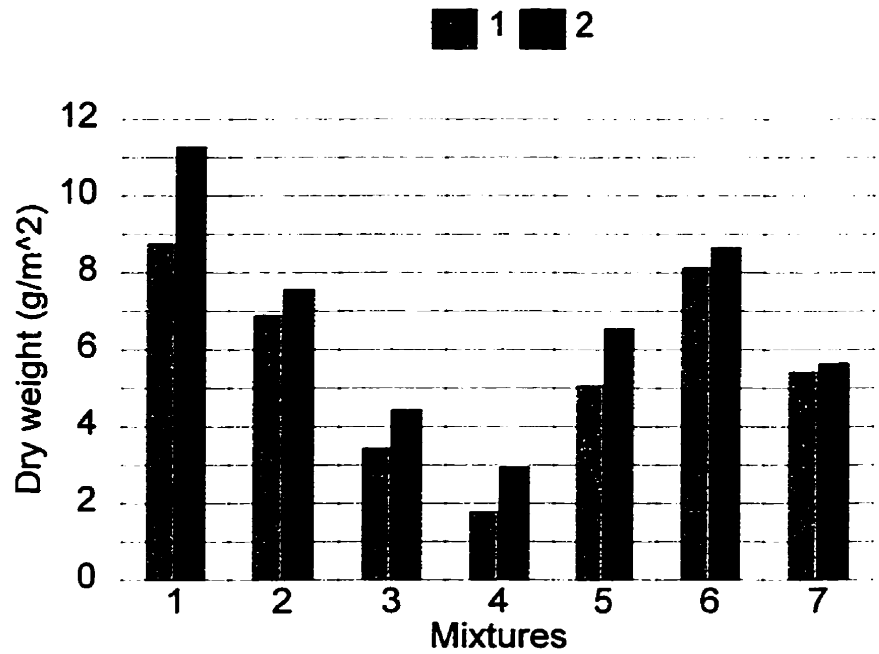
Figure 5.3: Dry weight clipping yield for the seven mixtures collected on (a) August 4, 1995 and (b) August 23, 1995.
(1 = Mow every week; and 2 = Mow every other week).

week compared to when the plots were mowed every other week. Mixture two produced more clippings when the plots were mowed every other week compared to every week.

The clippings collected on August 23/95 did not show a significant difference in clipping yield between mixtures or mowing frequency (Figure 5.3b). Plots seeded with mixture one produced the heaviest dry weight clipping yield of, on average, 4.28 g/m^2, 3.44 g/m^2 more than the average dry weight for plots seeded with mixture four which produced the lightest dry weight clipping yield. The dry weight clipping yield rankings of the seven mixtures are as follows: mixture one (4.28 g/m^2) > mixture six (4.06 g/m^2) > mixture two (3.88 g/m^2) > mixture seven (2.64 g/m^2) > mixture five (2.32 g/m^2) > mixture three (1.72 g/m^2) > mixture four (0.84 g/m^2).

The clippings collected September 5/95 had significant differences in dry weight yield between the seven mixtures ($p<0.0093$) (Figure 5.4a). The dry weight clipping yield was greatest for mixture one (10.04 g/m^2) > mixture six (8.40 g/m^2) > mixture two (7.24 g/m^2) > mixture five (5.81 g/m^2) > mixture seven (5.54 g/m^2) > mixture three (3.94 g/m^2) > mixture four (2.37 g/m^2). For the mixtures to have significantly different dry weight clipping yields the clipping yield had to be at least 3.68 g/m^2 different.

(a)



(b)

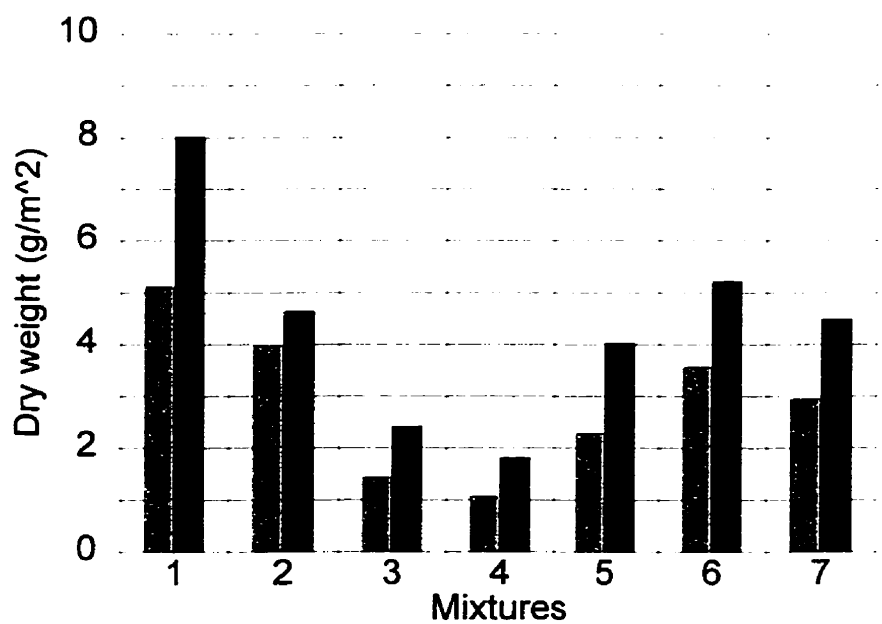


Figure 5.4: Dry weight clipping yield for the seven mixtures collected on (a) September 5, 1995 and (b) September 25, 1995.
(1 = Mow every week; and 2 = Mow every other week).

September 25/95 was the last date clippings were collected, and there was significant differences in dry weight yield between blocks, mixtures, and frequency (Figure 5.4b). The dry weight clipping yield was significantly different between blocks ($p<0.0390$). Block one produced, on average 0.78 g/m^2 more clippings than block two.

The statistical analysis of the clippings resulted in a significant difference ($p<0.0001$) in dry weight yield being observed between the seven mixtures. The clipping yield was greatest for plots seeded with mixture one, which produced, on average, a dry weight yield of 6.56 g/m^2, which was greater than mixture six (4.39 g/m^2) > mixture two (4.30 g/m^2) > mixture seven (3.72 g/m^2) > mixture five (3.15 g/m^2) > mixture three (1.92 g/m^2) > mixture four, which had an average dry weight yield of 1.44 g/m^2, which produced the lowest yield.

The mowing frequency also produced a significant difference ($p<0.0009$) in dry weight yield. Plots mowed every other week produced, on average, 1.46 g/m^2 more clippings than the plots that were mowed every week.

The overall clipping yield for the mowing frequency study, in 1995, had a significant difference ($p<0.0057$) between mixtures (Figure 5.5). The dry weight clipping yield was greatest for plots seeded with mixture one (48.35 g/m^2) > mixture two (35.26 g/m^2) > mixture six (33.87 g/m^2) > mixture seven (25.69 g/m^2) > mixture five (24.03 g/m^2) > mixture three (18.07 g/m^2) > mixture four (12.98 g/m^2). The clipping yields for the mixtures were significantly different if they differed by 15.76

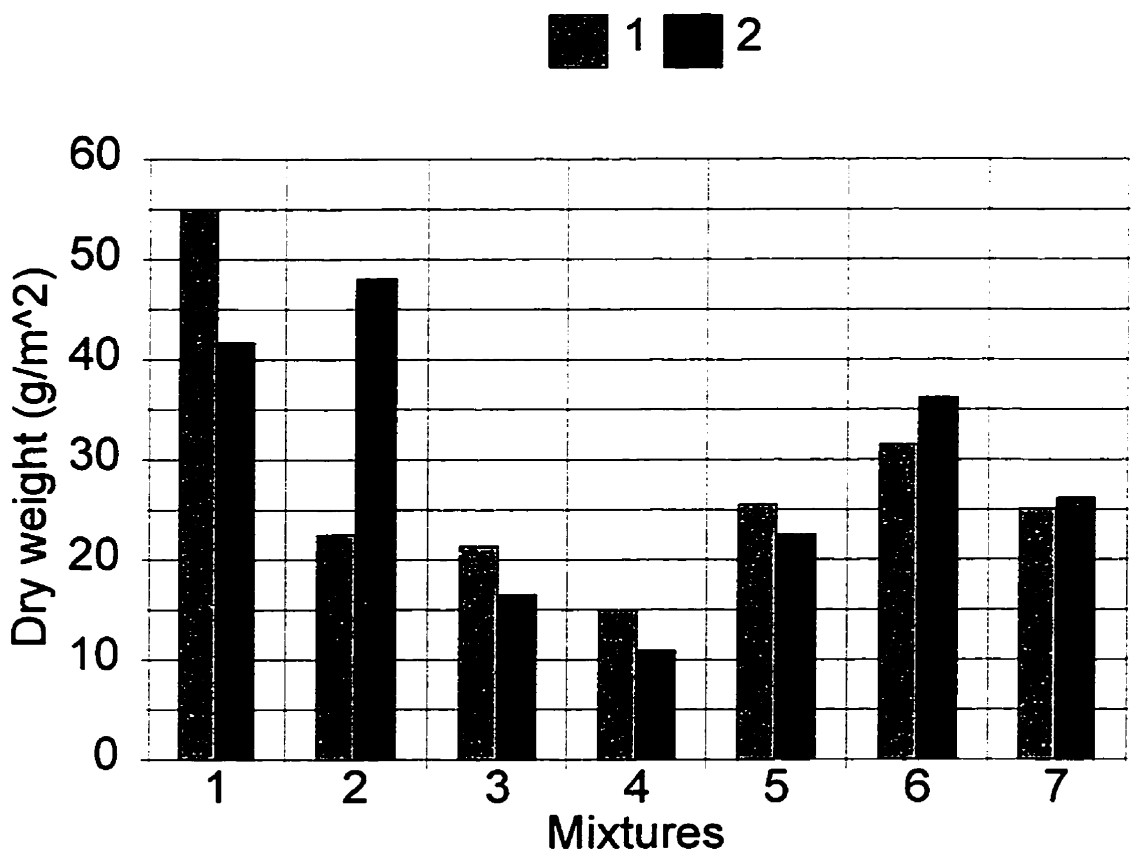


Figure 5.5: Total dry weight clipping yield for the seven mixtures from July 7 to September 25, 1995.
(1 = Mow every week; and 2 = Mow every other week).

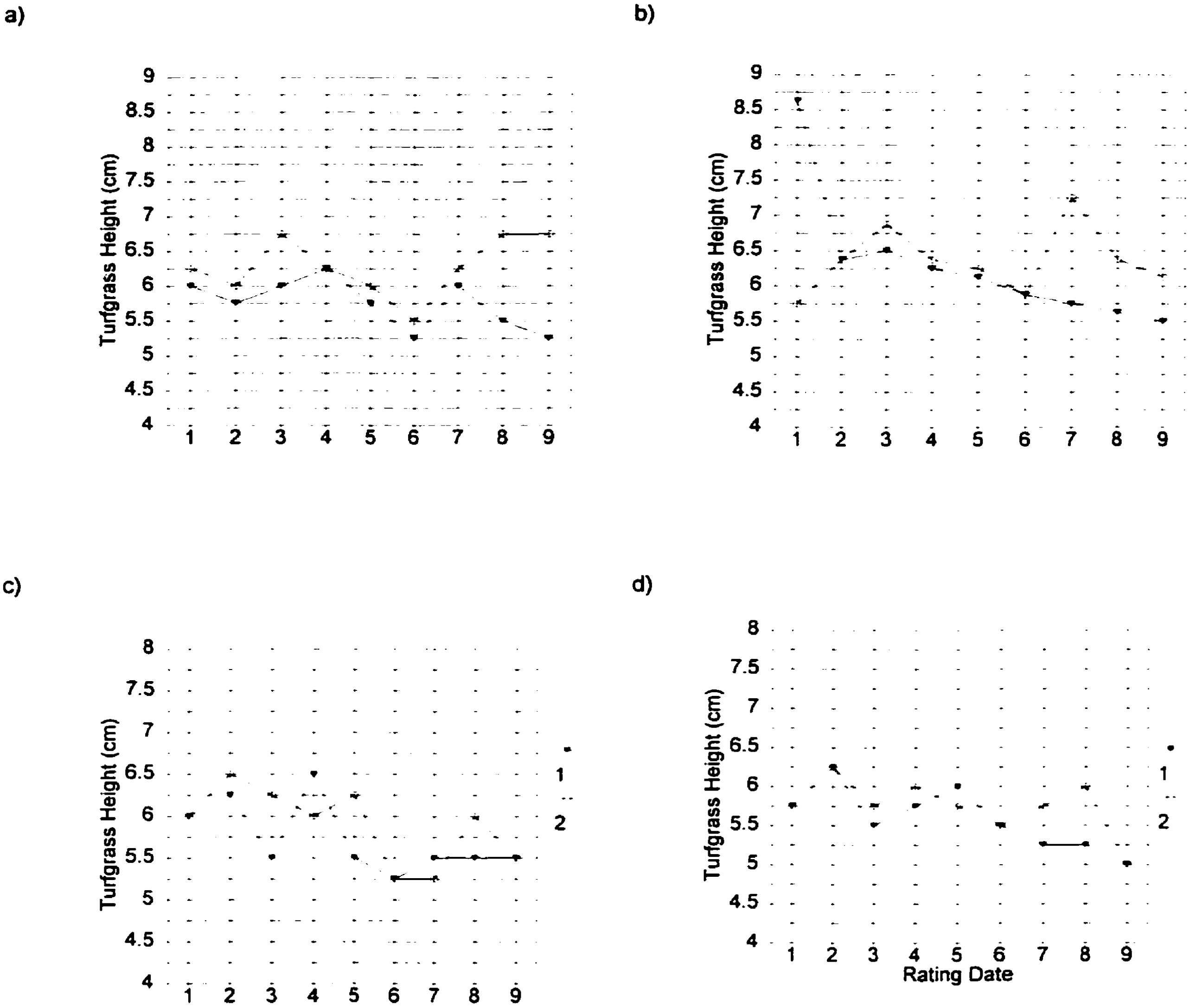
g/m^2 or more.

5.1.3.3 Results of height and colour data

All mixtures appeared to have two peaks in height, one between July 20 and July 27/95, and the second between August 23 and September 5/95 (Figures 5.6 and 5.7). There was only a 0.66 cm difference in the average height, for the 1995 growing season, between the tallest and shortest turfgrass mixture. Comparisons of individual rating dates show the obvious differences in height measurements. The average height for the 1995 growing season for plots seeded with mixture two (6.33 cm) > mixture six (6.25 cm) > mixture five (6.15 cm) > mixture one (6.02 cm) > mixture seven (6.01 cm) > mixture three (5.81 cm) > mixture four (5.67 cm). There appears to be similar trends in height measurements throughout the growing season for mixtures three and four, two and six, and five and seven.

The mowing frequencies did not exhibit a large difference between average heights. Plots mowed every week, regardless of mixture, produced grasses which were, on average, for the 1995 growing season, 5.91 cm tall, and the plots mowed every other week, regardless of mixture, produced grasses which were, on average for the 1995 growing season, 6.15 cm tall. There were once again obvious height differences when looking at Figures 5.6 and 5.7 between mowing frequencies.

Turfgrass colour trends were relatively consistent between mixtures, with the exception of mixture one, which had very low colour ratings (Figures 5.8 and 5.9).



Actual Rating Dates

1 = July 7/95	6 = Aug. 11/95
2 = July 13/95	7 = Aug 23/95
3 = July 20/95	8 = Sept. 5/95
4 = July 27/95	9 = Sept. 25/95
5 = Aug 4/95	

Figure 5.6: Mean turfgrass height for mixtures one to four, for nine sampling dates in the 1995 growing season. (a) Mean turfgrass height for mixture one. (b) Mean turfgrass height for mixture two. (c) Mean turfgrass height for mixture three. (d) Mean turfgrass height for mixture four.
(1 = mow every week, and 2 = mow every other week).

