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I am submitting herewith a thesis written by William Daniel Strunk entitled “Mowing and Light-weight Rolling of Creeping Bentgrass (*Agrostis stolonifera* L.) Putting Greens during summer heat stress periods in the Transition Zone” I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science in Plant Sciences.

John C. Sorochan

Major Professor

We have read this thesis
and recommend its acceptance:

J. Scott McElroy

Thomas J. Samples

Charles Hall

Thomas Nikolai

Accepted for the Council:

Anne Mayhew

Vice Chancellor and Dean of
Graduate Studies

(Original signatures are on file with the official student records.)

**MOWING AND LIGHT-WEIGHT ROLLING OF CREEPING BENTGRASS
(*Agrostis stolonifera* L.) PUTTING GREENS DURING SUMMER HEAT STRESS
PERIODS IN THE TRANSITION ZONE**

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ABSTRACT

A major challenge for golf course superintendents in the transition zone is to manage *Agrostis stolonifera* L. (creeping bentgrass) putting greens during heat stress periods of June, July, and August. In 2004 and 2005, a study was conducted to compare the effects of alternating rolling and mowing with traditional methods of everyday mowing on the green speed, turf quality, and disease occurrence creeping bentgrass putting greens in the transition zone. Treatments consisted of mowing six days week⁻¹ without rolling, mowing six days week⁻¹ with rolling three days week⁻¹, and mowing three days week⁻¹ alternating with rolling three days week⁻¹. Visual quality ratings for treatment effects determined a treatment and time interaction, which showed that alternating mowing with rolling had no significant change in turf quality throughout the study. In addition, mowing everyday maintained as high of quality through two months, but not at three months; while, mowing with rolling had significant decreases in quality by two months. There was no significance noted for disease incidence or root length among treatments or locations. Green speeds were statistically different for many of the collection dates for all locations. However, these speeds were only realistically different for 4 of 37 collection dates. Green speeds must exceed 15.2 centimeters of difference before the average golfer can distinguish a difference. A partial budgeting analysis was implemented to understand the economic effects as well. A mail survey was conducted in January 2006 to determine the standard mowing and rolling practices for golf courses in Tennessee, and it had a 37.5 percent response rate. A partial budgeting analysis was performed to determine the additional costs or savings generated by comparing mowing

six days week⁻¹, mowing six days week⁻¹ with rolling three days week⁻¹, and alternating mowing with rolling three days week⁻¹. Adding rolling three days week⁻¹ to a program of mowing six days week⁻¹ increased overall total cost as expected for both triplex and walk behind mowers over all golf course types. However, alternating mowing with rolling three days week⁻¹ has the potential to reduce total cost, particularly for courses using walk behind mowers, compared to only mowing six days week⁻¹.

TABLE OF CONTENTS

	<u>page</u>
PART I	1
Introduction	1
LITERATURE CITED	10
PART II	12
Effects of Mowing and Lightweight Green Rolling on Creeping Bentgrass Putting Greens during Heat Stress Conditions in the Transition Zone	12
ABSTRACT	13
INTRODUCTION	14
MATERIALS AND METHODS	16
RESULTS AND DISCUSSION	18
CONCLUSIONS	21
LITERATURE CITED	22
PART III	24
Partial Budget Analysis of Mowing and Lightweight rolling of Creeping Bentgrass Putting Greens	24
ABSTRACT	25
INTRODUCTION	26
MATERIALS AND METHODS	29
RESULTS AND DISCUSSION	31
CONCLUSIONS	37
LITERATURE CITED	39
APPENDICES	40
APPENDIX A	41
TABLES	41
APPENDIX B	59
FIGURES	59

VITA	64
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LIST OF TABLES

<u>Table</u>	<u>page</u>
Table 1. Mean squares for treatment effects on turfgrass quality of creeping bentgrass putting greens grown during summer heat stress at Knoxville, TN., USA, June – August, 2004 and 2005.....	42
Table 2. Main effects for the interaction of treatments and time for turfgrass quality [§] applied to creeping bentgrass putting greens during summer heat stress at Knoxville, TN, USA. June – August, 2004, and June – August, 2005.	43
Table 3. Mean squares for treatment effects on Dollar spot incidence of creeping bentgrass putting greens grown during summer heat stress at Knoxville, TN., USA, June – August, 2004 and 2005.	44
Table 4. Mean squares for treatment effects on root length of creeping bentgrass putting greens grown during summer heat stress at Knoxville, TN., USA, June – August, 2005.	45
Table 5. Main effects of time on root lengths at location B, a creeping bentgrass putting green, during summer heat stress at Knoxville, TN. 1 June- 31 August, 2005.	46
Table 6. Means of survey data collected from golf courses [§] in Tennessee concerning mowing and rolling practices on creeping bentgrass putting greens, 2005 – 2006, Knoxville, TN.....	47
Table 7. Frequencies of triplex greens mowers, walk behind greens mowers, and lightweight greens rollers used on golf courses in Tennessee determined from survey [§] data, 2005 – 2006, Knoxville, TN.....	49
Table 8. Equipment and cost data submitted by Jacobsen and Diversified Manufacturing Inc. for the Jacobsen Greens King IV Plus, Jacobsen PGM 22, and DMI Speed Roller, 2005 – 2006, Knoxville, TN.	50
Table 9. Mowing creeping bentgrass putting greens using triplex mowers (scenario a) and walk behind mowers (scenario b) six days week ⁻¹ by type of course and course size over a year assuming 36 weeks of mowing and/or rolling and 40 weeks of maintenance, 2005 – 2006, Knoxville, TN.	51
Table 10. Mowing creeping bentgrass putting greens using triplex mowers (scenario a) and walk behind mowers (scenario b) six days week ⁻¹ and rolling three days week ⁻¹ with a greens roller by type of course and course size over a year	

assuming 36 weeks of mowing and/or rolling and 40 weeks of maintenance, 2005 – 2006, Knoxville, TN.....	53
--	----

Table 11. Mowing creeping bentgrass putting greens using triplex mowers (scenario a) and walk behind mowers (scenario b) three days week ⁻¹ alternating with rolling three days week ⁻¹ with a greens roller by type of course and course size over a year assuming 36 weeks of mowing and/or rolling and 40 weeks of maintenance, 2005 – 2006, Knoxville, TN.	56
---	----

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
Figure 1. Effects of mowing six days week ⁻¹ (Mow), mowing six days week ⁻¹ with rolling three days week ⁻¹ (Mwr), and alternating mowing with rolling three days week ⁻¹ (Amr) on ball roll distance on three locations (a, b, and c) as recorded by a Stimpmeter. Knoxville, TN. 29 June- 31 August, 2004, and 1 June- 1 September, 2005. Error bars represent least significant differences at the 0.05 probability level.....	60
Figure 2. Mail survey sent to 96 member golf courses of Tennessee Turfgrass Association, December 2005 and January 2006, Knoxville, TN.	63

PART I
INTRODUCTION

With the rise in the popularity of golf, there is a rise in the number of people who are paying attention to the conditions of the golf course. These individuals see the immaculate courses that the professional golfers play on and expect local courses to be just as immaculate. However, the majority of local courses cannot meet the high standards of tournament course greens. Unfortunately, this does not stop the players from requesting certain standards. One of which is green speed as measured by a Stimpmeter.

A Stimpmeter is a device used to measure ball roll distance on a putting surface. It consists of a 914.4-millimeter (36-inch) aluminum bar with a v-shaped groove and a ball release notch, which is milled at 762 mm (30 in) above the end that is rested on the putting surface. The end which is placed on the ground has a beveled edge to promote a smooth transition from bar to ground. The notch is designed to release the ball when the bar is lifted to a 20 degree angle to ensure a constant velocity among measurements (USGA, 2005). Originally designed in 1937 by Edward Stimpson, the Stimpmeter was modified in the 1970's by the United States Golf Association (USGA, 2005). The Stimpmeter was designed to address the problem of accurately measuring speed of the putting surface. The intended purpose was to provide the superintendent with a tool for maintaining putting surfaces that are consistent for players. However, the Stimpmeter for a golfer has also become a means to compare courses (USGA, 2005). Therefore, superintendents must now address comparison issues as well as golfer expectations. This practice puts extra stress, not only on the course, but on the superintendent.

Addressing the green speed issue is especially difficult for superintendents managing greens in warm climates with cool-season grasses such as *Agrostis stolonifera* L. creeping bentgrass. One such geographic area is the transition zone, a region that extends from northeastern New Mexico to Virginia. Turf management in the transition zone is very difficult considering the extremes in both warm and cool temperatures. Warm season grasses may experience winter kill while cool season grasses may experience heat stress (Fry and Huang, 2004).

Cool season grasses such as creeping bentgrass perform best at air temperatures between 16 and 24° Celsius for optimum shoot growth (Waddington et al., 1992). Optimum root growth occurs at soil temperatures ranging from 10 to 18° Celsius (Fry and Huang, 2004). In summer, optimum temperatures for cool season grasses are seldom observed in the transition zone, particularly for creeping bentgrass on golf course putting greens. Creeping bentgrass is used to create some of the best putting surfaces in the world (Fry and Huang, 2004). However, at putting greens height, creeping bentgrass is especially susceptible to heat stress and injury (Fry and Huang, 2004).

High temperature stress occurs when air and soil temperatures rise above the optimum growth ranges (Waddington et al., 1992). Heat stress is generally categorized as: direct and indirect. Direct heat stress occurs when temperatures rise enough to cause immediate cell death (Fry and Huang, 2004). Generally, temperatures close to 49°C cause immediate cell death (Carrow, 1996). At extreme temperatures, proteins precipitate and denature (Waddington et al., 1992). Indirect heat stress occurs when temperatures rise above optimum levels for extended periods of time. These

temperatures are not initially lethal but can eventually cause turf injury or death (Fry and Huang, 2004). If there are large diurnal fluctuations, cool season grasses often withstand high daytime temperatures. However, the transition zone does not experience the large fluctuations in temperature. High humidity acts as a buffer preventing large fluctuations from daytime to nighttime temperatures (McCarty, 2001). While daytime temperatures may not reach the temperatures where direct heat stress occurs, high daytime and nighttime temperatures cause significant stress.

Symptoms of turf injury due to heat stress are difficult to distinguish because of the resemblance to pathological pests (Fry and Huang, 2004). Two major symptoms of heat stress are chlorosis and the reduction of shoot density. Overall turf quality and vigor may be reduced as well (Waddington et al., 1996). High temperature stress also reduces tillering, shoot growth, and leaf size (Waddington et al., 1996). Root growth is much more sensitive to heat stress than shoot growth. Often, roots have a reduction in mass, length, and viability before turf quality is effected (Fry and Huang, 2004).

During periods of indirect heat stress, turfgrass experience several physiological and metabolic alterations. As temperatures increase, the rate of photosynthesis decreases (Taiz and Zeiger, 1998; Fry and Huang, 2004). This is in part due to the abundance of atmospheric oxygen compared to carbon dioxide at higher temperatures (Taiz and Zeiger, 1998). In C_3 photosynthetic plants, such as cool season grasses, photorespiration occurs more readily when experiencing above-optimum growing temperatures. Photorespiration is the oxidation of ribulose-1, 5-bisphosphate, normally the carbon dioxide acceptor, by the enzyme ribulose-1, 5-bisphosphate carboxylase (rubisco) (Taiz and Zeiger, 1998; Fry

and Huang, 2004). Instead of fixing carbon, photorespiration actually releases carbon, a process requiring energy. During the summer in the transition zone, creeping bentgrasses may experience photorespiration by mid-morning, when temperatures rise above 30°C.

