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By

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ABSTRACT

STRATEGIES AND ANALYSIS OF MANAGEMENT PRACTICES FOR SPORTS FIELDS IN MICHIGAN

By

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Balancing and coordination of management practices of turfgrass under traffic are the ultimate challenge for any turfgrass professional. Sports fields present a particular challenge apart from the golf course because high traffic areas are relatively immobile, and play is not weather dependent. Most often, the task of a sports field manager is to build turfgrass density and health during the summer (or off-season) periods and try to maintain conditions throughout the playing season.

During the summer windows of 2002 and 2003, a randomized complete block design was used to evaluate three mowing height and six fertilizer treatment strategies before and after the playing season began. Gradually reducing the mowing height and using a resin-coated urea at 147 kg N ha^{-1}, with a 6% Reactive Layer Coating, provided the best playing surface in terms of turfgrass cover percent, traction, surface hardness, plant counts and root strength. Results were consistent for both years, and results were consistent both before, during and after simulated traffic was implemented by the Cady Traffic Simulator.

Management practices were evaluated in 2003 and 2004. A fractional factorial design was used to analyze six management factors; turfgrass species,

fertility, irrigation, overseeding, core cultivation and crumb rubber. Furthermore, six management systems were investigated using a combination of factors/cultural practices already mentioned. Repeated measures analysis was also used in the experiment. Playing surface characteristics included turfgrass cover percent, shear resistance, peak deceleration, time domain reflectometry and plant counts. Crumb rubber, fertility, turfgrass species, irrigation, core cultivation and overseeding were management factors ranked in order from highest to lowest F values. There were significant differences over time among all playing surface characteristics and management systems. The supina bluegrass/common bermudagrass (*Poa supina*, Schrad./*Cynodon dactylon* [L.] Pers.), management system, with a high maintenance regime, performed the best in terms of turfgrass cover percent, surface hardness, traction and plant counts. Plant counts, for this management system, were not significant indicating the playing surface had minimal changes taking place over the playing seasons. Crumb rubber was the single factor that was able to override or enhance other factors in the study regardless of maintenance regime. Interactions from the experiment emphasized the consistency of the playing surface due to a combination of an aggressive turfgrass, such as, supina bluegrass, a high fertility level at 196 kg N ha^{-1} , irrigation based on returning 50% evapotranspiration and crumb rubber (complimented with irrigation and core cultivation).

Every blade of grass has its Angel that bends over it and whispers ‘Grow, Grow’.

The Talmud

There is not a sprig of grass that shoots uninteresting to me.

Thomas Jefferson

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ABBREVIATIONS

3.8 cm Cont. (3.8 cm Continuous) - mowed at 3.8 cm throughout the study.
7.6 – Gr. – 3.8 cm (7.6-Gradual-3.8 cm) - maintained and mowed at 7.6 cm for 33 DAS and slowly dropped height to 3.8 cm.
7.6 – Ch. – 3.8 cm (7.6-Chop-3.8 cm) - mowed at 7.6 cm and scalped to 3.8 cm 68 DAS.

ARM – Agricultural Research Manager
BTS – Brinkman Traffic Simulator
C - Celsius
CC – core cultivation
CIT - Clegg Impact Soil Tester
Ch. - Chop
CR – crumb rubber
CTS – Cady Traffic Simulator
DAS – days after seeding
DAT – days after treatment
ET - evapotranspiration
FFD – fractional factorial design
F - fertility
g – gravities
G_{max} – maximum gravities or peak deceleration
h – hours
ha – hectare
I - irrigation
IBDU - isobutylidene diurea
K – potassium
kg – kilogram
N – nitrogen
P – phosphorous
PR/KB – perennial ryegrass/Kentucky bluegrass
RCU – resin-coated urea
RLC – reactive coating layer
S - species
SB/CB – supina bluegrass/common bermudagrass
SCU – sulfur-coated urea
TDR – time domain reflectometry
TST – Turf Shear Tester
Urea 2w - 16 kg N ha-1 starting on 15 June every 15 days equaling 49 kg N ha-1
v/v – volume/volume
yr - year

INTRODUCTION

According to the 2002 Michigan Rotational Survey, sponsored by the Michigan Department of Agriculture and the Michigan Agricultural Statistics Service, there were 13,500 acres reported for sports fields at university, college, primary and secondary facilities in Michigan. With repeated, vigorous use, and neglect of proper cultural practices, safety and playability of sports fields can become a serious problem (Harper et al, 1984, Rogers, et al., 1988). On the other hand, safety (injuries due to poor playing conditions) on golf courses is not an issue. For golf course management, the putting green is a heavily trafficked area, but golf course superintendents are able to move the pin to relieve traffic pressure and allow time for plant recovery. Play on sports fields is often concentrated making their management more challenging, but a sports field manager, typically, does not have the luxury of moving these trafficked areas during the playing season. After evaluating professional and college football fields, Cockerham (1989) suggested that 78% of the traffic was concentrated on 7% of the football field based on the number of cleat marks. He concluded that research efforts should target cultural practices in these areas of the field.

Soccer is an increasingly popular sport, and complexes have been built to satisfy public need. It is typical on these new complexes to schedule 200 games per field in a 6-7 month window (Kuhns, personal communication). This is an average of one game per day on each soccer field, assuming no interruptions, throughout the season. The importance of continuous cultural practices or management strategies throughout the playing season can be imperative, especially when little time is available for re-establishment during the growing year.

Playing field conditions will deteriorate as the season progresses thereby the potential for surface related injuries can hasten. A 1981 Pennsylvania study observed 210 football injuries that occurred on 24 practice and game fields at different high schools throughout the season. Of these injuries, 21% were classified as related to sports field conditions (Harper et al., 1984). Ekstrand and Nigg (1989) studied injuries in a male soccer league over a three-year period. They found 42% of the injuries were due to player factors (joint instability, muscle tightness or muscle weakness), but 24% of the injuries were due to poor playing conditions. Soil water conditions appeared to have a direct influence on the occurrence of knee injuries in the Australian Football League (Orchard et al., 1999, 2001). In the United Kingdom, Rahnama and Manning (2004) found, in their surveys of injuries in youth soccer, a 3:1 significant difference in the frequency of injury when pitches were "too hard/dry or too soft/wet" compared to pitches in "good condition".

Many sports field managers in Michigan do not consistently maintain sports fields at a high level (i.e. mowing 3-4x/week, an adequate fertilization program, and an installed irrigation system) because of budget restrictions. Furthermore, the expertise of maintaining these sports fields is somewhat limited. Surveys were sent to all Michigan high schools in December 1999 and 2000 (Lundberg, 2002). Based on survey responses, 88% of the schools have a football field to maintain, but only half were mowed more than once per week.

While 96% of these sports fields (football, soccer fields, etc) were fertilized three times per year. However, 83% of the respondents did not know the proper fertilizer application rates for the sports fields. Similar findings were uncovered among the turfgrass industry in Southern California, and stated that sports field managers were the most willing to promote proper management techniques (Klein and Green, 2002). The question must be asked; what are the minimal cultural practices needed to have a significant effect on sports fields?

"Minimal inputs" or "low inputs" refer to the minimum cultural practices on sports fields required to promote proper turfgrass vigor and soil conditions in a sports field situation.

The Michigan Rotational Survey (Kleweno and Matthews, 2002) reported that the top five cultural practices performed by schools were as follows.

Mowing/trim	92%
Fertilization	76%
Weed Control	70%
Overseeding	46%
Coring/Aeration	40%

The respondents surveyed also listed the top problems they deal with in a sports field situation;

Traffic	55%
Drought	54%
Weeds	48%
Poor Drainage	25%
Poor Soil	24%

The survey listed that 91% of the turfgrass species and/or mixtures consisted of Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne*, L.), and/or *Festuca*, spp. However, a sports field manager may not know which cultural practices are most paramount when resources are minimal.

When establishing a management program, a sports field manager must address two phases: *i*) a 70-day re-establishment window during the summer and *ii*) the other 295 days of the year. Sports fields are not actively growing or being played on during the winter months in Michigan therefore growing conditions are not conducive for plant recovery. Unlike the summer time when the sports field can actively grow and repair itself with good management practices, the sports field is in constant use during the fall and spring which necessitates a 295-day management program.

First, two cultural practices that most sports field managers perform are mowing and fertilization. Studies have been conducted to evaluate mowing and fertilization (Harrison, 1931; Evans, 1932; Juska et al., 1956; Goss and Law, 1967; Richie et al., 2002). In general, the more nitrogen used, the more plants are produced, and the higher the mowing height, the more root mass. However, these studies did not consider the interaction of these practices in a re-establishment situation in repairing the playing surface of a sports field in a limited time frame nor were playing surface characteristics evaluated.

Rogers and Waddington (1989) reported surface hardness and traction values on different mowing heights and verdure on an established tall fescue stand. Canaway (1990), Krick and Rogers (1995) and Cook et al., (1997) evaluated re-establishment methods, and evaluated the playing surface with measurements of surface hardness, traction and rooting. None of the researchers commenced any traffic testing or subsequent evaluations until, 365-day, 125-day and 140-day, respectively. More sports field management research is needed when time is limited to re-establish.

Second, a sports field manager must address their strategies (if any) during the playing season especially when inputs are limited. Research has been conducted to evaluate optimal performance of a variety of cultural practices for turfgrass establishment, vigor and growth in a variety of different turfgrass situations. Studies considered different turfgrasses and mixtures (Youngner 1961; Sherman and Beard 1975a; Canaway 1981, 1983; Brede and Duich 1984; Minner et al., 1993, Dunn et al., 2002; Minner and Valverde, 2004; Salehi and Khosh-Khui, 2004), overseeding (Davis, 1958; Beard, 1973; Gaussoin et al., 2001; Minner and Valverde 2004; Rossi personal communication, 2005), fertilizers, (Moberg et al., 1970; Brown et al., 1982; Hummel 1984, 1986, 1989; Landschoot and Waddington 1987; Fry, et al., 1993; Ebdon et al., 1999; Kopp and Guillard, 2002; Bowman, 2003), irrigation (Fry and Butler, 1989, Leinhauer et al., 1997, Richie et al., 2002, Johnson, 2003, Bastug and Buyuktas, 2003), core cultivation (Murray and Juska, 1977, Wilkinson and Miller, 1978, Murphy et al., 1992, Murphy and Rieke, 1994, Baker 2001 Lundberg, 2002), mulches/soil amendments (Dudeck et al., 1970, Waddington et al., 1974; Vanini, 1995, Baker et al., 2001, Sorochan and Rogers, 2001), and priming of seed with chemicals (Newell, 1997). This research does not easily translate to optimum results for preparing or maintaining sports fields during the playing season nor for evaluating playing surface characteristics (surface hardness, traction, turfgrass cover percent). These different cultural practices have distinct interactions depending on the turfgrass situation. The important concept that must not be overlooked, even when inputs are low, is to have a management strategy during the "other 295 days" of the year. Little research exists that considers multiple factors simultaneously, thus there is a need to evaluate the interaction of these factors.

In Denmark, sports field management received increased pressure, in particular weed control, when pesticides were phased out in 2003 (Larsen et al., 2004). Research was conducted on 37 different football (soccer) pitches at the same specific areas on the pitches over three years, comparing ground cover, weeds and bare areas, and different cultural practices. They concluded the rotation of cultural practices (core cultivation, verticutting, over-seeding, and topdressing) were significant to increasing turfgrass cover as the season progressed. More importantly, locality of the pitch, areas tested on the pitch, time of year and turfgrass percent cover at the beginning of the trial, had the most influence on turfgrass percent cover. However, the research team did not evaluate playing surface characteristics (traction, divoting resistance and surface hardness).

Research is needed to evaluate the effect of management practices on the qualitative and quantitative characteristics of the playing surface. Turfgrass cover percent, quality and density ratings are subjective measurements. Surface hardness, soil moisture and traction are examples of quantitative measurements that have been used to help evaluate playing surfaces.

Gramckow (1968) evaluated surface hardness or peak deceleration on different soils and turfgrasses. Clegg (1976) invented a portable device called the Clegg Impact Tester (CIT) for measuring surface hardness on dirt-based roads in western Australia. Lush (1985) introduced the concept of the CIT for testing surface hardness on cricket pitches. Numerous studies have been conducted to evaluate surface hardness on a variety of sports fields; soccer fields (Holmes and Bell, 1986; Baker, 1987, Miller, 2004, Vanini et al., 2004) football fields (Rogers et al., 1988) and research plots (Rogers and Waddington, 1992; Rogers et al., 1996; Lundberg, 2002). As soil moisture decreases, surface hardness increases causing agronomic factors to deteriorate as well increase the possibility of surface related injuries.

Traction is another playing surface parameter studied quite extensively in sports field research. Traction, or shear resistance, indicates the resistance of the playing surface to shearing or tearing. Higher traction measurements indicate the surface is more resistant to shearing. Although different devices have been used, traction measurements were reported by Gramckow (1968), Zebarth and Sheard (1985), Rogers and Waddington (1992), Rogers et al. (1998), Sorochan et al., (2001, 2005 and 2005 – two different articles) and Lundberg (2002) in a variety of turfgrass situations from healthy turfgrass stands to bare soil. In most of these studies, the Eijkelkamp shearing apparatus (Giesbeck, Netherlands) was used. A new device, the Clegg Turf Shear Tester (TST) (Wembley DC, Western Australia), measures divoting resistance and has been used on a limited basis (Henderson, 2003). Unlike the Eijkelkamp shearvane being user-dependent and subjective in reading the gauge, the TST is not user-dependent and has a digital readout box for more accurate measurements.

Plant counts are another quantitative method that can be used to analyze turfgrass cover for sports field research (Sorochan et al., 2001; Lundberg, 2002). By counting the number of plants in a given area, a higher number of plants can signal a better playing surface in regards to turfgrass cover and traction.

Root mass has been used to evaluate primarily mowing and fertility interactions (Harrison, 1931; Evans, 1932; Juska et al., 1956; Goss and Law, 1967; Richie et al., 2002) and in some cases, sports fields (Krick, 1995; Vanini 1995; Cook et al., 1997). However, root mass can provide a great deal of variability due to the small area typically used to extract the roots from the soil and does not necessarily indicate root strength. A possible better way to study the effects of rooting might be the use of root pulls to measure the strength of pulling the turf from the surface until it is displaced. Typically a larger area (> 30 cm^2) is required to displace turf. This way of measuring rooting is more indicative of sports field dynamics (the athlete shearing the playing surface on a turn or a stop), and possibly provides a better measurement for sports field research. Little research exists in evaluating root strength in regards to sports field research.

A study in Michigan was conducted to evaluate multiple factors and made recommendations based on evaluation of playing surface characteristics. Surveys were sent to each high school in December of 1999 and 2000 (Lundberg

2002). From these surveys, cultural practices (mowing, fertilizing and core cultivation) were quantified in order to attain acceptable field conditions throughout the playing season. Under controlled conditions, and based on playing surface characteristics (surface hardness, traction, turfgrass cover percent and plant counts), sports field use could be extended 3-5 weeks (or 5-6 game extension) by mowing twice per week, fertilizing a total 245 kg N ha^{-1} (low amount per application with high frequency over the year), and core cultivating twice per year (Calhoun et al., 2002). Although results were obtained on a sand-based root zone, results were confounded and ambiguous due to lack of irrigation on the native soil site. Data were only taken during fall seasons.

The playing surface of a sports field can degrade due to lack of intensity of cultural practices put forth by the sports field manager. Identifying the most important cultural practices and analyzing their interaction is especially a concern for low input sports fields. One management tool that could enhance other management practices would be the use of topdressing crumb rubber (Rogers et al., 1998). Research has revealed its ability to lower and stabilize surface hardness values, improve traction (Rogers et al., 1998), and maintain proper infiltration rates after compaction under laboratory conditions (Baker et al., 2001). However, it is unclear how crumb rubber interacts with other cultural practices over time, and it can be cost prohibitive.

Consistently implementing management strategies over a long period of time could relieve pressure on the sports field in preparing it in a 70-day window. For example, if a sports field manager has 60% turfgrass cover compared to only

30% turfgrass cover after a playing season, the sports field would probably re-establish itself more quickly if there was more turfgrass cover available after a playing season. This in turn could provide a better playing surface for the upcoming playing season; less damage to the playing surface has to be repaired.

Once best strategies are identified for both a 70-day re-establishment window and for a 295-day maintenance window then it might be possible to justify funds to provide better quality sports fields.

Specific Objectives

1) a.) Clarify the impact of best management strategies in regards to mowing height and fertilization on re-establishment of a sports field during a 70-day window.

   b) Quantify these effects during and after a 25-day simulated traffic period.

2) a) Identify the most important factors for sports fields having low inputs.

   b) Provide the sports field managers of Michigan with management strategies that enhance playing surface characteristics (surface hardness, traction and turfgrass cover percent) thus providing improved playability and safety of sports fields.