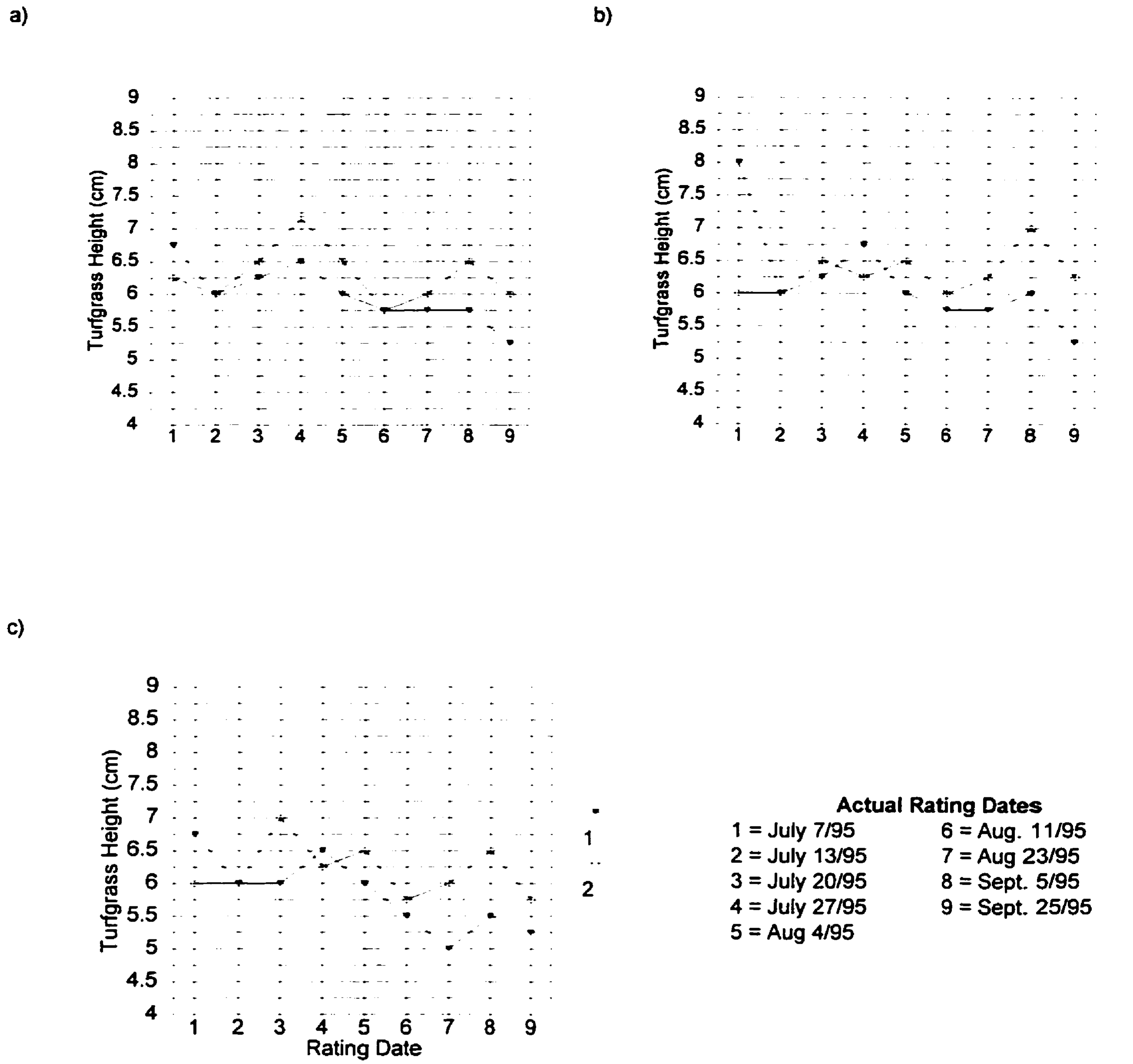
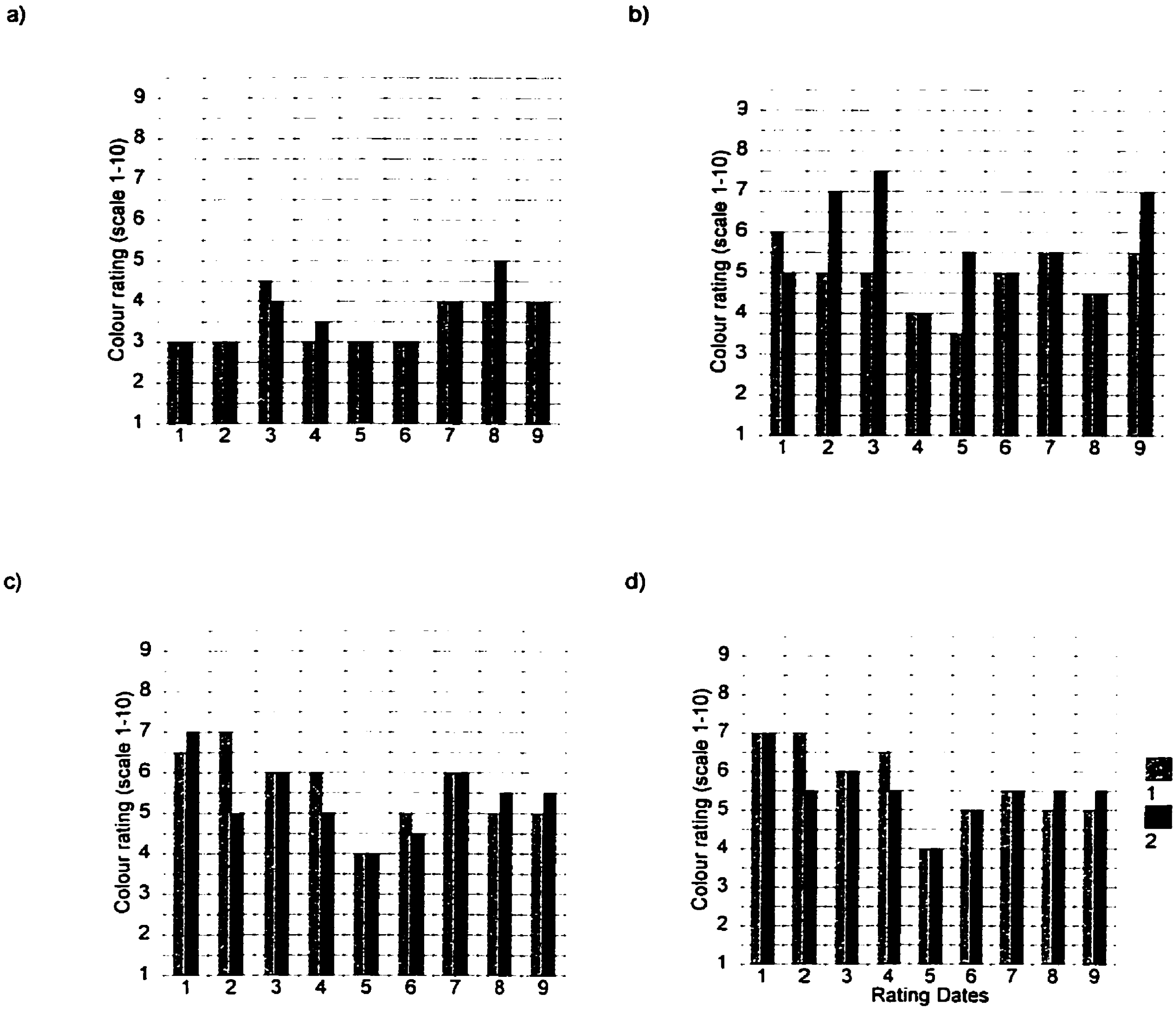


Figure 5.7: Mean turfgrass height for mixtures five to seven, for nine sampling dates in the 1995 growing season. (a) Mean turfgrass height for mixture five. (b) Mean turfgrass height for mixture six. (c) Mean turfgrass height for mixture seven.
(1 = mow every week, and 2 = mow every other week).



Actual Rating Dates

1 = July 7/95	6 = Aug. 11/95
2 = July 13/95	7 = Aug 23/95
3 = July 20/95	8 = Sept. 5/95
4 = July 27/95	9 = Sept. 25/95
5 = Aug 4/95	

Figure 5.8: Mean turfgrass colour for mixtures one to four, for nine sampling dates in the 1995 growing season. (a) Mean turfgrass colour for mixture one. (b) Mean turfgrass colour for mixture two. (c) Mean turfgrass colour for mixture three. (d) Mean turfgrass colour for mixture four.

(1 = mow every week, and 2 = mow every other week).

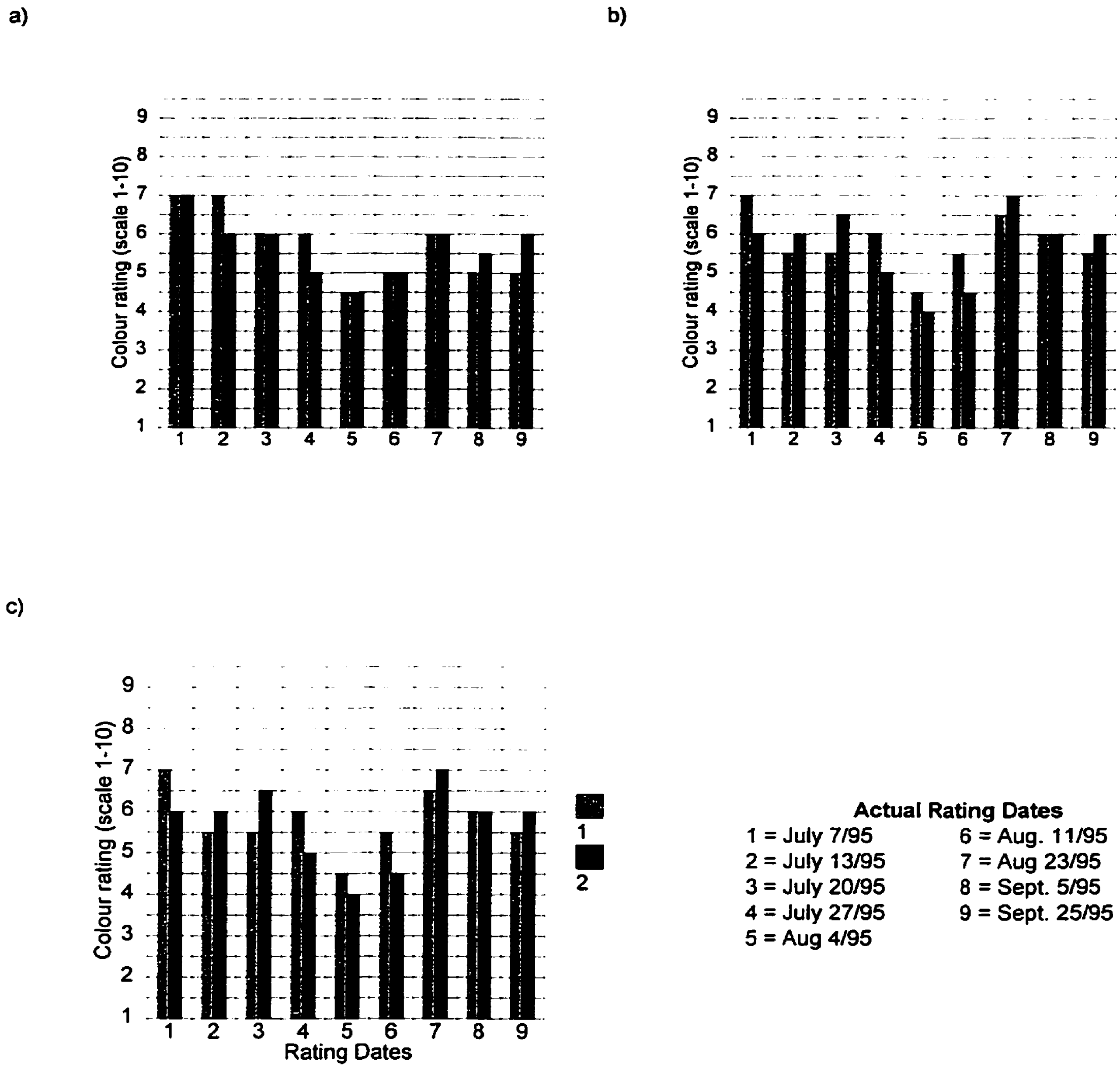


Figure 5.9: Mean turfgrass colour for mixtures five to seven, for nine sampling dates in the 1995 growing season. (a) Mean turfgrass colour for mixture five. (b) Mean turfgrass colour for mixture six. (c) Mean turfgrass colour for mixture seven.
(1 = mow every week, and 2 = mow every other week).

All mixtures had high colour ratings in the early part of the field season, on July 7. After July 7, 1995 the colour ratings declined and the lowest colour rating was between July 27 and August 4/95. Following this decline in colour quality, turfgrass colour began to improve again in the fall season. On average, for the 1995 growing season mixture seven had the highest colour rating of 5.78 > mixture six (5.73) > mixture five (5.70) > mixture four (5.59) > mixture three (5.5) > mixture two (5.28) > mixture one had the lowest colour ranking of 3.56. Mixture two was the most visually affected by mowing frequency compared to the other mixtures. Each mixture had at least one date specific colour rating, in the 1995 growing season, where the colour was different between the two mowing frequencies.

5.2 Discussion of the Mowing Frequency Study

5.2.1 Turfgrass mixtures

In the mowing frequency study seven cool-season turf mixtures were evaluated. See Appendix A, Table A3, for the composition of the mixtures. To determine the slow growth and low maintenance potential of each of the mixtures clipping yield, height and colour were measured.

Clipping Yield: Some mixtures had heavier wet and dry weight clipping yields than others. Wet weight clipping yields for 1994 were greatest for plots seeded with mixture two and lowest for plots seeded with mixture one. In 1995 plots seeded with mixture one had the highest wet weight clipping yield. Plots seeded with mixture four had a low wet weight clipping yield in both the 1994 and 1995 growing seasons. Mixture four was comprised of Canada bluegrass, hard fescue, chewings fescue, red fescue and perennial ryegrass, and likely had a low plot cover due to the lower establishment rate of mixtures (Beard, 1973) and the mixture composition.

Dry weight clipping yields were significantly different between mixtures in the 1995 growing season, and they followed the same trend as the wet weight yields. Mixture one, a monostand of sheeps fescue, consistently produced the greatest clipping yield in the 1995 growing season, and mixture four produced the least.

Height: Another desirable low maintenance characteristic of turfgrass is species which is slow growing. Differences in height between mixtures were measurable and visually apparent. Interestingly, both mixtures two and six, which have similar growth peaks were both seeded with mixtures that contained 45 and 50% fescue, respectively. This trend also happens with mixtures five and seven, where they have similar growth peaks during the growing season, and both were seeded with mixtures that contained 75 and 85% fescue, respectively. Mixtures three and four, which were seeded with mixtures containing 65 and 60% fescue respectively, do have trends in height throughout the growing season. Both mixtures three and four have the same heights for both mowing frequencies on July 7, August 11, and September 25/95. It appears turfgrass mixture composition may actually play a role in turfgrass height. Turfgrass height is one measurement of shoot growth, so it was not surprising that the mixtures with similar seed composition had similar growth trends.

Colour: Mixture one (sheeps fescue) had low colour ratings for the whole growing season, and appeared to increase in quality as the temperature dropped in the fall. Beard (1973) supports these findings, he found sheeps fescue to be a low quality low maintenance turfgrass that has poor colour quality. All of the average colour ratings for the seven for the 1995 growing season fall below six, the minimum aesthetically acceptable rating. The low fertilizer input and virtually no irrigation were likely the two factors causing the low colour quality throughout the 1995 growing season.