Temperature also affects the rate of respiration. Increases in temperatures above 30°C result in accelerated respiration rates (Taiz and Zeiger, 1998). Heightened respiration rates causes depletion in carbohydrate reserves. Lower carbohydrate reserves prevent root growth and cause root dieback, as root cells have lower priority than shoot cells (Carrow, 1996). Also, high temperature stress often effects gene expression, causing a decrease in protein synthesis (Fry and Huang, 2004). This sequence of events leads to shoot density and vigor loss.

Golf course superintendents are among the most innovative of plant managers. They manipulate and modify practices such as mowing or lightweight greens rolling in order to achieve the ultimate playing surfaces. In order to achieve the desired characteristics of putting surfaces, daily mowing is preferred. Less frequent mowing often results in less shoot density and wider leaves (Beard, 2002). However, many country clubs are closed one day per week. Greens are not mown, which in turn aids in overall turfgrass vigor (Beard, 2002). Other rest days for putting greens generally occur after topdressing, cultivation, or granular fertilization (Beard, 2002). Creeping bentgrass putting greens are normally maintained at a mowing height between 3.2 and 4.8 millimeters (McCarty, 2001). During summer heat stress periods, mowing can be reduced to five days per week with a slight increase in mowing height in order to promote a healthier stand of turf (McCarty, 2001). Raising mowing heights and reducing the

number of times greens are mown is not always a feasible option for superintendents. Golfers have high expectations and desire the best playing conditions possible.

Historically, rollers were used to smooth putting surfaces before mechanical green mowing was available. In 1830, Edward Budding invented the first mechanical mower (Beard, 2002). However, with a lack of technology, this mower did not produce a desirable putting surface. In 1901, Walter Davis, a greens keeper, suggested that rolling should occur regularly from the months of May until October (Travis, 1901). This practice of rolling helped increase green speeds and smooth the surface of sand based to sandy-loam based greens, which was very important considering the lack in mower technology at the time (Piper et al., 1921). As mower technology improved, rolling greens became less important. By the 1950's, rolling greens was an uncommon practice (Beard, 2002). Also, the increase in inland golf courses, where greens are constructed from native soils with high amounts of silt and clay, reduced the popularity of rolling. Superintendents were afraid to roll native soil greens because of the issues with compaction of soils high in silt and clay (Nikolai, 2005).

With the introduction of lightweight greens rollers in the late 1980's and the increased popularity of sand-based root zones, rolling greens has since become a common practice (Hartwiger et al., 2001). Lightweight greens rollers smooth the putting surface and increase speeds for several hours (Danneberger et al., 1993; Hamilton et al., 1994). Rolling can also reduce Dollar Spot (*Sclerotinia homoeocarpa*) infestation, moss occurrence, and black cutworm activity (Nikolai et al., 2001). Studies suggest that rolling sand based greens up to three times per week does not change bulk density or

water infiltration (Hamilton et al., 1994; Nikolai, 2005). However, frequency of rolling is important in benefiting or harming the turf.

Plant growth regulators are chemicals that affect shoot growth by inhibiting cell division, changing plant hormone production, or reducing amino acid production (Fry and Huang, 2004). These chemicals are separated into one of three categories: herbicides, type I, and type II (McCarty, 2001). Herbicides act as plant growth regulators at low rates because of the destructive nature to amino acid production. Type I regulators are mainly foliar absorbed chemicals that inhibit cell division. Type II plant growth regulators inhibit the biosynthesis of gibberellic acid (McCarty, 2001). One such type II plant growth regulator is trinexapac-ethyl, or Primo. Introduced in the early 1990's, Trinexapac-ethyl, a late gibberillic acid synthesis inhibitor, is labeled for use on all major turfgrasses (Shepard and Dipaola, 2000).

There are many benefits associated with applications of Trinexapac-ethyl, particularly creeping bentgrass putting greens. Trinexapac-ethyl benefits turfgrasses by providing darker green color, increased shoot density, and enhanced stress tolerance (Shepard and Dipaola, 2000). Trinexapac-ethyl applications also reduce the amount of vertical growth, but do not reduce rooting or tillering. Therefore, there is a reduction in scalping from mowers, and more energy can be redistributed to lateral shoot and root growth. In addition, heat stress tolerance is enhanced in creeping bentgrass putting greens treated with Trinexapac-ethyl, and green speeds remain consistent throughout the day (Shepard and Dipaola, 2000).

Golf course appearance and playability is influenced by maintenance budgets. Restricted budgets require expert management strategies with more efficient uses of labor and equipment (Beard, 2002). However, golfer expectations continue to rise while budgets lag behind (Pioppi, 2004). There are three approaches to manage budget restraints of golf course maintenance. The first approach is efficiently using personnel and strict record keeping practices. Labor costs, on average, generally represent 60 to 70 percent of the total maintenance budget for a typical golf course (Beard, 2002). Labor costs can be reduced by purchasing high-capacity and fuel efficient equipment, skillful scheduling of projects, and careful hiring (Beard, 2002). The second approach is to improve cultural practices and turf management strategies (Beard, 2002). Healthy turf reduces the costs associated with disease suppression and control, insect damage, and weed infestation. However, some turfgrass species such as creeping bentgrass require intensive management, particularly in temperate climates, which increases applicable cost. The final approach is to lower golfer expectations, which are often unreasonable. Golfers do not have the education in golf course management to accurately predict the cost of their expectations. Therefore, it is imperative that a superintendent communicates with golfers in order to reduce expectations to what is truly possible (Pioppi, 2004).

Golf course superintendents, managing creeping bentgrass greens, in the transition zone will inevitably have to deal with heat stress. However, there are several actions a superintendent can take to minimize turf decline associated with indirect heat stress. One action to alleviate summer heat stress is to increase mowing height. Studies suggest that raising mowing heights by 0.8 to 1.5 mm has a significant effect on overall

turf quality (Beard, 2002; Huang et al., 2004). However, increasing mowing height will ultimately lessen the overall green speed which may not be suitable for some golfers.

Another option for superintendents is to reduce the number of mowing times per week to five (McCarty, 2001). Once again, golfer expectations and desires make the reduction of mowing events impossible to complete. With heat stress and golfer expectations in mind, is it possible to prevent the desiccation of putting green without lowering the standards?

Lightweight rolling has been investigated to determine the associated positive and negative side effects. Considering the benefits, which include increases in rooting, green speed, and disease prevention, it seems that the use of a lightweight greens roller could replace a mowing event without significantly affecting the speed of the putting surface. Green speed differences of 152.4 mm (6 in) are undetectable to the average golfer as measured with a Stimpmeter (Karcher et al., 2001). Therefore, as long as Stimpmeter ball roll distance is within six inches of normal readings for that particular green when being mown, the average golfer will not be able to differentiate.

Essentially, three questions must be answered. Does alternating light weight rolling with mowing of putting greens improve turf quality during periods of indirect heat stress? Does alternating lightweight rolling with mowing produce acceptable green speeds within six inches of traditional management practices? Is there any cost savings associated with alternating light weight greens rolling with mowing? This research will potentially answer these questions, and provide valuable insight to the golf course superintendent.

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PART II

EFFECTS OF MOWING AND LIGHTWEIGHT GREEN ROLLING ON CREEPING BENTGRASS PUTTING GREENS DURING HEAT STRESS CONDITIONS IN THE TRANSITION ZONE

ABSTRACT

A major challenge for golf course superintendents in the transition zone is to manage *Agrostis stolonifera* L. (creeping bentgrass) putting greens during June, July, and August. Heat stress and disease pressure make it difficult to maintain a high quality and consistent putting surface. Research has shown that rolling greens can increase green speed and the performance of the putting surface. In 2004 and 2005, a study was conducted to compare the effects of alternating rolling and mowing with traditional methods of everyday mowing on green speed, turf quality, and disease occurrence for creeping bentgrass putting greens in the transition zone during summer heat stress. Treatments consisted of mowing six days week⁻¹ without rolling, mowing six days week⁻¹ with rolling three days week⁻¹, and mowing three days week⁻¹ alternating with rolling three days week⁻¹. Visual quality ratings for treatment effects determined a treatment and time interaction. Alternating mowing with rolling had no significant change in turf quality throughout the study. In addition, mowing everyday maintained as high of quality through two months, but not at three months. Mowing with rolling had significant decreases in quality by two months. There was no significance noted for disease incidence or root length among treatments or locations. Green speeds were statistically different for many of the collection dates for all locations. However, these speeds were only realistically different for 4 of 37 collection dates. Green speeds must exceed 15.2 centimeters of difference before the average golfer can distinguish a difference. Therefore, results from this study determined that alternating mowing with

rolling will maintain the highest quality putting surface during periods of summer heat stress.

INTRODUCTION

Golf course superintendents must constantly face and overcome problems associated with putting green maintenance. Often used as comparison of superintendents, putting green management and maintenance requires patience, imagination, and resilience. Ideally, a superintendent wishes to produce the highest quality putting surface possible. The playability of the green, which is the culmination of turfgrass quality, putting green speed, and smoothness of the surface, is important to superintendent and golfer alike. However, species selection and geographic location, as well as other factors, largely determine the level of quality that is attainable. *Agrostis stolonifera* L. (creeping bentgrass) produces the best putting surface, and is preferred over any other turfgrass (Fry and Huang, 2004). However, the adaptation of creeping bentgrass is limited. In some locations, under intensive management, creeping bentgrass can be grown even though the climate is outside of its ideal region of adaptation. One such location is the transition zone which extends from southern Virginia to parts of New Mexico and Texas. The main characteristic for this geographic region is the extremes in both warm and cold temperatures which limits both warm and cool-season grasses growth.

Within the transition zone, creeping bentgrass putting greens suffer largely from indirect heat stress during the summer months. Indirect heat stress is defined as extended periods of temperatures above optimum growth ranges ($\geq 30^{\circ}\text{C}$) that results in a reduction

of shoot density, shoot growth, tillering, root length, and overall turf quality (Waddington et al., 1996; Fry and Huang, 2004). Traditionally, the management practices for creeping bentgrass putting greens include mowing everyday to insure a desirable putting surface (Beard, 2002). However, continuous mowing during periods of indirect heat stress can reduce turfgrass shoot density (Beard, 2002; Fry and Huang, 2004). Conversely, reductions in mowing frequency and increases in mowing height will help prevent decreased shoot density and reduced turf vigor (McCarty, 2001). However, creeping bentgrass will exhibit a more coarse leaf texture with lower shoot density under less frequent mowing regimes resulting in decreased putting green speeds (Beard, 2002). There is potential, however, to reduce the number of times a green is mown per week with the addition of lightweight greens rolling and the use of plant growth regulators without adverse effects to the playability of the putting surface.

The use of lightweight greens rollers is considered a recently reintroduced practice for grooming a putting surface. Benefits of lightweight greens rolling include smoothing of the playing surface, increases in green speed, and reductions of pest occurrence such as Dollar Spot (Danneberger et al., 1993; Hamilton et al., 1994; Nikolai et al., 2001). In addition to lightweight greens rolling, the use of plant growth regulators is another tool for superintendents. Plant growth regulators, particularly trinexapac-ethyl (Primo), reduce shoot elongation and growth, increase shoot density, increase rooting, and reduce the need for daily mowing (Shepard and Dipaola, 2000). With the combination of lightweight greens rolling and Trinexapac-ethyl applications, the

frequency of mowing events can be reduced during periods of indirect heat stress without reducing the overall playability of the putting surface.