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EFFECTS OF MOWING HEIGHT AND FERTILIZATION ON SPORTS FIELD DURING AND AFTER A 70-DAY RE-ESTABLISHMENT WINDOW

ABSTRACT

A 2002 Michigan Rotational Survey, sponsored by the Michigan Department of Agriculture and Michigan Agricultural Statistics Service, reported there were 13,500 acres of sports fields at university, college, primary and secondary facilities. According to the survey, the two cultural practices sports turf managers performed most consistently, regardless of maintenance level, were mowing and fertilization. Little information exists for sports field managers on the optimal ways to re-establish the most trafficked areas on a sports field during a 70-day window or the summer season. The impact of these two practices was quantified in a study conducted at Michigan State University in 2002 and 2003. The objectives were to *i*) clarify the impact of best management practices in regards to mowing height and fertilization on re-establishment of sports field turf during a 70-day window and *ii*) quantify these effects during and after a 25-day simulated traffic period. Simulated traffic was applied with the Cady Traffic Simulator after 70 days. Data collected were turfgrass cover percent ratings, traction, peak deceleration, volumetric water content, root pull, root mass, chlorophyll index and plant counts. The gradually reducing mowing height treatment was significantly higher for turfgrass cover percent ratings only at the end of the 70-day window for both years. The more dominant factor of this study was fertilization. Fertilization was applied at the start of the experiment

(1 June) during both years whereas mowing was not begun until four to five weeks into the experiment. Various fertilizer strategies were employed, and significant differences existed among them during the re-establishment window and traffic regime. Among the six fertilizer strategies, the resin coated urea at 147 kg N ha^{-1}, with a 6% Reactive Layer Coating, was most effective in providing the strongest and most uniform surface throughout the study according to playing surface measurements.

INTRODUCTION

Re-establishment of sports fields is a continuous process for sports field managers. They cannot relocate a field, or part of the sports field, during or until after the playing season is complete unless additional space is available. After evaluating professional and college football fields, Cockerham (1989) suggested that 78% of the traffic is concentrated on 7% of the football field based on the number of cleat marks. He concluded research efforts should be targeted toward cultural practices in these areas of the field. The need for best management practices or strategies for re-establishing sports fields, after the playing season has finished, is a necessity for sports field managers.

The 2002 Michigan Rotational Survey (Kleweno and Matthews, 2002) reported 13,500 acres of sports fields at university, college, primary and secondary facilities. According to the survey, two practices sports turf managers performed most consistently, regardless of maintenance level, were mowing and fertilization.

Mowing is a common and essential practice for any turfgrass professional to implement. Youngner (1961) evaluated the effects of mowing height on wear tolerance using cool-season turfgrasses and an "accelerated wear" machine. A mowing height of 5.0 cm performed better compared to 1.3 cm because of "restricted grass development". Physiological effects of mowing have been investigated and continually discussed (Beard, 1973, Liu and Huang, 2002, Narra, et al., 2004). When mowing height is decreased, there is an increase in shoot density, plants per unit area and chlorophyll content, and a decrease in rooting (Beard, 1973). Recently, evaluating different mowing heights has been critical for determining proper fungicide programs on golf course putting greens (Bruneau, et al., 2001) or weed control on tall fescue (*Festuca arundinacea* Schreb.) (Voigt, et al., 2001). Rogers and Waddington (1989) reported playing surface characteristics (surface hardness and traction) values on different mowing heights and verdure on an established tall fescue stand. They did not investigate the role of nitrogen fertility in this study. Lundberg (2002) observed mowing twice per week at a consistent 5.0 cm mowing height increased plant counts compared to once per week. Sorochan et al., (2005) evaluated different mowing heights for supina bluegrass (*Poa supina* Schrad.) under simulated traffic situations.

Fertilization is paramount for proper turfgrass health, and it is relatively inexpensive compared to other cultural practices (Turgeon, 2004). Extensive research has been conducted on fertilizers and their effects on turfgrass (Moberg et al., 1970, Brown et al., 1982; Waddington and Turner, 1980; Hummel, 1980, 1984 1986, 1989; Fry, et al., 1993, Ebdon et al., 1999, Kopp and Guillard, 2002; Bowman, 2003). Hummel (1980) evaluated 12 nitrogen sources on a sandy clay loam for establishment of a Kentucky bluegrass (*Poa pratensis* L.)/perennial ryegrass (*Lolium perenne* L.) mixture, and based on clipping yields, color and turfgrass cover percent, he concluded ammonium nitrate, urea and isobutylidene diurea (IBDU) performed the best. Ammonium nitrate performed better compared to urea, and it was speculated that urea volatilized quicker than ammonium nitrate. Playing surface characteristics were not measured in this study.

Slow-release fertilizers can provide potential benefits for the sports field manager, including, longer turfgrass response, less nitrogen leaching, less surface run-off, less volatilization and fewer applications for healthy turfgrass response compared to quick release fertilizers (fertilizers that release or dissolve once in contact with water) (Christians 2004). Typically with urea, multiple applications are needed to attain the responses observed by using slow-release fertilizers over a long period of time. Waddington and Turner (1980) and Hummel and Waddington (1984, 1986) have investigated sulfur-coated urea (SCU) as a slow release fertilizer. Although SCU performed excellent in their studies, different responses can be generated due to variations in the coating thickness, coating methods, number of applications and timing of applications throughout the year (Carrow et al., 2001).

Resin-coated ureas (RCU) are another alternative for slow release fertilizers in the turfgrass industry. Unlike SCU, release rate of nitrogen is not dependent upon outside factors such as rainfall/irrigation, microbial activity and pH. As the polymer expands, urea/water solution is slowly released via the expanded pores in the polymer (Carrow et al., 2001). Hummel (1989) found a single-spring application of RCU-100 (number based on 7-day dissolution rates), at 196 kg N ha^{-1} provided superior color compared to split treatments throughout the year. Fry et al., (1993) also noted various responses of RCU in established turf based on resin thickness.

Studies have been conducted in evaluating a combination of mowing and fertility practices (Harrison, 1931; Evans, 1932; Juska et al., 1956; Goss and Law, 1967; Richie et al., 2002). These various studies found more shoots were produced with a lower mowing height and in conjunction with a higher rate of nitrogen. However, the research did not focus on sports field management situations when time for preparation was a factor nor did the studies evaluate playing surface characteristics.

Limited research exists that investigates best management practices in re-establishing sports fields during a restricted time window while also evaluating the playing surface characteristics (surface hardness, traction, etc) after traffic has resulted. The playing surface must function in terms of turfgrass cover and color, and must be evaluated for strength of surface in terms of playing surface characteristics, such as traction, surface hardness, and rooting.

Canaway (1990) and Krick (1995) compared perennial ryegrass (*Lolium perenne* L.) established from seed and Kentucky bluegrass (*Poa pratensis* L.) sod for soccer fields before the playing season on a sand-based root zone. Sod produced a superior playing quality surface compared to seed when evaluating playing surface characteristics. Cook et al., (1997) evaluated turfgrass establishment using hydroseeding (a mixture of primarily water, seed, fertilizer and mulch sprayed on the intended target area) and compared the results to seed and sod on a sand-based root zone. However, simulated traffic on these studies was not initiated until 125, 365 and 140 days after treatment (DAT), respectively. Furthermore, these studies implement practices (sodding and hydroseeding) that can be expensive and labor intensive from year to year.

Sports fields are active during the spring and fall seasons or not actively growing during the winter months in Michigan. Therefore growing conditions are not conducive for plant recovery. The 70-day summer window is ideal for sports fields to actively grow and repair itself. These practices get increasingly complicated when school and park crews leave for vacation or inclement weather occurs during summer. The need for strategies that are less expensive and time-consuming is evident.

The objectives were to *i*) clarify the impact of best management practices in regards to mowing height and fertilization on re-establishment of sports field turf during a 70-day window, and *ii*) quantify these effects during and after a 25-day simulated traffic period. The hypothesis is that a low continuous mowing height treatment combined with a steady continuous nitrogen source would provide the strongest surface in a 70-day window before and after simulated traffic.

MATERIALS AND METHODS

This study was conducted in 2002 and 2003 at the Hancock Turfgrass Research Center (HTRC) on the campus of Michigan State University in East Lansing, MI. The experiment was a randomized complete block design with two-factors and three replications. Three mowing heights and six fertilizer treatments were evaluated (Table 1) and re-randomized, in 2003, to avoid any edge effects from the first year. Plot size was 1.8 x 2.7 m. In 2002, sod cutters were used to strip out the existing sod, and in 2003, a Koro Field Topmaker (Pols International BV, The Netherlands) was used to strip the turf from the 2002 experiment. The soil was a sand-based profile (Table 2) and was sterilized each year with Basamid G® (Tetrahydro-3,5,-Dimethyl-2H-1,3,5, Thiadiazine-2 Thione) (Certis USA, Columbia,MD) at 392 kg ha^{-1}.

In both years, seeding and fertilizer treatments began on 1 June. A 30:70 sports grass mixture (by weight) of perennial ryegrass (*Lolium perenne* L. var. SR4400, SR4500 and Manhattan III) and Kentucky bluegrass (*Poa pratensis* L. var. Champagne and Rugby II) was seeded at 196 kg ha^{-1}. Lebanon Country Club® 13-25-12 (Lebanon Turf Products, Lebanon, PA) was applied at 49 kg N ha^{-1} and subsequent fertilizer treatments were applied (Table 1). Germination blankets (Model No. pr1715; A.M. Leonard, Piqua, OH) were placed over the top of the plot and removed after 15 days. Fertilizer treatments applied were Andersons™ urea (46-0-0) (Maumee, OH) at 49 kg N ha^{-1} on 1 July (Urea) and 16 kg N ha^{-1} every two weeks starting on 16 June, 1 July and 18 July (Urea 2w), Lesco™ Poly-Plus® sulfur-coated urea (39-0-0, 12% sulfur coating) (Strongsville,

Table 1. Individual treatments for mowing and fertilizer study, 2002 and 2003.

Mowing Treatments
1) 3.8 cm Continuous - mowed at 3.8 cm throughout the study.
2) 7.6-Gradual-3.8 cm† - maintained and mowed at 7.6 cm for 33 DAS and slowly dropped height to 3.8 cm.
- 3 July - 15 July - 4 mowings at 7.6 cm
- 16 July - 24 July - 2 mowings at 6.3 cm
- 25 July - 30 July - 2 mowings at 5.1 cm
- 31 July - 3 Sept - 9 mowings at 3.8 cm
3) 7.6-Chop-3.8 cm - mowed at 7.6 cm and scalped to 3.8 cm 68 DAS.

Fertilizer Treatments	Total N used ‡
1) Urea - 49 kg N ha^{-1} only on 1 July	98 kg N ha^{-1}
2) Urea 2w - 16 kg N ha^{-1} starting on 15 June every 15 days equaling 49 kg N ha^{-1}	98 kg N ha^{-1}
3) SCU - 147 kg N ha^{-1}	196 kg N ha^{-1}
4) RCU2 - 98 kg N ha^{-1}	147 kg N ha^{-1}
5) RCU3 - 147 kg N ha^{-1}	196 kg N ha^{-1}
6) RCUThin - 196 kg N ha^{-1}	245 kg N ha^{-1}

† In 2002, mowing started on 25 June and was mowed at 7.6 cm until 15 July. Six mowings occurred until 15 July.

‡ Total N used includes starter fertilizer application (13-25-12) at 49 kg N ha^{-1} plus treatments on 1 June.

Analysis of fertilizers - Urea 46-0-0, SCU 39-0-0, RCU2 and RCU3 43-0-0 and RCUThin 44-0-0.

Seed and starter fertilizer (13-25-12) was applied on 1 June to all treatments.

Fertilizer treatments 3 - 6 were only applied on 1 June.

Table 2. Particle size distribution of sand-based root zone.

Size Class	mm	% Retained
Fine gravel	3.4 - 2.0	0.7
V. coarse sand	2.0 - 1.0	7.0
Coarse sand	1.0 - 0.5	35.8
Medium sand	0.50 - 0.25	47.3
Fine sand	0.25 - 0.10	8.6
V. fine sand	0.10 - 0.05	0.4
Silt + Clay	> 0.05	0.2

OH) at 147 kg N ha^{-1} (SCU) and Polyon® resin-coated urea (RCU) (43-0-0, 6% Reactive Layer Coating (RLC)) at 98 kg N ha^{-1} (RCU2) and 147 kg N ha^{-1} (RCU3) and (44-0-0, 4% RLC) (Pursell Industries, Sylacauga, AL) at 196 kg N ha^{-1} (RCUThin). Based on visual quality throughout the experiment, potassium, phosphorous and micronutrients were supplemented. In both years, Andersons™ 0-26-26 fertilizer and Andersons™ Trace Element Package (Maumee, OH) were applied at 49 kg P ha^{-1} and normal rate, respectively, on 27 June and 25 July. In both years, Lebanon Country Club® 18-3-18 (Lebanon Turf Products, Lebanon, PA) was broadcasted to all treatments at 24.5 kg N ha^{-1} on 6 August and 19 August to supplement nutrients during traffic phase. Irrigation was applied daily during re-establishment and as necessary throughout the experiment to prevent moisture stress.

A Watchdog Data Logger (Model: Series 250, Spectrum Technologies, Inc., Plainfield, IL) was used to record soil temperature, ambient temperature and humidity. Data was recorded every hour from 5 June through the duration of the experiment for each year.

Mowing began on 25 June 2002 and 3 July 2003, and treatments were mowed twice per week throughout the experiment (Table 1). During the initial 70 days, the 3.8 cm Continuous strategy was mowed with a 43 cm wide McLane mower (McLane Manufacturing, Inc, Paramount, CA), and the 7.6 – Gradual - 3.8 cm (mowing height lowered weekly) (7.6 – Gr. – 3.8 cm) and 7.6 - Chop – 3.8 cm (7.6 – Ch. – 3.8 cm) treatments were mowed with a Honda rotary mower (Model: Harmony HRB216 Quadracut System™, Honda Motor Company, Alpharetta, GA). With 68 days after seeding (DAS), 7.6 – Ch. – 3.8 cm treatment was scalped down with an eXmark mower (Model: Lazer Z HP, eXmark® Corporation, Beatrice, NE) to a height of 3.8 cm. From this point on, the mowing treatments were mowed at 3.8 cm height for the duration of the experiment. Clippings were returned at all times.

A traffic regime was applied on 12 August to 4 September in 2002 and 11 August to 3 September in 2003. Traffic was applied by the Cady Traffic Simulator (CTS) uniformly to all plots. The CTS was a modified Jacobsen® Aero King 30 (A Textron Company, Charlotte, NC) self-propelled core cultivation machine with "rubber feet" (Figure 1) and weighed 680 kg (Henderson et al., 2005).

Data were collected during re-establishment and traffic phases. Turfgrass cover percent ratings, shear resistance, divoting resistance, peak deceleration, time domain reflectometry, root mass, chlorophyll index, root pulls and plant count values were measured. Once traffic began, data were collected in traffic lanes except in non-traffic lanes on 4 Sept 2002 and 3 Sept 2003.

Turfgrass cover percent ratings were estimated qualitatively. Data were collected on 19 Jun, 26 Jun, 2 Jul, 19 Jul and 5 Aug 2002, and 20 Jun, 25 Jun, 30 Jun, 7 Jul, 14 Jul, 21 Jul, 29 Jul, 4 Aug, 12 Aug, 19 Aug, 27 Aug and 3 Sept 2003.

Traction values were measured by both the Eijkelkamp shear vane Type 1B (Giesbeck, The Netherlands) for shearing resistance and the Clegg Turf Shear Tester (TST) (Wembley DC, Western Australia) for divoting resistance with

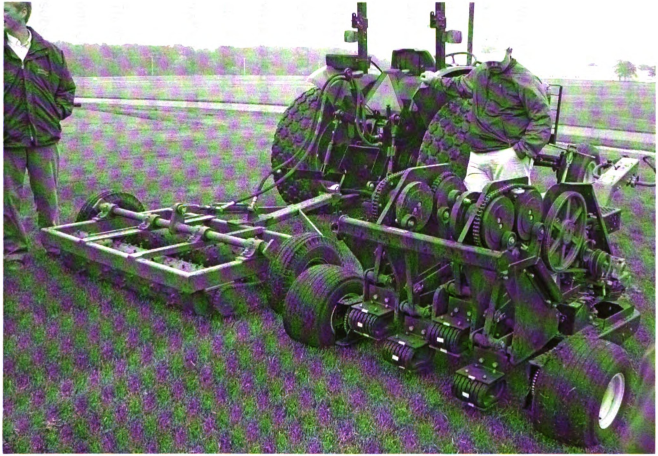


Figure 1. The Brinkman Traffic Simulator and Cady Traffic Simulator. Notice the “rubber feet” on the Cady Traffic Simulator.

a plate depth of 40 mm. Three measurements were recorded for each device and were measured in Nm. Data were collected for the Eijkelkamp shearvane on 11 Jul, 17 Jul, 24 Jul, 15 Aug, 23 Aug, and 4 Sep (traffic and non-traffic lanes) 2002, and 1 Aug, 7 Aug, 13 Aug, 21 Aug, 28 Aug and 3 Sept (traffic and non-traffic lanes) 2003. Data were collected for the TST in traffic and non-traffic lanes on 3 Sept 2003.