5.2.2 Mowing frequency

The widely accepted aesthetic appearance of turfgrass is dense, weed free and dark green in colour. To achieve this aesthetic quality lawn maintenance must be practiced, and one lawn maintenance regime that must be considered is mowing frequency. Studies have shown mowing frequency to increase shoot density (Madison, 1962b), and very frequent mowings tend to decrease shoot growth and carbohydrate reserves (Madison, 1962a; Turgeon, 1980).

To determine the effects of the two mowing frequencies on the seven mixtures, clipping yields, turfgrass height and colour were measured and the results of these variables are summarized below.

Clipping Yield: Dry weight yields collected in 1995 from plots mowed every week compared to plots mowed every other week did not show significant differences. Low frequency of mowing (every other week) did not increase clipping yield. According to Madison (1960) dry weight production is directly related to the mowing frequency, as mowing frequency increases so does dry weight yield. This is contrary to what the results of the mowing frequency study found. Several possible explanations include the mowing was not frequent enough, the turfgrass mixtures required more nitrogen than the actual application rate of 1 lb of N/1000 ft^2, or the mixtures required more watering.

Height: Mowing frequency appeared to affect turfgrass height. Between the August 23 and September 5 rating dates, all of the mixtures showed a peak in height for the turfgrasses which were mowed every other week, compared to those mowed every week. This peak in turfgrass height in the plots that were mowed biweekly, was likely due to the higher amount of carbohydrates in the roots, compared to the carbohydrate reserves in the more frequently mowed turfgrasses.

Colour: Colour was rather sporadic, showing some differences between mowing frequencies. Although there does appear to be a visual trend in the differences in colour between the two mowing frequencies.

CHAPTER SIX

CONCLUSIONS

The purpose of this study was to evaluate a variety of cool-season turfgrass species for their slow growth and low maintenance potential. The final intention of this study is to recommend a turfgrass mixture and maintenance regime that meets the criteria of slow growth and low maintenance for the City of Winnipeg. A review of literature related to turfgrass selection, turfgrass management and the environmental impacts of turfgrass management was completed to establish the ecology and management of turfgrass systems. The desire to reduce the environmental impact of anthropogenic activities has led researchers to study the suitability of turfgrass species that require less maintenance and produce less waste. In the City of Winnipeg, yard waste comprises 20% of the total waste produced annually (Ross, 1997). To address the environmental impacts of turfgrass management two studies were conducted with the intention that the results would allow recommendations to be made on how to reduce some of the negative impacts turfgrass management has on the environment. One study focused on the effects of two different clipping disposal methods and fertilizer rates on ten cool-season turfgrass mixtures, and the other study measured the effects mowing frequency had on seven commercially available turfgrass mixtures.

6.1 Clipping Disposal and Fertilizer Rate Study

6.1.1 Turfgrass mixtures

Clipping Weight: Statistical analysis of the dry weight clipping yield data found significant differences between mixtures. In 1995, monostands containing Kentucky bluegrass (mixture one) and sheeps fescue (mixture four) produced the lightest clipping weights compared to the other monostands. In 1996 mixtures one (Kentucky bluegrass) and five (perennial ryegrass) produced the least clippings. In the 1995 growing season, the monostands of perennial ryegrass (mixture five) and creeping red fescue (mixture three) produced the heavier clipping weights. In 1996, the monostands of sheeps fescue (mixture four) and creeping red fescue (mixture three) produced the heavier clippings.

The polystands that produced the lightest clipping yields were mixtures ten (comprised of Kentucky bluegrass and perennial ryegrass) and eight (containing Canada bluegrass, sheeps fescue, and perennial ryegrass). The polystands that produced the heavier clipping yields were mixtures seven (Canada bluegrass, creeping red fescue, and perennial ryegrass) and mixture six (Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass) (Figure 4.23).

Height: Although not statistically tested, the height measurements varied between mixtures. Generally, the height was closely correlated with the clipping weight (Figure 4.23). The turfgrass mixtures that produced the higher clipping yields were the ones with the higher height measurements, and the shorter turfgrass mixtures produced the lighter clipping yields.

Colour: The colour ratings also showed visual variations between mixtures. The monostands that produced the darkest green colour were mixtures one (Kentucky bluegrass) and four (sheeps fescue) in the establishing year, but in 1996 creeping red fescue (mixture three) was the darkest green, followed by mixture one (Kentucky bluegrass). Monostands that produced grasses with low aesthetic appeal included mixtures two (Canada bluegrass) and three (creeping red fescue) in 1995, and mixtures two and five (perennial ryegrass) in 1996. The polystands that produced the desired dark green colour were mixtures eight (Canada bluegrass, sheeps fescue, and perennial ryegrass) and ten (comprised of Kentucky bluegrass and perennial ryegrass) and in 1996 mixtures seven (Canada bluegrass, creeping red fescue, and perennial ryegrass) and mixture six (Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass) (Figure 4.23). The low aesthetic quality polystands include mixture seven (Canada bluegrass, creeping red fescue, and perennial ryegrass) and mixture six (Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass) in the establishment year (1995). In 1996 the least visually pleasing growth occurred in mixtures eight (Canada bluegrass, sheeps fescue, and perennial ryegrass) and ten (comprised of Kentucky bluegrass and perennial ryegrass).

Nitrogen Content in the Clippings: Statistical analysis of the nitrogen content in the clippings found that there was significant differences between the mixtures.

Results from the 1995 and 1996 growing seasons found the turfgrasses with the highest percent nitrogen in the leaf tissue also produced the highest clipping yield. This trend can be seen in perennial ryegrass in the 1995 growing season and creeping red fescue in the 1996 growing season. The exception to the correlation of high clipping yield with high nitrogen content was Kentucky bluegrass. Kentucky bluegrass produced the lowest clipping yields both years, yet consistently had the second highest leaf nitrogen content.

Percent nitrogen in the clippings did not appear to be related to colour in either growing season. But, there appeared to be a correlation between nitrogen and plot cover (Figure 4.23).

6.1.2 Clipping disposal

Overall, grasscycling versus clipping removal appeared to have a statistically significant effect on clipping yield for the 1995 growing season, the establishment year, but did not appear to have an effect on height, colour, nitrogen content, or plot cover of the seeded grasses.

In 1996 clipping disposal produced a significant difference in clipping yield for the September 14/96 collection date. Grasscycling actually reduced the dry weight clipping yield in the plots where it was practiced, compared to the dry weight clipping yield collected in the clipping removal plots. Although not statistically significant this trend was also seen on the other three collection dates in 1996. Clipping disposal did not appear to influence the height, colour, nitrogen content of the turfgrass clippings, or plot cover.

6.1.3 Fertilizer rate

Clipping Yield, Height, Colour, and Nitrogen Content in the Clippings: The plots treated with the high fertilizer rate consistently produced higher clipping yields, taller plants, greener grass, and a greater percentage of nitrogen in the clippings compared to the plots treated with the low fertilizer rate.

Effects of fertilizer rate on mixture composition were also measured. Both fine fescues had greater number of tillers in polystands when plots were treated with less nitrogen, and the clippings were removed (Figure 4.22a). Perennial ryegrass and Kentucky bluegrass had a greater number of tillers in monostands and polystands when plots were treated with the higher nitrogen rate (Figures 4.22b and 4.21a). The plot cover of Canada bluegrass in polystands did not appear to be affected by nitrogen rate (Figure 4.21b).

6.2 Mowing Frequency Study

6.2.1 Turfgrass mixtures

Seven cool-season turfgrass mixtures were used in this study. See Appendix A, Table 2, for the composition of the mixtures. To determine the slow growth and low maintenance potential of each of the mixtures wet weight clipping yield, dry weight clipping yield, height and colour were measured.

The desirable slow growth and low maintenance turfgrass mixture would produce the lightest amount of clippings. Analysis of the wet weight clipping yields for 1994 found mixtures one (monostand of sheeps fescue) and two (Pickseed's

Cottage N' Country) produced the lowest clipping weight, however in 1995, mixture one produced the highest clipping weight. Mixture four (OSECO's Blue Chip Low Maintenance/Reclamation Mixture) consistently produced a low wet weight clipping yield in 1994 and 1995. Dry weight clipping yields were consistent with wet weight clipping yields in the 1995 growing season.

6.2.2 Mowing frequency

Dry Weight Clipping Yields: To maintain an aesthetically pleasing turfgrass that is dense, weed free, and green in colour, turfgrass management must be imposed. The results collected in 1995 showed that mowing frequency, i.e., weekly mowings compared to biweekly mowings, did not affect the total clipping yields for the 1995 growing season. Although, the September 25/95 collection date did show a significant difference in dry weight clipping yield between the mowing frequencies.

Some species appeared to more affected than others by the mowing frequencies (Figures 4.24 - 4.27). Mixture two (Pickseed's Cottage N' Country) and six (Pickseed's Town and Country) appeared to produce more clippings when the mowing frequency was reduced.

Height and Colour: Mowing frequency did not appear to affect the average height or colour for the 1995 growing season. Yet, comparisons of individual rating dates show that there were some increases in both height and colour for both mowing frequencies.

RECOMMENDATIONS

6.3 Clipping Disposal and Fertilizer Rate Study

Recommendations, based on the collected observations and measurements, on the slow growth/low maintenance potential of the turfgrasses are summarized in this section. These recommendations would be of interest to city planners, golf course managers, contractors and home-owners who are interested in reducing turfgrass management. The criteria used for recommendations include clipping weight, height and colour. Data from 1996 was used for evaluating desirable species and mixtures, because the stands were more established and mature than in the 1995 growing season.

6.3.1 Turfgrass species

Clipping Weight and Height: Desirable low maintenance characteristics of turfgrass include low clipping yield and short growth habit. Based on 1996 height and weight data only, the desirable monostand was mixture one (Kentucky bluegrass). The desirable polystands, were mixtures ten (Kentucky bluegrass and perennial ryegrass) and eight (Canada bluegrass, sheeps fescue, and perennial ryegrass).

Colour: Aesthetically pleasing turfgrass is thought to be dark green in colour. Based on 1996 data, the greenest monostands were mixtures three (creeping red fescue) and one (Kentucky bluegrass). The most aesthetically pleasing turfgrass polystands, were mixtures seven (Canada bluegrass, creeping red fescue, and perennial ryegrass) and six (Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass).

The recommended turfgrass monostand for overall low maintenance as determined from this study, was Kentucky bluegrass. Kentucky bluegrass rated well for low clipping yield, short height and dark green colour. The only undesirable characteristics of Kentucky bluegrass are its higher nitrogen requirements, and slow establishment rate.

It is undesirable to seed a lawn with only one grass species, due to its lower resistance to disease and insect infestations. If a lawn composed of only one grass species is infested it is likely the whole lawn will be susceptible to disease and insect injury. Despite some monostands having low clipping weights, the susceptibility to injury lowers their potential for use.

Another recommendation is to continue using perennial ryegrass as a nurse crop. Some of the benefits of using perennial ryegrass as a nurse crop in Manitoba are that it has a fast establishment rate reducing competition between weeds, and it has a very poor cold tolerance resulting in poor overwintering causing the perennial ryegrass to die out. Which allows the plot cover of desirable slower establishing turfgrass species to increase.

The recommended turfgrass polystand for overall low maintenance, i.e., low clipping yield, short height, and acceptable colour was mixture eight (Canada bluegrass, sheeps fescue, and perennial ryegrass). This study found mixture six (Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass) to be the second choice in polystand mixtures. Mixture eight was ranked slightly higher than mixture six, although the colour was not ranked as high, due to its lower production of clippings, and shorter growth pattern.

6.3.2 Clipping disposal

Plots where grasscycling was imposed did not show a statistical difference in total clipping yields for the 1996 growing season, compared to the clipping removal plots. Yet, there was a significant difference in the September 1996 collection, where grasscycling actually reduced the average weight of clippings produced in the plots compared to plots imposed with the clipping removal regime.

Clipping disposal did not appear to affect height, colour, nitrogen content, or plot cover, but it could greatly affect the amount of maintenance required for lawn care. The goals of reducing the amount of yard waste that goes to landfill sites and reducing the maintenance required for lawn care can be achieved by adopting grasscycling as a turfgrass management regime.

The recommended clipping disposal method for low maintenance and reduced yard waste is a grasscycling regime. To increase the decomposition rate of grass clippings, and to reduce impacts such as shading of returned clippings to the turfgrass system it is recommended to retrofit lawnmowers with mulching blades and mulching plugs. The mulching blade and plug recycles the clippings chopping the clippings into smaller pieces than does a conventional lawnmower blade.

6.3.3 Fertilizer rate

Clipping Yield, Height, Colour, and Nitrogen Content in the Clippings: Plots treated with the high fertilizer rate produced higher clipping yields, taller and greener plants, and clippings with more nitrogen. Based on these results the use of high fertilizer use would be recommended if aesthetic quality was the only decision-making component. But the purpose of the study was to find species or mixtures that were able to grow with lower nitrogen inputs. Mixtures eight (Canada bluegrass, sheeps fescue, and perennial ryegrass), seven (Canada bluegrass, creeping red fescue, and perennial ryegrass), and six (Canada bluegrass, creeping red fescue, sheep fescue, and perennial ryegrass) all had acceptable establishment in plots treated with the low fertilizer rate (Figures 4.21 and 4.22).

Mixture Composition: Plot cover data collected in 1995 found that both fine fescues produced more tillers in polystands when the plots were treated with the lower nitrogen rate (Figure 4.22a). It was also found that growth of Canada bluegrass did not appear to be affected by nitrogen levels (Figure 4.21b). But since colour is also a criteria for turfgrass selection and both Canada bluegrass and sheeps fescue had low colour ratings throughout the growing seasons, creeping red fescue is recommended for use in low maintenance turfgrass mixtures, if fertilizer rate and colour are the major criteria for selection. One disadvantage of creeping red fescue is that it produces large amounts of clippings (Figure 4.7b) and may increase mowing requirements. To reduce the impact of creeping red fescue on clipping yield it is recommended that this species be used in small percentages in mixtures.

Fertilizers should be added to lawns at the lower recommended rate. Excessive fertilizer use can cause negative impacts to turfgrass, including reduced root development and therefore increased susceptibility to drought, loss of applied nitrogen due to leaching, and increased clipping yields.

Overall Recommendations for the Clipping Disposal and Fertilizer Rate Study

The recommendations arising from this study are directed to turfgrass management in Winnipeg and/or surrounding areas with similar climate and soil conditions. The recommendation for low maintenance and slow growing turfgrass seed mixtures is to use either mixture eight (Canada bluegrass, sheeps fescue, and perennial ryegrass) or mixture six (Canada bluegrass, creeping red fescue, sheeps fescue, and perennial ryegrass). If a turfgrass mixture is being designed, two low maintenance turfgrass species to include in a polystand would be Kentucky bluegrass and creeping red fescue. The practice of grasscycling needs to be encouraged. To reduce the environmental impacts of fertilizer use, the use of a slow-release fertilizer at a low application rate, i.e., 0.5 lbs of nitrogen/1000 ft^2, is encouraged. Literature suggests the optimum fertilizer application be twice annually, preferably in early spring (prior to June) and early to late fall (mid-late September) when the cool-season turfgrass species are actively growing.

Longterm Management: These recommendations are based on a two year field study. To understand the longterm management implications of the clipping disposal and fertilizer rates additional study years may be desirable to determine the mixture composition potential over time.