In this experiment, mowing and rolling treatments are examined for their potential to replace a mowing event with lightweight greens rolling when Trinexapac-ethyl applications are made during summer heat stress periods. The ultimate goal is to reduce the stress level of the turfgrass without reducing the overall playability of the greens. However, golfer expectations are very high, so green speed must remain consistent with traditional means of putting green management. As long as green speeds remain within six inches of traditionally managed putting surfaces, the average golfer will not be able to distinguish a difference (Karcher et al., 2001).

MATERIALS AND METHODS

Two creeping bentgrass (*Agrostis stolonifera* L.) putting greens were used to evaluate the effects of mowing (Flex 21, The Toro Company, Bloomington, IL.) and lightweight rolling (Speed Roller, Diversified Manufacturing, Inc., Lockport, NY) practices during summer heat stress periods from June through August, 2004 and 2005 at the University of Tennessee Intercollegiate Golf Practice Facility in Knoxville, TN. Two locations (A and B) were on a 10-year-old 'Penncross' creeping bentgrass putting green with a sand-peat (90:10) root zone and a 7.6 cm mat layer, and a third location (C), established in April 2005, was a 'Crenshaw' creeping bentgrass putting green with a similar sand-peat (90:10) root zone. Locations A and B were on the same putting green, but they were different in year and location on the green. Each putting green was mown at 3.7 millimeters. Nitrogen was applied at a rate of 4.88 kg N ha⁻¹ every seven to 10

days using Harrell's 28-5-18 Bentgrass Special (Harrell's Fertilizer, Lakeland, FL) from April to October. Phosphorus, potassium, and micronutrients were applied in the spring and fall according to soil test reports. Irrigation was applied as needed to prevent wilt (applied three times week⁻¹ at a 2.0 cm depth during periods of no rainfall). Light sand topdressing was applied on a two week schedule.

At each site, 1.2 by 4.9 meter plots were established for mowing six times week⁻¹ (Mow), mowing six times week⁻¹ with lightweight rolling three times week⁻¹ (Mwr), or alternating mowing three times week⁻¹ and lightweight rolling three times week⁻¹ (Amr). Mowing and rolling treatments began on 1 June 2004 and ended on 31 August 2004 on location A. Treatments were repeated on the same dates in 2005 for locations B and C. Fungicides were applied on a curative basis only. Once a disease had occurred and was identified, data was collected, and subsequent curative fungicide applications were made. Trinexapac-ethyl (Syngenta Corporation, Wilmington, DE), a type II plant growth regulator, was applied to all plots at 0.398 L ha⁻¹ every 21 days to prevent scalping.

Data collection consisted of root length, green speed, disease infestation, and quality. Root length data was collected on the first of each month from 1 June through 1 September, 2005. Three cores were taken from plots at random using a Core Profile Sampler (Standard Golf Company, Cedar Falls, IA). Cores measured 1.9 by 25 cm. Sand was removed from cores by hand using a container of water, and root length was measured in centimeters. Green speeds were collected by measuring ball roll distance using a Stimpmeter (United States Golf Association, Far Hills, NJ). Instructions provided by the USGA were followed while using the Stimpmeter. Green speeds were

measured weekly at the end of the week for the duration of the study. Disease ratings were collected when symptoms were visible. Data was collected and curative fungicides were applied. Quality ratings were collected on the first of each month from 1 June through 1 September. A one to nine quality scale was used with nine representing ideal putting green turf that is dark green, dense, and uniform and one representing dead turf. Treatments were arranged as a single factor with three treatments (Mow, Mwr, and Amr) in a randomized complete block design with three replications for putting green speed and disease infestation. Statistical analysis for putting green speed and disease infestation was completed with Agricultural Research Manager, version 6.18 (Gylling Data Management, Inc., Brookings, SD). For turfgrass quality and root length, treatments were arranged in a three by three factorial with time as a factor. Significant treatment means for turfgrass quality and root length were separated according to Fisher's protected least significant difference test using PROC MIXED, SAS, version 9.1 (SAS Institute, Inc., Cary, NC).

RESULTS AND DISCUSSION

Ratings for turfgrass quality showed significance at many levels across all three locations (Table 1)¹. The data from location C differs from the other locations. Since construction of this green began in January of 2005 and was sodded in April, the initial quality of the green was poor and improved over time as the turf established and matured. Therefore, results and discussion for data collected from locations A and B will

¹ All tables and figures are located in the Appendix.

differ from location C. In 2004, mowing treatments were not significantly different; the interaction of mowing treatments and time were significant. Time was expected to be significant because the effects of summer heat stress; where, temperatures were above optimum for creeping bentgrass putting greens for much of the study period. A decrease in quality was expected over the study period, and an interaction between time and mowing treatments. This indicates that the mowing treatments affected the amount of quality degradation on the turf over time (Table 2). The treatment of alternating mowing with rolling (Amr) had significantly higher quality turf after three months than the other two treatments except for mowing six days week⁻¹ (Mow) on location B. In addition, no significant decrease occurred over time with the Amr treatment. The Mow treatment had a significant decrease in quality after two months; while, Mwr had significant decreases in turfgrass quality at three months for location A and each month for location B, respectively. The data concluded that Amr will maintain a higher quality turf over Mow and Mwr. Therefore, for putting greens in the transition zone exposed to summer heat stress Amr will maintain high turf quality over time; while, Mow and Mwr will have lower turf quality over time. Nikolai (2005) mentions that Mwr will significantly improve turf quality on putting green managed in Michigan. However, our results indicate that Mwr should not be done during the summer months in Tennessee. This is likely a result of the high temperature stress. For location C, quality increased for all treatments over time as the green matured. However, Amr quality was greater than Mow, which was greater than Mwr.

There were no significant differences for disease occurrence between mowing treatments and time (Table 3). This is likely a result of the replication significance. Therefore, the effects of mowing treatments and time could not determine differences in disease incidence. No significance occurred for root length among mowing treatments (Table 4). As expected root length decreased over time (location B), but no significant differences occurred between mowing treatments (Table 5). No differences occurred for location C because the roots were still establishing when mowing treatments were initiated.

Significant differences for ball roll distance occurred at all locations. For location A, three out of the eleven collection dates had significant differences for all three mowing treatments (Figure 1). All other dates showed no significant differences for Mow and Mwr treatments. However, on six of the eleven dates tested Mwr had significantly greater green speed than the Amr treatment. This is consistent with another study demonstrating that mowing and rolling increases green speeds greater as compared to mowing or rolling alone (Nikolai, 2005). For location B, significant differences occurred for putting green speeds among mowing treatments for all thirteen collection dates. In all instances, Mwr had the longest ball roll distance. Amr had the shortest ball roll distance among the three treatments. For location C, thirteen of fourteen collection dates showed that Mwr had ball roll distances significantly faster than either Mow or Amr. However, Amr was not significantly different from Mow for eight of fourteen collection dates.

Statistically, ball roll distance for the treatments of Mow, Mwr, and Amr, much of the time, were significantly different. Although statistically different, according to

Karcher et al., (2001), ball roll distances were not realistically different. Differences of six inches or less of ball roll distance as measured by a Stimpmeter on typical golf course putting greens are indistinguishable to the average golfer (Karcher et al., 2001). Green speeds within six inches realistically are the same. Over all three locations, ball roll distance would be realistically different between Mow and Amr on only four of 37 collection dates. This indicates that while Amr significantly decreases putting green speeds compared to Mow, golfer perception would be undetectable.

CONCLUSIONS

Alternating mowing three days week⁻¹ with rolling three days week⁻³ (Amr) produced a higher quality turf compared to mowing six days week⁻¹ (Mow) and mowing six days week⁻¹ with rolling three days week⁻¹ (Mwr) when indirect heat stress is present without ultimately slowing green speeds compared with Mow. Also, Amr does not increase or decrease the amount of disease occurrence or the depth of roots during these high temperature stress periods. McCarty (2001) suggested reducing mowing frequency during high temperature stress to a maximum of five times week⁻¹ to improve turf quality. Results of this research suggested that reducing mowing frequencies and implementing a rolling regiment will improve turf quality significantly when mowing and rolling are alternated. Superintendents managing creeping bentgrass on putting greens in locations where summer heat stress is an issue should consider alternating mowing with rolling to improve turf quality. This research warrants further investigations in creeping bentgrass putting green management during summer heat stress periods to fully understand the turf quality differences in regards to aerification and seasonal transitions.

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PART III

PARTIAL BUDGET ANALYSIS OF MOWING AND LIGHTWEIGHT ROLLING OF CREEPING BENTGRASS PUTTING GREENS

ABSTRACT

Researchers often develop new methods for managing turf, but they may not fully understand the economic impact that accompanies new management systems. To the end user, the golf course superintendent, new management systems do not always comply with budget constraints. A full population mail survey was conducted in January 2006 to determine the standard mowing and rolling practices for golf courses in Tennessee. After two mailing attempts, a 37.5 percent response rate was achieved. From survey data and equipment parameters provided by Jacobsen, a Textron Company, a partial budgeting analysis was performed to determine the additional costs or savings generated by comparing mowing six days week⁻¹, mowing six days week⁻¹ with rolling three days week⁻¹, and alternating mowing with rolling three days week⁻¹. Adding rolling three days week⁻¹ to a program of mowing six days week⁻¹ increased overall total cost as expected for both triplex and walk behind mowers over all golf course types. However, alternating mowing with rolling three days week⁻¹ has the potential to reduce total cost, particularly for courses using walk behind mowers, compared to only mowing six days week⁻¹. Public, private, 18-hole, and 27+ hole courses have a difference of \$3020.08, \$-79.62, \$-666.10, and \$4761.36 from mowing six days week⁻¹ to alternating mowing with rolling, respectively. Golf course superintendents have the possibility to reduce or increase total cost of mowing and rolling putting greens when using a triplex mower. However, the cost of mowing for golf courses using walk behind mowers significantly decreased in total cost when alternating mowing and rolling was employed.

INTRODUCTION

To be successful, a golf course superintendent must be capable of performing a wide variety of tasks simultaneously. Much of a superintendent's time is spent as a turf manager. The "perceived performance" of the golf course ultimately determines the "effectiveness" of the superintendent. Rightfully so, many hours are spent on tweaking turfgrass fertility programs, implementing preventative and curative cultural practices, scouting for disease and insect infestation, and improving putting green performance. The ultimate goal is delivering the best golfing experience possible according to diverse customer expectations. However, there are occasions when limits are placed on the amount of effort that can be invested. Such occasions occur because of budget constraints.

Implementing a budget for all golf course maintenance procedures is one of many tasks included in the responsibilities of a superintendent. Budgets typically consist of three main components: capital improvements, capital expenses, and operating expenses (Beard, 2002). Capital improvements cover any expenses incurred relative to improvements to facilities and property. Such expenses include renovations and construction. Capital expenses are comprised of the purchasing of equipment such as utility vehicles, mowers, hand-tools, and other motorized equipment (Beard, 2002). The operating expense category includes all of the expenses associated with the daily operation of the golf course. Included are such line items as personnel salaries and wages, fertilizer, water, irrigation facilities, chemicals, drainage facilities, bunker sand,

topdressing mix, petroleum, equipment parts and services, and equipment depreciation (Beard, 2002).

Golf course budgets are affected by a variety of factors. The biggest factor determining the size of budget needed is most often the golfer's standards of quality and playability of the golf course (Beard, 2002). Larger budgets are required for golf courses where pristine conditions must exist to fulfill golfer expectations. Higher expectations require more maintenance workers, better equipment, and more supplies. All of these add to the cost of maintaining a golf course. Another factor that has an effect on the size of budget required is the number of days the course is open for play and the number of rounds played annually (Beard, 2002). These numbers indicate the amount of traffic and wear the golf course is submitted throughout the year. Increased traffic on a golf course adversely affects the health of the turf, which in turn increases the need for additional maintenance. Other factors affecting budget requirements are course design and layout, acreage, mowing frequency (for greens, fairways, tees, and rough), water sources, drainage, and the quality of labor (Beard, 2002).