The Clegg Impact Soil Tester (CIT) (Lafayette Instrument Co., Lafayette, IN) was used to measure peak deceleration (G_{max}) values. A 2.25 kg hammer was dropped in three random locations per plot from a height of 0.46 m (Rogers and Waddington, 1990). Data were collected on 11 Jul, 17 Jul, 24 Jul, 2 Aug and 4 Sept (traffic and non-traffic lanes) 2002, and 7 Aug, 13 Aug, 21 Aug, 28 Aug and 3 Sept (traffic and non-traffic lanes) 2003.

Time Domain Reflectometry (TDR) values were measured with a Trime FM gauge and FM3 probe with 50 mm rods (Mesa Systems Co. Medfield, MA). One TDR measurement (v/v) was recorded throughout the treatment area. Data were collected on 11 Jul, 17 Jul, 24 Jul, 2 Aug and 4 Sept (traffic and non-traffic lanes) 2002, and 1 Aug, 7 Aug, 13 Aug, 21 Aug, 28 Aug, 3 Sept (traffic and non-traffic lanes) 2003.

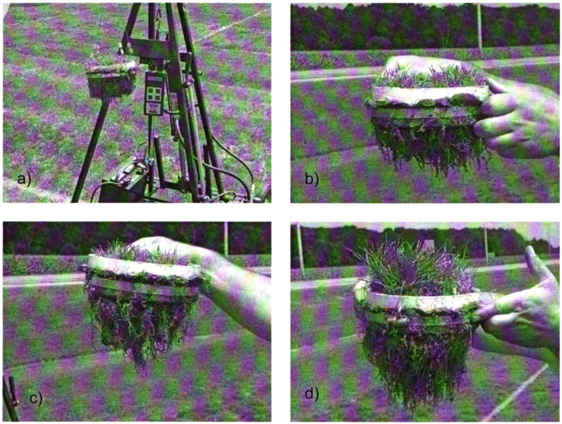
Roots were collected on 11 July 2002, 25 July and 26 August 2003. Three subsamples were extracted from each plot with a soil probe having a 32 mm diameter. Cores were partitioned at 0-50, 50-100 and 100-150 mm. Each subsample was placed in a fleaker with distilled water and 5 ml of sodium hexametaphosphate and shaken for 24 hours in order to disperse soil particles away from the roots. Roots were separated from the soil by flushing water through the fleakers and sieving the roots.

Chlorophyll readings were taken with a CM 1000 chlorophyll meter (Model: Field Scout™; Spectrum Technologies; Plainfield, IL). Twenty subsamples were taken and an average was recorded. Data were collected on 25 Jun, 14 Jul and 29 Jul 2003

Root pulls were taken on 8 Aug 2002 and 6 Aug 2003. This process was similar to the description by Bhowmik, (et al., 1993). A root column made of PVC pipe (one sample per plot) measuring 150 mm in diameter and 50 mm deep, with a fine mesh (Phifer Pet Screen®, Phifer Wire Products, Inc., Tuscaloosa, AL) clamped (178 mm ring clamps) to the bottom of the column, was placed in the sand and graded to the surface for each treatment. At 65 DAS and prior to the traffic phase, root pulls were measured using the Michigan State Root Pull machine (Sorochan, et al., 1999)(Figure 2). The columns were pulled, and the force required to displace them from the soil were measured in newtons with a digital force gauge (Model: DFI 200, Chatillon Inc., Greensboro, NC).

Plant counts were obtained using a soil probe having a 32 mm diameter. Three counts were recorded for each plot. Data were collected on 20 Aug (traffic and non-traffic lanes) and 4 Sept 2002, and 13 Aug and 3 Sept (traffic and non-traffic lanes) 2003.

Data were analyzed using the Agricultural Research Manager (ARM) program (Version 6.1.11, Gylling Data Management, Inc. 2002). Root washing analysis was analyzed separately for each 50 mm depth and the 150 mm total



Figures 2 a) A Michigan State Root Pull machine being used as a root pull apparatus on 6 Aug 2003. b) A root circle pulled from a 3.8 cm Continuous mowing treatment. c) A root circle pulled from a 7.6 – Gradual - 3.8 cm mowing treatment. d) A root circle pulled from a 7.6 – Chop – 3.8 cm mowing treatment.

depth. Treatment means were separated using Fisher's Protected LSD values at the 0.05 level.

RESULTS AND DISCUSSION

Turfgrass cover percent

Mowing height was only significant at the end of the 70-day trial, 5 August 2002 and 4 August 2003 for turfgrass cover percent (Tables 3 and 4). These dates represented the last turfgrass cover percent ratings observed before traffic was initiated. Both years, there were significant differences among fertilizers for every date regardless of traffic and non-traffic areas. RCU3 was in the highest statistical category for every measuring date.

Although RCU3 had the second highest amount of nitrogen, as did SCU, these two products responded differently. SCU releases nitrogen once water comes in contact with the urea prill via cracks and imperfections in the sulfur coating. RCUs combine irrigation/rainfall and high temperature (> 26 C) to slowly release nitrogen. The process is initated when the RCU prill uptakes water, expands with heat and then slowly releases nitrogen via expanded pores in the coating at a steady rate (Carrow et al., 2001). Even though RCUThin had a higher nitrogen rate, the coating thickness was too thin to control the release of nitrogen. It was concluded the nitrogen released too quickly and was therefore not available for the plants. Fry et al., (1993) also noted various responses of RCU in established turf based on resin thickness. Consequently, the RCUThin fertilizer responded similarly to Urea, Urea 2w and SCU fertilizer strategies. The latter fertilizer strategies have been common practices for establishment of turfgrass stands that supports the reasoning for evaluating these fertilizer strategies in this experiment. Canaway (1990) used soluble fertilizers for four

Table 3. Mean squares for treatment effects for turfgrass cover percent on a perennial ryegrass/Kentucky bluegrass stand, East Lansing, MI. 2002-03.

		Mean squares																
		2002					2003											
Source	df	19-Jun	26-Jun	2-Jul	19-Jul	5-Aug	20-Jun	25-Jun	30-Jun	7-Jul	14-Jul	21-Jul	29-Jul	4-Aug	12-Aug	19-Aug	27-Aug	3-Sep
Rep	2	1016.6**	229.6	379.1***	245.6***	158.1*	121.5**	353.2***	329.1**	547.6**	501.8**	283.2	508.3***	234.9	139.4	1293.0***	333.8	1246.2***
Mowing (M)	2	172.2	68.5	109.7	6.2	104.0*	23.4	8.8	43.1	128.2	46.3	66.2	83.1	316.7*	42.1	154.2	189.4	69.9
Fertilizer (F)	5	958.8***	1797.4***	867.7***	205.7***	227.3***	141.5***	477.1***	1240.0***	1876.0***	1359.6***	1079.8***	528.7***	709.4***	838.5***	1523.0***	726.2***	2074.9***
M x F	10	101.1	48.5	44.2	13.5	23.2	16.2	48.7*	51.4	126.6	45.7	68.7	44.6	35.9	62.7	96.4	50.5	177.1
Error	34	163.7	76.7	44.9	26.2	30.3	21.5	22.4	43.9	92.8	88.1	116.1	49.6	77.3	82.5	141.1	127.4	141.9

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

Table 4. Effects of mowing height and fertilizer treatments on turfgrass cover percent on a perennial ryegrass/Kentucky bluegrass stand at the Hancock Turfgrass Research Center, East Lansing, MI.

	2002					2003											
Treatments	19-Jun	26-Jun	2-Jul	19-Jul	5-Aug	20-Jun	25-Jun	30-Jun	7-Jul	14-Jul	21-Jul	29-Jul	4-Aug	12-Aug	19-Aug	27-Aug	3-Sep
	%																
Mowing																	
3.8 cm Cont.	42	54	77	91	84	9	23	30	52	66	68	75	77	66	49	65	40
7.6-Gr.-3.8 cm	38	50	72	90	85	11	24	33	57	66	68	77	81	69	51	63	41
7.6-Ch.-3.8 cm	36	52	73	90	80	10	23	32	54	63	65	73	73	68	46	58	37
LSD (0.05)	NS	NS	NS	NS	4	NS	NS	NS	NS	NS	NS	NS	6	NS	NS	NS	NS
Fertilizers†, ‡																	
Urea	27	32	62	90	82	7	15	18	42	64	64	73	76	66	39	52	27
Urea 2w	31	47	72	87	82	9	19	22	43	54	62	74	74	60	42	58	34
SCU	37	49	69	86	78	12	22	30	47	54	57	67	68	61	43	57	32
RCU2	44	62	83	93	86	16	32	44	69	78	78	80	81	74	62	68	49
RCU3	56	73	88	98	92	13	32	47	76	83	84	87	92	84	68	77	66
RCUThin	36	49	70	87	79	5	19	29	49	58	58	68	69	61	38	59	28
LSD (0.05)	12	8	6	5	5	5	5	6	9	9	10	7	9	9	11	11	12
No. of Passes	0	0	0	0	0	0	0	0	0	0	0	0	0	8	16	28	34

NS = Non-significant at the 0.05 level

3.8 cm Cont. = 3.8 cm Continuous, 7.6-Gr.-3.8 = 7.6 - 3.8 cm Gradual mowing height, 7.6-Ch.-3.8 = 7.6 - 3.8 cm Chop mowing height

† All fertilizer strategies received 49 kg N ha^{-1} of 13-25-12 on 1 June.

‡ Urea, urea applied on 1 July at 49 kg N ha^{-1}; Urea 2w, urea applied every two weeks; SCU, 147 kg N ha^{-1} sulfur-coated urea; RCU2, 98 kg N ha^{-1} polymer-coated urea applied on 1 June; RCU3, 147 kg N ha^{-1} polymer-coated urea applied on 1 June; RCUThin, has a thinner coating compard to the other polymer coated-ureas and 196 kg N ha^{-1} polymer-coated urea applied on 1 June.

applications for his study however, yellowing of the turf was observed when establishing a turfgrass stand on a sand-based root zone. IBDU was applied for the fifth and final application. The rate of fertilizer and rate of release are important factors for sports field managers to consider when re-establishing turfgrass stands, especially when limited by a short window of time and when utilizing a sand-based root zone.

Mowing treatments (started on 3 July for both years) had approximately 35-day compared to fertilizer treatments applied at the beginning of the 70-day re-establishment window. Even though more than one third of the plant was being removed from the 7.6 cm Chop treatment 68 DAS, there were little differences among mowing treatments for turfgrass cover percent. More realistically, the treatment could have been maintained at 10 or 15 cm, with fewer mowings before the time came to "Chop" the height down to 3.8 cm.

There were no significant differences among Urea, Urea 2w, SCU and RCUThin for 9 of 17 measurement dates for both years. RCU3 was 14% and 18% higher compared to SCU on 5 Aug 2002 and 4 Aug 2003, respectively, before traffic commenced. Hummel (1986, 1989) and Fry et al., (1993) concluded coating thickness and density were important factors that determined release of urea regardless of coating type. Hummel and Waddington (1986) observed N release characteristics for SCU being curvilinear with the most rapid response in the first two weeks following application. RCUs, on the other hand, have a minimal response following application, but then they released curvilinearly over a 200-day period at 25 C (Fujita, 1983). Soil temperatures in the month of June, for 2002, averaged from 25 – 28 C from 1200 – 1800 h. In June 2003, average soil temperatures ranged from 19 – 25 C from 1200 – 1800 h. This might explain why turfgrass percent cover was higher in 2002 compared to 2003.

It should be noted turfgrass cover percentages did not reach 100% possibly due to germination blankets, seed mixture and seeding rate. Germination blankets improved the response of the seedlings to germinate (compared to areas outside the experiment that did not get covered). However, due to excessive rain, wind or removal of the blankets, some seed was displaced or adhered to the blanket during germination and were therefore removed when the blanket was removed. Proper seed spacing, uniformity and surface development were not achieved with some treatments due to seed moving underneath the blankets and/or the dominance of perennial ryegrass (a bunch-type grass) germinating more quickly than Kentucky bluegrass. Canaway (1990) suggested when using perennial ryegrass on a sand-based root zone, one option may be to double the rate. Therefore, a seeding rate of 392 kg ha^{-1}, instead of 196 kg ha^{-1}, might have improved turfgrass cover percent even though a 30:70 (perennial ryegrass : Kentucky bluegrass) sports field mixture was used. Harper (et al., 1984), Lundberg (2002) and Larsen (et al., 2004) found that turfgrass cover at the end of the playing season was influenced by turfgrass cover at the beginning of the playing season.

The results present maybe due to a more accelerated wear compared to other data in the literature using different traffic simulators (Canaway, 1990, Krick, 1995, Cook, 1997, Carrow, et al, 2001, Sorochan et al, 2001). The CTS is possibly a more aggressive machine compared to traditional wear machines to date. Henderson et al., (2005) provides an excellent review of simulated traffic machines. The CTS displays an up-and-down motion similar to an athlete running across the playing surface. The action is more forceful compared to the Brinkman Traffic Simulator (which is commonly used for the sports turfgrass research at Michigan State University) that rolls across the playing surface (Henderson, 2005).

On 4 Sept 2002, there was an interaction in the trafficked lane, but it was inconclusive and considered an anomaly.

Shear resistance and Turf Shear Tester

Shear resistance revealed a difference only among mowing treatments occurring on 17 July 2002 (Tables 5 and 6). Among fertilizers for shear resistance, all dates were significant for both years except 23 August 2002. On 3 September 2003, the TST was significant only in the traffic lane.

Shear resistance and TST values are quantitative measures that clearly ascertained differences in strength of the surface after the 70-day re-establishment window, and during and at the end of the 25-day traffic regime. RCU3 had significantly higher shear resistance values compared to SCU. Shear vane values were slightly lower than values recorded by Krick (1995) for seeded perennial ryegrass, but establishment days were longer for their experiment. At the end of the 25-day traffic regime, only RCU2 and RCU3 had shear vane values above 10 Nm. On Kentucky bluegrass and supina bluegrass (*Poa supina*

Table 5. Mean squares for treatment effects for shear resistance and turf shear tester (TST) on a trafficked and non-trafficked (NT) perennial ryegrass/ Kentucky bluegrass stand, East Lansing, MI.

		Mean squares															
		2002							2003								
		Shear resistance														TST	
Source	df	11-Jul	17-Jul	24-Jul	15-Aug	23-Aug	4-Sep	4 Sep NT	1-Aug	7-Aug	13-Aug	21-Aug	28-Aug	3-Sep	3 Sept NT	3-Sep	3 Sept NT
Rep	2	5.1	12.1**	4.4	0.3	2.7	11.8**	12.8	5.0	5.6	3.5	17.6**	74.5***	17.0	3.1	166.8**	81.3
Mowing (M)	2	8.3	7.7	0.3	3.2	3.2	2.6	0.1	4.3	2.4	0.9	0.3	22.6	2.0	3.5	14.0	61.2
Fertilizer (F)	5	31.0***	16.6***	10.7*	19.5***	7.0	6.1*	3.8	55.7***	51.4***	41.1***	40.4***	57.6***	89.1***	28.4***	344.0***	106.2
M x F	10	3.5	3.2	2.7	3.8	2.3	10.0***	2.2	4.2	3.2	4.5	3.5	11.1	13.7	3.3	51.7	32.5
Error	34	3.0	2.0	3.5	3.2	4.7	1.9	2.5	4.4	2.7	4.0	3.1	8.4	8.8	4.4	30.4	59.8

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

Table 6. Effects of mowing height and fertilizer treatments on shear resistance and turf shear tester (TST) on a trafficked and non-trafficked (NT) perennial ryegrass/Kentucky bluegrass stand at the Hancock Turfgrass Research Center, East Lansing, MI.