6.4 Mowing Frequency Study

6.4.1 Turfgrass mixtures

Wet Weight Clipping Yields: Clipping yield data, from the 1995 growing season indicates that mixture four (OSECO's Blue Chip Low Maintenance/Reclamation Mixture composed of 20% Canada bluegrass, 20% hard fescue, 20% chewings fescue, 20% red fescue, and 20% perennial ryegrass) and mixture three (Pickseed's Envirogreen composed of 20% Kentucky bluegrass, 40% creeping red fescue, 25% hard fescue and 15% perennial ryegrass) be recommended for use in situations where low maintenance, slow growth is desired.

6.4.2 Mowing frequency

Dry Weight Clipping Yields: Clipping yield data, from the 1995 growing season indicates that mowing frequency does not significantly affect the clipping yields collected for the majority of the species. As indicated in the summary both mixtures two (Pickseed's Cottage N' Country) and six (Pickseed's Town and Country) produced heavier clipping yields when the mowing frequency was reduced, i.e., when the once every other week frequency was imposed. Therefore, to reduce the amount of lawn maintenance the recommendation from this study is that biweekly mowing should be implemented in most situations.

6.5 Further Research

1) To determine the effect of grasscycling alone on turfgrass growth and soil nutrients a control with no fertilizer must be imposed.

2) To assess the suitability of native grasses for low maintenance turfgrass these native species need to be included in turfgrass studies.

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APPENDIX A-Turfgrass Mixtures

Table A1: Grass Seed Mixtures used in the City of Winnipeg in 1992.

Mixture	Purpose	Description
1	Boulevard seeding	**50% Kentucky Bluegrass** 50% each of any two cultivars listed: Park, Baron, Flyking, Touchdown, Liberty, Regent, Sydsport, Banff **25% Creeping Red Fescue** **25% Turf type perennial Ryegrass** One of the following: Elka, Manhattan II, Repell, Blazer, Fiesta II, Gattor, Seville
2	Overseeding existing turf on boulevards, parks and athletic fields.	**75% Kentucky Bluegrass** 50% each of any two cultivars listed: Bronco, Baron, Nugget, Touchdown, Liberty, Welcome, Sydsport, Banff **25% Creeping Red Fescue**
3	Re-seeding boulevards prone to severe drought and winter injury.	**40% Kentucky bluegrass** (Wabash, Huntsville, Banff, Bronco) **40% Chewings Fescue** (Jamestown or Centre) **20% Turf type perennial Ryegrass** One of the following: Elka, Manhattan II, Repell, Blazer, Fiesta II, Gattor, Seville
4	A quick establishment blend for boulevards and parks.	**30% Hybrid perennial Ryegrass, turf type** One of the following Fiesta II, Manhattan II, Elka, Pennant, Repell, Gator, Seville **60% Kentucky Bluegrass** 50% each of any two cultivars listed: Bronco, Baron, Ram I, Touchdown, Liberty, Welcome, Sydsport, Banff, Cynthia, Midnight **10% Creeping Red Fescue**
5	Athletic fields	**60% Kentucky Bluegrass** Any three of the following in equal amounts: Regent, Baron Glade, Midnight, Emundi, A-34, Nugget, Sophia, Touchdown, Banff, Bronco, America **20% Perennial Ryegrass** Any of the following: Fiesta II, Manhattan II, Elka, Pennant, Repell, Lowgrow **20% Turf type Tall Fescue** Any one of the following: Repell II, Jaguar, Williamette, Shortstop, Mustang
7	Bowling/golf greens	**Bentgrass** Penncross
8	Bowling/golf greens	**Bentgrass** Penneagle

Reference: Ashley Langridge, 1996.

Table A2: Turfgrass Mixtures Seeded in the Fertilizer Rate and Clipping Disposal Study, Seeded in 1995.

Mixture	Weight of seed sown grams/ square metre	Description
1	10 g/square metre	100% Kentucky Bluegrass
2	10 g/square metre	100% Canada Bluerass
3	20 g/square metre	100% Creeping Red Fescue
4	20 g/square metre	100% Sheeps Fescue
5	40 g/square metre	100% Perennial Ryegrass
6	3 g/square metre 6 g/square metre 6 g/square metre 4 g/square metre	30% Canada Bluegrass 30% Sheeps Fescue 30% Creeping Red Fescue 10% Perennial Ryegrass
7	4.5 g/square metre 9 g/square metre 4 g/square metre	45% Canada Bluegrass 45% Creeping Red Fescue 10% Perennial Ryegrass
8	4.5 g/square metre 9 g/square metre 4 g/square metre	45% Canada Bluegrass 45% Sheeps Fescue 10% Perennial Ryegrass
9	9 g/square metre 9 g/square metre 4 g/square metre	45% Creeping Red Fescue 45% Sheeps Fescue 10% Perennial Ryegrass
10	9 g/square metre 4 g/square metre	90% Kentucky Bluegrass 10% Perennial Ryegrass

Table A3: Turfgrass Mixtures Seeded in the Mowing Frequency Study, Seeded in 1994.

Mixture		Description
1	Dawson Seed Co.'s Bighorn Sheep Fescue	100% Sheeps Fescue
2	Pickseed's Cottage N' Country	10% Canada Bluegrass 20% Mustang Tall Fescue 25% Creeping Red Fescue 5% White Clover 20% Timothy 20% Annual Ryegrass
3	Pickseed's Envirogreen	20% Kentucky Bluegrass 40% Jasper Creeping Red Fescue 25% Spartan Hard Fescue 15% Lowgrow Perennial Ryegrass
4	OSECO's Blue Chip Low Maintenance/ Reclamation	20% Canada Bluegrass (Certified) 20% Hard Fescue (Certified) 20% Chewings Fescue (Certified) 20% Red Fescue (Certified) 20% Perennial Ryegrass (Certified)
5	Bishop's Low Maintenance Mixture	10% Serra Hard Fescue 10% MX-86 Sheeps Fescue 10% Park Kentucky Bluegrass 25% Koket Chewings Fescue 30% Creeping Red Fescue 15% Omega II Perennial Ryegrass
6	Pickseed's Town and Country (average lawn seed)	50% Creeping Red Fescue 40% Kentucky Bluegrass 10% Fiesta II Perennial Ryegrass
7	Dawson Seed Co.'s Enviro Turf	15% Shade Master Creeping Red Fescue 20% Longfellow Chewings Fescue 25% Serra Hard Fescue 25% Auror Hard Fescue 15% Seville Perennial Ryegrass

APPENDIX B-Experimental Design

Figure 1: Experimental Design of the Clipping Disposal and Fertilizer Rate Study Showing Whole-plot and Split-plot Setup

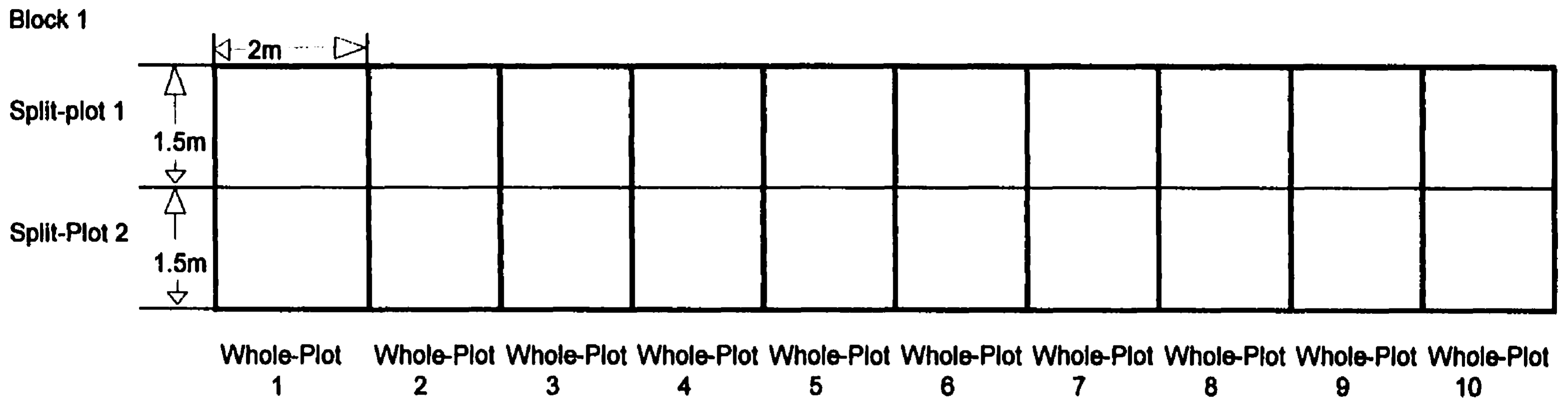


Figure 2: Experimental Design of the Clipping Disposal and Fertilizer Rate Study Showing Whole-plot, Split-plot, and Split-split-plot Setup

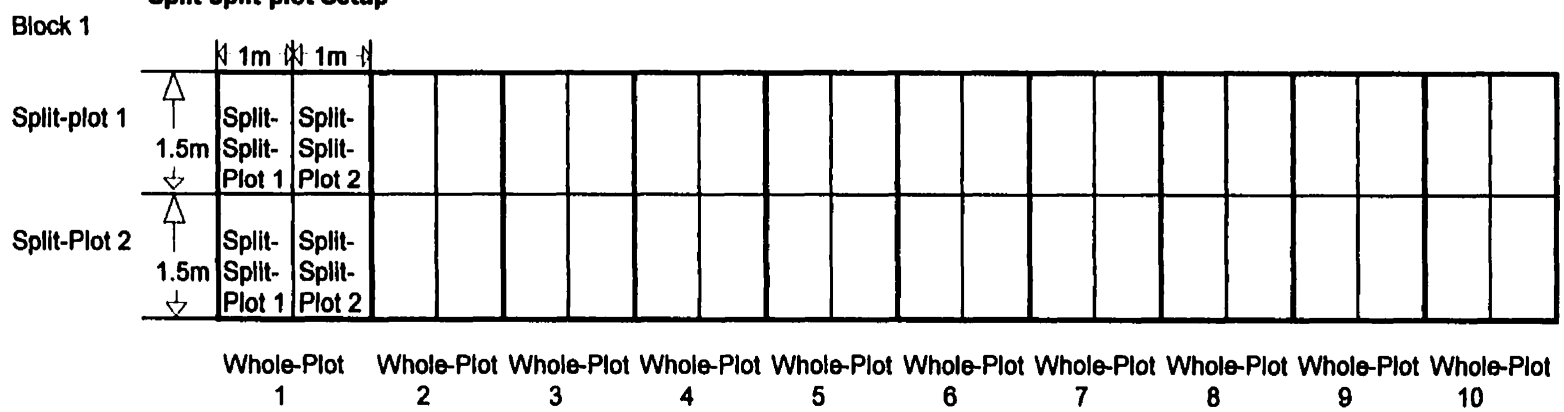


Figure 3: Experimental Design of Turfgrass Mixtures (whole-plots) in the Clipping Disposal and Fertilizer Rate Study

Turfgrass mixtures are as outlined in Appendix A: Table A2

Saunderson Road

	Whole-plot 1	Whole-plot 2	Whole-plot 3	Whole-plot 4	Whole-plot 5	Whole-plot 6	Whole-plot 7	Whole-plot 8	Whole-plot 9	Whole-plot 10
Block 1	10	3	4	5	6	9	7	8	1	2
Block 2	4	8	2	7	1	5	9	3	6	10
Block 3	3	5	8	1	6	2	10	9	4	7
Block 4	7	6	4	2	3	5	8	1	10	9

1 = Turfgrass mixture 1
2 = Turfgrass mixture 2
3 = Turfgrass mixture 3
4 = Turfgrass mixture 4
5 = Turfgrass mixture 5
6 = Turfgrass mixture 6
7 = Turfgrass mixture 7
8 = Turfgrass mixture 8
9 = Turfgrass mixture 9
10 = Turfgrass mixture 10

Figure 4: Experimental Design of Clipping Disposal Methods (split-plots) in the Clipping Disposal and Fertilizer Rate Study

Saunderson Road

		Whole-plot 1	Whole-plot 2	Whole-plot 3	Whole-plot 4	Whole-plot 5	Whole-plot 6	Whole-plot 7	Whole-plot 8	Whole-plot 9	Whole-plot 10
Block 1	Split-plot 1					**Clipping**	**Removal**				
	Split-plot 2					**Grasscycling**					
Block 2	Split-plot 1					**Clipping**	**Removal**				
	Split-plot 2					**Grasscycling**					
Block 3	Split-plot 1					**Clipping**	**Removal**				
	Split-plot 2					**Grasscycling**					
Block 4	Split-plot 1					**Grasscycling**					
	Split-plot 2					**Clipping**	**Removal**				

Figure 5: Experimental Design for Fertilizer Rates (split-split-plots) Applied to the Clipping Disposal and Fertilizer Rate Study in 1996

Saunderson Road

	Whole-plot 1		Whole-plot 2		Whole-plot 3		Whole-plot 4		Whole-plot 5		Whole-plot 6		Whole-plot 7		Whole-plot 8		Whole-plot 9		Whole-plot 10	
Block 1	1	2	2	1	1	2	2	1	1	2	2	1	2	1	1	2	1	2	1	2
	1	2	1	2	2	1	1	2	2	1	2	1	1	2	1	2	2	1	2	1
Block 2	1	2	1	2	2	1	1	2	1	2	1	2	2	1	1	2	1	2	1	2
	1	2	1	2	1	2	2	1	1	2	1	2	1	2	1	2	1	2	1	2
Block 3	1	2	1	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	2	1
	1	2	2	1	1	2	1	2	1	2	1	2	1	2	2	1	1	2	2	1
Block 4	1	2	1	2	1	2	1	2	2	1	2	1	1	2	1	2	2	1	1	2
	1	2	2	1	1	2	2	1	2	1	1	2	1	2	1	2	2	1	2	1

1 = LOW FERTILIZER RATE (application of 0.541 lbs/1000 sq ft, twice/yr)
2 = HIGH FERTILIZER RATE (application of 1.081 lbs/1000 sq ft, twice/yr)

Figure 6: Experimental Design for Fertilizer Rates (split-split-plots) Applied to the Clipping Disposal and Fertilizer Rate Study in 1996

The four * values are different than 1995

Saunderson Road

	Whole-plot 1		Whole-plot 2		Whole-plot 3		Whole-plot 4		Whole-plot 5		Whole-plot 6		Whole-plot 7		Whole-plot 8		Whole-plot 9		Whole-plot 10	
Block 1	1	2	2	1	1	2	2	1	1	2	2	1	2	1	1	2	1	2	1	2
	1	2	1	2	2	1	1	2	2	1	2	1	1	2	2*	1*	2	1	2	1
Block 2	1	2	1	2	2	1	1	2	1	2	1	2	2	1	1	2	1	2	1	2
	1	2	1	2	1	2	2	1	1	2	1	2	1	2	1	2	1	2	1	2
Block 3	1	2	1	2	2	1	2	1	1	2	2	1	1	2	2*	1*	2	1	2	1
	1	2	2	1	1	2	1	2	1	2	1	2	1	2	2	1	1	2	2	1
Block 4	1	2	1	2	1	2	1	2	2	1	2	1	1	2	1	2	2	1	1	2
	1	2	2	1	1	2	2	1	2	1	1	2	1	2	1	2	2	1	2	1

1= LOW FERTILIZER RATE(application of 0.541 lbs/1000 sq ft, twice/yr)
2= HIGH FERTILIZER RATE(application of 1.081 lbs/1000 sq ft, twice/yr)

Figure 7: Experimental Design of Turfgrass Mixtures (whole-plots) in the Mowing Frequency Study