When budget constraints occur, superintendents are forced to deal with such reductions with only three approaches. One approach requires the superintendent to develop a relationship with the membership as an employee and as an educator. Communication with golfers is the best way to lower golfer expectations to coincide with actual budget size (Pioppi, 2004). In general, golfers do not fully understand the financial impact of their expectations. Golfers should be educated by the superintendent regarding the cost associated with maintaining a golf course. The superintendent should

then, with the help of the owner or greens' committee, develop a prioritized list of maintenance procedures (Beard, 2002). Understanding the aspects of the golf course that are most important to the golfers will ultimately lead to success when managing budgets. The other two approaches to dealing with tight budgets require changes to either labor usage or cultural practices. Labor generally comprises 60 to 70 percent of the golf course budget (Beard, 2002). Any actions that reduce the amount of labor required to maintain a golf course will have a significant impact on the overall budget (Beard, 2002). Manipulating cultural practices can also have a significant impact on the overall budget. Essentially, the ultimate goal is to use labor efficiently while implementing cultural practices to improve or maintain turf quality.

In this experiment, the costs associated with mowing and lightweight rolling of putting greens were examined. Understanding the cost of mowing and lightweight rolling of greens is important in dealing with budget constraints while obtaining the level of greens quality golfers' expect. Putting surfaces are the most important to golfers, and therefore should be maintained intensively (Fry and Huang, 2004). Researchers developing best management practices in terms of the turf may not fully understand the economic impact involved. However, the use of partial budgeting allows investigators to determine the additional costs or returns associated with introducing a new management scheme that only affects a portion of the overall operation (Dalsted et al., 1992). There are three categories of partial budgets. Substituting enterprises and changing the size of an operation are two of the categories of partial budgeting (Kay, 1986). In this instance, the most important category of partial budgeting is the substitution of one input for

another. This category includes actions such as substituting equipment with labor and increasing or decreasing fertilizer and chemical inputs (Kay, 1986). Unlike other budgets, partial budgeting only deals with relevant costs and returns, and determines the change in net returns (Lessley et al., 1991). Partial budgets can be separated into four categories, which include additional costs, additional returns, reduced costs, and reduced returns (Lessley et al., 1991). The totaled amount in each category determines whether there is an increase or decrease in net income.

Understanding the economic impact of new procedures is important to the turf manager. In this experiment two problems need to be addressed. The first problem is determining the standard practices currently being employed for mowing and rolling of putting greens in Tennessee. Partial budgeting is not possible without knowing what management practices are already in place. The second problem is to determine the additional costs or returns associated with mowing, rolling, and alternating mowing with rolling of putting greens. This research will provide valuable insight into the economic issues involved with putting green maintenance.

MATERIALS AND METHODS

A mail survey was conducted to determine the standard management system for mowing and lightweight rolling of putting greens in Tennessee. All survey procedures adhered to those outlined in Dillman, Mail and Telephone Surveys: the Total Design (1978). The sample frame for the survey was all golf courses affiliated with the Tennessee Turfgrass Association which included 134 member courses. Given the relatively small number of golf courses in the state, a full population survey was

employed. Before the survey was mailed, a pretest was conducted during the University of Tennessee Turfgrass Field Day. After corrections and additions were incorporated into the survey, each course was sent a mail survey in December of 2005. A repeat mailing occurred three weeks later in January of 2006. The survey included questions pertaining to mowing and rolling putting greens (Figure 2). From the survey, average labor wage, mower and roller brand popularity, mowing and rolling frequency, putting green size, and mowing and rolling times were determined. With this information, the standard mowing and rolling practices could be identified, providing the basis for a partial budgeting analysis.

To fully implement a partial budget analysis, equipment cost must be determined on a square footage basis. Total equipment cost hour⁻¹ encompasses the acquisition cost hour⁻¹, maintenance cost hour⁻¹, and fuel consumption hour⁻¹ (Taylor, 2005).

$$\text{Eq. 1} \quad \text{Acquisition cost hour}^{-1} = \frac{\text{Purchase Price} + \text{Interest} - \text{Salvage Value}}{\text{Projected Lifetime Hours}}$$

Purchase price, salvage value, projected lifetime hours, estimated lifetime maintenance costs, and fuel consumption hour⁻¹ were provided by the manufacturers.

$$\text{Eq. 2.} \quad \text{Maintenance cost hour}^{-1} = \frac{\text{Estimated Lifetime Maintenance Cost}}{\text{Projected Lifetime Hours}}$$

Finally, with acquisition cost hour⁻¹, maintenance cost hour⁻¹, and fuel consumption hour⁻¹, total equipment cost hour⁻¹ was determined.

$$\text{Eq. 3.} \quad \text{Equip}_{\text{Total}} \text{ cost hour}^{-1} = \frac{\text{Acquisition} + \text{Maintenance} + \text{Fuel Consumption}}{\text{Hour}}$$

Once the total equipment cost hour⁻¹ was determined, cost ft⁻² was completed using mower or roller width and speed.

Eq. 4.

$$\text{Ft}^2 \text{ hour}^{-1} = \text{Width (in)} * \text{Speed (mph)} * \text{Conversion}$$

Eq. 5.

$$\text{Cost ft}^{-2} = \text{Equip}_{\text{Total}} \text{ cost hour}^{-1} * (\text{Ft}^2 \text{ hour}^{-1})^{-1}$$

With equipment cost based on square footage, partial budget analysis was completed. Recent research showed that alternating mowing with rolling under trinexapac-ethyl produced a higher quality of putting surface for creeping bentgrass under heat stress in Tennessee (Part II). The proposed changes for the partial budget were alternating mowing with lightweight rolling in lieu of mowing six days week⁻¹ and mowing six days week⁻¹ with the addition of rolling three days week⁻¹. The labor wage used for the budget was determined by the mail survey. Statistical analysis of the mail survey was conducted using SPSS (SPSS, Inc., Chicago, IL).

RESULTS AND DISCUSSION

A mail survey was used to determine common practices of mowing and rolling of creeping bentgrass (*Agrostis stolonifera* L.) putting greens among golf courses in Tennessee. The mail survey was sent to the entire population of golf courses (96) listed with the Tennessee Turfgrass Association; of this sample frame, 36 golf courses replied yielding a 37.5 percent response rate after two separate mailings in December 2005 and January 2006. The survey revealed many aspects of putting green mowing and rolling within the state (Table 6). Data from the survey was separated into two categories: (1)

public versus private courses and (2) those with 18 holes and those with 27+ holes. The average putting green square footage ranged from 140,745.5 to 280,500.0, respectively. The range in square footage was expected because of the differing sizes of the various golf course operations. Mowing times were separated by type of mower including triplex or walk behind. These times were dependent on the number of mowing units used during one mowing. For private golf courses, it takes an estimated 163.57 minutes to mow 176,704.44 ft² with one triplex mower. However, it takes an estimated 210.91 minutes to mow the same area with five walk behind mowers. On the other hand, public golf courses averaged 140,745.4 ft² of putting greens with a triplex mowing time of 165.0 minutes with an average of two triplex mowers and a walk behind mowing time of 135.0 minutes with five mowers. Golf courses with 18 holes averaged 123,932.1 ft² of putting greens, and the associated mowing time for triplex mowing was 157.9 minutes using one triplex unit. When five walk behind greens mowers were used, mowing times averaged 205.5 minutes. For golf courses with more than 18 holes, the average area for putting greens was 280,500.0 ft² with mowing times of 187.0 and 155.0 minutes with two triplex mowers or seven walk behind mowers, respectively. Other differences can be noted between the mechanical maintenance for the differing mowers. For the private golf course, mechanical maintenance for a week on a triplex mower averaged 7.86 hours. However, mechanical maintenance for a week on a walk behind mower for private golf courses averaged 12.14 hours, a difference of 4.28 hours. Public golf courses had a difference of 6.7 hours of mechanical maintenance between triplex mowers and walk behind mowers. On average, 18-hole golf courses had a difference of 6.86 hours, while

27+ hole golf courses had a difference of 6.97 hours. An increase in mechanical maintenance was expected considering the number of mowing units used during a single mowing for walk behind mowing. The more units used during a mowing requires more maintenance such as adjusting mowing heights and reel to bed knife contact. Rolling greens was a common practice among the responding golf courses, but the frequency of rolling differed across golf course types. Public golf courses averaged a rolling frequency of 59 times in a year, while private golf course averaged 102.15 times within a year. When the courses were separated by number of holes, rolling frequency was very similar. Golf courses with 18 holes averaged a rolling frequency of 87.36 times year⁻¹, while golf courses with 27 holes averaged 82.0 times year⁻¹ for rolling frequency. Private golf courses used more roller units during a single rolling event, two units, compared to all other categories of courses which only used one unit. The average wage for the different categories of golf courses was also determined. As expected, private golf courses had higher average wage (\$8.92) compared to public courses (\$8.21). A larger difference in average wage was noticed between 18 and 27+ hole golf courses, which was \$0.95 more for 18-hole courses.

The survey also determined mower and roller popularity among all responding golf course in Tennessee (Table 7). The Toro 3100 triplex mower was the most popular triplex mower with 46.2 percent of the total respondents indicating usage. The most popular walk behind mower being used in Tennessee is the Toro 1000 (50.0 percent). For lightweight greens rollers, the Salsco brand of roller was the most popular with 25.0

percent of the total. The Toro 3100 triplex equipped with rolling units and the Smithco brand were the second most popular rollers, each with 13.9 percent of the total.

Data regarding equipment acquisition and operating parameters were requested from all equipment companies listed from the mail survey. However, only Jacobsen, a Textron Company, provided information on the Greens King IV Plus triplex mower and the PGM 22 walk behind mower. Diversified Manufacturing Inc. supplied information on the Speed Roller, a lightweight greens roller. Each of these companies provided the manufacturer's retail price, projected lifetime hours, estimated lifetime maintenance cost, salvage value, fuel consumption hour^{-1} , mowing or rolling speed, and mower or roller effective width (Table 8). From the information provided, acquisition, maintenance, and equipment cost hour^{-1} was determined for each unit, along with the $\text{ft}^2 \text{ hour}^{-1}$ and the cost ft^{-2} . For the Jacobsen Greens King IV Plus, the cost ft^{-2} was $\$5.97 \times 10^{-5} \text{ ft}^{-2}$. The PGM 22 had a cost ft^{-2} of $\$8.59 \times 10^{-5} \text{ ft}^{-2}$. The DMI Speed Roller had a cost of $\$1.90 \times 10^{-5} \text{ ft}^{-2}$. The Speed Roller was expected to have a lower cost ft^{-2} because of the low retail price and faster rolling speed compared to the mowers.

With the information provided by the mail survey and the equipment companies, partial budgeting analyses was completed for three different putting green management scenarios for triplex mowing and walk behind mowing. The first scenario consisted of mowing six days week^{-1} for 36 weeks for triplex mowing (a) and walk behind mowing (b). The number of mowings year^{-1} was 216 for all four categories of golf courses (Table 9). The average putting green area for each course type in square footage was determined

from the mail survey as well as average wage hour^{-1} , cost mower $^{-1}$ ft^{-2} , mowing time, number of mowing units used, and mechanical maintenance hours.

For public golf courses, the total equipment cost of mower(s) used for 36 weeks of mowing is \$3,627.55 using two mowers. The total mowing labor cost was \$9,753.48, and the total equipment maintenance labor cost was \$1,083.72. The total cost for all parameters for 36 weeks of mowing for public golf courses in Tennessee was \$14,464.75 at a cost ft^{-2} of \$0.10.