	2002						2003								
	Shear resistance													TST	
Treatments	11-Jul	17-Jul	24-Jul	15-Aug	23-Aug	4-Sep	1-Aug	7-Aug	13-Aug	21-Aug	28-Aug	3-Sep	3 Sept NT	3-Sep	3 Sept NT
	Nm														
Mowing															
3.8 cm Cont.	15.8	17.0	17.5	16.1	12.7	11.4	13.1	14.4	14.6	12.3	9.9	7.7	19.3	49	113
7.6-Gr.-3.8 cm	16.7	18.2	17.8	16.4	11.9	10.9	14.0	14.9	14.8	12.1	11.1	8.1	19.9	53	108
7.6-Ch.-3.8 cm	17.1	18.0	17.6	15.5	12.1	10.7	13.8	14.2	14.3	12.3	8.8	7.5	19.0	51	106
LSD (0.05)	NS	1.0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizers†, ‡															
Urea	14.0	16.6	16.7	15.6	11.8	10.7	11.7	12.7	12.9	10.6	8.6	5.0	17.4	39	97
Urea 2w	15.3	16.6	16.6	16.1	11.7	10.3	11.6	14.9	13.8	11.1	9.7	7.4	18.5	47	109
SCU	16.4	17.7	17.2	15.1	11.5	10.1	13.3	13.2	13.7	11.0	7.3	6.9	18.5	48	112
RCU2	18.9	19.8	18.5	17.9	13.4	11.7	16.0	16.3	17.1	14.4	13.0	11.3	21.1	61	112
RCU3	18.4	18.9	19.4	17.4	13.4	12.3	17.4	18.2	17.4	15.4	13.1	11.8	22.0	70	118
RCUThin	16.3	16.7	17.5	13.9	11.7	11.1	11.8	11.9	12.5	10.8	8.0	4.3	18.7	39	106
LSD (0.05)	1.7	1.4	1.8	1.7	NS	1.3	2.0	1.6	1.9	1.7	2.8	2.8	2.0	11	NS
No. of Passes	0	0	0	8	18	30	0	0	6	18	26	34	0	34	0

NS = Non-significant at the 0.05 level

3.8 cm Cont. = 3.8 cm Continuous, 7.6-Gr.-3.8 = 7.6 - 3.8 cm Gradual mowing height, 7.6-Ch.-3.8 = 7.6 - 3.8 cm Chop mowing height

† All fertilizer strategies received 49 kg N ha^{-1} of 13-25-12 on 1 June.

‡ Urea, urea applied on 1 July at 49 kg N ha^{-1}; Urea 2w, urea applied every two weeks; SCU, 147 kg N ha^{-1} sulfur-coated urea; RCU2, 98 kg N ha^{-1} polymer-coated urea applied on 1 June; RCU3, 147 kg N ha^{-1} polymer-coated urea applied on 1 June; RCUThin, has a thinner coating compared to the other polymer coated-ureas and 196 kg N ha^{-1} polymer-coated urea applied on 1 June.

Schrad.) grown under low irradiance, Stier and Rogers (2001) observed 10 Nm to be of minimal acceptance for sports fields. It should also be noted that RCU2 values were significantly higher than SCU and RCUThin for all dates except 24 Jul 2002. RCU2 nitrogen amount was less than SCU and RCUThin (98 kg N ha^{-1} compared to 147 kg N ha^{-1} and 196 kg N ha^{-1} without starter fertilizer, respectively). The importance of the type of coating and coating thickness were possible key factors in releasing of nitrogen from the RCU2 fertilizer compared to SCU and RCUThin.

Peak deceleration

Peak deceleration values are listed in Tables 7 and 8. There were no significant differences for mowing heights except on 7 August 2003 (non traffic lanes). Among fertilizer treatments, significant differences were only detected in the traffic areas in 2003. RCU3 was in the highest statistical category for every measuring date.

Peak deceleration values were relatively low. However, there was a consistent trend developing throughout the traffic regime in 2003. Treatments with lower G_{max} values (Urea, Urea 2w, SCU and RCUThin) had more sand exposed at the surface and less turfgrass cover. Treatments with higher G_{max} values had less sand and more turfgrass cover exposed at the surface when using fertilizer treatments, such as RCU2 and RCU3. Rogers and Waddington (1989, 1990), on a silt loam and silty clay loam, respectively, found surface hardness increased as turfgrass cover decreased. In 1989, they only detected differences with a 0.5 kg hammer compared to the 2.25 kg and 4.5 kg hammers

Table 7. Mean squares for treatment effects for peak deceleration on a perennial ryegrass/Kentucky bluegrass stand, East Lansing, MI. 2002-03.

		Mean squares											
		2002						2003					
Source	df	11-Jul	17-Jul	24-Jul	2-Aug	4-Sep	4 Sep NT	7-Aug	13-Aug	21-Aug	28-Aug	3-Sep	3 Sep NT
Rep	2	37.6	14.2	45.6*	11.3	365.0**	162.0	30.9	9.3	60.9**	435.1***	367.1***	57.0*
Mowing (M)	2	11.7	24.4	4.8	7.6	38.7	11.8	96.0***	24.9	3.0	17.0	11.5	13.8
Fertilizer (F)	5	12.7	9.3	4.3	16.4	44.2	22.0	26.3*	61.9*	28.4*	33.7*	54.4*	26.3
M x F	10	10.1	16.7	14.9	6.1	51.9	47.4	1.9	14.4	12.0	18.6	43.8*	13.7
Error	34	13.3	9.3	10.8	10.6	54.3	27.4	10.3	17.4	9.6	13.1	18.2	16.9

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

NS, not significant

Table 8. Effects of mowing height and fertilizer treatments on peak deceleration on a trafficked and non-trafficked (NT) perennial ryegrass/Kentucky bluegrass stand at the Hancock Turfgrass Research Center, East Lansing, MI.

Treatments	2002						2003					
	11-Jul	17-Jul	24-Jul	2-Aug	4-Sep	4 Sep NT	7-Aug	13-Aug	21-Aug	28-Aug	3-Sep	3 Sep NT
	G_{max}											
Mowing												
3.8 cm Cont.	41	45	49	47	48	76	63	40	40	47	42	65
7.6-Gr.-3.8 cm	41	44	48	47	46	77	60	40	40	46	43	65
7.6-Ch.-3.8 cm	40	43	48	46	49	75	58	42	40	48	42	67
LSD (0.05)	NS	NS	NS	NS	NS	NS	2	NS	NS	NS	NS	NS
Fertilizers†, ‡												
Urea	42	43	49	46	47	74	60	39	38	45	42	66
Urea 2w	41	43	48	47	48	76	63	39	38	46	40	67
SCU	42	44	49	48	45	76	59	40	41	46	42	65
RCU2	39	46	47	46	48	76	59	45	41	48	44	64
RCU3	41	44	49	49	52	76	60	42	41	50	47	64
RCUThin	40	43	48	45	48	79	62	38	41	47	41	68
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	4	3	4	4	NS
No. of Passes	0	0	0	0	30	0	0	6	18	26	34	0

NS = Non-significant at the 0.05 level

3.8 cm Cont. = 3.8 cm Continuous, 7.6-Gr.-3.8 = 7.6 - 3.8 cm Gradual mowing height, 7.6-Ch.-3.8 = 7.6 - 3.8 cm Chop mowing height

† All fertilizer strategies received 49 kg N ha^{-1} of 13-25-12 on 1 June.

‡ Urea, urea applied on 1 July at 49 kg N ha^{-1}; Urea 2w, urea applied every two weeks; SCU, 147 kg N ha^{-1} sulfur-coated urea; RCU2, 98 kg N ha^{-1} polymer-coated urea applied on 1 June; RCU3, 147 kg N ha^{-1} polymer-coated urea applied on 1 June; RCUThin, has a thinner coating compard to the other polymer coated-ureas and 196 kg N ha-1 polymer-coated urea applied on 1 June.

when verdure was present on a tall fescue stand. Mowing height differences were trivial even though these heights were consistently maintained from 1-3 years pending on the study. Contrary to past research results presented, the CIT, with the 2.25 kg hammer, was sensitive enough to detect differences and provided quantitative information on playing surface characteristics in particular the uniformity of the playing surface on a sand-based root zone.

There was a significant mowing height x fertilizer interaction for peak deceleration on 3 September 2003. However, it was concluded the interaction an anomaly and made no practical sense.

Time Domain Reflectometry

For time domain reflectometry, there were no significant differences for mowing height and fertilizer treatments except on 13 August 2003 for mowing height (Tables 9 and 10).

Root mass

There were no significant differences for root mass for mowing height or fertilizer treatments (Tables 11 and 12). Although main effects of root mass were not significant, there was a significant mowing height x fertilizer treatments interaction at a 50 – 100 mm depth on 11 July 2002 (Figure 3). A shorter mowing height yields a shallower the rooting depth compared to a higher mowing height yielding a deeper rooting depth (Harrison, 1931; Evans, 1932; Juska et al., 1956; Goss and Law, 1967; Beard, 1973). On this date, turfgrass cover percent on any of the plots was less than 20%. Furthermore, applications of Urea were applied on 1 July at 49 and 16 kg N ha-1 for Urea and Urea 2w, respectively: a

Table 9. Mean squares for treatment effects on time domain reflectrometry on a perennial ryegrass/Kentucky bluegrass stand, East Lansing, MI. 2002-03.

		Mean squares												
		2002						2003						
Source	df	11-Jul	17-Jul	24-Jul	2-Aug	4-Sep	4-Sep NT	1-Aug	7-Aug	13-Aug	21-Aug	28-Aug	3-Sep	3-Sep NT
Rep	2	7.7	7.9	35.3***	12.3	6.3*	13.6	57.0***	7.0	5.7*	25.4	60.4**	108.7***	27.3**
Mowing (M)	2	6.5	1.2	3.3	2.7	2.1	3.1	0.3	3.1	4.8*	18.9	9.2	11.3	4.5
Fertilizer (F)	5	3.0	3.9	3.7	6.9	1.4	6.7	6.2	2.7	2.3	13.1	10.4	9.0	2.2
M x F	10	7.9	4.0	6.5	3.9	2.3	4.0	4.3	2.2	2.3	10.5	5.2	6.4	2.4
Error	34	5.3	4.2	3.5	5.6	1.6	6.5	4.8	4.6	1.4	9.4	9.6	6.7	4.2

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

NS, not significant

Table 10. Effects of mowing height and fertilizer treatments on time domain reflectometry on a trafficked and non-trafficked (NT) perennial ryegrass/Kentucky bluegrass stand at the Hancock Turfgrass Research Center, East Lansing, MI.

Treatments	2002						2003						
	11-Jul	17-Jul	24-Jul	2-Aug	4-Sep	4-Sep NT	1-Aug	7-Aug	13-Aug	21-Aug	28-Aug	3-Sep	3-Sep NT
	v/v												
Mowing													
3.8 cm Cont.	19.7	20.7	18.8	18.6	7.2	8.7	19.9	17.7	11.8	20.6	14.2	14.4	16.8
7.6-Gr.-3.8 cm	20.9	20.9	19.5	18.9	6.9	8.0	19.8	17.5	11.2	19.9	15.0	15.9	16.6
7.6-Ch.-3.8 cm	20.1	21.2	18.8	18.1	6.6	8.0	19.6	16.9	10.8	18.6	13.6	14.8	15.9
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.8	NS	NS	NS	NS
Fertilizers†, ‡													
Urea	19.9	20.0	18.7	17.5	6.7	7.3	18.2	16.3	11.2	17.4	12.4	14.1	15.9
Urea 2w	19.5	21.5	18.4	19.1	7.1	9.6	19.9	17.8	11.1	19.8	14.4	15.5	16.8
SCU	20.1	20.6	18.9	17.4	7.0	7.3	20.0	17.1	12.1	19.4	15.3	14.6	16.4
RCU2	20.1	21.6	20.0	18.8	6.9	8.3	19.6	17.6	10.5	20.2	13.7	16.8	17.1
RCU3	20.8	21.2	19.6	19.6	7.4	8.6	20.6	17.6	11.4	20.6	14.6	15.3	15.8
RCUThin	21.0	20.5	18.5	18.7	6.3	8.4	20.3	17.7	11.3	20.6	15.2	14.2	16.7
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
No. of Passes	0	0	0	0	30	0	0	0	6	18	26	34	0

NS = Non-significant at the 0.05 level

3.8 cm Cont. = 3.8 cm Continuous, 7.6-Gr.-3.8 = 7.6 - 3.8 cm Gradual mowing height, 7.6-Ch.-3.8 = 7.6 - 3.8 cm Chop mowing height

† All fertilizer strategies received 49 kg N ha^{-1} of 13-25-12 on 1 June.

‡ Urea, urea applied on 1 July at 49 kg N ha^{-1}; Urea 2w, urea applied every two weeks; SCU, 147 kg N ha^{-1} sulfur-coated urea; RCU2, 98 kg N ha^{-1} polymer-coated urea applied on 1 June; RCU3, 147 kg N ha-1 polymer-coated urea applied on 1 June; RCUThin, has a thinner coating compared to the other polymer coated-ureas and 196 kg N ha^{-1} polymer-coated urea applied on 1 June.

Table 11. Mean squares for treatment effects for root mass on a perennial ryegrass/Kentucky bluegrass stand, East Lansing, MI. 2002-03.

		Mean squares											
		2002				2003							
		11-Jul				25-Jul				26-Aug			
Depth		mm											
Source	df	0-50	50-100	100-150	Total	0-50	50-100	100-150	Total	0-50	50-100	100-150	Total
Rep	2	0.365*	0.033	0.063*	0.932**	0.025	0.088	0.043	0.436**	0.365	0.044	0.060	0.934
Mowing (M)	2	0.141	0.009	0.024	0.066	0.029	0.034	0.002	0.109	0.018	0.036	0.034	0.065
Fertilizer (F)	5	0.103	0.015	0.010	0.221	0.034	0.025	0.005	0.108	0.034	0.037	0.007	0.072
M x F	10	0.123	0.068*	0.009	0.071	0.057	0.015	0.019	0.153	0.056	0.023	0.023	0.144
Error	34	0.099	0.026	0.015	0.170	0.043	0.022	0.015	0.093	0.136	0.035	0.012	0.157

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

NS, not significant

Table 12. Effects of mowing height and fertilizer treatments on root mass on a perennial ryegrass/Kentucky bluegrass stand at the Hancock Turfgrass Research Center, East Lansing, MI.

	2002				2003							
	11-Jul				25-Jul				26-Aug			
	depth (mm)											
Treatments	0-50	50-100	100-150	0-150	0-50	50-100	100-150	0-150	0-50	50-100	100-150	0-150
	grams											
Mowing												
3.8 cm Cont.	0.59	0.37	0.23	1.19	0.30	0.23	0.14	0.68	0.68	0.34	0.18	1.19
7.6-Gr.-3.8 cm	0.75	0.39	0.17	1.31	0.22	0.18	0.15	0.55	0.63	0.40	0.22	1.24
7.6-Ch.-3.8 cm	0.60	0.41	0.24	1.25	0.27	0.26	0.16	0.69	0.63	0.42	0.26	1.31
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizers†, ‡												
Urea	0.84	0.43	0.26	1.53	0.34	0.25	0.16	0.75	0.63	0.40	0.21	1.25
Urea 2w	0.57	0.33	0.21	1.10	0.21	0.16	0.14	0.51	0.57	0.35	0.23	1.15
SCU	0.69	0.39	0.22	1.30	0.22	0.20	0.13	0.56	0.64	0.32	0.23	1.19
RCU2	0.58	0.40	0.24	1.21	0.34	0.31	0.13	0.78	0.72	0.44	0.25	1.41
RCU3	0.60	0.36	0.16	1.13	0.24	0.21	0.20	0.65	0.60	0.48	0.17	1.24
RCUThin	0.60	0.43	0.19	1.22	0.22	0.21	0.15	0.58	0.71	0.33	0.21	1.25
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
No. of Passes	0	0	0	0	0	0	0	0	24	24	24	24

NS = Non-significant at the 0.05 level

3.8 cm Cont. = 3.8 cm Continuous, 7.6-Gr.-3.8 = 7.6 - 3.8 cm Gradual mowing height, 7.6-Ch.-3.8 = 7.6 - 3.8 cm Chop mowing height

† All fertilizer strategies received 49 kg N ha^{-1} of 13-25-12 on 1 June.

‡ Urea, urea applied on 1 July at 49 kg N ha^{-1}; Urea 2w, urea applied every two weeks; SCU, 147 kg N ha^{-1} sulfur-coated urea; RCU2, 98 kg N ha^{-1} polymer-coated urea applied on 1 June; RCU3, 147 kg N ha^{-1} polymer-coated urea applied on 1 June; RCUThin, has a thinner coating compared to other polymer coated-ureas and 196 kg N ha^{-1}.