Saunderson Road

	Whole-plot 14	**Mixture 1: Dawson Seed Co.'s Bighorn Sheep Fescue * monostand**
	Whole-plot 13	**Mixture 2: Pickseed's Cottage N' Country**
	Whole-plot 12	**Mixture 3: Pickseed's Envirogreen**
Block 2	Whole-plot 11	**Mixture 4: OSECO's Blue Chip Low Maintenance/Reclamation Mixture**
	Whole-plot 10	**Mixture 5: Bishop's Low Maintenance Mixture**
	Whole-plot 9	**Mixture 6: Pickseed's Town and Country *average lawn seed blend**
	Whole-plot 8	**Mixture 7: Dawson Seed Co.'s Enviro Turf**
	Whole-plot 7	**Mixture 7: Dawson Seed Co.'s Enviro Turf**
	Whole-plot 6	**Mixture 6: Pickseed's Town and Country * average lawn seed blend**
	Whole-plot 5	**Mixture 5: Bishop's Low Maintenance Mixture**
Block 1	Whole-plot 4	**Mixture 4: OSECO's Blue Chip Low Maintenance/Reclamation Mixture**
	Whole-plot 3	**Mixture 3: Pickseed's Envirogreen**
	Whole-plot 2	**Mixture 2: Pickseed's Cottage N' Country**
	Whole-plot 1	**Mixture 1: Dawson Seed Co.'s Bighorn Sheeps Fescue * monostand**

Figure 8: Experimental Design of the Mowing Frequency Study Showing Whole-plot and Split-plot Setup

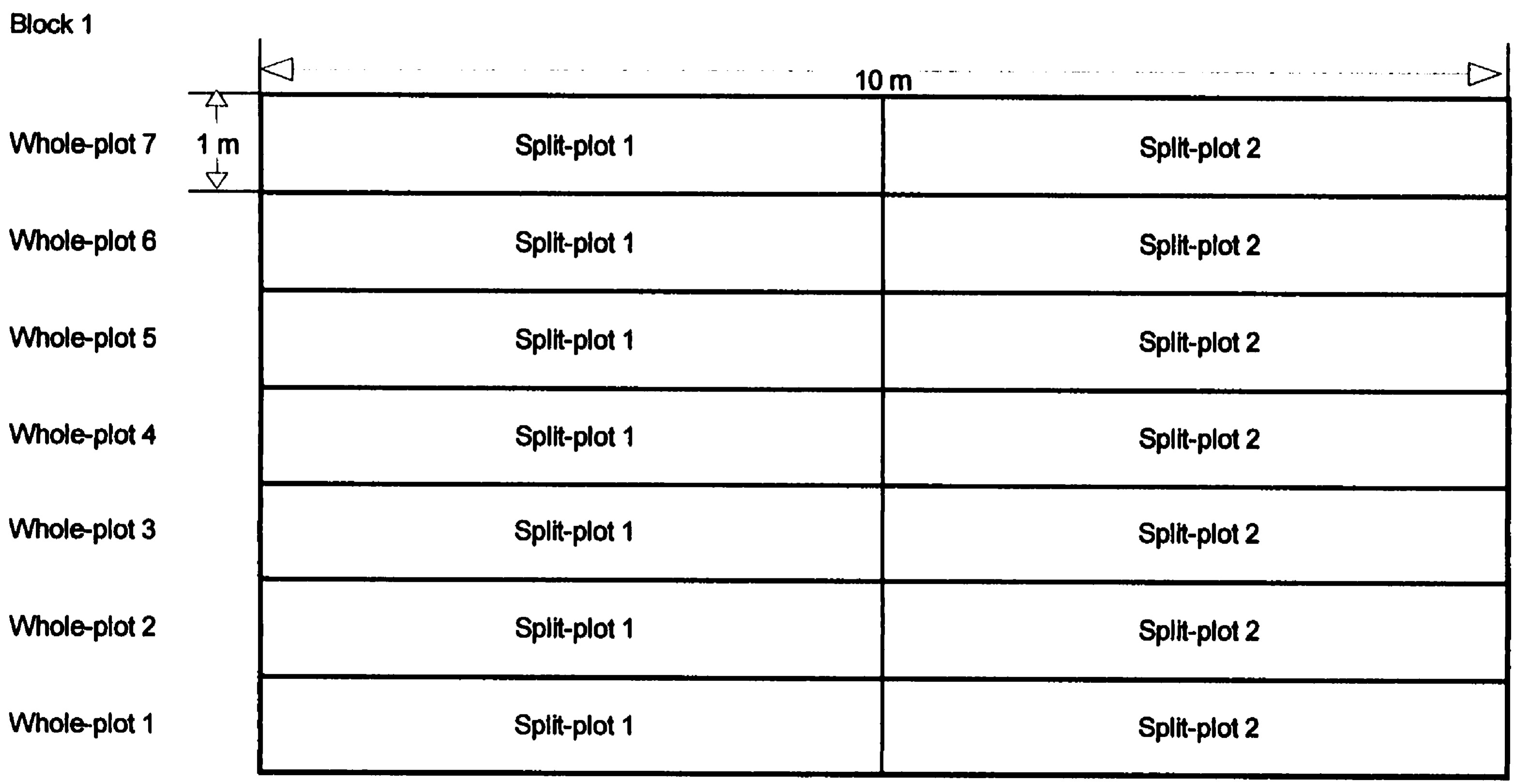


Figure 9: Experimental Design Indicating the Mowing Frequencies (split-plots) in the Mowing Frequency Study

	Whole-plot 14	Mow once per week	Mow every other week
	Whole-plot 13	Mow every other week	Mow once per week
	Whole-plot 12	Mow once per week	Mow every other week
Block 2	Whole-plot 11	Mow once per week	Mow every other week
	Whole-plot 10	Mow once per week	Mow every other week
	Whole-plot 9	Mow once per week	Mow every other week
	Whole-plot 8	Mow once per week	Mow every other week
	Whole-plot 7	Mow every other week	Mow once per week
	Whole-plot 6	Mow every other week	Mow once per week
	Whole-plot 5	Mow once per week	Mow every other week
Block 1	Whole-plot 4	Mow once per week	Mow every other week
	Whole-plot 3	Mow once per week	Mow every other week
	Whole-plot 2	Mow every other week	Mow once per week
	Whole-plot 1	Mow once per week	Mow every other week

APPENDIX C-Turfgrass Characteristics

Characteristics of the Five Cool-Season Turfgrass Species in the Clipping Disposal and Fertilizer Rate Study

a) Kentucky Bluegrass (*Poa pratensis*)

Kentucky bluegrass is the most commonly used cool-season turfgrass because it can survive extremes such as drought, flooding, cold temperatures, and it has a good regrowth capability and fall colour retention (Beard, 1973; Schultz, 1989). It forms a medium textured, green to dark green turf of good shoot density. Kentucky bluegrass prefers well drained, fertile, medium textured soils with a pH between 6 and 7 (Beard, 1973). Nitrogen fertility requirement ranges from 0.4 to 0.7 lbs. of actual nitrogen per 1000 sq ft per growing month.

Some problems with using Kentucky bluegrass as a low maintenance turfgrass include a substantial reduction in shoot growth during extended periods of water and temperature stress, summer dormancy may occur resulting in the aboveground foliage becoming brown and inactive (Beard, 1973), to be aesthetically pleasing Kentucky bluegrass requires a medium to medium high intensity of maintenance (Beard, 1973), and the establishment rate of Kentucky bluegrass is quite slow. It is considerably slower than perennial ryegrass and creeping red fescue (Beard, 1973).

Kentucky Bluegrass is a dark-green perennial sod-forming grass. The stem can grow 30-60 cm tall, the leaves are 5-15 cm long, and the inflorescence is a pyramidal shaped panicle 5-15 cm long (Oakes, 1990). Recommended seeding rate 5-10 g/m^2 (1-2 lb/1000 sq. ft) (Schultz, 1989).

b) Canada Bluegrass (*Poa compressa*)

Canada Bluegrass is a hardy, perennial, sod-forming grass. The stem can grow up to 15-60 cm tall, the leaves are 5-10 cm long, and the inflorescence is a panicle 5-10 cm long (Oakes, 1990). Recommended seeding rate 5-10 g/m^2 (1-2 lb/1000 sq. ft) (Schultz, 1989).

c) Creeping Red Fescue (*Festuca rubra*)

Creeping Red Fescue is an upright, perennial, with creeping rhizomes. The colour of creeping red fescue is medium to dark green, and the vertical shoot growth rate is slower than most cool-season turfgrasses (Beard, 1973). Establishment rate is fairly good, it establishes faster than kentucky bluegrass, but somewhat slower than perennial ryegrass (Beard, 1973). Creeping red fescue is superior to most cool-season turfgrasses in shade tolerance (Beard, 1973). Creeping red fescue requires low amounts of supplemental water and nitrogen, and is more drought tolerant than Kentucky bluegrass. Nitrogen requirements are 0.2 to 0.5 lb per 1000 sq ft per growing month, which is quite low compared to most cool-season turfgrass species (Beard, 1973). Two limitations of creeping red fescue are that it is less tolerant to commonly used herbicides than are other cool-season turfgrasses, and it does not preform well on sports fields and golf greens because of its weak rhizome system and slow recuperative rate. (Beard, 1973).

The stem grows between 40-90 cm in height, the leaves are 20-50 cm long, and the inflorescence is a panicle 5-20 cm long (Oakes, 1990). Recommended seeding rate

10-20 g/m^2 (2-4 lbs./1000 sq. ft) (Schultz, 1989).

d) Fine-Leaved Sheeps Fescue (*Festuca filiformis*)

Fine-Leaved Sheeps Fescue is an upright perennial without rhizomes. Sheeps fescue grows best under non-irrigated conditions where there is a low soil fertility level and no supplemental nitrogen fertilization.

One of the problems of using sheeps fescue is that it has a rather blueish-green look to it making it less aesthetically appealing than some of the other grass species. Sheeps fescue is commonly used as a low quality turf for roadside, roughs and other nonuse areas (Beard, 1973).

The stem grows between 18-55 cm in height, the leaves are 11-23 cm long, and the inflorescence is a panicle 1-4 cm long (Achene, 1990). Recommended seeding rate 10-20 g/m^2 (2-4 lbs./1000 sq. ft) (Schultz, 1989).

e) Perennial Ryegrass (*Lolium perenne*)

Perennial ryegrass is used as a nurse crop in turfgrass mixtures because it is a short-lived perennial that establishes itself quickly. It has a rapid rate of seed gemination, establishment and vertical leaf extension (Beard, 1973). The nitrogen fertility requirement of perennial ryegrass ranges from 0.4 to 1 lbs. per 1000 sq ft per growing month, which is a fairly high nitrogen level.

One problem with perennial ryegrass is that it does not tolerate climatic extremes of cold, heat, or drought, and it has the lowest cold temperature hardiness of all of the perennial cool-season turfgrasses.

Generally, perennial ryegrass should compose no more than 20 to 25% of the seed mixture on a seed number basis. When the perennial ryegrass content in the seed mixture is high, it results in excessive competition with the desirable less competitive turfgrass species, such as kentucky bluegrass (Beard, 1973). Recommended seeding rate 20-40 g/m^2 (4-8 lbs./1000 sq. ft) (Schultz, 1989).

Characteristics of the Cool-Season Turfgrass Species in the Mowing Frequency Study

In addition to the five cool-season turfgrass species used in the clipping disposal and fertilizer rate study chewings fescue, hard fescue, tall fescue, and timothy were also used in the mowing frequency study.

f) Chewings fescue (*Festuca rubra* var. *commutata* Gaud.)

Chewings fescue is a bunch grass and does not form a sod. It is unable to withstand extreme cold and heat stress. It has good wear and drought tolerance. The nitrogen requirements of 0.2 to 0.4 lbs. of actual nitrogen per 1000 sq ft per growing month, is extremely low (Beard, 1973).

g) Hard fescue (*Festuca ovina* var. *duriuscula* L. Koch)

Hard fescue forms a very dense sod, with a tufted appearance. Its tolerance for drought is in between the highly drought tolerant sheeps fescue and the less tolerant creeping red fescue. It has a slightly higher nitrogen fertility requirement than sheeps fescue. It is primarily used in low quality turf areas (Beard, 1973).

h) Tall fescue (*Festuca arundinacea* Schreb.)

Tall fescue grows well in the transition zone between the cool and warm humid regions. Some of the advantages of tall fescue are that it is one of the most heat, drought, and wear tolerant cool-season turfgrasses, and it grows well in a wide range of soil conditions.

Disadvantages of using tall fescue as high quality turfgrass include its very coarse leaves and wide leaf blades, making it aesthetically unpleasing, and its susceptibility to cold temperatures which result in tall fescue thinning out. Nitrogen requirements range from 0.4 to 1.0 lbs. of actual nitrogen per 1000 sq ft per growing month (Beard, 1973).

i) Timothy (*Phleum pratense* L.)

Timothy is a bunch grass with a grayish-green coloration. It is well adapted to cool humid conditions, and establishes rapidly from seed.

Some problems with timothy as a high quality turfgrass are that it has a low tolerance to heat, drought and wear stresses, it does not tolerate being mowed at low heights, and it has a nitrogen requirement ranging from 0.5 to 1.0 lb per 1000 sq. ft per growing month, which is fairly high maintenance. Therefore, it is no surprise that timothy is commonly found in low quality turf areas such as road sides.

APPENDIX D-Climatic Conditions

Table D1: Air Temperature, Soil Temperature, and Total Precipitation for 1995

Month	Actual Date	Mean Temperature (C)	Minimum Temperature (C)	Maximum Temperature (C)	Soil Temperature (C)	Total Precipitation (mm)
January	1	-19.48	-22.73	-13.63	-2.47	0.00
January	2	-23.97	-25.87	-22.34	-3.45	0.00
January	3	-21.11	-29.07	-14.15	-3.97	0.00
January	4	-13.37	-16.61	-9.40	-3.62	0.00
January	5	-19.72	-26.06	-15.14	-3.72	0.00
January	6	-18.20	-26.25	-14.26	-4.03	0.00
January	7	-20.28	-28.45	-15.24	-3.60	0.00
January	8	-24.06	-30.90	-17.34	-4.08	0.00
January	9	-12.07	-17.34	-9.13	-3.41	0.00
January	10	-6.91	-9.23	-4.91	-2.58	0.00
January	11	-7.34	-9.07	-6.16	-2.16	0.00
January	12	-10.36	-11.28	-9.07	-2.06	0.00
January	13	-14.25	-22.67	-10.29	-2.04	0.00
January	14	-16.66	-24.26	-9.42	-2.39	0.00
January	15	-5.79	-9.79	-1.69	-2.15	0.00
January	16	-4.15	-10.82	-1.34	-1.66	0.00
January	17	-10.01	-13.48	-7.40	-1.53	0.00
January	18	-10.14	-13.76	-8.20	-1.51	0.00
January	19	-10.16	-11.24	-8.71	-1.49	0.00
January	20	-14.13	-19.29	-10.69	-1.48	0.00
January	21	-21.66	-26.07	-17.15	-1.62	0.00
January	22	-24.06	-29.56	-16.11	-1.90	0.00
January	23	-19.57	-25.80	-10.45	-2.10	0.00
January	24	-18.42	-24.18	-13.74	-2.15	0.00
January	25	-16.63	-21.99	-10.21	-2.21	0.00
January	26	-12.46	-20.45	-5.17	-2.18	0.00
January	27	-8.57	-11.00	-5.94	-1.86	0.00
January	28	-12.33	-15.67	-9.03	-1.68	0.00
January	29	-5.42	-15.49	3.79	-1.79	0.76