For private golf courses, the total cost of all parameters was \$10,334.18 with a cost ft^{-2} of \$0.06. The difference between public and private courses is the number of mowers, only one mower for private, the average putting green area, 35,958.94 ft^2 more for private courses, and 0.03 hours less for mowing time on private courses, even though, the average labor wage and maintenance labor cost were more for private golf courses.

Golf courses with only 18 holes had a total cost of all parameters of \$8,358.63 for 123,932.11 ft^2 using one mower with a average labor wage \$8.77, 2.63 hours of mowing time, and 5.06 hours of maintenance labor cost. The total cost ft^{-2} was \$0.07. Golf courses with more than 18 holes had the same cost ft^{-2} as 18-hole courses, but the total cost of all parameters over 36 weeks was \$10,557.13 more. This was expected because of the increased averaged square footage of the putting greens for 27+ hole golf courses. The walk mowing scenario (b) had a major increase in total cost for all parameters compared to triplex mowing. This was largely due to a major increase in the number of mowers used, which increases the mowing labor cost. With 216 mowings over a 36 week period, the total cost ft^{-2} for public, private, 18-hole, and 27+ hole golf courses was

\$0.26, \$0.31, \$0.39, and \$0.25, respectively. The total of all costs over the 36 week period ranged from \$36,293.07 for public golf courses to \$70,318.32 for 27+ hole golf courses.

Scenario 2 (a and b) consisted of mowing six times week⁻¹ with rolling three times week⁻¹ (table 10). In these scenarios, equipment cost of rollers and rolling labor cost was included. Maintenance labor cost did not increase because rollers require little to no daily maintenance. Rolling for public golf courses added an additional \$346.38 of equipment cost and \$3,865.92 of labor cost. Rolling greens added \$543.59 in equipment cost and \$4,703.12 in labor cost for private golf courses using two rollers. Golf courses with only 18-holes had an increase in cost by \$358.37 in equipment and \$4,487.04 in labor. In both scenarios, a and b, the addition of lightweight rolling into an existing mowing program of six days week⁻¹ increased total cost of all parameters for the entire year.

Scenario 3 (a and b) alternated mowing three days week⁻¹ with rolling three days week⁻¹ of putting greens (table 11). Additional rolling cost remained the same as in scenario 2; however, mowing frequency was reduced by half from 216 to 108 mowings. Maintenance costs were also reduced by half due to the reduction in mowing frequency. Public golf courses using triplex mowers had a total cost of \$11,444.67 at a cost of \$0.08 ft⁻². Private clubs had a total cost of \$10,413.80, costing \$0.06 ft⁻² using a triplex. Golf courses that consist of only 18 holes using one triplex had a total cost of \$9,024.73, which equals \$0.07 ft⁻². Courses that have 27+ holes using two triplex mowers had total cost of \$14,154.40 for the year, which cost \$0.05 ft⁻². Public golf courses using five walk

behind mowers have a total cost of \$22,358.33 when alternating mowing with rolling, which equates \$0.16 ft⁻². Private golf courses have a total cost of \$32,541.91 when using five walk behind mowers and two rollers, costing \$0.18 ft⁻². Five walk behind mowers and one roller were used on 18-hole courses costing \$28,907.00 total for the year with a cost of \$0.23 ft⁻². Golf courses consisting of 27+ holes used seven walk behind mowers and one roller. The total cost for the 27+ hole golf courses was \$39,855.68 or \$0.14 ft⁻².

CONCLUSIONS

Adding rolling three days week⁻¹ to a program of mowing six days week⁻¹ increased overall total cost as expected for both triplex and walk behind mowers over all golf course types. However, alternating mowing with rolling three days week⁻¹ has the potential to reduce total cost, particularly for courses using walk behind mowers, over only mowing six days week⁻¹. Public, private, 18-hole, and 27+ hole courses have a difference of \$3020.08, \$-79.62, \$-666.10, and \$4761.36 from mowing six days week⁻¹ to alternating mowing with rolling, respectively. Golf course superintendents have the possibility to either reduce or increase total cost of mowing and rolling putting greens when using a triplex mower depending on the size of the course. However, golf courses using walk behind mowers saw significant decreases in total cost when alternating mowing and rolling was employed. Public golf courses experienced a reduction of cost by \$13,934.24, while private golf courses reduced total cost by \$22,048.49. Golf courses with 18 holes saved \$19,216.17, and courses with 27+ holes saved \$30,462.64. The savings experienced with courses using walk behind mowers is attributed to the reduction of labor cost. When using walk behind mowers, one laborer is required for each mowing

unit. From the mail survey, the number of walk behind mowers used for a single mowing event ranged from five to seven depending on the course type. However, the survey indicated that golf courses use one to two rollers for a single rolling event, which is a significant reduction of labor. Therefore, golf courses alternating mowing with rolling three days week⁻¹ to improve turf quality will not significantly increase costs when using triplex mowers. Courses using walk behind mowers will see significant savings and increased turf quality by alternating mowing with rolling three days week⁻¹. IN addition to the economic savings, higher turfgrass quality is another benefit of the alternating mowing with rolling practice during periods of high temp stress (Part II).

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APPENDICES

APPENDIX A
TABLES

Table 1. Mean squares for treatment effects on turfgrass quality[†] of creeping bentgrass putting greens grown during summer heat stress at Knoxville, TN., USA, June – August, 2004 and 2005.

Source [§]	df	Location [‡]		
		A	B	C
R	2	NS	NS	NS
Trt(T)	2	NS	**	**
Time(M)	2	***	***	***
T x M	4	*	**	*

*, **, *** Significant to the 0.05, 0.01, and 0.001 probability levels, respectively.

† Turfgrass quality was rated visually on a 1 to 9 scale with 1 = dead or brown turf and 9 = dark green turf.

‡ Three locations were used in study. Location A was a ‘Pennncross’ putting green in 2004. Location C was the same green as A in a different location and randomization. Location C was a ‘Crenshaw’ putting green established in 2005.

§ Sources of variation were treatments and time consisting of mowing six days week⁻¹ (Mow), mowing six days week⁻¹ with rolling three days week⁻¹ (Mwr), and mowing three days week⁻¹ alternating with rolling three days week⁻¹ (Amr) at one, two, and three months.

Table 2. Main effects for the interaction of treatments[†] and time[‡] for turfgrass quality[§] applied to creeping bentgrass putting greens during summer heat stress at Knoxville, TN, USA. June – August, 2004, and June – August, 2005.

Treatment	Locations [¶]								
	A			B			C		
	1	2	3	1	2	3	1	2	3
Mowing	8.00AB [#]	7.67AB	7CD	7.00A	7.00A	6.00B	5.00D	5.70AB	5.67B
Mowing with rolling	8.00AB	7.5BC	6.67D	7.00A	6.23B	5.43C	5.00D	5.33C	5.17CD
Alternating mowing with rolling	8.33A	8.17AB	8.00AB	7.00A	7.00A	6.87A	5.00D	6.00A	5.93AB

[†] The treatments were mowing six days week⁻¹ (Mow), mowing six days week⁻¹ with rolling three days week⁻¹ (Mwr), or alternating mowing three days week⁻¹ with rolling three days week⁻¹ (Amr).

[‡] Collection dates for turfgrass quality ratings were at 1, 2, and 3 months after initiation of the study.

[§] Turfgrass quality was rated visually on a 1 to 9 scale with 1 = dead or brown turf and 9 = dark green turf.

[¶] Three locations were used in study. Location A was a ‘Penncross’ putting green in 2004. Location C was the same green as A in a different location and randomization. Location C was a ‘Crenshaw’ putting green established in 2005.

[#] Interaction means followed by the same letter are not significantly different according to LSD_(0.05).

Table 3. Mean squares for treatment effects on Dollar spot incidence[†] of creeping bentgrass putting greens grown during summer heat stress at Knoxville, TN., USA, June – August, 2004 and 2005.

Source [§]	df	Locations [‡]					
		A			B	C	
		14-Jun	7-Jul	16-Aug	20-Jul	20-Jul	1-Aug
R	2	NS	NS	*	*	*	*
Trt	2	NS	NS	NS	NS	NS	NS

*, **, *** Significant to the 0.05, 0.01, and 0.001 probability levels, respectively.

† When disease incidence occurred, the disease of identified, and the number of disease spots were collected for each plot.

‡ Three locations were used in study. Location A was a ‘Pennncross’ putting green in 2004. Location C was the same green as A in a different location and randomization. Location C was a ‘Crenshaw’ putting green established in 2005.

§ Sources of variation were treatments consisting of mowing six days week⁻¹ (Mow), mowing six days week⁻¹ with rolling three days week⁻¹ (Mwr), and mowing three days week⁻¹ alternating with rolling three days week⁻¹ (Amr).

Table 4. Mean squares for treatment effects on root length[†] of creeping bentgrass putting greens grown during summer heat stress at Knoxville, TN., USA, June – August, 2005.

Source [§]	df	Locations [‡]	
		B	C
R	2	NS	NS
Trt(T)	2	NS	NS
Time(M)	2	*	NS
T * M	4	NS	NS

*, **, *** Significant to the 0.05, 0.01, and 0.001 probability levels, respectively.

[†] Root lengths were measured in millimeters beginning at the start of the experiment and continuing on a monthly basis until the end.

[‡] Three locations were used in study. Location A was a ‘Penncross’ putting green in 2004. Location B was the same green as A in a different location and randomization. Location C was a ‘Crenshaw’ putting green established in 2005.

[§] Sources of variation were treatments and time consisting of mowing six days week⁻¹ (Mow), mowing six days week⁻¹ with rolling three days week⁻¹ (Mwr), and mowing three days week⁻¹ alternating with rolling three days week⁻¹ (Amr) at one, two, and three months.

Table 5. Main effects of time[†] on root lengths‡ at location B§, a creeping bentgrass putting green, during summer heat stress at Knoxville, TN. 1 June- 31 August, 2005.

Time	Root length means¶ (mm)
0 Months	99.96A
1 Month	99.97A
2 Months	105.11A
3 Months	81.93B

† Collection times were zero, one, two, and three months after initiation of study.

‡ Root lengths were measured in millimeters beginning at the start of the experiment and continuing on a monthly basis until the end.

§ Location B is a ‘Penncross’ creeping bentgrass putting green used in 2005.

¶ Means followed by the same letter do not significantly differ at the 0.05 probability level.

Table 6. Means[†] of survey[‡] data collected from golf courses[§] in Tennessee concerning mowing and rolling practices on creeping bentgrass putting greens, 2005 – 2006, Knoxville, TN.

Course Type [¶]	Number of Courses	Average Putting Green Area (ft ²)	Mowing Time for Triplex Mowers (minutes)	Mowing Time for Walk Behind Mowers (minutes)	Mowing Time for All Greens with All Mowers (minutes)	Number of Triplex Mowers used mow ⁻¹	Number of Walk Behind Mowers used mow ⁻¹	Mechanical Maintenance for Triplex Mowers week ⁻¹ (hours)	Mechanical Maintenance for Walk Behind Mowers week ⁻¹ (hours)
Public	18	140,745.50	165.00	135.00	160.00	2	5	3.30	10.00
Private	18	176,704.44	163.57	210.91	192.50	1	5	7.86	12.14
18 Holes	28	123,932.11	157.94	205.45	176.61	1	5	5.06	11.95
27+ Holes	8	280,500.00	187.00	155.00	175.00	2	7	3.70	10.67

Table 6. Continued

	Frequency of Rolling (times year ⁻¹)	Rolling Time for all Greens (minutes)	Number of Rollers used rolling ⁻¹	Average Wage
Public	59	218	1.2	\$8.21
Private	102.15	195.28	1.5	\$8.92
18 Holes	87.36	201.59	1.41	\$8.77
27+ Holes	82	210	1.33	\$7.82

† Means were determined using SPSS (SPSS, Inc., Chicago, IL).