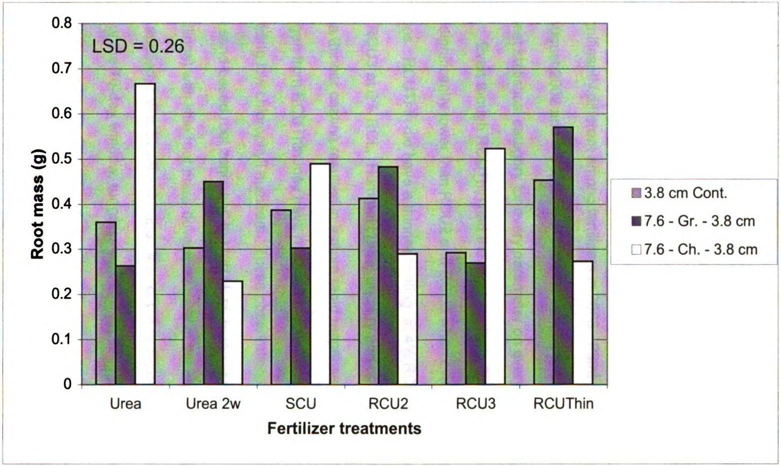


Figure 3. Effects of mowing height x fertilizer strategies interaction on root mass at a 50 – 100 mm depth on a trafficked perennial ryegrass/Kentucky bluegrass stand on 11 July 2002.

three-fold application difference among treatments. The difference in mowing height between 7.6 – Grad. – 3.8 cm and 7.6 – Ch. – 3.8 cm treatments was only 1.3 cm on 11 July 2002.

Chlorophyll indices, root pulls and plant counts

Chlorophyll indices, root pull and plant counts are listed in Tables 13 and 14. Chlorophyll indices were significantly different for the various fertilizers. Root pull values were significantly different among mowing heights in 2002, and a significantly different among fertilizers in 2003. Plant counts were significant on 20 August 2002 and 3 September 2003 for various fertilizers. RCU3 was in the highest statistical category for every parameter on every measuring date.

Even though RCUThin had the most applied nitrogen, its chlorophyll index was significantly lower than RCU2 and RCU3 when evaluating chlorophyll indices. RCUThin did have a thinner coating, at 4% RCL, compared to RCU2 and RCU3 at 6% RCL. Hummel (1989) and Fry and coworkers (1993) observed that a thinner coating resulted in a more rapid response. Most of the applied nitrogen from RCUThin may have released before 25 June 2003, thereby providing low chlorophyll numbers. These observations are important especially on a sand-based root zone, and the turf stand being re-established (hence new seedlings) with little root mass developed early in the experiment. Before traffic was applied, it was observed (regardless of the fertilizer source) that near the end of the 70-day window, turfgrass was starting to yellow, and a fertilizer application was required. There was no indication of increased chlorophyll content with a lower mowing height (3.8 cm Continuous).

Table 13. Mean squares for treatment effects for chlorophyll indices, root pull and plant counts on a trafficked and non-trafficked (NT) perennial ryegrass/Kentucky bluegrass stand, East Lansing, MI. 2002-03.

		Mean squares												
		2003			2002	2003	2002				2003		
		Chlorophyll indices			Root pull		Plant counts						
Source	df	25-Jun	14-Jul	29-Jul	8-Aug	6-Aug	11-Jul	20-Aug	20 Aug NT	5-Sep	13-Aug	3-Sep	3 Sep NT
Rep	2	1161.5*	2146.7	1783.9	4734.7	17098.4	96.8	32.6	21.0	10.6	22.9	21.2	8.9
Mowing (M)	2	532.9	2170.2	989.4	17991.6*	9612.0	15.6	33.6	11.4	9.5	10.7	5.7	2.0
Fertilizer (F)	5	8032.3*	47308.6*	15645.7*	5565.4	24927.1*	56.2	60.4**	25.0	12.7	11.3	29.8**	23.1
M x F	10	461.0	597.0	401.8	1016.3	5463.5	62.9	6.4	31.4	6.5	14.8	19.7*	27.8
Error	34	253.1	1143.7	721.3	4310.7	8470.0	38.6	16.7	29.7	17.1	16.0	8.2	24.1

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

NS, not significant

Table 14. Effects of mowing height and fertilizer treatments on chlorophyll indices, root pull and plant counts on a trafficked and non-trafficked (NT) perennial ryegrass/Kentucky bluegrass stand at the Hancock Turfgrass Research Center, East Lansing, MI.

	2003			2002	2003	2002			2003		
	Chlorophyll indices			Root pull		Plant counts					
Treatments	25-Jun	14-Jul	29-Jul	8-Aug	6-Aug	20-Aug	20 Aug NT	4-Sep	13-Aug	3-Sep	3 Sep NT
				N		plants * 100 cm^{2}					
Mowing											
3.8 cm Cont.	113	198	198	395	324	222	299	182	238	169	273
7.6-Gr.-3.8 cm	123	219	203	417	368	254	280	175	219	162	272
7.6-Ch.-3.8 cm	114	215	212	457	357	233	295	164	231	154	265
LSD (0.05)	NS	NS	NS	45	NS	NS	NS	NS	NS	NS	NS
Fertilizers†, ‡											
Urea	83	203	177	447	330	191	312	154	218	136	275
Urea 2w	94	145	194	456	383	258	288	165	231	160	286
SCU	112	160	176	416	305	229	319	191	227	169	246
RCU2	156	256	226	421	405	284	280	164	234	164	295
RCU3	150	334	279	407	397	236	264	184	253	200	264
RCUThin	105	165	173	390	278	217	288	185	215	143	250
LSD (0.05)	15	33	26	NS	89	48	NS	NS	NS	35	NS
No. of Passes	0	0	0	0	0	12	0	30	0	34	0

NS = Non-significant at the 0.05 level

3.8 cm Cont. = 3.8 cm Continuous, 7.6-Gr.-3.8 = 7.6 - 3.8 cm Gradual mowing height, 7.6-Ch.-3.8 = 7.6 - 3.8 cm Chop mowing height

† All fertilizer strategies received 49 kg N ha^{-1} of 13-25-12 on 1 June.

‡ Urea, urea applied on 1 July at 49 kg N ha^{-1}; Urea 2w, urea applied every two weeks; SCU, 147 kg N ha^{-1} sulfur-coated urea; RCU2, 98 kg N ha^{-1} polymer-coated urea applied on 1 June; RCU3, 147 kg N ha^{-1} polymer-coated urea applied on 1 June; RCUThin, has a thinner coating compared to other polymer coated-ureas and 196 kg N ha^{-1} polymer-coated urea applied on 1 June.

Root pulls are another way of assessing root strength via dislodging roots from the root zone. Although they were inconsistent, root pull results were able to detect significant differences among mowing heights in 2002 and fertilizer treatments in 2003. One possible reason for the inconsistency might be that in 2002, the growing season was warmer (in 2002, soil temperatures averaged from 25 – 28 C from 1200 – 1800 h, compared to 2003, soil temperatures averaged 19 – 25 C from 1200 – 1800 h) therefore nitrogen may have been released more quickly, plants responded and a higher turfgrass cover percent resulted. Furthermore, mowing commenced 8 days earlier in 2002 that may have played a role in detecting significant differences in mowing height for root pulls. In general, this might be a better way of diagnosing rooting particularly for sports fields due to a larger area being displaced (Figure 2). Root pulls are a quantitative measurement that utilizes more surface area, (a 150 mm ring diameter compared to a 32 mm soil probe diameter), and it requires less handling when compared to root washings. When comparing perennial ryegrass seed and Kentucky bluegrass sod, Krick (1995) found no differences in root mass, using a soil probe, except at the 7 – 14 cm depth. Cook (et al., 1997) removed two soil cores and assessed root mass visually on a scale from 1 – 10, with 10 indicating a high root density, but made no quantitative assessment.

A shorter mowing height produced more plants per square area than a higher mowing height (Harrison, 1931; Evans, 1932; Juska et al., 1956; Goss and Law, 1967; Beard, 1973). This was particularly evident with the 3.8 cm Continuous and 7.6 – Ch. – 3.8 cm mowing treatments for RCU3 (6% RLC) versus RCUThin (4% RLC) fertilizer treatments (Figure 4). RCUThin treatments had a tendency to respond like Urea and Urea 2w even though there was more available nitrogen and a resin coating around the urea. Most of the release of RCUThin may have taken place within the first 30 days (as indicated by the chlorophyll indices, Table 14) with no additional fertility until after 6 August 2003 thus a low response. There was no interaction response in 2002, and this could be due to an insufficient number of subsamples thereby causing an erratic measurement (only three subsamples were taken for both years). Plus the turfgrass stand was a 30:70 perennial ryegrass: Kentucky bluegrass mixture, the stand was primarily perennial ryegrass. Perennial ryegrass is a bunch type grass, and during germination, seeds were dislodged by wind and/or rainfall/irrigation events. Clumping and erratic movement of seed resulted in both years. This may explain why this interaction was not consistent.

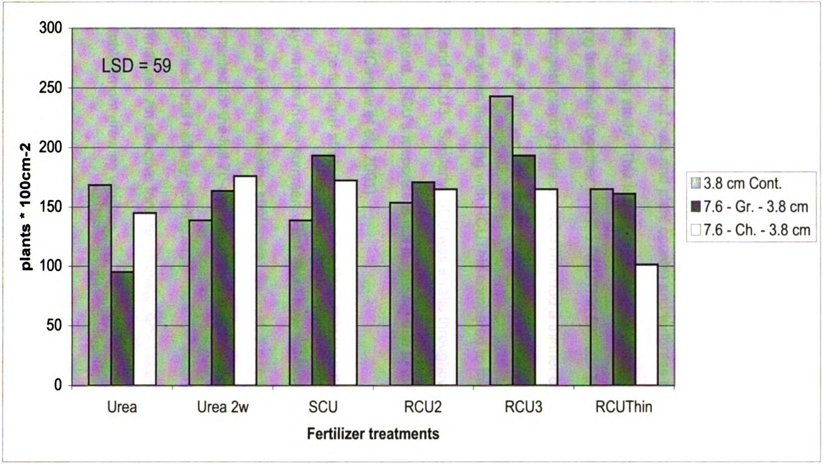


Figure 4. Effects of mowing height x fertilizer strategies interaction on plant counts on a trafficked perennial ryegrass/Kentucky bluegrass stand after 34 passes with the Cady Traffic Simulator on 3 September 2003.

CONCLUSIONS

Gradually reducing the mowing height from 7.6 to 3.8 cm and using a RCU3 (at 6% RLC and 147 kg N ha^{-1}) on a sand-based root zone was the best management strategy. It produced the strongest playing surface when considering all characteristics (turfgrass cover percent, shear resistance, peak deceleration, root pulls and plant counts) and turfgrass response (chlorophyll indices) in this study. This is contrary to the hypothesis that the 3.8 Continuous mowing treatment together with the RCUThin fertilizer treatment would produce the strongest playing surface. RCUThin had a thinner coating even though a higher rate of nitrogen was used. In other words, there was less of a turfgrass response when fertilizing with RCUThin compared to the fertilizer treatments RCU2 and RCU3. Similarly, SCU was erratic throughout the course of the experiment. SCU's response is not surprising due to the nature of its coating and release (Carrow et al., 2001).

The fertilizer strategy was more important than the mowing strategy for a 70-day window in the summer. First, there may not have been a wide enough difference between mowing strategies. Second, the fertilizer strategy was implemented for the full 70-day window while the mowing strategy was not implemented until halfway into the experiment because the young seedlings were too immature. An effective fertilizer strategy (product and rate) is paramount in a re-establishment growing window.

Implementing a mowing and fertilizer strategy, a sports field manager could reduce labor costs, and/or redirect labor to other projects, while also producing a better quality and safer surface for the upcoming playing season.

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ANALYSIS OF CULTURAL PRACTICES AND MANAGEMENT SYSTEMS FOR SPORTS FIELDS IN MICHIGAN

ABSTRACT

Management practices for turfgrass under traffic conditions are the ultimate challenge for any turfgrass professional especially when funding is limited. From initial construction and establishment, the dynamics of a sports field become management dependent. The objective was to *i*) identify the most important factors for sports fields having low inputs, and *ii*) furnish the sports field managers of Michigan with management strategies that enhance playing surface characteristics (surface hardness, traction and turfgrass cover percent) thus producing sports fields that are playable and safe. A fractional factorial design (FFD) of management systems was implemented to assess different cultural practices (turfgrass species mixtures, fertility, irrigation, overseeding, core cultivation and crumb rubber topdressing). Only main effects, two-way and three-way interactions of the experimental design were analyzed. Repeated measure analysis were used to analyze factors and systems over time with compound symmetry heterogeneous variance/covariance structure. Data collected were: peak deceleration, shear resistance, turfgrass cover percent, soil moisture and plant counts. In 500 days, management systems with the highest inputs performed the best in terms peak deceleration, shear resistance, turfgrass percent cover and plant counts. In 2004, plants counts for supina bluegrass/common bermudagrass (*Poa supina*, Schrad./*Cynodon dactylon* [L.]

Pers.), with the highest inputs treatment, were not different over the duration of the experiment. Based on F values from the FFD, it was concluded crumb rubber, fertility and turfgrass species, in this order, were the most important cultural practices for the conditions of this experiment. Interactions from the experiment emphasized the consistency of the playing surface due to an aggressive turfgrass, such as, supina bluegrass, the importance of fertility at 196 kg N ha^{-1}, irrigation based on returning 50% evapotranspiration loss from previous days and crumb rubber (complimented with irrigation and core cultivation). Specifically, crumb rubber was able to override or enhance other factors in the study regardless of level.

INTRODUCTION

Management practices for turfgrass under traffic (i.e. during the playing season of a football or soccer field) are the ultimate challenge for any turfgrass professional, especially when funding is limited. Sports fields present different challenges from golf courses because the high traffic areas are relatively immobile, and the play is not weather dependent. Golf courses move hole and tee locations daily, and golf is generally not played in cold weather (< 10 C), which is a time for minimal plant recovery. The play on sports fields can take place in any type of weather and is often concentrated. This makes the management of sports fields even more challenging. After evaluating professional and college football fields, Cockerham (1989) suggested that 78% of the traffic is concentrated on 7% of the football field based on the number of cleat marks. He concluded research efforts should be targeted towards cultural practices in these areas of the sports field.

The task of a sports field manager is to increase turfgrass density and health during the summer (or off-season) periods (i.e. 70-day rest and recovery period) and then maintain conditions throughout the playing season while maintaining consistency of the playing surface through the "other 295 days". Sports fields are not actively growing or being played on during the winter months in Michigan, but this is a time when conditions are not conducive for repair. During the summer when the sports field can actively grow and repair itself with good management practices, the sports field is in constant use during the fall and the spring; this necessitates a 295-day management program. One way of monitoring sports field conditions is via playing surface characteristics (surface hardness, traction and turfgrass percent cover). This can be done either on the most trafficked areas of the sports field (van Wijk, 1980, Holmes and Bell, 1986, Baker, 1987, Rogers et al., 1988) or throughout the playing surface (Miller, 2004, Vanini et al., 2004).

Proper cultural practices lead to better surface playing characteristics and potentially reduce surface-related injuries (Rogers et al., 1988, Orchard et., 1999, 2001). In 1981, a Pennsylvania study observed 210 football injuries occurred at 24 practice and game fields at different high schools throughout the season. Of these injuries, 21% were rated as definitely or possibly related to field conditions (Harper et al., 1984). Ekstrand and Nigg (1989) studied injuries in a male soccer league over a three-year period. They found 24% of the injuries were due to poor playing conditions. Soil water played an instrumental role on the playing surfaces for sports fields in the Australian Football League, and it appeared to have a direct influence on the occurrence of knee injuries (Orchard et al., 1999, 2001). In the United Kingdom, Rahnama and Manning (2004), in their surveys of injuries in youth soccer, found a 3:1 significant difference of pitches that were either "too soft/hard" compared to a soccer pitch in "good conditions".

Many sports field managers in Michigan cannot maintain sports fields consistently at a high maintenance level (i.e. mowing 3-4x/week, an adequate, frequent [number of applications] fertilization program, an installed irrigation system) due to budget restrictions or constraints. The expertise of maintaining these sports fields maybe somewhat limited. In Michigan, surveys were sent to each high school in December 1999 and 2000 (Lundberg, 2002). The surveys revealed 88% of the schools have a football field to maintain, but only half are mowed more than once per week. While 96% of these sports fields were fertilized, on average, three times per year, 83% of the respondents were unaware of the fertilizer application rates for the sports fields. Lack of funding and expertise could be the reason for the poor quality of many sports fields in Michigan. Similar findings from surveys were uncovered among the turfgrass industry in Southern California, and it was stated that sports field managers were the most willing to promote proper management techniques (Klein and Green, 2002). What is the potential for minimal cultural practices that benefit sports fields so they are safe and reliable? Are there any cultural practices that would be considered "large budget items" initially, and yet would be justified and beneficial in a sports field management regime?

"Minimal inputs" or "low inputs" refer to the minimum cultural practices on sports fields required to promote proper turfgrass vigor and soil conditions in a sports field situation. Lundberg (2002) evaluated, under controlled conditions, mowing practices (1x/week or 2x/week), with low infrequent, medium frequent and high frequent fertility programs and core cultivation (none or 2x/week) on both a sand-based and native soils. Best results on a sand-based root zone revealed mowing 2x/week, frequent medium fertility, and with core cultivation 2x/year.

In 2002, the Michigan Rotational Survey (Kleweno and Matthews, 2002) reported a variety of services, including cultural practices, reported by schools. The top five cultural practices performed by the respondents are listed.