January	30	-1.34	-6.68	2.57	-1.41	1.27
January	31	-11.25	-17.88	-4.97	-1.33	0.00
February	1	-10.28	-19.80	1.44	-1.70	0.00
February	2	-8.38	-13.48	-1.80	-1.53	0.00
February	3	-18.48	-24.56	-13.50	-1.73	0.00
February	4	-22.08	-29.07	-14.93	-2.29	0.00
February	5	-13.63	-17.19	-11.09	-2.47	0.00
February	6	-17.71	-21.54	-11.88	-2.43	0.00
February	7	-8.30	-21.97	-0.52	-2.60	0.00
February	8	-9.80	-16.20	-2.40	-2.17	0.00
February	9	-22.79	-26.52	-16.22	-2.31	0.00
February	10	-20.70	-28.23	-16.28	-2.69	0.00
February	11	-21.37	-26.25	-18.25	-2.76	0.00
February	12	-22.11	-25.41	-17.17	-2.87	0.00
February	13	-19.93	-25.46	-14.67	-3.03	0.00
February	14	-18.92	-26.36	-13.18	-2.97	0.00
February	15	-21.11	-29.21	-12.76	-2.92	0.00
February	16	-15.14	-18.66	-10.05	-2.83	0.00
February	17	-9.02	-16.17	-5.25	-2.52	0.00
February	18	-10.79	-18.35	-4.05	-2.29	0.00
February	19	-10.01	-15.73	-7.22	-2.12	0.00
February	20	-7.07	-13.18	-0.86	-2.03	0.00
February	21	-1.34	-10.70	7.45	-1.86	4.06
February	22	-7.46	-13.00	-2.43	-1.64	0.00
February	23	-9.55	-13.24	-4.43	-1.69	0.00
February	24	-12.26	-14.51	-9.53	-1.82	0.00
February	25	-8.96	-13.96	-5.75	-1.77	0.00
February	26	-18.24	-22.09	-13.70	-1.80	0.00
February	27	-21.39	-25.68	-16.33	-2.22	0.00
February	28	-21.10	-26.87	-15.42	-2.53	0.00
March	1	-11.87	-22.04	-5.15	-2.66	0.00
March	2	-15.18	-24.44	-5.16	-2.37	0.00
March	3	-24.59	-28.39	-22.31	-2.50	0.00
March	4	-19.34	-23.45	-15.55	-2.76	0.00
March	5	-16.78	-18.73	-14.24	-2.76	0.00

March	6	-17.56	-20.42	-13.19	-2.74	0.00
March	7	-20.20	-28.31	-12.85	-2.86	0.00
March	8	-12.62	-24.52	-6.30	-2.96	0.00
March	9	-3.20	-9.39	3.00	-2.56	0.25
March	10	2.34	-4.49	9.87	-2.06	0.00
March	11	4.29	3.09	6.14	-1.02	0.00
March	12	4.29	2.39	5.87	0.19	0.51
March	13	-0.87	-3.96	2.76	0.12	0.00
March	14	-4.57	-6.82	-1.78	0.09	0.00
March	15	1.11	-4.65	6.14	0.05	2.29
March	16	3.91	-0.31	8.73	0.09	2.29
March	17	3.24	0.42	6.23	0.11	0.25
March	18	-0.16	-0.89	1.17	0.11	0.00
March	19	1.65	-1.10	3.52	0.12	0.00
March	20	2.56	0.48	5.28	0.15	0.00
March	21	3.27	-1.43	9.01	3.95	0.00
March	22	2.10	-0.14	4.29	13.37	1.78
March	23	5.71	1.96	10.57	18.49	0.00
March	24	4.82	2.81	8.72	18.54	0.00
March	25	2.82	1.77	3.73	18.03	12.45
March	26	4.13	0.63	8.99	20.80	0.51
March	27	-0.50	-2.68	1.45	9.05	0.00
March	28	-2.06	-4.87	0.78	1.69	0.00
March	29	-1.38	-5.74	2.97	1.19	0.00
March	30	-0.39	-2.75	2.19	0.82	3.81
March	31	-0.48	-5.64	4.09	4.91	0.25
April	1	2.18	-3.49	6.86	11.69	0.00
April	2	-13.01	-15.94	-3.52	-1.00	0.00
April	3	-11.37	-16.07	-6.48	-3.53	0.00
April	4	-6.27	-9.80	-3.60	-2.65	0.00
April	5	-5.13	-11.29	-0.46	-0.88	3.56
April	6	-3.37	-9.39	-0.50	-0.77	0.00
April	7	-6.96	-11.01	-3.17	-2.75	0.00
April	8	-3.90	-11.09	2.24	-2.28	0.00
April	9	0.49	-5.88	7.21	1.02	0.00

April	10	2.56	-1.54	7.26	3.06	0.00
April	11	5.47	-0.32	12.31	3.42	0.00
April	12	6.21	0.50	12.71	4.60	0.00
April	13	7.91	-1.47	16.23	5.44	0.00
April	14	6.19	2.14	10.01	3.20	0.00
April	15	2.75	0.90	5.17	2.88	0.00
April	16	4.74	1.00	10.70	5.23	0.00
April	17	4.54	0.14	9.22	4.57	0.00
April	18	3.76	-2.57	11.37	4.89	0.00
April	19	8.19	-0.59	15.16	6.65	0.00
April	20	4.18	-0.11	9.04	5.04	0.00
April	21	7.19	-2.16	16.18	5.75	0.00
April	22	6.37	0.48	11.92	6.82	0.00
April	23	5.01	-1.72	10.80	5.72	0.00
April	24	2.55	-1.69	7.13	4.26	0.00
April	25	0.76	-2.46	4.24	3.30	0.00
April	26	0.84	-1.96	4.90	3.09	0.51
April	27	4.15	0.04	10.18	5.20	0.51
April	28	7.99	1.08	14.13	7.24	0.00
April	29	7.42	-1.23	13.71	7.65	0.00
April	30	7.37	2.28	11.74	7.32	0.00
May	1	8.61	-2.10	16.53	8.62	2.79
May	2	10.18	5.96	15.45	10.14	0.51
May	3	7.17	1.60	13.09	7.98	0.25
May	4	8.38	-1.79	17.06	9.35	0.00
May	5	12.25	0.41	21.19	11.51	0.00
May	6	13.68	9.16	19.18	12.41	3.05
May	7	14.30	10.07	21.08	12.49	0.51
May	8	13.86	8.74	20.80	12.87	0.00
May	9	14.54	5.62	22.33	14.44	0.00
May	10	10.79	5.46	16.10	14.37	1.27
May	11	2.26	1.50	3.54	7.52	1.52
May	12	4.37	1.31	7.56	6.79	1.52
May	13	8.14	0.34	17.95	9.24	0.00
May	14	5.74	-2.14	12.90	8.04	4.57

May	15	8.89	4.84	14.45	9.25	1.02
May	16	12.36	1.28	20.77	11.18	0.00
May	17	16.71	6.21	25.27	14.20	0.00
May	18	10.87	6.68	15.77	12.10	0.76
May	19	9.28	3.19	14.20	11.67	0.00
May	20	10.53	0.65	17.37	12.36	0.00
May	21	7.75	6.46	10.33	10.16	23.37
May	22	9.33	4.41	13.76	11.25	0.00
May	23	8.94	2.47	15.11	11.55	0.00
May	24	12.50	2.91	20.06	13.19	0.00
May	25	14.93	4.19	22.35	14.99	0.00
May	26	15.83	10.96	21.77	15.91	0.00
May	27	17.61	10.29	23.11	17.32	0.00
May	28	21.58	10.56	30.12	18.30	0.00
May	29	24.90	15.19	33.92	20.41	0.00
May	30	24.70	15.34	32.03	21.68	0.00
May	31	21.23	13.35	28.38	20.18	0.00
June	1	21.00	13.27	29.09	20.09	0.00
June	2	21.74	15.01	30.83	21.15	1.02
June	3	24.39	15.03	31.83	22.02	0.00
June	4	24.67	15.55	31.05	23.59	0.25
June	5	17.42	7.31	27.62	21.78	1.02
June	6	9.83	7.15	14.19	15.04	0.00
June	7	12.85	3.19	19.48	16.84	0.00
June	8	17.27	7.68	25.89	18.56	0.00
June	9	15.61	9.32	20.95	18.17	0.00
June	10	17.58	7.33	25.65	18.69	0.00
June	11	21.41	8.56	29.70	20.89	0.00
June	12	23.15	14.26	30.66	22.74	0.00
June	13	22.99	16.57	32.08	22.63	4.32
June	14	26.75	17.94	34.92	23.85	0.00
June	15	29.01	23.50	34.54	26.46	0.00
June	16	31.26	23.31	38.41	28.12	0.00
June	17	30.12	24.20	36.63	28.61	0.00
June	18	27.87	19.31	35.59	28.61	0.00

June	19	26.02	18.78	36.00	27.25	11.43
June	20	24.17	17.85	31.88	25.26	0.00
June	21	24.13	18.94	31.78	25.38	0.25
June	22	21.06	17.13	26.11	23.89	0.25
June	23	17.46	16.26	18.79	19.98	0.51
June	24	18.29	14.01	22.41	20.59	0.00
June	25	20.34	15.06	24.97	21.54	0.00
June	26	23.03	17.26	27.47	23.16	0.00
June	27	23.08	17.37	29.16	24.54	0.00
June	28	14.13	11.67	17.37	19.54	3.05
June	29	14.36	11.12	19.00	17.25	3.56
June	30	16.47	9.14	22.36	18.14	0.00
July	1	19.21	10.54	26.79	20.82	0.00
July	2	19.55	14.40	25.80	21.53	0.00
July	3	19.11	15.43	24.02	20.39	0.00
July	4	15.36	13.62	17.25	17.44	4.83
July	5	18.02	12.81	23.28	18.71	0.00
July	6	19.21	11.17	28.31	20.59	0.76
July	7	21.16	13.99	26.12	22.29	0.00
July	8	23.01	13.92	30.38	22.81	0.00
July	9	22.84	16.65	27.58	24.17	0.00
July	10	24.07	16.67	31.91	24.10	3.05
July	11	27.45	21.47	32.74	26.79	0.00
July	12	24.82	19.50	30.67	26.53	0.00
July	13	22.73	17.16	28.13	24.99	0.00
July	14	21.24	14.41	29.70	23.53	14.22
July	15	18.84	16.53	22.16	20.95	7.62
July	16	19.77	15.74	24.21	21.04	0.00
July	17	20.35	13.80	26.04	21.63	0.00
July	18	19.82	16.44	24.81	22.03	1.02
July	19	20.72	13.98	26.77	23.21	0.00
July	20	20.84	16.63	25.67	23.19	0.00
July	21	20.04	13.85	26.10	23.31	0.00
July	22	22.99	17.49	29.19	24.64	0.00
July	23	18.62	14.42	22.24	23.35	0.76

July	24	18.80	11.97	25.70	22.17	0.00
July	25	21.96	14.36	28.19	24.26	0.00
July	26	22.89	17.70	29.16	24.27	0.00
July	27	21.11	15.23	25.83	23.00	0.00
July	28	21.01	11.02	28.56	23.87	0.00
July	29	23.77	14.81	29.77	24.76	0.51
July	30	18.25	13.60	24.23	22.89	0.00
July	31	21.28	13.69	28.58	23.44	0.00
August	1	22.37	16.50	30.79	24.46	0.00
August	2	18.73	12.59	24.54	23.02	0.00
August	3	20.96	11.97	28.82	23.98	0.00
August	4	23.82	13.32	31.92	25.70	0.00
August	5	24.13	17.40	30.75	26.48	0.00
August	6	26.02	19.36	33.57	27.91	0.00
August	7	24.17	18.16	31.44	26.79	2.79
August	8	20.76	14.67	27.11	22.46	0.00
August	9	18.17	12.78	23.54	21.38	0.00
August	10	17.64	10.48	24.07	21.95	0.00
August	11	20.00	12.97	26.53	22.66	0.00
August	12	21.19	13.09	31.18	23.43	2.29
August	13	18.02	13.77	23.86	19.47	0.00
August	14	23.37	12.72	33.20	22.58	0.00
August	15	24.93	17.97	31.35	25.81	0.00
August	16	26.34	20.11	33.33	26.11	0.00
August	17	20.83	14.02	24.54	23.02	75.90
August	18	19.52	13.04	26.67	19.28	0.00
August	19	21.13	14.52	27.80	20.34	0.00
August	20	19.37	12.09	26.40	21.50	0.00
August	21	19.84	13.85	28.64	20.88	17.02
August	22	16.28	12.40	21.81	19.14	0.00
August	23	18.08	14.92	22.68	19.86	0.00
August	24	17.98	14.19	24.30	20.62	0.25
August	25	18.89	11.06	27.75	21.01	0.00
August	26	20.06	14.74	27.65	21.64	3.81
August	27	18.39	14.04	23.55	20.74	0.00

August	28	20.66	11.88	28.06	21.39	25.40
August	29	20.34	14.05	23.21	20.75	1.27
August	30	16.99	11.74	23.22	19.00	0.25
August	31	18.99	10.04	28.20	20.41	0.00
September	1	18.56	13.43	23.51	20.55	0.00
September	2	20.19	9.61	30.19	21.07	0.00
September	3	20.83	14.59	27.82	21.93	0.00
September	4	19.13	11.98	25.83	20.59	0.25
September	5	14.52	8.39	17.89	17.46	29.21
September	6	9.77	3.87	16.24	14.27	0.00
September	7	12.57	5.23	20.41	15.02	0.00
September	8	11.18	5.44	17.70	15.18	0.00
September	9	16.94	9.39	23.85	16.87	0.00
September	10	18.68	12.93	26.01	18.68	0.00
September	11	20.80	15.08	28.97	19.61	0.00
September	12	14.62	6.55	20.60	17.58	0.00
September	13	12.78	3.30	21.48	15.33	0.00
September	14	17.22	10.31	24.49	17.29	0.00
September	15	12.40	5.39	16.27	15.52	0.00
September	16	11.10	3.80	17.95	13.40	0.00
September	17	6.84	3.43	9.85	11.22	1.78
September	18	5.37	2.55	8.71	9.26	0.00
September	19	3.64	0.38	7.94	8.70	2.29
September	20	3.32	0.47	7.26	7.84	1.02
September	21	4.86	-1.60	12.83	8.38	0.00
September	22	7.33	-1.43	16.44	9.31	0.00
September	23	12.33	6.31	19.42	11.76	0.00
September	24	13.79	7.53	23.13	13.56	0.00
September	25	12.75	5.91	22.41	13.62	0.00
September	26	15.83	5.50	27.17	14.81	0.00
September	27	17.14	10.73	26.35	15.49	4.06
September	28	14.12	7.52	24.11	14.41	0.00
September	29	11.65	8.39	14.61	12.64	0.00
September	30	10.37	5.31	16.56	11.77	0.00
October	1	8.43	2.55	14.21	10.69	5.84

October	2	9.31	3.20	14.12	11.71	2.79
October	3	7.26	1.74	11.77	9.65	0.00
October	4	8.71	4.69	11.48	10.41	0.00
October	5	5.73	2.42	8.68	8.34	0.00
October	6	6.26	0.42	13.60	8.75	0.00
October	7	7.76	0.42	15.31	9.26	0.00
October	8	9.44	5.28	14.72	10.01	0.00
October	9	12.09	3.08	20.62	10.50	0.00
October	10	14.17	8.78	22.30	12.13	0.00
October	11	13.68	8.15	21.28	12.40	0.00
October	12	6.49	2.40	10.03	9.44	9.65
October	13	4.61	1.87	7.10	6.62	0.00
October	14	4.35	-0.55	11.40	6.14	0.00
October	15	6.97	-1.53	14.16	6.59	0.00
October	16	7.64	2.62	10.90	7.48	0.00
October	17	3.20	-0.59	6.32	5.49	6.60
October	18	3.87	2.15	5.22	5.83	8.89
October	19	2.87	-1.21	7.71	5.21	1.52
October	20	-0.44	-4.23	3.04	2.97	0.00
October	21	2.89	-1.51	8.71	3.60	0.00
October	22	3.07	-1.64	7.91	4.05	0.00
October	23	3.30	-3.29	10.50	3.89	0.00
October	24	4.45	-0.80	9.66	4.79	0.00
October	25	3.81	-3.43	10.02	3.97	0.00
October	26	5.58	1.11	11.61	5.15	0.00
October	27	3.05	-0.06	5.39	4.83	2.29
October	28	-0.87	-2.78	1.67	2.77	0.00
October	29	-1.70	-4.55	1.29	2.36	0.00
October	30	-1.46	-6.17	2.09	1.20	0.00
October	31	0.59	0.11	1.68	1.99	6.86
November	1	-3.31	-7.56	0.14	2.17	0.00
November	2	-9.77	-16.14	-7.41	2.11	0.00
November	3	-10.41	-16.54	-4.33	1.97	0.00
November	4	-3.84	-11.90	2.37	1.74	0.00
November	5	-1.75	-6.13	2.29	1.88	0.00