‡ Mail survey sent to golf courses in Tennessee with one repeat mailing. Survey was sent in December 2005 and January 2006 with a 37.5 percent response rate totaling 36 responses.

§ Golf courses for the survey were collected from the Tennessee Turfgrass Association lists.

¶ Survey data was separated by course type: public or private and 18 holes or 27+ holes.

Table 7. Frequencies[†] of triplex greens mowers, walk behind greens mowers, and lightweight greens rollers used on golf courses[‡] in Tennessee determined from survey[§] data, 2005 – 2006, Knoxville, TN.

Triplex Mower Brand	Model	Frequency	Percent of Total
Toro	3000	2	7.6
Toro	3050	2	7.6
Toro	3100	12	46.2
Toro	3150	4	15.4
John Deere	2500	3	11.5
Jacobsen	Greens King IV	1	3.9
Jacobsen	Greens King VI	1	3.9
Ransome	G Flex I	1	3.9
Total		26	100
Walk Behind Mower Brand	Model	Frequency	percent of total
Toro	1000	7	50.0
Toro	Flex 21	2	14.3
John Deere	180	2	14.3
John Deere	220	3	21.4
Total		14	100.0
Roller Brand and Model	Model	Frequency	Percent of Total
Craftsman	N/A	1	2.8
DMI	Speed Roller	1	2.8
Homemade	N/A	1	2.8
Jacobsen	Greens King IV	2	5.6
Salsco	N/A	9	25.0
Smithco	N/A	5	13.9
Toro	3050	1	2.8
Toro	3100	5	13.9
Toro	Tri-roll	1	2.8
Woodbay	Greens Iron	1	2.8
Unknown	N/A	1	2.8
Total		36	100.0

[†] Mower and roller frequencies determined using SPSS (SPSS, Inc., Chicago, IL).

[‡] Golf courses for the survey were collected from the Tennessee Turfgrass Association lists containing 96 member courses.

[§] Mail survey sent to golf courses in Tennessee with one repeat mailing. Survey was sent in December 2005 and January 2006 with a 37.5 percent response rate.

Table 8. Equipment[†] and cost[‡] data submitted by Jacobsen and Diversified Manufacturing Inc. for the Jacobsen Greens King IV Plus, Jacobsen PGM 22, and DMI Speed Roller, 2005 – 2006, Knoxville, TN.

	Jacobsen		DMI
	Greens King IV Plus	PGM 22	Speed Roller
MSRP (\$)	24000	7000	9200
Projected lifetime hours	5000	3000	5000
Estimated lifetime Maintenance cost (\$)	2560	225	250
Salvage Value (\$)	2000	500	1000
Fuel Consumption per hour (gal hr ⁻¹)	1.11	0.17	0.85
Speed (mph)	3.70	2.90	8.00
Width (in)	62.00	22.00	38.00
Acquisition Cost per hour (\$ hr ⁻¹)	4.40	2.17	1.64
Maintenance Cost per hour (\$ hr ⁻¹)	0.51	0.08	0.05
Equipment Cost per hour (\$ hr ⁻¹)	6.02	2.41	2.54
Area per hour (ft ² hr ⁻¹)	100936	28072	133760
Cost per area (\$ ft ⁻²)	0.0000597	0.0000859	0.0000190

[†] Equipment data was submitted by the respective company, Jacobsen and Diversified

Manufacturing, Inc.

[‡] Acquisition, maintenance, and equipment cost were determined using Huston's (2003) methods.

Table 9. Mowing[†] creeping bentgrass putting greens using triplex[‡] mowers (scenario a) and walk behind mowers (scenario b) six days week⁻¹ by type[§] of course and course size over a year assuming 36 weeks of mowing and/or rolling and 40 weeks of maintenance, 2005 – 2006, Knoxville, TN. Scenario 1a.

Parameter/cost item	Public	Private	18-hole	27+ hole
a. Annual mowings	216	216	216	216
b. Average Putting Green Area (ft ²)	140,745.50	176,704.44	123,932.11	280,500.00
c. Average wage hour ⁻¹ (\$)	\$8.21	\$8.92	\$8.77	\$7.82
Equipment cost of mower(s)				
d. Cost mower ⁻¹ ft ²	\$0.0000597	\$0.0000597	\$0.0000597	\$0.0000597
e. Number of mowers mowing ⁻¹	2	1	1	2
f. Total cost mowing ⁻¹ (b x d x e)	\$16.79	\$10.54	\$7.39	\$33.47
g. Total equipment cost year ⁻¹ (a x f)	\$3,627.55	\$2,277.17	\$1,597.10	\$7,229.55
Mowing labor cost				
h. Mowing Time for Triplex Mowers (hours)	2.75	2.73	2.63	3.12
i. Total labor cost mowing ⁻¹ (c x e x h)	\$45.16	\$24.32	\$23.09	\$48.74
j. Total mowing labor cost year ⁻¹ (i x a)	\$9,753.48	\$5,252.56	\$4,986.48	\$10,528.85
Maintenance labor cost				
k. Maintenance hours for Triplex Mowers week ⁻¹	3.30	7.86	5.06	3.70
l. Maintenance cost week ⁻¹ (k x c)	\$27.09	\$70.11	\$44.38	\$28.93
m. Total Maintenance cost year ⁻¹ (l x weeks)	\$1,083.72	\$2,804.45	\$1,775.05	\$1,157.36
Total costs				
n. Total costs year ⁻¹ (g + j + m)	\$14,464.75	\$10,334.18	\$8,358.63	\$18,915.76
o. Total cost ft ² of putting green (n ÷ b)	\$0.1028	\$0.0585	\$0.0674	\$0.0674

Table 9 Continued. Scenario 1b.

Parameter/cost item	Public	Private	18-hole	27+ hole
a. Mowings year ⁻¹	216	216	216	216
b. Average Putting Green Area (ft ²)	140,745.50	176,704.44	123,932.11	280,500.00
c. Average wage per hour (\$)	\$8.21	\$8.92	\$8.77	\$7.82
Equipment cost of mower(s)				
d. Cost mower ⁻¹ ft ²	\$0.0000859	\$0.0000859	\$0.0000859	\$0.0000859
e. Mowers used mowing ⁻¹	5	5	5	7
f. Total cost mowing ⁻¹ (b x d x e)	\$60.46	\$75.90	\$53.24	\$168.68
g. Total equipment cost year ⁻¹ (a x f)	\$13,058.77	\$16,395.14	\$11,498.77	\$36,435.82
Mowing labor cost				
h. Mowing Time for W/B Mowers (hours)	2.25	3.52	3.42	2.58
i. Total labor cost mowing ⁻¹ (c x e x h)	\$92.36	\$156.78	\$150.15	\$141.41
j. Total mowing labor cost year ⁻¹ (i x a)	\$19,950.30	\$33,863.71	\$32,432.34	\$30,544.92
Maintenance labor cost				
k. Maintenance hours for W/B Mowers week ⁻¹	10.00	12.14	11.95	10.67
l. Maintenance cost week ⁻¹ (k x c)	\$82.10	\$108.29	\$104.80	\$83.44
m. Total Maintenance cost year ⁻¹ (l x # weeks)	\$3,284.00	\$4,331.55	\$4,192.06	\$3,337.58
Total costs				
n. Total costs year ⁻¹ (g + j + m)	\$36,293.07	\$54,590.40	\$48,123.17	\$70,318.32
o. Total cost ft ² of putting green (n ÷ b)	\$0.2579	\$0.3089	\$0.3883	\$0.2507

† Averages based upon 2005 and 2006 mail survey results (Table 6).

‡ The example greens mowers were Jacobsen's Greens King IV Plus triplex and the PGM 22 walk behind. The University of Tennessee does not promote or endorse any products used in this study.

§ Golf courses were separated by exclusiveness and size of operation.

Table 10. Mowing[†] creeping bentgrass putting greens using triplex mowers[‡] (scenario a) and walk behind mowers (scenario b) six days week⁻¹ and rolling three days week⁻¹ with a greens roller by type[§] of course and course size over a year assuming 36 weeks of mowing and/or rolling and 40 weeks of maintenance, 2005 – 2006, Knoxville, TN.

Scenario 2a.

Parameter/cost item	Public	Private	18-hole	27+ hole
a. Mowings year ⁻¹	216	216	216	216
b. Rollings year ⁻¹	108	108	108	108
c. Average Putting Green Area (ft ²)	140,745.50	176,704.44	123,932.11	280,500.00
d. Average wage per hour (\$)	\$8.21	\$8.92	\$8.77	\$7.82
Equipment cost of mower(s)				
e. Cost mower ⁻¹ ft ²	\$0.0000597	\$0.0000597	\$0.0000597	\$0.0000597
f. Mowers used mowing ⁻¹	2	1	1	2
g. Total cost mowing ⁻¹ (c x e x f)	\$16.79	\$10.54	\$7.39	\$33.47
h. Total equipment cost year ⁻¹ (b x g)	\$3,627.55	\$2,277.17	\$1,597.10	\$7,229.55
Equipment cost of roller(s)				
i. Cost roller ⁻¹ ft ²	\$0.0000190	\$0.0000190	\$0.0000190	\$0.0000190
j. Rollers used rolling ⁻¹	1	2	1	1
k. Total cost rolling ⁻¹ (c x i x j)	\$3.2072	\$5.0332	\$3.3183	\$7.0842
l. Total equipment cost year ⁻¹ (b x k)	\$346.38	\$543.59	\$358.37	\$765.10
Mowing labor cost				
m. Mowing hours for Triplex Mowers	2.75	2.73	2.63	3.12
n. Total labor cost mowing ⁻¹ (c x e x h)	\$45.16	\$24.32	\$23.09	\$48.74
o. Total mowing labor cost year ⁻¹ (i x a)	\$9,753.48	\$5,252.56	\$4,986.48	\$10,528.85
Rolling labor cost				
p. Rolling Time for all greens (hours)	3.63	3.25	3.36	3.50
q. Total labor cost rolling ⁻¹ (d x p x j)	\$35.80	\$43.55	\$41.55	\$36.40
r. Total rolling labor cost year ⁻¹ (q x b)	\$3,865.92	\$4,703.12	\$4,487.04	\$3,931.43
Maintenance labor cost				
s. Maintenance hours for Triplex week ⁻¹	3.30	7.86	5.06	3.70
t. Maintenance cost week ⁻¹ (s x d)	\$27.09	\$70.11	\$44.38	\$28.93
u. Total Maintenance cost year ⁻¹ (t x weeks)	\$1,083.72	\$2,804.45	\$1,775.05	\$1,157.36
Total costs				
v. Total costs year ⁻¹ (h + l + o + r + u)	\$18,677.05	\$15,580.89	\$13,204.04	\$23,612.28
w. Total cost ft ² of putting green (b ÷ c)	\$0.1327	\$0.0882	\$0.1065	\$0.0842

Table 10 continued. Scenario 2b.