Mowing/trim	92%
Fertilization	76%
Weed Control	70%
Overseeding	46%
Coring/Aeration	40%

The respondents surveyed also listed the top problems they deal with in a sports field situation;

Traffic	55%
Drought	54%
Weeds	48%
Poor Drainage	25%
Poor Soil	24%

The survey listed that 91% of the turfgrass species and/or mixtures consisted of Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne*, L.), and/or *Festuca*, spp. However, a sports field manager may not know which cultural practices are paramount when resources are minimal.

Proper management practices can reduce traffic, drought and weed problems, and provide better quality sports fields, thereby aiding decision makers on budgeting for cultural practices that are most important for a minimal maintenance situation. However, there might be other practices which could further enhance the playability of the sports field by improving the consistency of the playing surface via increased turfgrass cover and traction, decrease surface hardness (crumb rubber) and decreased labor (multiple applications) costs with fertilization and overseeding.

Turfgrass species, mixtures and blends have been researched extensively (Youngner , 1961, Sherman and Beard 1975a, Canaway 1981, 1983, Brede and Duich 1984, Minner et al., 1993, Dunn et al., 2002, and Minner and Valverde, 2004). Typically, a sports field mixture of Kentucky bluegrass/perennial ryegrass is recommended for cool, humid regions such as Michigan due to quick establishment (perennial ryegrass), strong rhizomatous growth (Kentucky bluegrass) and wear tolerance (Brede and Duich, 1984; Christians, 2004). Supina bluegrass (*Poa supina* Schrad.) is another cool-season turfgrass that has been recently researched and does particularly well in cool, humid regions under high traffic situations (Berner, 1980, Leinhauer et al., 1997, Stier et al., 1997, Sorochan et al., 2005). Due to its stoloniferous growth habit and recuperative ability in high traffic situations, supina bluegrass performed capably in Michigan compared to Kentucky bluegrass in regards to traffic tolerance, turfgrass density and shear resistance (Sorochan et al., 2001).

Overseeding is usually implemented as a continuing practice to maintain turfgrass density for sports fields. In Iowa, Minner and Valverde (2004) reported perennial ryegrass and Kentucky bluegrass consistently provided turfgrass cover better than supina bluegrass when simulated traffic was applied and overseeding was applied during rest periods. However, they did not comment on summer heat stress and low nitrogen fertility might have contributed to supina bluegrass's lower traffic tolerance in the two-year study. In another study, Minner and Valverde (2004) overseeded perennial ryegrass, Kentucky bluegrass, tall fescue (*Festuca arundinacea* Schreb.), fine fescue (*Festuca rubra*), supina bluegrass, creeping bentgrass (*Agrostis stolonifera*), velvet bentgrass (*Agrostis canina*) and colonial bentgrass (*Agrostis capillaries*), multiple times, during traffic simulation and found perennial ryegrass (at 490 kg ha^{-1} per week for six weeks after simulated traffic was initiated) provided the best turfgrass cover. Similarly in New York, Rossi (personal communication, 2005) overseeded perennial ryegrass, Kentucky bluegrass and tall fescue during a simulated traffic period. He found high, frequent seeding rates of perennial ryegrass (weekly at 392 or 490 kg ha^{-1} throughout the simulated traffic regime) maintained turfgrass cover and quality the best. Rossi reported that tall fescue was less effective, and he noted Kentucky bluegrass was ineffective. Although there were rest periods during the summer, minimal inputs (below typical ranges of a management practice) were not considered, and playing surface characteristics, such as surface hardness or traction, were not evaluated. School budgets may not be able to accommodate continual overseeding throughout the playing season. During a four-year study under simulated traffic conditions, Sorochan et al. (2001) found they did not have to overseed supina bluegrass, and it eventually became the dominant turfgrass regardless of initial seeding ratios with Kentucky bluegrass.

Another overseeding approach would be to mix bermudagrass (Cynodon dactylon [L.] Pers.), with a cool season grass, for the summer months in order to have consistent turfgrass cover regardless of the time of year (Davis, 1958; Beard, 1973; Dunn et al., 1994; Gaussoin et al., 2001; and Salehi and Khosh-Khui, 2004). Early attempts have been made; they have not been successful (Davis, 1958, Beard, 1973), however they did not evaluate supina bluegrass in these mixtures. In temperate regions in the northern United States, Gaussoin et al. (2001) reported overseeding bermudagrass annually within trafficked areas on sports fields with cool-season grasses in order to establish turfgrass cover for the upcoming playing season. In order for this approach to work in Michigan, bermudagrasses would require an improved cold tolerance and possibly winter survival. In Arkansas, Richardson et al., (2005) has investigated seeded bermudagrasses quite extensively and found the cultivar 'Yukon' to have the best winter survival and spring green-up. 'Yukon' bermudagrass might be able to thrive a more northern climate like Michigan. Conversely, cool-season grasses are becoming more heat and drought tolerant thus reducing the potential for warm season grasses to thrive during summer time windows (Turgeon, 2004). Supina bluegrass has poor heat and drought tolerance (Berner, 1980, Leinhauer, 1997) possibly allowing bermudagrass to thrive during the summer stress periods. Both supina bluegrass and common bermudagrass are aggressive cool and warm-season grasses, respectively, with very good recuperative ability when climatic conditions are optimal. The potential exists for not reseeding these grasses, reducing inputs and increasing turfgrass cover by transitioning when weather conditions are optimal for either turfgrass.

Fertilization practices (particularly nitrogen) are essential for sports fields because of the need to encourage on-going development and growth of seedlings (re-establishment) and promote recuperation of turfgrass under trafficked conditions. Numerous fertilization studies have been undertaken to evaluate different products (i.e. urea, sulfur-coated urea, resin-coated urea, urea formaldehyde) and their effects on turfgrass (Moberg et al., 1970, Brown et al., 1982, Hummel 1984, 1989, Landschoot and Waddington 1987, Ebdon et al., 1999, Kopp and Guillard, 2002, Bowman, 2003). Beard (1973) reviewed different turfgrass species and their nitrogen requirements. Both perennial ryegrass and Kentucky bluegrass range from 147 kg N ha^{-1} to 245 kg N ha^{-1} depending on the use, cultivars, and soil type. Sorochan et al. (2001, 2005) found optimal fertilization rates for supina bluegrass, under simulated traffic conditions, at 196 kg N ha^{-1} and 294 kg N ha^{-1} on loam and sandy soils, respectively. Using a native soil site opposed to a sports field soil mix with a high sand content could require less fertilization and labor.

The role of fertility and its relationship with turfgrass wear tolerance and compaction has been investigated. Results suggest nitrogen fertility will not alleviate or accelerate crown tissue repair in compacted areas, especially during stress periods, when conditions for recovery are not ideal (Sills and Carrow, 1983, Krick, 1995). With an increase in compaction, Sills and Carrow (1983) noticed in spite of increasing nitrogen rate or changing nitrogen carrier, there was no improvement in turfgrass quality.

Compaction, which detrimentally affects both soil physical properties and turfgrass response, is an on-going problem in high traffic situations especially on loam and clay soils. Soil compaction increases bulk density, reduces percolation and infiltration, reduces soil aeration and porosity, and decreases rooting (Letey et al., 1966, Waddington at al., 1974, Carrow, 1980, Sills and Carrow, 1983). To alleviate compaction, core cultivation is a widely accepted practice because it allows for minimal disturbance to the surface while still providing improvements to soil physical properties and turfgrass response (Murray and Juska, 1977, Wilkinson and Miller, 1978, Murphy et al., 1992, Murphy and Rieke, 1994, Baker 2001 Lundberg, 2002). Typically, sports fields in Michigan are built on native soil sites, and cultivation becomes most important on sports fields (Rogers et al. 1988). Unfortunately, the 2002 Michigan Rotational Survey (Kelweno and Matthews, 2002) indicates only 40% of the respondents used core cultivation as a tool for sports field management.

Research has been designed for assessing water requirements and practices for turfgrass species cultivars and functionally for home lawns and golf courses (Fry and Butler, 1989, Leinhauer et al., 1997, Richie et al., 2002, Johnson, 2003, Bastug and Buyuktas, 2003). According to Carrow et al. (2002), "Priority No. 1 is water." Little research exists for irrigation practices in relation to sports fields and water conservation. One way of regimenting irrigation practices is via evapotranspiration (ET) rates. ET is a combination of water loss from the soil (evaporation) and the plant (transpiration). One management practice to regulate water management is the use of "ET returned". "ET returned" means if 6 cm of ET was lost from a turfgrass area on one day then 50% ET returned would be 3 cm of water being replaced to this area the following day. Fry and Butler (1989) found that tall fescue in cool and transition zone regions could be either irrigated at 50% ET returned every second day or at 75% ET rate returned every two to seven days. Johnson (2003) found 70% ET returned in two day cycles, on a Kentucky bluegrass stand, provided better overall turfgrass quality, but he also reported the turf was more susceptible to drought stress with infrequent precipitation or delayed irrigation cycles. He also found, in another study, 50% ET returned to be acceptable for overseeding fine fescues into buffalograss (*Buchloë dactyloides* Nutt.) in Utah (Johnson, 2003). Leinhauer et al. (1997) found significant differences in ET rates between supina bluegrass, creeping bentgrass (*Agrostis stolonifera*) and creeping red fescue (*Festuca rubra trichophylla*) under no compaction but no significant differences were found among the species under compaction stress. Bastug and Buyuktas (2003) found 75% ET rate returned provided acceptable turfgrass quality on a golf course in a Mediterranean climate. Depending on the turfgrass and climatic region, 50 – 70% ET returned to the turfgrass system is warranted. Judicious water returns is an important concept for both water conservation and optimization of sports field playing surface characteristics.

The importance of returning ET rates, or a percentage of the rate, cannot be underestimated in its relation to soil moisture and sports field characteristics. Typically, soil moisture has been measured in regards to sports field characteristics, such as traction (Zebarth and Sheard, 1985, Rogers and Waddington, 1989) and surface hardness (Gramckow, 1968, Rogers et al., 1988, Rogers and Waddington, 1992). There is an inverse relationship with soil moisture for both traction and surface hardness. As soil moisture decreases, traction increases (Zebarth and Sheard, 1985) and surface hardness increases (Gramckow, 1968, Rogers and Waddington, 1992). Minner and Valverde (2004) evaluated soil moisture with various traffic intensities (concentrated – all simulated traffic at once a week, compared to dispersion – simulated traffic spread throughout the week) on Kentucky bluegrass and concluded greater turfgrass cover under dry conditions than wet conditions. They also found less traffic injury to Kentucky bluegrass when traffic was concentrated compared to dispersion of simulated traffic. Baker (2001) reported irrigation practices to be more important than core cultivation practices in reducing surface hardness for horse racing tracks. Sports fields in Michigan are under constant traffic stress. By evaluating irrigation practices, even with minimal inputs, a sports field manager could possibly provide better playing conditions by applying a percentage of the ET rates and implementing water conservation practices. Sports field managers with irrigation systems use techniques that promote overwatering which produces an inefficient use of water (Throssell et al., 1997) thereby minimizing optimal playing surface characteristics. There are benefits associated with reduced or proper water inputs in regards to playing surface characteristics.

The crown tissue of the plant is the point of regeneration for shoots, roots, stolons and/or rhizomes (Beard, 1973). One answer to improving wear tolerance, in high traffic areas, is the use of crumb rubber (Rogers et al., 1998). Crumb rubber is a by-product of used car tires that is chopped up into various sizes and topdressed to the turfgrass community (Rogers et al., 1998, Baker et al., 2001). Crumb rubber can be effective in improving turfgrass competitiveness by protecting the crown tissue area and by improving and sustaining soil physical properties via tilling into the profile (Vanini 1995, Boniak et al., 2001 Chong et al., 2001), core cultivation (Rogers et al., 1996) or topdressing (Rogers et al., 1998, Baker et al., 2001). The most effective way to introduce crumb rubber to the soil turfgrass community is to topdress crumb rubber. Also, this method is minimally disruptive to the surface (Vanini, 1995). Damage to the crown tissue area from continuous traffic can adversely affect growth and regeneration (Thurman and Pokorny, 1969). Crumb rubber can protect the crown tissue of the plant from damage and allow the turfgrass stand to persist longer in a high traffic area (i.e. the middle of a sports field) (Vanini, 1995). Over time, topdressing with crumb rubber can also provide consistency of the playing surface for traction and surface hardness (Rogers et al., 1998). It also improves or maintains the integrity of soil physical properties for a longer period of time (Baker, 2001). Rogers et al. (1998) observed an increase in spring green-up, and found no deleterious effects to plant health.

Even though the upfront cost of crumb rubber is expensive (approximately $30,000 to topdress crumb rubber over 7450 m^2 to a 12 mm depth), the potential benefits for improvement could be advantageous for minimal inputs for sports fields because of the stabilizing effect on surface hardness, turfgrass cover and traction (Vanini, 1995; Rogers et al., 1998). Using crumb rubber as a tool in a maintenance program may aid sports field managers in providing a safer and more reliable sports field by improving playing surface characteristics as well as promoting plant and soil relationships. There are potential savings, both monetary and surface-related injuries, using crumb rubber in a continuous maintenance regime.

In any management system, all factors interact. However, there is a factor or a combination of factors that can dominate a system. Different researchers have made claims on the most important cultural practice: overseeding (Minner and Valverde, 2004), irrigation (Carrow et al., 2002) and core cultivation (Rogers et al., 1988). For evaluating sports field conditions with minimal inputs, it might be important to evaluate which factor(s) dominate(s) the system. This study will be evaluating six factors: turfgrass species mixtures, fertility, irrigation, overseeding, core cultivation and crumb rubber. In the 2002 Michigan Rotational Survey (Kleweno and Matthews, 2002), it should be noted that mowing and weed control ranked high on services performed, 92% and 70%, respectively. They were not included in this study. There have been numerous studies evaluating mowing practices (height and frequency) in relation to other cultural practices (Evans, 1932; Davis, 1958; Biran et al. 1981; Richie et al, 2002; Lundberg, 2002). This is a practice already being performed, and perhaps the aforementioned cultural practices could provide other solutions to managing a sports field with minimal inputs. Weed control can be improved by utilizing other cultural practices, and it can be expensive or prohibitive on an annual basis. Although thresholds have to be determined for minimal inputs on sports fields, the focus of this research was to identify cultural practices more specific to playing surface characteristics and the subsequent enhancement of these characteristics.

There have been few studies that have addressed sports field management issues with multiple factors. Recently, Lundberg (2002) evaluated mowing, fertility and core cultivation on both a sand-based root zone and loam soil using a 85% Kentucky bluegrass/15% perennial ryegrass (by weight) mixture and Kentucky bluegrass monostand, respectively. In a controlled setting, recommendations for the sand-based experiment were given, but the native site experiment had no irrigation, and the results were confounded. Results were only evaluated in the fall seasons. Larsen et al. (2004) evaluated 37 soccer pitches *in situ* using 12 different management schemes to improve turfgrass percent cover and reduce weed encroachment. The experimental design used was an incomplete block design, and treatments were limited to four different factors i.e. vertical cutting, fertilizing, overseeding and topdressing. The more cultural practices implemented (i.e. vertical cutting, overseeding and topdressing), the more turfgrass cover presented. However, they did not evaluate playing surface characteristics.

Experimental designs to evaluate multiple factors (more than three factors) within management systems can be quite cumbersome and expensive. A fractional factorial design (FFD) can be utilized as a unique assessment tool in order to pre-screen which factors are the most important to a particular problem (Kuehl, 2000). The application of FFDs have been useful in a variety of disciplines: a fertilizer experiment for optimization of rice growth (Okuno, 1981), cryopreservation of fish sperm (Babiak et al., 2000), toxicity of pesticides on lumbricid species (Bauer and Römbke, 2001), zinc and cadmium availability in soils on toxicity to *Enchytraeus albidus* (Lock, et al., 2000) and nickel hyperaccumulation in plants (Martens and Boyd, 2000).

Specifically, the FFD can be used when treatments exceed resources. Only main effects and low-order interactions are of importance, and identification of certain factors is required (Babiak et al., 2000, Kuehl, 2000). For instance, a study, with six factors at two levels (2 x 2 x 2 x 2 x 2 x 2) would require 64 treatments without replication. By using an FFD at _ fraction, only 32 treatments would be needed to conduct an experiment without replication. However, the FFD does not identify the best management practices because not all combinations are being represented in the study (Babiak, 2000). The goal then is to identify which factors are driving a particular management system via main effects and low-order interactions over time. From this research, more intricate experiments may be designed to explore more definitive solutions.

The objective was to *i*) identify the most important factors for sports fields having low inputs, and *ii*) provide the sports field managers of Michigan with management strategies that enhance playing surface characteristics (surface hardness, traction and turfgrass cover percent) thus providing improved playability and safety of sports fields. The hypothesis was that the management systems with the highest inputs would be the best systems based on the conditions of this experiment, and crumb rubber would be the highest ranking cultural practice.