November	6	-8.45	-11.48	-5.38	1.75	0.00
November	7	-9.34	-10.87	-7.57	1.53	0.00
November	8	-6.56	-9.89	-4.04	1.44	0.00
November	9	-10.48	-15.07	-6.34	1.67	0.00
November	10	-18.27	-22.37	-13.91	1.77	0.00
November	11	-18.47	-24.28	-9.32	1.58	0.00
November	12	-10.77	-17.70	-6.36	1.47	0.00
November	13	-5.45	-7.78	-2.97	1.67	0.00
November	14	-3.83	-6.49	-2.83	1.89	0.00
November	15	-5.65	-10.14	-2.66	1.97	0.00
November	16	-4.01	-5.20	-1.45	2.01	0.00
November	17	-2.73	-4.71	-0.33	2.08	0.00
November	18	2.23	-0.72	6.21	2.13	8.38
November	19	-4.19	-8.67	-0.72	2.05	0.00
November	20	-10.80	-13.37	-6.66	1.90	0.00
November	21	-10.43	-18.14	-5.66	1.73	0.00
November	22	-17.26	-21.35	-13.58	1.40	0.00
November	23	-10.43	-13.58	-8.01	1.40	0.00
November	24	-13.81	-17.53	-10.07	1.26	0.00
November	25	-18.06	-20.90	-14.54	0.64	0.00
November	26	-16.12	-19.19	-14.02	0.30	0.00
November	27	-16.74	-22.44	-12.35	0.16	0.00
November	28	-14.57	-23.52	-7.40	0.05	0.00
November	29	-7.51	-11.06	-4.73	0.21	0.00
November	30	-15.03	-18.37	-11.07	0.32	0.00
December	1	-7.80	-12.07	-3.75	0.37	0.00
December	2	-9.33	-13.67	-5.11	0.44	0.00
December	3	-4.16	-13.77	0.70	0.46	0.00
December	4	-15.85	-18.53	-8.05	0.49	0.00
December	5	-19.37	-23.61	-16.12	0.31	0.00
December	6	-21.60	-26.07	-16.18	0.09	0.00
December	7	-21.95	-25.33	-18.13	-0.03	0.00
December	8	-26.12	-28.34	-23.52	-0.41	0.00
December	9	-27.87	-30.11	-24.84	-0.65	0.00
December	10	-29.18	-31.91	-26.68	-0.85	0.00

December	11	-30.35	-35.43	-25.13	-1.05	0.00
December	12	-14.37	-25.29	-8.79	-1.00	0.00
December	13	-10.70	-14.62	-8.30	-0.58	0.00
December	14	-17.06	-24.39	-12.38	-0.43	0.00
December	15	-17.19	-23.55	-13.61	-0.51	0.00
December	16	-14.97	-19.34	-12.33	-0.44	0.00
December	17	-17.15	-21.91	-9.12	-0.51	0.00
December	18	-11.48	-15.12	-8.78	-0.53	0.00
December	19	-10.45	-14.66	-8.29	-0.37	0.00
December	20	-8.99	-10.19	-7.79	-0.33	0.00
December	21	-12.35	-17.34	-7.75	-0.35	0.00
December	22	-6.34	-12.00	-3.31	-0.44	0.00
December	23	-8.87	-17.47	-4.25	-0.26	0.00
December	24	-10.61	-15.98	-3.19	-0.25	0.00
December	25	-4.59	-11.27	-0.78	-0.20	0.00
December	26	-14.20	-21.43	-10.93	-0.31	0.00
December	27	-10.66	-16.98	-5.92	-0.42	0.00
December	28	-15.23	-21.46	-9.40	-0.54	0.00
December	29	-10.36	-13.55	-6.86	-0.57	0.00
December	30	-5.80	-7.09	-4.08	-0.39	0.00

Table D2: Air Temperature, Soil Temperature, and Total Precipitation for 1996

Month	Actual Date	Mean Temperature (C)	Minimum Temperature (C)	Maximum Temperature (C)	Soil Temperature (C)	Total Precipitation (mm)
January	1	-15.56	-19.09	-12.33	-0.40	0.00
January	2	-14.55	-18.06	-12.26	-0.52	0.00
January	3	-25.24	-29.52	-17.74	-0.62	0.00
January	4	-28.54	-31.32	-23.69	-0.84	0.00
January	5	-29.64	-35.31	-22.15	-1.02	0.00
January	6	-20.09	-31.51	-12.56	-1.08	0.00
January	7	-9.64	-15.89	-4.20	-0.87	0.00
January	8	-6.92	-8.22	-5.38	-0.62	0.00
January	9	-4.00	-6.89	-1.55	-0.42	0.00
January	10	-4.68	-10.11	0.55	-0.30	0.00
January	11	1.44	-5.49	6.56	-0.24	9.65
January	12	-11.51	-18.86	-5.50	-0.17	0.00
January	13	-24.70	-30.10	-18.87	-0.53	0.00
January	14	-22.67	-30.90	-17.63	-0.98	0.00
January	15	-16.98	-19.91	-15.58	-0.97	0.00
January	16	-23.19	-27.31	-19.61	-0.86	0.00
January	17	-30.82	-33.09	-27.31	-1.32	0.00
January	18	-31.88	-36.49	-26.14	-1.59	0.00
January	19	-31.24	-38.87	-25.21	-1.58	0.00

January	20	-25.36	-31.99	-18.75	-1.57	0.00
January	21	-25.94	-30.20	-19.98	-1.52	0.00
January	22	-25.90	-32.57	-17.40	-1.50	0.00
January	23	-27.83	-32.71	-19.42	-1.55	0.00
January	24	-30.36	-36.27	-21.21	-1.63	0.00
January	25	-28.14	-34.25	-19.59	-1.71	0.00
January	26	-26.51	-30.84	-23.00	-1.82	0.00
January	27	-28.50	-34.51	-24.61	-1.89	0.00
January	28	-26.42	-30.12	-22.80	-1.97	0.00
January	29	-31.40	-35.30	-27.73	-1.79	0.00
January	30	-31.17	-34.12	-28.18	-1.81	0.00
January	31	-35.82	-38.14	-33.54	-1.91	0.00
February	1	-33.79	-38.73	-29.05	-1.98	0.00
February	2	-29.87	-34.09	-23.92	-2.03	0.00
February	3	-23.24	-30.66	-15.21	-2.02	0.00
February	4	-21.67	-28.33	-17.29	-1.97	0.00
February	5	-6.93	-17.97	3.39	-1.82	2.03
February	6	-0.95	-6.08	4.88	-1.54	0.00
February	7	-5.07	-11.42	0.19	-1.24	0.00
February	8	-1.14	-9.35	2.92	-1.06	3.05
February	9	-1.74	-4.28	0.76	-0.87	1.02
February	10	-4.89	-5.98	-3.32	-0.66	0.00
February	11	-7.28	-10.39	-4.82	-0.53	0.00
February	12	-3.62	-8.98	-1.37	-0.46	0.00
February	13	-10.73	-13.39	-2.81	-0.44	0.00

March	10	-1.89	-8.65	4.28	-1.13	0.00
March	11	2.35	-1.73	9.27	-0.93	2.29
March	12	1.10	-4.80	8.45	-0.35	0.00
March	13	-4.57	-9.45	1.51	0.15	0.00
March	14	-1.20	-10.93	4.17	0.12	0.76
March	15	0.48	-5.74	5.03	0.12	2.29
March	16	-6.77	-8.02	-4.94	0.18	0.00
March	17	-7.50	-9.53	-5.06	0.16	0.00
March	18	-8.45	-11.03	-6.18	0.13	0.00
March	19	-7.64	-16.33	2.89	0.13	0.00
March	20	-4.64	-11.32	1.61	0.13	0.00
March	21	-6.61	-11.88	-3.21	0.11	0.00
March	22	-11.59	-16.10	-7.04	0.07	0.00
March	23	-14.48	-16.24	-12.62	0.04	0.00
March	24	-20.20	-25.22	-15.97	-0.17	0.00
March	25	-19.15	-27.84	-12.39	-0.47	0.00
March	26	-11.40	-15.56	-7.39	-0.60	0.00
March	27	-11.12	-19.41	-1.82	-0.65	0.00
March	28	-8.49	-17.81	-0.78	-0.70	0.00
March	29	-4.56	-11.97	-0.59	-0.71	0.00
March	30	-7.40	-14.55	-0.58	-0.61	0.00
March	31	-10.97	-21.64	-4.43	-0.54	0.00
April	1	-9.47	-16.52	-5.25	-0.55	0.00
April	2	-4.76	-7.19	-0.84	-0.50	0.25
April	3	-5.95	-12.15	0.45	-0.45	0.76

February	14	-16.02	-20.27	-12.59	-0.46	0.00
February	15	-16.79	-26.23	-10.97	-0.54	0.00
February	16	-20.50	-25.19	-16.18	-0.65	0.00
February	17	-15.82	-25.82	-10.01	-0.72	0.00
February	18	-4.91	-14.45	5.82	-0.76	5.33
February	19	-15.67	-20.87	-6.72	-0.73	0.00
February	20	-7.52	-15.43	-1.43	-0.72	0.00
February	21	-1.03	-4.66	1.71	-0.72	1.52
February	22	0.31	-4.47	2.15	-0.62	9.91
February	23	-9.89	-15.55	-4.18	-0.48	0.00
February	24	-18.39	-21.38	-15.53	-0.41	0.00
February	25	-19.45	-22.49	-16.01	-0.49	0.00
February	26	-19.87	-21.58	-17.59	-0.72	0.00
February	27	-21.09	-24.55	-15.58	-1.01	0.00
February	28	-14.00	-22.81	-7.64	-1.09	0.00
February	29	-13.67	-21.35	-7.99	-1.10	0.00
March	1	-22.15	-26.11	-16.55	-1.13	0.00
March	2	-20.06	-29.53	-10.44	-1.14	0.00
March	3	-19.06	-25.80	-10.76	-1.17	0.00
March	4	-21.96	-27.49	-16.57	-1.21	0.00
March	5	-23.00	-32.51	-13.68	-1.26	0.00
March	6	-21.16	-29.15	-15.80	-1.33	0.00
March	7	-12.77	-17.39	-7.67	-1.40	0.00
March	8	-12.63	-22.66	-4.46	-1.37	0.00
March	9	-5.07	-10.75	1.38	-1.28	0.00

April	4	-4.38	-10.51	0.89	-0.39	1.27
April	5	-5.70	-14.82	5.09	-0.34	0.76
April	6	-4.02	-16.16	4.85	-0.31	0.00
April	7	1.22	-1.84	7.09	-0.28	0.00
April	8	3.66	-0.02	8.41	-0.08	0.00
April	9	4.78	2.18	8.48	0.12	0.00
April	10	0.19	-2.93	2.21	0.16	0.00
April	11	-2.08	-7.28	1.29	0.20	0.00
April	12	0.94	-7.25	11.02	0.20	0.00
April	13	1.72	-3.00	6.58	0.20	0.00
April	14	1.23	-3.32	4.39	0.20	2.29
April	15	1.72	-6.45	7.24	0.20	0.00
April	16	6.64	2.34	11.65	0.32	0.00
April	17	6.74	2.99	13.79	0.35	0.00
April	18	0.92	-1.34	4.25	0.38	0.00
April	19	-0.24	-2.30	2.96	0.28	6.35
April	20	-1.79	-4.41	1.98	0.18	0.76
April	21	1.05	-5.01	7.69	0.19	1.27
April	22	2.64	-2.44	5.71	0.22	0.25
April	23	1.87	-2.40	4.79	0.19	10.67
April	24	0.48	-1.94	2.34	0.27	7.37
April	25	-1.78	-5.89	2.05	0.21	6.60
April	26	1.36	-7.85	7.38	0.19	0.00
April	27	4.77	-1.44	10.90	0.16	0.00
April	28	9.75	1.49	14.44	9.86	0.00

April	29	8.93	3.70	11.73	13.37	0.00
April	30	3.10	-0.37	7.20	4.44	0.00
May	1	4.18	-2.16	10.46	4.23	0.00
May	2	4.95	-1.77	10.72	6.09	0.00
May	3	8.32	-1.79	15.95	8.72	0.00
May	4	10.82	0.18	18.05	11.09	0.00
May	5	10.39	3.16	15.79	11.75	0.00
May	6	10.25	4.69	15.05	12.75	0.00
May	7	9.06	0.28	16.25	11.94	0.51
May	8	1.66	-1.45	6.47	8.03	0.00
May	9	2.46	-2.84	7.91	7.24	0.00
May	10	5.28	-1.75	10.93	7.80	0.00
May	11	8.25	-0.52	14.76	8.85	0.00
May	12	11.61	2.60	19.53	11.10	0.00
May	13	11.32	9.25	14.45	11.08	0.00
May	14	10.81	7.43	15.21	11.46	8.38
May	15	11.92	6.88	18.78	12.16	12.70
May	16	12.88	10.87	15.03	12.94	19.81
May	17	14.12	9.70	20.77	13.74	4.06
May	18	10.38	6.63	16.33	25.97	38.35
May	19	11.36	6.51	16.05	13.38	0.00
May	20	9.61	6.41	13.26	12.57	1.27
May	21	8.62	3.21	13.92	11.26	0.00
May	22	10.35	5.24	15.01	12.97	0.00
May	23	11.67	2.92	18.41	13.68	0.00

May	24	14.56	6.51	21.13	15.45	0.00
May	25	17.08	7.98	23.73	17.21	0.00
May	26	17.40	9.01	24.29	17.33	0.00
May	27	18.17	7.84	25.93	18.21	0.00
May	28	18.31	8.23	26.04	18.78	0.00
May	29	18.71	9.19	25.00	18.14	0.00
May	30	16.19	13.95	19.59	16.87	12.95
May	31	17.96	13.48	25.27	17.68	3.30
June	1	11.34	6.18	14.89	15.49	0.00
June	2	11.45	5.55	19.69	14.23	0.00
June	3	17.78	7.22	25.13	16.68	0.00
June	4					
June	5			23.24	16.01	0.00
June	6	19.72	9.15	26.47	17.76	0.00
June	7	22.96	15.32	29.36	20.40	0.00
June	8	25.27	16.71	32.86	22.41	0.00
June	9	24.53	16.79	33.86	23.69	1.27
June	10	24.19	15.41	34.28	23.49	0.00
June	11	21.65	14.59	26.22	22.79	0.00
June	12	21.84	12.49	29.47	21.76	0.00
June	13	24.69	16.30	32.39	23.29	0.00
June	14	22.56	15.06	28.47	24.07	0.25
June	15	19.23	13.18	25.22	22.76	0.00
June	16	22.54	13.35	30.10	23.39	0.00
June	17	23.12	16.40	29.84	24.03	0.00