Parameter/cost item	Public	Private	18-hole	27+ hole
a. Mowings year ⁻¹	216	216	216	216
b. Rollings year ⁻¹	108	108	108	108
c. Average Putting Green Area (ft ²)	140,745.50	176,704.44	123,932.11	280,500.00
d. Average wage hour ⁻¹ (\$)	\$8.21	\$8.92	\$8.77	\$7.82
Equipment cost of mower(s)				
e. Cost per mower ft ²	\$0.0000859	\$0.0000859	\$0.0000859	\$0.0000859
f. Mowers used mowing ⁻¹	5	5	5	7
g. Total cost mowing ⁻¹ (c x e x f)	\$60.46	\$75.90	\$53.24	\$168.68
h. Total equipment cost year ⁻¹ (b x g)	\$13,058.77	\$16,395.14	\$11,498.77	\$36,435.82
Equipment cost of roller(s)				
i. Cost roller ⁻¹ ft ²	\$0.0000190	\$0.0000190	\$0.0000190	\$0.0000190
j. Rollers used rolling ⁻¹	1	2	1	1
k. Total cost rolling ⁻¹ (c x i x j)	\$3.2072	\$5.0332	\$3.3183	\$7.0842
l. Total equipment cost year ⁻¹ (b x k)	\$346.38	\$543.59	\$358.37	\$765.10
Mowing labor cost				
m. Mowing Time for W/B Mowers (hours)	2.25	3.52	3.42	2.58
n. Total labor cost mowing ⁻¹ (c x e x h)	\$92.36	\$156.78	\$150.15	\$141.41
o. Total mowing labor cost year ⁻¹ (i x a)	\$19,950.30	\$33,863.71	\$32,432.34	\$30,544.92
Rolling labor cost				
p. Rolling Time (hours)	3.63	3.25	3.36	3.50
q. Total labor cost rolling ⁻¹ (d x p x j)	\$35.80	\$43.55	\$41.55	\$36.40
r. Total rolling labor cost year ⁻¹ (q x b)	\$3,865.92	\$4,703.12	\$4,487.04	\$3,931.43
Maintenance labor cost				
s. Maintenance hours for W/B week ⁻¹	10.00	12.14	11.95	10.67
t. Maintenance cost week ⁻¹ (s x d)	\$82.10	\$108.29	\$104.80	\$83.44
u. Total Maintenance cost year ⁻¹ (t x # weeks)	\$3,284.00	\$4,331.55	\$4,192.06	\$3,337.58
Total costs				
v. Total costs year ⁻¹ (h + l + o + r + u)	\$40,505.37	\$59,837.11	\$52,968.59	\$75,014.84
w. Total cost ft ⁻² of putting greens (b ÷ c)	\$0.2878	\$0.3386	\$0.4274	\$0.2674

Table 10 Continued.

† Averages based upon 2005 and 2006 mail survey results (Table 6).

‡ The example greens mowers were Jacobsen's Greens King IV Plus triplex and the PGM 22 walk behind. The greens roller example was the DMI Speed Roller. The University of Tennessee does not promote or endorse any products used in this study.

§ Golf courses were separated by exclusiveness and size of operation.

Table 11. Mowing[†] creeping bentgrass putting greens using triplex mowers[‡] (scenario a) and walk behind mowers (scenario b) three days week⁻¹ alternating with rolling three days week⁻¹ with a greens roller by type[§] of course and course size over a year assuming 36 weeks of mowing and/or rolling and 40 weeks of maintenance, 2005 – 2006, Knoxville, TN. Scenario 3a.

Parameter/cost item	Public	Private	18-hole	27+ hole
a. Mowings year ⁻¹	108	108	108	108
b. Rollings year ⁻¹	108	108	108	108
c. Average Putting Green Area (ft ²)	140,745.50	176,704.44	123,932.11	280,500.00
d. Average wage hour ⁻¹ (\$)	\$8.21	\$8.92	\$8.77	\$7.82
Equipment cost of mower(s)				
e. Cost mower ⁻¹ ft ⁻²	\$0.0000597	\$0.0000597	\$0.0000597	\$0.0000597
f. Mowers used mowing ⁻¹	2	1	1	2
g. Total cost mowing ⁻¹ (c x e x f)	\$16.79	\$10.54	\$7.39	\$33.47
h. Total equipment cost year ⁻¹ (b x g)	\$1,813.77	\$1,138.59	\$798.55	\$3,614.78
Equipment cost of roller(s)				
i. Cost roller ⁻¹ ft ⁻²	\$0.0000190	\$0.0000190	\$0.0000190	\$0.0000190
j. Number of rollers used rolling ⁻¹	1	2	1	1
k. Total cost rolling ⁻¹ (c x i x j)	\$3.2072	\$5.0332	\$3.3183	\$7.0842
l. Total equipment cost year ⁻¹ (b x k)	\$346.38	\$543.59	\$358.37	\$765.10
Mowing labor cost				
m. Mowing hours for Triplex Mowers	2.75	2.73	2.63	3.12
n. Total labor cost mowing ⁻¹ (c x e x h)	\$45.16	\$24.32	\$23.09	\$48.74
o. Total mowing labor cost year ⁻¹ (i x a)	\$4,876.74	\$2,626.28	\$2,493.24	\$5,264.42
Rolling labor cost				
p. Rolling Time (hours)	3.63	3.25	3.36	3.50
q. Total labor cost rolling ⁻¹ (d x p x j)	\$35.80	\$43.55	\$41.55	\$36.40
r. Total rolling labor cost year ⁻¹ (q x b)	\$3,865.92	\$4,703.12	\$4,487.04	\$3,931.43
Maintenance labor cost				
s. Maintenance hours for Triplex week ⁻¹	1.65	3.93	2.53	1.85
t. Maintenance cost week ⁻¹ (s x d)	\$13.55	\$35.06	\$22.19	\$14.47
u. Total Maintenance cost year ⁻¹ (t x weeks)	\$541.86	\$1,402.22	\$887.52	\$578.68
Total costs				
v. Total costs year ⁻¹ (h + l + o + r + u)	\$11,444.67	\$10,413.80	\$9,024.73	\$14,154.40
w. Total cost ft ⁻² of putting green (b ÷ c)	\$0.0813	\$0.0589	\$0.0728	\$0.0505

Table 11 continued. Scenario 3b.

Parameter/cost item	Public	Private	18-hole	27+ hole
a. Mowings year ⁻¹	108	108	108	108
b. Rollings year ⁻¹	108	108	108	108
c. Average Putting Green Area (ft ²)	140,745.50	176,704.44	123,932.11	280,500.00
d. Average wage hour ⁻¹ (\$)	\$8.21	\$8.92	\$8.77	\$7.82
Equipment cost of mower(s)				
e. Cost mower ⁻¹ ft ²	\$0.0000859	\$0.0000859	\$0.0000859	\$0.0000859
f. Number of mowers used mowing ⁻¹	5	5	5	7
g. Total cost mowing ⁻¹ (c x e x f)	\$60.46	\$75.90	\$53.24	\$168.68
h. Total equipment cost year ⁻¹ (b x g)	\$6,529.38	\$8,197.57	\$5,749.39	\$18,217.91
Equipment cost of roller(s)				
i. Cost roller ⁻¹ ft ²	\$0.0000190	\$0.0000190	\$0.0000190	\$0.0000190
j. Number of rollers used rolling ⁻¹	1	2	1	1
k. Total cost rolling ⁻¹ (c x i x j)	\$3.2072	\$5.0332	\$3.3183	\$7.0842
l. Total equipment cost year ⁻¹ (b x k)	\$346.38	\$543.59	\$358.37	\$765.10
Mowing labor cost				
m. Mowing hours for W/B Mowers	2.25	3.52	3.42	2.58
n. Total labor cost mowing ⁻¹ (c x e x h)	\$92.36	\$156.78	\$150.15	\$141.41
o. Total mowing labor cost year ⁻¹ (i x a)	\$9,975.15	\$16,931.85	\$16,216.17	\$15,272.46
Rolling labor cost				
p. Rolling Time for all greens (hours)	3.63	3.25	3.36	3.50
q. Total labor cost rolling ⁻¹ (d x p x j)	\$35.80	\$43.55	\$41.55	\$36.40
r. Total rolling labor cost year ⁻¹ (q x b)	\$3,865.92	\$4,703.12	\$4,487.04	\$3,931.43
Maintenance labor cost				
s. Maintenance hours for W/B Mowers week ⁻¹	5.00	6.07	5.98	5.34
t. Maintenance cost week ⁻¹ (s x d)	\$41.05	\$54.14	\$52.40	\$41.72
u. Total Maintenance cost year ⁻¹ (t x weeks)	\$1,642.00	\$2,165.78	\$2,096.03	\$1,668.79
Total costs				
v. Total of all costs year ⁻¹ (h + l + o + r + u)	\$22,358.83	\$32,541.91	\$28,907.00	\$39,855.68
w. Total cost ft ² of putting green (b ÷ c)	\$0.1589	\$0.1842	\$0.2332	\$0.1421

Table 11 continued.

† Averages based upon 2005 and 2006 mail survey results (Table 6).

‡ The example greens mowers were Jacobsen's Greens King IV Plus triplex and the PGM 22 walk behind. The greens roller example was the DMI Speed Roller. The University of Tennessee does not promote or endorse any products used in this study.

§ Golf courses were separated by exclusiveness and size of operation.