MATERIALS AND METHODS

In 2003, an experiment was conducted at the Hancock Turfgrass Research Center (HTRC) on the campus of Michigan State University in East Lansing, MI. Six management factors/practices at two levels were implemented: turfgrass species mixtures, fertility, irrigation, overseeding, core cultivation and crumb rubber (Table 15). The experiment was a fractional factorial design (FFD). Additionally, six management systems [perennial ryegrass/Kentucky bluegrass (PR/KB) 1, 2 and 3, and supina bluegrass/common bermudagrass (SB/CB) 1, 2 and 3] within the plot area were replicated three times (Tables 16 & 17). It should also be noted that 1, 2, and 3 represent low, medium and high maintenance levels or a combination of the different factors working together, but not necessarily representing the same practice at each level. For example, PR/KB 2 does not have the exact same practices as SB/CB 2. The treatments within the FFD represented different possible combinations to aid in explanation of the effectiveness of the six management systems. Repeated measures analysis (RMA) was used to evaluate treatments over time (Kuehl, 2000). Although the soil was characterized as a sandy clay loam (49% sand, 26% silt and 25% clay), the soil profile was described as a Aubbeenaubbee - Capac sandy loam complex (Fine-loamy, mixed mesic Aeric Ochraqualfs). The soil had a pH of 7.6 and contained 16 and 115 mg kg $^{-1}$ P and K, respectively. Plot areas measured 2.55 m x 3 m.

On 19 May 2003, a Koro Field Topmaker (Pols International BV, The Netherlands) was used to remove the existing turfgrass stand. Once debris was

Table 15. Factors tested for sports field management study, 2003 and 2004.

Factors	Setting 0	Setting 1
A) Grass Mixtures	50% Perennial ryegrass / 50% Kentucky bluegrass (by weight) 196 kg ha^{-1}	50% Supina bluegrass / 50% Common Bermuda (by weight) 98 kg ha^{-1}
B) Fertility	123 kg N ha^{-1} yr^{-1}	196 kg N ha^{-1} yr^{-1}
C) Irrigation	No additional irrigation	Supplemental irrigation at 50% ET
D) Reseeding	No reseeding	50% reduced rate of either mixture
E) Core Cultivation	No core cultivation	Core cultivated spring and fall after seasonal traffic was applied
F) Crumb Rubber	No crumb rubber	125 mm crumb rubber depth

Perennial ryegrass var. SR4400, SR4500 and Manhattan III and Kentucky bluegrass var. Champagne and Rugby II

Supina bluegrass var. Supranova and Common bermudagrass var. Yukon (by weight).

N = Nitrogen, ET = evapotranspiration

Table 16. Factors and systems for sports field management study, 2003 and 2004.

	Systems					
Maintenance	Low	Medium	High	Low	Medium	High
Factors	PR/KB 1	PR/KB 2	PR/KB 3	SB/CB 1	SB/CB 2	SB/CB3
Grass Mixture	0	0	0	1	1	1
Fertility	0	0	1	0	0	1
Irrigation	0	1	1	0	0	1
Reseeding	1	0	1	1	0	0
Core Cultiv.	0	1	1	0	1	1
Crumb Rubber	0	1	0	0	1	1

PR/KB - perennial ryegrass/Kentucky bluegrass; SB/CB - supina bluegrass/common bermudagrass

Table 17. A scheme of 2 ^{n} fractional factorial design for six factors including six different systems.

Treatment	Factors A	B	C	D	E	F	System
1	0	0	0	0	0	1	
2	1	0	0	0	0	0	
3	0	1	0	0	0	0	
4	1	1	0	0	0	1	
5	0	0	1	0	0	0	
6	1	0	1	0	0	1	
7	0	1	1	0	0	1	
8	1	1	1	0	0	0	
9	0	0	0	1	0	0	PR/KB 1
9	0	0	0	1	0	0	PR/KB 1
9	0	0	0	1	0	0	PR/KB 1
10	1	0	0	1	0	1	
11	0	1	0	1	0	1	
12	1	1	0	1	0	0	
13	0	0	1	1	0	1	
14	1	0	1	1	0	0	
15	0	1	1	1	0	0	
16	1	1	1	1	0	1	
17	0	0	0	0	1	0	
18	1	0	0	0	1	1	SB/CB 2
18	1	0	0	0	1	1	SB/CB 2
18	1	0	0	0	1	1	SB/CB 2
19	0	1	0	0	1	1	
20	1	1	0	0	1	0	
21	0	0	1	0	1	1	PR/KB 2
21	0	0	1	0	1	1	PR/KB 2
21	0	0	1	0	1	1	PR/KB 2
22	1	0	1	0	1	0	
23	0	1	1	0	1	0	
24	1	1	1	0	1	1	SB/CB 3
24	1	1	1	0	1	1	SB/CB 3
24	1	1	1	0	1	1	SB/CB 3
25	0	0	0	1	1	1	
26	1	0	0	1	1	0	
27	0	1	0	1	1	0	
28	1	1	0	1	1	1	
29	0	0	1	1	1	0	
30	1	0	1	1	1	1	
31	0	1	1	1	1	1	
32	1	1	1	1	1	0	
33	0	1	1	1	1	0	PR/KB 3
33	0	1	1	1	1	0	PR/KB 3
33	0	1	1	1	1	0	PR/KB 3
34	1	0	0	1	0	0	SB/CB 1
34	1	0	0	1	0	0	SB/CB 1
34	1	0	0	1	0	0	SB/CB 1

Numbers 0 and 1 represent one of two treatments for each factor. 0 represents the absence or low level of a treatement. 1 represents the presence or high level of a treatment.

removed, a Toro greens core cultivation machine (Model: Greens Aerator 09120, Minneapolis, MN), with 1.27 cm hollow tines was used to core cultivate the plot to ensure no hard pan formed from the blades of the Koro machine. On 23 May, the soil profile was sterilized with Basamid G® (Tetrahydro-3,5,-Dimethyl-2H-1,3,5, Thiadiazine-2 Thione) (Certis, USA, Columbia, MD) at a 392 kg ha^{-1}. On 3 June, re-entry was allowed, and the surface of the soil was lightly disturbed to a depth of 3-6 mm with hand rakes before seeding began. There were two turfgrass seed mixtures; PR/KB; 50% perennial ryegrass (*Lolium perenne* L. var. 33% SR4400, 33% SR4500, and 34% Manhattan III) and 50% Kentucky bluegrass (*Poa pratensis* L var. 50% Champagne and 50% Rugby II) (by weight), and SB/CB; 50% supina bluegrass (*Poa supina* Schrad. var. Supranova) and 50% common bermudagrass (*Cynodon dactylon* [L.] Pers. var. Yukon) (by weight). The mixtures seeded for the PR/KB and SB/CB were at 196 kg ha^{-1} and 98 kg ha^{-1}, respectively. Lebanon Country Club® (Lebanon Turf Products, Lebanon, PA) starter fertilizer (13-25-12) was applied at 49 kg P ha^{-1}. Germination blankets (Model No. pr1715; A.M. Leonard, Piqua, OH) were placed over the top of the plot and removed 16 June.

Establishment and maintenance schedule are listed on Table 18. The establishment phase was initiated from 3 June to 10 Aug 2003. During this phase, irrigation was applied daily to avoid any wilt stress. From 26 June to 8 July, a Honda rotary mower (Model: Harmony HRB216 Quadracut System™, Honda Motor Company, Alpharetta, GA) was used to minimize rutting of the surface and to allow treatments to develop longer. On 9 July an eXmark®

Table 18. Establishment and maintenance schedule for sports field management study, 2003 and 2004.

2003		Low	High
3-Jun	Setup/seed/fertilize/blankets	49 kg N ha^{-1}	
23-Jun	Fertilize whole plot - 19-2-15	24.5 kg N ha^{-1}	
30-Jun	Mowing started at 5.0 cm at 2x/wk		
14-Jul	6 mm crumb rubber application		
23-Jul	Fertilize 25-5-15	37 kg N ha^{-1}	
27-Jul	6 mm crumb rubber application		
6-Aug	Fertilize 21-3-21	24.5 kg N ha^{-1}	
	Nitrogen Total for Establishment 2003	**135 kg N ha^{-1}**	
11-Aug	Traffic begins, Irrigation starts		
14-Sep	Fertilize 21-3-21		24.5 kg N ha^{-1}
21-Oct	Fertilize 21-3-21	24.5 kg N ha^{-1}	24.5 kg N ha^{-1}
24-Oct	Traffic Ends		
23-Oct	Irrigation Off		
15-Nov	Cored/Re-seed/Fert 21-3-21	24.5 kg N ha^{-1}	24.5 kg N ha^{-1}
	Nitrogen Total for Fall 2003	**49 kg N ha^{-1}**	**74.5 kg N ha^{-1}**
2004			
31-Mar	Traffic Begins		
12-Apr	Fertilize 21-3-21 (irrigation started)		24.5 kg N ha^{-1}
6-May	Fertilize 21-3-21	24.5 kg N ha^{-1}	24.5 kg N ha^{-1}
28-May	Traffic Ends		
3-Jun	Cored/Re-seed/Fert 21-3-21	24.5 kg N ha^{-1}	24.5 kg N ha^{-1}
19-Jul	Fertilize 21-3-21	24.5 kg N ha^{-1}	24.5 kg N ha^{-1}
12-Aug	Traffic begins		
6-Sep	Fertilize 21-3-21		24.5 kg N ha^{-1}
22-Sep	Fertilize 21-3-21		24.5 kg N ha^{-1}
18-Oct	Fertilize 21-3-21	24.5 kg N ha^{-1}	24.5 kg N ha^{-1}
25-Oct	Irrigation Off		
11-Nov	Traffic Ends		
23-Nov	Fertilize 21-3-21	24.5 kg N ha^{-1}	24.5 kg N ha^{-1}
	Nitrogen Total for 2003 and 2004	**172 kg N ha^{-1}**	**271 kg N ha^{-1}**

mower (Model: Lazer Z HP, eXmark® Corporation, Beatrice, NE) was used for the duration of the experiment. Irrespective of mower type, the turf was mowed twice per week at a mowing height of 5 cm. Clippings were returned at all times except from 20 April to 15 May 2004 in order to control supina bluegrass seedheads being spread throughout the plot. During this collection time frame, the Honda rotary motor was used to collect clippings. During the establishment period, a total of 135 kg N ha^{-1} was applied to the plot. Throughout the experiment, Lesco® (Strongsville, OH) 21-3-21 fertilizer, at 24.5 kg N ha^{-1}, was applied to their respective treatments at either 123 kg N ha^{-1} $year^{-1}$ or 196 kg N ha^{-1} $year^{-1}$. Crumb rubber (6 mm particle size) was applied to the respective turfgrass species mixtures on 14 July and 27 July 2003 in 6 mm applications for a total of 12 mm topdressed to the appropriate plots. At each application, crumb rubber was sprinkled evenly across the surface by hand and raked in four directions to spread as evenly as possible.

Weather data was collected and recorded by a weather station at the HTRC (Appendix A). Irrigation, by hand watering, began on 16 Aug 03 (Appendix B) and was based on evapotranspiration (ET) rate. The ET rate was halved, and the appropriate water amounts were applied with a hose at a predetermined nozzle setting to apply a constant amount of water for a period of time. Appropriate treatments did not continue for more than six days without water or rainfall throughout the experiment.

On 15 November 2003 and 3 June 2004, appropriate treatments were re-seeded at 50% the original seeding rate and/or core cultivated. Seeds were applied across the treatment, and seed-to-soil contact was ensured. A Toro Greens core cultivation machine (Minneapolis, MN), using 1.27 cm hollow tines and having 5 cm x 5 cm spacing between aerification holes, was used, and cores were broken and soil returned to the plot area.

A traffic regime was initiated on 11 August to 24 October 2003, 31 March to 28 May 2004 and 16 August to 11 November 2004 (Appendix C). At total of 338 passes were applied with the Brinkman Traffic Simulator (BTS) (Cockerham and Brinkman, 1989) with 112 passes completed by 24 October 2003, 80 passes completed by 28 May 2004 and 146 passes completed by 11 November 2004. The BTS was pulled using a John Deere 5200 tractor (Moline, IL) and weighed approximately 571 kg (with water in the drums). Two passes simulated the traffic received between the 40-yard lines and inside the hashmarks for one National Football League game based on cleat marks (Cockerham, 1989). Beginning 14 September 2004 and for the duration of the experiment, traffic direction was alternated every other day and changed on a 90° due to bumps forming on the surface.

Turfgrass percent cover, peak deceleration, shear resistance, volumetric soil moisture and plant count values were measured and taken in the traffic areas.

Turfgrass cover percent was estimated qualitatively. Data were collected on 11 Aug, 11 Sept, 3 Oct and 11 Nov 2003, and 29 Mar, 14 Apr, 2 Jun, 9 Aug, 20 Sept, 21 Oct and 11 Nov 2004.

Clegg Impact Soil Tester (CIT) (Lafayette Instrument Co., Lafayette, IN) was used to measure peak deceleration (G_{max}) values. A 2.25 kg hammer was dropped in three random locations per treatment area from a height of 0.46 m (Rogers and Waddington, 1990). Data were collected on 11 Aug, 11 Sept, 3 Oct and 11 Nov 2003, and 29 Mar, 16 Apr, 2 Jun, 9 Aug, 6 Sept, 21 Oct and 11 Nov 2004.

Shear resistance values were measured by the Eijkelkamp shear vane Type 1B (Rogers and Waddington, 1990) (Eijkelkamp Agrisearch Equipment BV, The Netherlands). Three measurements (Nm) were recorded and averaged throughout the treatment area. Data were collected on 11 Aug, 11 Sept, 3 Oct and 11 Nov 2003, and 29 Mar, 16 Apr, 18 May, 2 Jun, 9 Aug, 6 Sept, 21 Oct and 11 Nov 2004.

Volumetric water content measured with a Trime FM gauge and FM3 probe with 50 mm rods (Mesa Systems Co. Medfield, MA). One time domain reflectometry (TDR) measurement (v/v) was recorded throughout the treatment area. Data were collected on 6 Aug and 11 Nov 2003, and 29 Mar, 18 May, 2 Jun, 9 Aug, 21 Oct and 21 Nov 2004.

Plant counts were obtained using a soil probe with 32 mm diameter. Three subsample counts were recorded and averaged for each treatment area. Data were collected on 29 Mar, 16 Apr, 2 Jun, 4 Aug and 12 Nov 2004.

On 23 November 2004, undisturbed soil cores were extracted, measured and recorded. Each sample provided a volume of 347.72 cm^3. Direct treatment comparisons were assessed between the presence and absence of crumb rubber; in other words, all factors were the same. An unbalanced 3:1 ratio existed between no crumb rubber and crumb rubber plots, respectively. A total of nine undisturbed cores were extracted from no crumb rubber treatments and five undisturbed cores from crumb rubber treatments.

Bulk density was determined by the method described by Blake and Hartage (1986). Calculated porosity was determined by dividing the bulk density by the average particle density (2.65 g/cc) and subtracting from one. Porosity was measured as soil water lost from saturation to matric potentials of -0.0020, -0.0040, -0.0070, -0.010, -0.033, -0.10 MPa and over dry (105 °C). Saturated hydraulic conductivity was measured using a constant head in the laboratory (Klute and Dirksen, 1992).

STATISTICS

The experiment was carried out in a FFD (2^{6-1} design). Data were analyzed using SAS, Version 8.2 (SAS, 2001) and main effects, two-way and three-way interactions were identified. PROC GLM (General Linear Model) was used, and this analysis was completed by evaluating each date separately. All six factors were included. The significant factors for each playing surface characteristic were identified. Main effects and significant interactions were identified at the 0.05 level for each testing date. The next step identified three-way interactions, however significance was analyzed at the 0.01 level due to the lack of replication in the experiment. From the previous analysis, significant main effects and interactions were reanalyzed, and significance was determined at the 0.05 level.

Once these factors were identified, PROC MIXED analysis was utilized and then time was added as a factor. Main effects, two-way and three-way interactions were identified and accepted at the 0.05 level. Data were re-analyzed eliminating non-significant interactions and high-order (four, five and six-way). Finally, data were re-analyzed using repeated measures in the model. The model was accepted by attaining the lowest Akaike's Information Criteria (AIC). Compound symmetry heterogeneous (csh) provided the best variance/covariance structure.

Comparison of management systems were analyzed as a two-factor analysis with system and time being the factors. PROC MIXED was used for analysis along with repeated measures analysis. The model was accepted by attaining the lowest Akaike's Information Criteria (AIC). Compound symmetry heterogeneous (csh) provided the best variance/covariance structure.

Soil cores were analyzed in unbalanced design with a 3:1 ratio of no crumb rubber compared to crumb rubber plots. PROC MIXED was used for analysis, and treatment means were separated using Fisher's Protected LSD values at the 0.05 level.