June	18	17.57	12.31	21.22	20.78	4.57
June	19	19.20	12.44	24.83	18.78	0.00
June	20	13.86	8.32	19.01	17.52	0.00
June	21	10.84	6.66	16.41	15.93	0.00
June	22	10.17	5.77	13.14	14.25	2.54
June	23	15.29	9.19	21.51	16.94	0.00
June	24	14.88	8.42	21.74	16.23	3.05
June	25	20.24	15.98	23.05	18.78	0.00
June	26	28.49	20.02	35.35	23.69	0.00
June	27	27.61	23.15	32.95	24.99	2.79
June	28	23.43	18.67	30.47	23.26	1.02
June	29	20.73	14.49	26.37	21.61	0.00
June	30	21.55	15.36	28.07	21.98	0.00
July	1	23.42	13.70	30.75	24.27	0.00
July	2	23.49	13.29	30.41	24.80	0.00
July	3	23.99	17.54	30.29	25.20	0.00
July	4	24.38	20.62	29.72	25.31	0.25
July	5	22.33	16.65	26.13	24.91	0.00
July	6	16.85	12.36	24.85	20.75	11.68
July	7	15.62	13.09	20.21	18.19	4.57
July	8	17.74	9.57	24.89	20.37	0.00
July	9	19.96	10.35	26.41	22.75	6.60
July	10	18.44	15.08	24.33	21.71	5.33
July	11	19.89	15.32	25.49	21.77	0.00
July	12	21.34	14.37	29.40	23.52	0.00

July	13	21.10	16.06	26.64	24.11	0.00
July	14	21.17	14.04	27.88	24.28	0.00
July	15	21.41	14.12	26.74	22.98	12.95
July	16	24.74	19.05	30.26	24.80	0.00
July	17	23.21	18.93	28.27	24.66	0.51
July	18	20.65	17.12	25.97	22.88	0.00
July	19	19.53	14.45	25.73	21.32	14.99
July	20	21.23	15.09	27.87	22.06	0.51
July	21	18.37	12.04	23.89	20.68	0.00
July	22	17.71	14.89	21.14	20.03	0.00
July	23	18.52	14.36	23.73	19.94	2.03
July	24	19.22	12.57	25.70	21.22	0.00
July	25	17.74	12.17	24.83	20.04	0.00
July	26	19.08	14.47	24.68	21.22	0.00
July	27	17.01	13.23	20.96	20.27	0.00
July	28	19.21	14.58	26.54	21.26	8.13
July	29	20.05	13.68	25.88	21.53	0.00
July	30	20.65	12.79	27.06	22.41	0.00
July	31	21.08	12.87	28.16	22.55	0.00
August	1	22.63	16.44	28.33	23.55	0.00
August	2	23.38	16.98	29.09	23.98	0.00
August	3	22.33	18.85	28.97		77.00
August	4	22.99	16.65	28.72	26.11	0.00
August	5	21.31	16.10	24.35	24.23	0.00
August	6	17.67	14.07	23.50	21.67	9.65

August	7	15.68	12.21	19.43	19.28	0.00
August	8	17.14	12.67	22.67	20.77	0.00
August	9	20.06	11.20	27.77	21.72	0.00
August	10	21.31	14.58	25.50	22.64	0.00
August	11	19.10	10.50	26.09	22.02	0.00
August	12	19.16	14.83	24.86	22.21	0.00
August	13	19.20	13.46	25.40	22.14	0.00
August	14	21.56	13.13	29.15	22.73	0.00
August	15	22.94	15.54	31.13	24.14	0.00
August	16	23.29	15.05	32.87	24.16	0.00
August	17	23.42	18.40	28.97	24.60	0.00
August	18	18.04	14.04	21.79	21.87	32.00
August	19	19.49	11.21	26.84	21.00	0.51
August	20	19.15	16.06	23.15	21.04	10.67
August	21	18.57	12.97	24.63	20.33	0.00
August	22	20.88	13.25	29.41	21.36	0.00
August	23	22.35	14.15	33.32	21.79	0.00
August	24	17.11	11.89	21.35	19.86	0.00
August	25	17.92	10.21	25.07	19.56	0.00
August	26	20.66	13.43	28.24	20.35	0.00
August	27	21.02	14.00	28.29	21.10	0.00
August	28	21.58	13.25	30.58	21.28	0.00
August	29	22.98	14.23	31.65	21.75	0.00
August	30	24.23	16.57	32.06	23.04	0.00
August	31	20.48	16.57	27.59	21.64	6.10

September	1	20.92	15.16	28.48	20.60	0.25
September	2	19.75	14.17	25.90	19.83	0.00
September	3	16.53	9.68	22.17	18.57	2.54
September	4	19.24	13.92	26.22	18.22	4.83
September	5	18.83	12.80	24.86	19.41	0.51
September	6	16.88	8.48	25.19	17.93	0.00
September	7	19.59	12.69	27.62	18.55	0.51
September	8	19.38	14.55	25.66	19.86	12.19
September	9	14.23	10.22	17.20	17.55	5.59
September	10	12.27	9.63	15.37	14.81	0.00
September	11	12.71	9.29	15.06	14.63	0.00
September	12	12.66	5.60	20.37	14.94	0.00
September	13	11.37	2.20	19.68	14.38	0.00
September	14	13.01	4.89	21.09	14.66	0.00
September	15	12.98	6.51	17.71	14.59	0.00
September	16	13.76	7.17	21.58	15.43	0.00
September	17	14.27	5.32	23.60	15.55	0.00
September	18	15.33	8.10	23.76	15.95	0.00
September	19	13.25	7.90	19.58	14.85	2.03
September	20	13.64	12.21	16.47	15.17	5.59
September	21	13.16	10.57	16.58	14.97	0.25
September	22	11.02	6.00	17.18	13.21	0.76
September	23	7.76	1.36	15.03	11.24	1.02
September	24	10.08	3.69	19.32	11.97	0.00
September	25	8.39	5.61	10.11	10.61	18.80

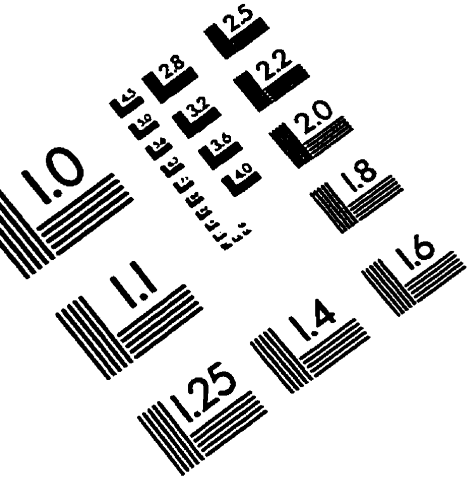
September	26	9.69	7.82	11.27	10.87	1.52
September	27	8.31	4.55	10.69	10.12	0.00
September	28	5.63	0.53	10.10	8.80	0.00
September	29	7.22	4.05	12.31	9.65	2.79
September	30	4.00	0.41	6.97	7.71	5.33
October	1	3.88	-0.46	9.72	6.30	0.00
October	2	3.95	-2.84	10.74	6.21	0.00
October	3	10.61	3.15	17.48	8.78	0.00
October	4	15.70	10.31	23.47	11.98	0.00
October	5	6.60	-0.10	10.89	10.39	0.00
October	6	5.58	-3.77	12.30	7.74	0.00
October	7	10.51	7.07	16.94	10.10	0.00
October	8	5.16	0.93	9.59	8.81	0.00
October	9	8.68	0.35	15.97	8.53	0.00
October	10	11.13	5.98	19.45	9.75	0.00
October	11	11.40	1.90	22.91	10.34	0.00
October	12	7.79	2.96	13.16	9.74	0.00
October	13	9.25	4.48	12.67	8.93	0.00
October	14	12.95	7.71	19.83	10.39	0.00
October	15	8.62	3.59	14.79	9.17	0.00
October	16	5.11	3.52	6.30	6.80	0.00
October	17	3.18	0.71	7.74	5.54	0.00
October	18	8.32	2.60	13.13	7.23	0.00
October	19	9.31	5.41	15.07	8.45	0.51
October	20	6.77	4.54	9.31	8.55	1.52

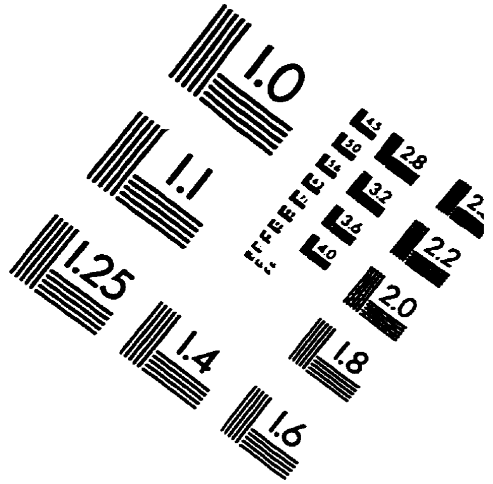
October	21	3.26	1.88	4.67	6.93	0.00
October	22	3.09	1.50	5.51	6.20	0.00
October	23	2.97	-3.24	10.04	5.42	0.00
October	24	4.15	1.73	5.88	5.79	0.25
October	25	5.44	3.89	6.67	6.36	17.53
October	26	4.05	1.07	6.90	5.40	0.00
October	27	3.94	0.34	9.61	4.67	0.00
October	28	4.41	-6.35	8.80	5.83	0.00
October	29	-9.36	-11.73	-6.35	0.59	0.00
October	30	-5.35	-10.61	-2.76	-0.16	0.00
October	31	-7.18	-9.81	-4.01	-0.78	0.00
November	1	-3.05	-10.61	3.61	-0.72	0.00
November	2	1.93	-2.36	9.99	0.07	0.00
November	3	-0.93	-2.96	2.55	0.39	0.00
November	4	-0.13	-3.55	3.27	0.55	0.00
November	5	0.22	-0.31	0.51	1.25	0.00
November	6	-1.16	-7.10	1.20	1.36	1.27
November	7	-1.14	-5.98	1.15	1.51	0.00
November	8	-6.85	-8.28	-4.95	1.54	0.00
November	9	-8.49	-12.13	-5.91	1.29	0.00
November	10	-12.01	-16.42	-7.94	1.04	0.00
November	11	-14.78	-20.08	-6.24	0.64	0.00
November	12	-16.19	-21.58	-9.23	0.15	0.00
November	13	-12.65	-21.66	-4.89	-0.30	0.00
November	14	-3.09	-5.80	-0.51	-0.08	0.00

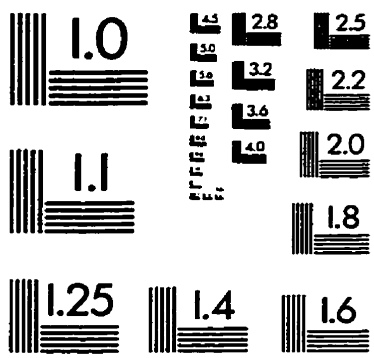
November	15	-6.59	-10.10	-2.71	0.03	0.00
November	16	-8.65	-10.04	-5.64	0.01	0.00
November	17	-13.01	-17.09	-10.05	0.03	0.00
November	18	-17.46	-20.60	-14.98	-0.02	0.00
November	19	-11.29	-18.33	-6.64	-0.06	0.00
November	20	-18.82	-23.43	-9.70	0.03	0.00
November	21	-17.56	-23.46	-14.38	0.00	0.00
November	22	-17.80	-23.59	-12.90	-0.04	0.00
November	23	-17.80	-24.75	-13.54	-0.07	0.00
November	24	-21.04	-25.92	-15.97	-0.15	0.00
November	25	-21.80	-27.10	-15.80	-0.27	0.00
November	26	-17.96	-27.09	-11.63	-0.37	0.00
November	27	-10.58	-19.91	-4.81	-0.35	0.00
November	28	-5.18	-8.21	-3.36	-0.18	0.00
November	29	-7.43	-8.85	-5.22	-0.03	0.00
November	30	-10.67	-15.54	-8.61	-0.02	0.00
December	1	-12.37	-17.44	-8.96	-0.09	0.00
December	2	-13.48	-15.34	-11.38	-0.08	0.00
December	3	-8.79	-11.50	-6.79	-0.04	0.00
December	4	-7.07	-10.08	-4.74	0.05	0.00
December	5	-5.10	-6.18	-4.12	0.14	0.00
December	6	-4.00	-4.88	-3.29	0.19	0.00
December	7	-8.13	-14.65	-4.31	0.21	0.00
December	8	-7.19	-9.34	-4.68	0.19	0.00
December	9	-10.57	-13.26	-7.67	0.19	0.00

December	10	-3.31	-8.16	-0.39	0.18	0.00
December	11	-3.26	-7.78	-0.84	0.22	0.00
December	12	-9.59	-19.47	-5.16	0.28	0.00
December	13	-15.75	-20.37	-11.31	0.32	0.00
December	14	-19.18	-23.96	-12.15	0.31	0.00
December	15	-12.78	-17.51	-8.99	0.27	0.00
December	16	-15.89	-19.70	-13.47	0.20	0.00
December	17	-21.04	-23.73	-19.67	0.02	0.00
December	18	-24.88	-28.33	-20.77	-0.33	0.00
December	19	-15.75	-20.73	-13.20	-0.53	0.00
December	20	-25.37	-30.74	-17.33	-0.49	0.00
December	21	-27.88	-31.44	-22.30	-0.57	0.00
December	22	-27.55	-33.04	-23.90	-0.66	0.00
December	23	-30.52	-33.15	-27.86	-0.74	0.00
December	24	-31.59	-35.94	-27.30	-0.84	0.00
December	25	-27.39	-30.34	-23.15	-0.92	0.00
December	26	-24.49	-29.15	-20.10	-0.95	0.00
December	27	-22.93	-33.52	-19.35	-0.95	0.00
December	28	-29.78	-34.87	-25.41	-0.92	0.00
December	29	-23.66	-26.71	-21.41	-0.98	0.00
December	30	-14.71	-25.62	-8.27	-0.92	0.00

IMAGE EVALUATION TEST TARGET (QA-3)

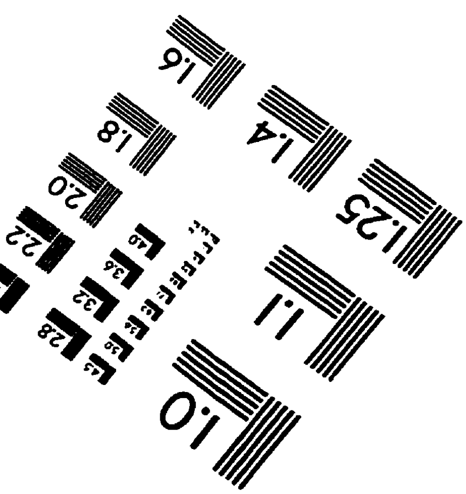


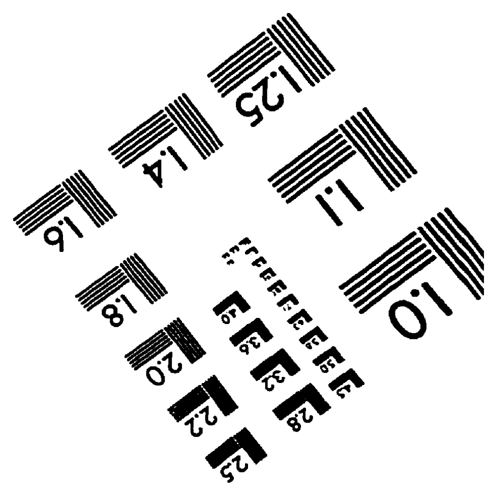




150mm

6″





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