APPENDIX B

FIGURES

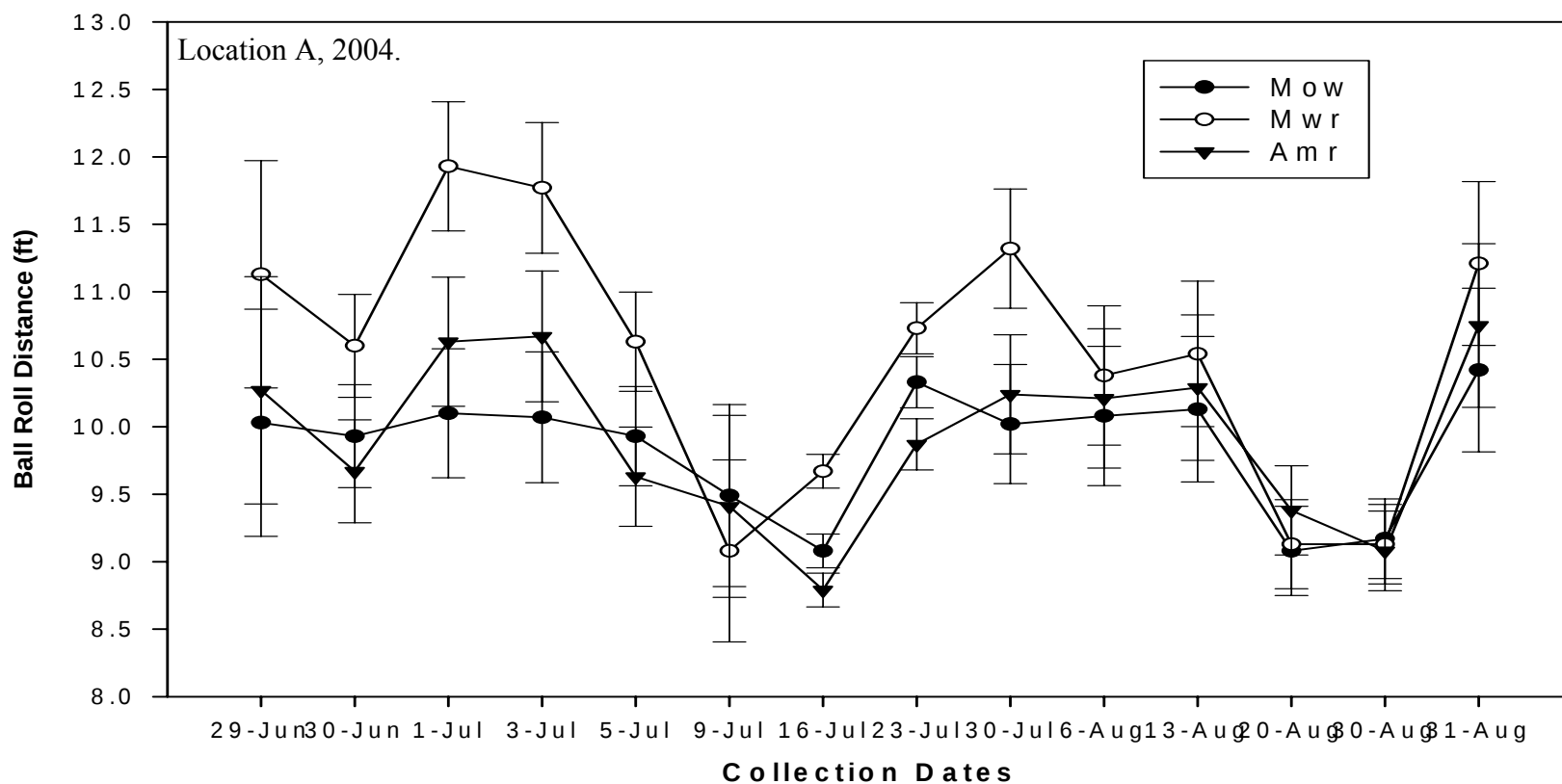


Figure 1. Effects of mowing six days week⁻¹ (Mow), mowing six days week⁻¹ with rolling three days week⁻¹ (Mwr), and alternating mowing with rolling three days week⁻¹ (Amr) on ball roll distance on three locations (a, b, and c) as recorded by a Stimpmeter. Knoxville, TN. 29 June- 31 August, 2004, and 1 June- 1 September, 2005. Error bars represent least significant differences at the 0.05 probability level.

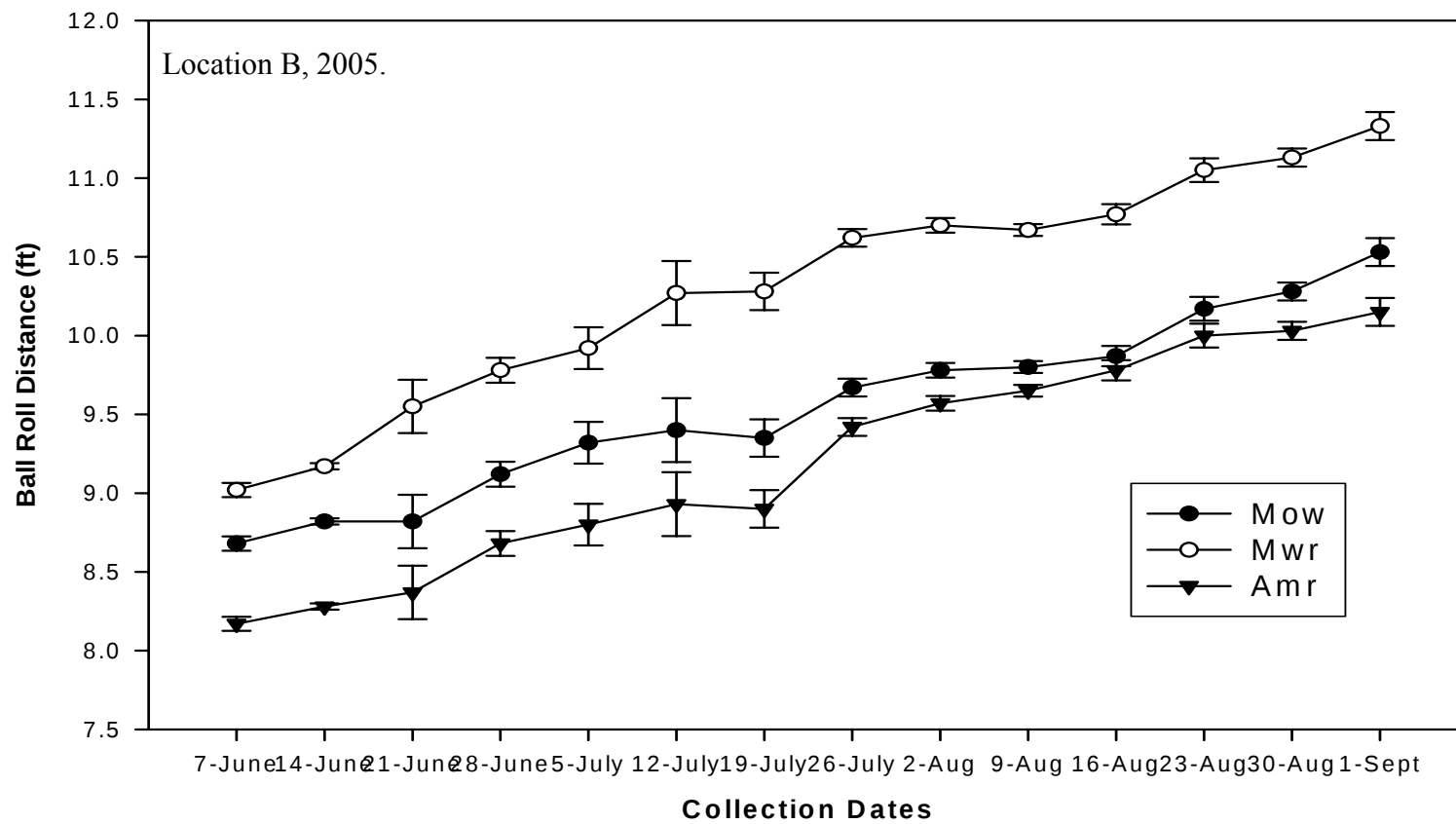


Figure 1 continued.

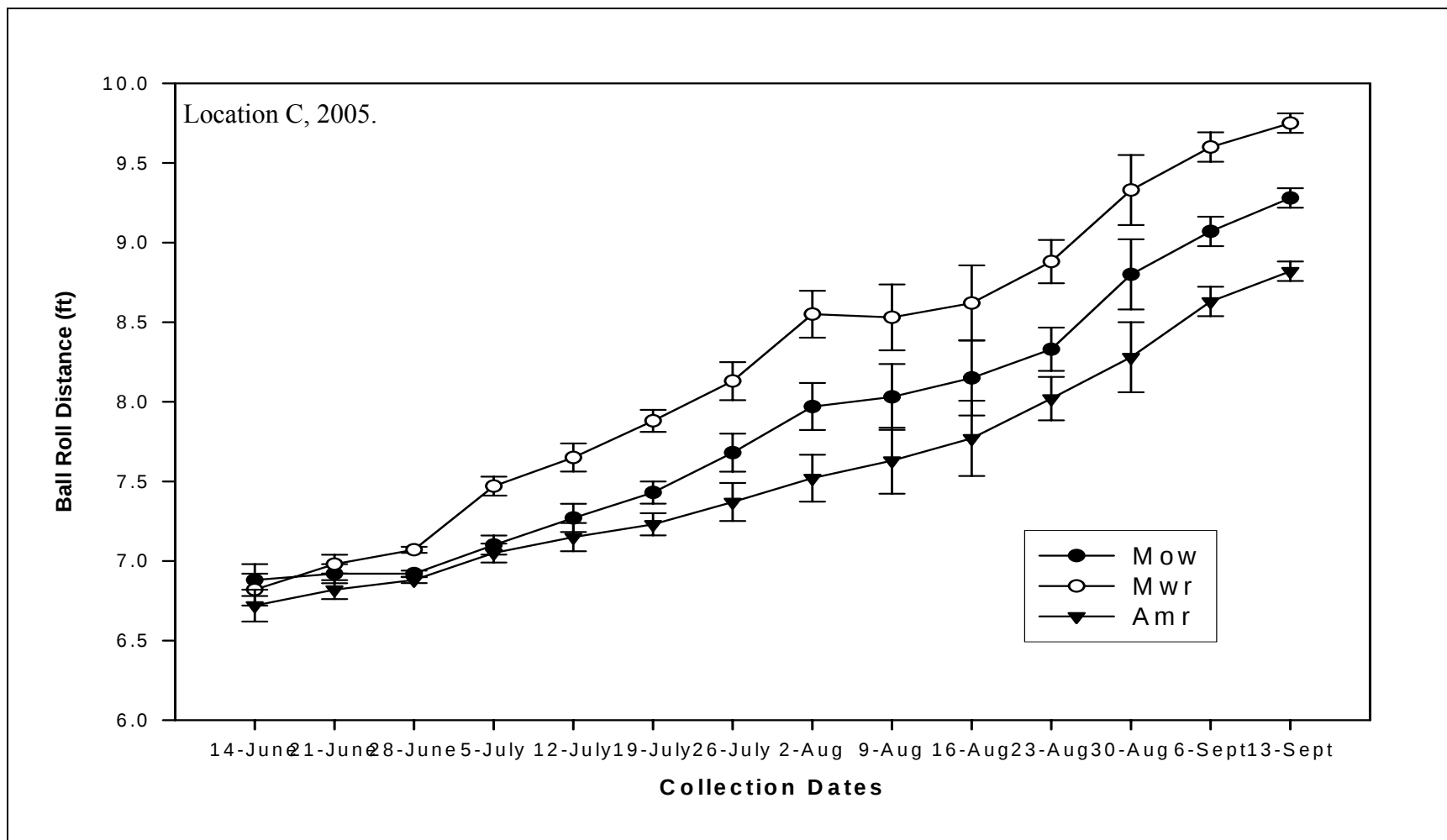


Figure 1 continued.



This survey is important to a master's research project dealing with heat stress on creeping bentgrass putting greens in the transition zone. The results are very important to some economical issues in putting green management.

Golf Course: _____
Superintendent: _____

Number of Holes: _____
Type of Course: _____ (private, public...)

Section I: Mowing

1. What is the square footage of your greens (including practice, nursery, and playing greens): _____ ft²
 2. What mower(s) do you use to mow greens (ex. Jacobsen PGM 22)?

<u>Brand</u>	<u>How Many?</u>
a. _____	_____
b. _____	_____
 3. How long does it take to mow all of your greens: _____ hrs _____ mins
 4. How many mowing units do you send out at one time: _____ units
 5. How many hours per week on average does your mechanic spend on greens mowing units (back-lapping, grinding, reel contact...): _____ hrs
-

Section II: Rolling

1. Do you roll your greens: _____ yes _____ no
 2. If so, how often: _____ times per _____
 3. What type of roller do you use (ex. DMI Speedroller)?

<u>Brand</u>	<u>How Many?</u>
a. _____	_____
b. _____	_____
 4. How long does it take to roll all of your greens: _____ hrs _____ mins
 5. How many rolling units do you send out at one time: _____ units
 6. What is the average wage paid to maintenance employees: _____ per hour
-

Thank you for completing this survey. The information you have provided is invaluable to the research at the University of Tennessee.

Figure 2. Mail survey sent to 96 member golf courses of Tennessee Turfgrass Association, December 2005 and January 2006, Knoxville, TN.

VITA

William Daniel Strunk was born in Knoxville, Tennessee on December 8, 1980. He grew up in Maryville, a small suburb outside of Knoxville, and graduated from Maryville High School in the spring of 1999. That next fall, Dan began his academic career at the University of Tennessee. He graduated in fall of 2003 with a Bachelor's of Science in Plant Sciences and Landscape Systems with a concentration in turfgrass management. In the spring of 2004, Dan accepted an assistantship to continue his education at the University of Tennessee towards a Master's degree in plant sciences. At the completion of this thesis, Dan plans to continue his education at the University of Missouri, Columbia in pursuit of a Ph.D.