RESULTS AND DISCUSSION

Main and interaction effects for re-analyzed data for individual factors for each playing surface characteristic are listed in Tables 19 and 20, and re-analyzed data of playing surface characteristics for management systems are listed in Tables 21 and 22.

Turfgrass cover percent

Turfgrass cover percent values are listed in Table 23. There were significant differences for every date except on 11 Aug 2003, and every system was significant across dates. As the intensity level of the management system increased as did turfgrass cover percent. Turfgrass species mixtures, fertility, irrigation and crumb rubber were all factors. From 11 Aug to 11 Nov 03 and 9 Aug to 11 Nov 04, turfgrass cover percent decreased significantly for all systems coinciding with simulated traffic applications. However, from 29 Mar to 2 Jun 2004, PR/KB 1 decreased significantly, but SB/CB 2 increased significantly. A possible reason for all management systems maintaining or increasing turfgrass cover percent was that 29 Mar to 14 Apr, there was 0.26 cm of precipitation, whereas from 15 Apr to 2 Jun, there was 25.12 cm of precipitation. PR/KB 1 had a low fertility rate and was overseeding 2x/year. The SB/CB species treatments actually improved turfgrass cover as the spring season progressed. Due to its stoloniferous growth habit and excellent recuperative ability (Berner, 1980; Sorochan et al., 2001), supina bluegrass was very competitive even during traffic conditions.

Table 19. The F and p values of re-analyzed data for all main and interaction fixed effects for cultural practices on turfgrass cover percent, peak deceleration and shear resistance, 2003 and 2004.

Turfgrass cover percent				Peak deceleration				Shear resistance			
Effect	df	F-value	p-value	Effect	df	F-value	p-value	Effect	df	F-value	p-value
Species (S)	1	45.89	<.0001	Species (S)	1	4.83	0.0342	Species (S)	1	12.73	0.0010
Fertility (F)	1	139.75	<.0001	Irrigation (I)	1	9.28	0.0043	Fertility (F)	1	62.40	<.0001
Irrigation (I)	1	12.40	0.0012	Core Cultivation (CC)	1	43.05	<.0001	Irrigation (I)	1	17.15	0.0002
S x I	1	7.09	0.0110	S x CC	1	0.75	0.3908	S x I	1	14.08	0.0006
Crumb Rubber (CR)	1	374.48	<.0001	Crumb Rubber (CR)	1	362.47	<.0001	Crumb Rubber (CR)	1	41.27	<.0001
S x CR	1	14.35	0.0006	S x CR	1	1.51	0.2271	S x CR	1	3.02	0.0903
S X F	1	4.78	0.0355	I x F	1	5.77	0.0215	F x CR	1	6.25	0.0170
F X CR	1	0.06	0.8111	CC x CR	1	1.21	0.2775	I x CR	1	0.19	0.6622
S x F x CR	1	9.93	0.0033	Day (D)	11	550.33	<.0001	Day (D)	11	96.14	<.0001
Day (D)	9	253.90	<.0001	S x D	11	3.17	0.0004	S x D	11	5.11	<.0001
S x D	9	26.31	<.0001	I x D	11	22.39	<.0001	F x D	11	13.80	<.0001
F x D	9	28.24	<.0001	CC x D	11	5.76	<.0001	I x D	11	7.62	<.0001
I x D	9	6.02	<.0001	CR x D	11	51.96	<.0001	CR x D	11	29.31	<.0001
CR x D	9	30.00	<.0001	I x CR x D	11	4.45	<.0001	S x CR x D	11	2.30	0.0096
S x I x D	9	2.92	0.0024	CC x CR x D	11	1.86	0.0431	F x CR x D	11	1.32	0.2082
F x CR x D	9	3.67	0.0002					I x CR x D	11	2.17	0.0150
I x CR x D	9	1.78	0.0633								

Table 20. The F and p values of re-analyzed data for all main and interaction fixed effects for cultural practices on time domain reflectometry and plant counts, 2003 and 2004.

Time domain reflectometry				Plant counts			
Effect	df	F-value	p-value	Effect	df	F-value	p-value
Species (S)	1	9.51	0.0022	Species (S)	1	28.89	<.0001
Fertility (F)	1	0.84	0.2434	Fertility (F)	1	55.44	<.0001
Irrigation (I)	1	2.01	0.3271	Irrigation (I)	1	0.73	0.3971
S x F	1	2.82	0.1317	Crumb Rubber (CR)	1	21.10	<.0001
Crumb Rubber (CR)	1	21.00	<.0001	F x I	1	0.75	0.3903
S x CR	1	2.93	0.0851	Day (D)	4	73.57	<.0001
F x CR	1	0.20	0.5451	S x D	4	3.88	0.0049
Day (D)	7	47.86	<.0001	F x D	4	3.63	0.0073
CR x D	7	5.22	<.0001	I x D	4	2.94	0.0224
				CR x D	4	2.68	0.0335
				F x I x D	4	2.03	0.0920

Table 21. The F and p values of re-analyzed data for all main and interaction fixed effects for management systems turfgrass cover percent,peak deceleration, and shear resistance, 2003 and 2004.

Cover Percent				Peak deceleration				Shear resistance			
System	Day	F-value	p-value	System	Day	F-value	p-value	System	Day	F-value	p-value
2003	11-Sep	9.53	<.0001	2003	11-Aug	3.54	0.0049	2003	11-Aug	6.31	<.0001
	3-Oct	37.77	<.0001		11-Sep	93.72	<.0001		11-Sep	13.41	<.0001
	11-Nov	17.45	<.0001		3-Oct	18.47	<.0001		3-Oct	1.64	0.1549
2004	29-Mar	33.67	<.0001		11-Nov	1.21	0.3070		11-Nov	3.08	0.0115
	14-Apr	24.74	<.0001	2004	29-Mar	3.40	0.0064	2004	29-Mar	1.99	0.0841
	2-Jun	8.94	<.0001		16-Apr	11.29	<.0001		16-Apr	2.69	0.0237
	9-Aug	15.12	<.0001		18-May	20.13	<.0001		18-May	5.13	0.0002
	20-Sep	25.78	<.0001		2-Jun	5.63	<.0001		2-Jun	20.45	<.0001
	21-Oct	41.85	<.0001		9-Aug	5.83	<.0001		9-Aug	8.81	<.0001
	11-Nov	29.54	<.0001		6-Sep	8.66	<.0001		6-Sep	9.70	<.0001
PR/KB 1		22.25	<.0001		21-Oct	37.82	<.0001		21-Oct	10.85	<.0001
PR/KB 2		50.83	<.0001		21-Nov	8.47	<.0001		21-Nov	16.01	<.0001
PR/KB 3		19.56	<.0001	PR/KB 1		91.10	<.0001	PR/KB 1		17.76	<.0001
SB/CB 1		31.46	<.0001	PR/KB 2		13.99	<.0001	PR/KB 2		3.22	0.0006
SB/CB 2		30.13	<.0001	PR/KB 3		49.86	<.0001	PR/KB 3		17.45	<.0001
SB/CB 3		18.66	<.0001	SB/CB 1		70.79	<.0001	SB/CB 1		22.81	<.0001
				SB/CB 2		22.18	<.0001	SB/CB 2		9.13	<.0001
				SB/CB 3		11.00	<.0001	SB/CB 3		11.38	<.0001

Table 22. The F and p values of re-analyzed data for all main and interaction effects for management systems on time domainreflectometry and plant counts, 2003 and 2004.

Time domain reflectometry				Plant counts			
System	Day	F-value	p-value	System	Day	F-value	p-value
2003	6-Aug	0.49	0.7804	2004	29-Mar	4.16	0.0032
	11-Nov	0.24	0.9423		16-Apr	2.72	0.0303
2004	29-Mar	6.02	<.0001		2-Jun	3.43	0.0099
	18-May	2.64	0.0295		4-Aug	4.75	0.0013
	2-Jun	1.28	0.2799		12-Nov	13.03	<.0001
	9-Aug	5.37	0.0021	PR/KB 1		11.00	<.0001
	21-Oct	0.17	0.9744	PR/KB 2		7.37	0.0001
	21-Nov	0.97	0.4412	PR/KB 3		9.23	<.0001
PR/KB 1		5.70	<.0001	SB/CB 1		4.99	0.0019
PR/KB 2		9.62	<.0001	SB/CB 2		10.04	<.0001
PR/KB 3		5.51	<.0001	SB/CB 3		0.68	0.6120
SB/CB 1		4.32	0.0008				
SB/CB 2		11.47	<.0001				
SB/CB 3		4.88	<.0001				

Table 23. Effects of management systems on turfgrass percent cover ratings using repeated measures at the Hancock Turfgrass Research Center.

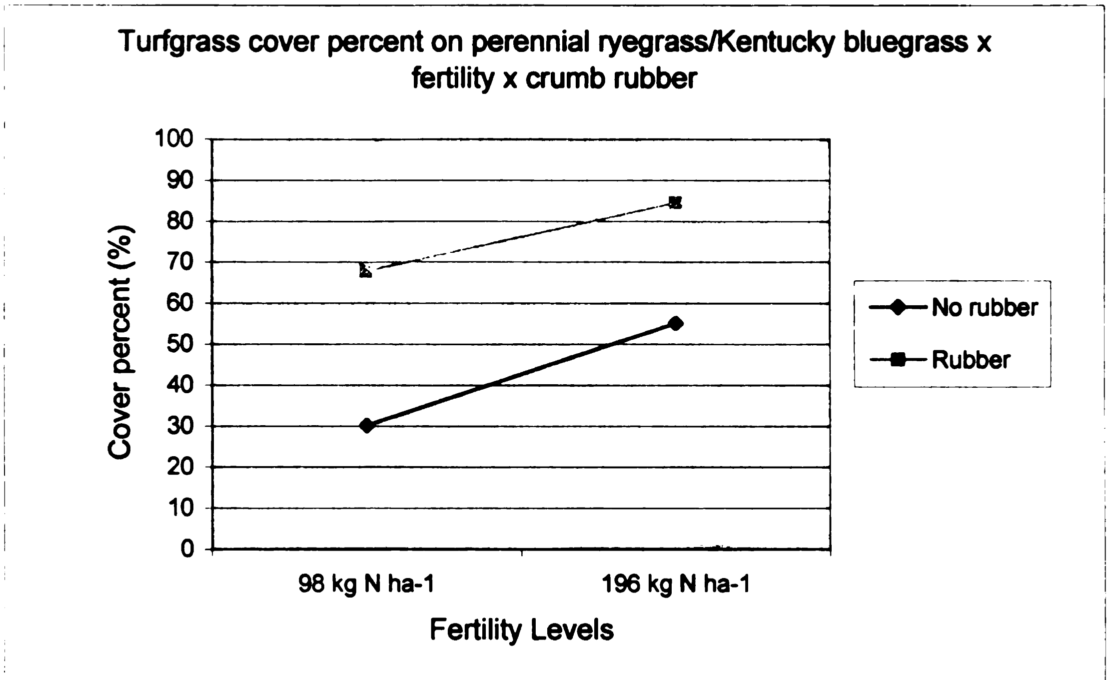
	2003				2004						
System	11-Aug	11-Sep	3-Oct	11-Nov	29-Mar	14-Apr	2-Jun	9-Aug	20-Sep	21-Oct	11-Nov
	%										
PR/KB 1	A 100	DEF 23 c	CD 33 cd	D 26 c	B 57 b	C 40 b	C 40 c	B 60 d	DEF 23 c	EF 15 de	F 10 cd
PR/KB 2	A 100	B 88 a	B 87 a	D 60 a	B 87 a	B 82 a	BC 78 ab	B 91 ab	CD 66 a	E 36 c	F 17 c
PR/KB 3	A 100	DEF 50 b	F 40 c	EF 42 b	C 67 b	DE 52 b	CD 62 b	B 87 b	C 66 a	C 65 b	F 37 b
SB/CB 1	A 100	C 54 b	D 28 d	E 6 d	D 28 c	DE 15 c	D 30 c	B 72 c	D 23 c	E 10 e	E 7 d
SB/CB 2	A 100	BC 80 a	CD 63 b	E 39 b	D 57 b	E 45 b	C 63 b	B 82 bc	E 43 b	F 26 cd	F 18 c
SB/CB 3	A 100	AB 85 a	C 71 b	D 45 b	BC 82 a	C 73 a	AB 87 a	A 99 a	C 78 a	AB 85 a	D 53 a
Days into Expt.	1	32	54	93	232	248	297	365	407	438	459
No. of Passes	0	56	82	112	0	20	80	0	64	112	146
Accum. Passes	0	56	82	112	112	132	196	192	256	304	338

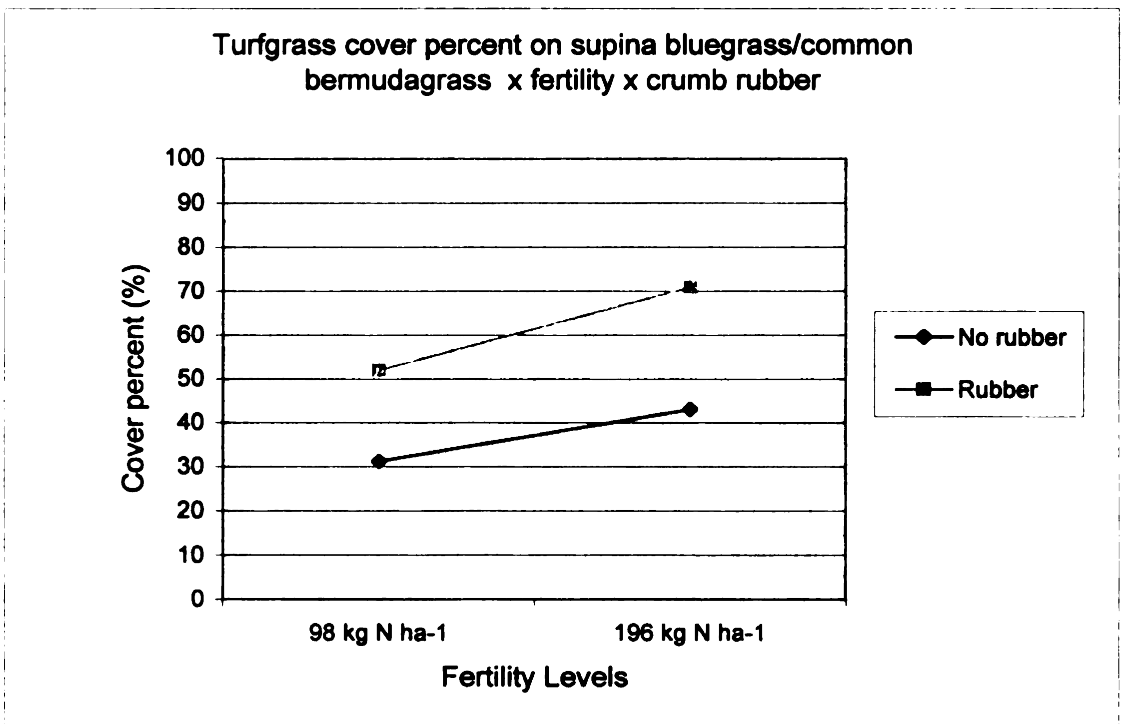
Means preceded by the same uppercase letter (within rows) and means followed by the same lowercase letters (within columns) are not significantly different at $p > 0.05$. No letters across a row (management system) or down a column (date) means there is no significance at $p > 0.05$.

Statistically, overseeding was not an effective cultural practice for the conditions of this experiment. With minimal inputs, overseeding at half the rates of the establishment rate after completion of the traffic proved to be ineffective to influence turfgrass cover percent. Crumb rubber, irrigation, fertility and turfgrass species were more effective in contributing to turfgrass cover percent. Little research is available for overseeding rates of sports field research. Minner and Valverde (2004) and Rossi (personal communication, 2005) found overseeding perennial ryegrass at 490 kg ha^{-1}, during the simulated traffic season, was most effective in promoting turfgrass cover percent. Larsen et al. (2004) found topdressing with overseeding aided turfgrass cover and recovery in a three-year study due to enhanced seed to soil contact. Crumb rubber topdressing could potentially provide a more favorable environment for seed to germinate, but crumb rubber was not applied each year, and rate and/or frequency of overseeding (twice per year) was too low.

There was a species x fertility x crumb rubber interaction for turfgrass cover percent values (Figure 5). The importance of crumb rubber cannot be overstated; it resulted with at least a 20 – 30% increase in turfgrass cover percent regardless of fertility level. Depending upon turfgrass species mixture treatment, there was a significant difference with PR/KB at 98 kg N ha^{-1} level and SB/CB at 196 kg N ha^{-1} level. This indicates that regardless of grass mixture and fertility levels, the presence of crumb rubber can improve turfgrass cover percent. It should be noted this figure does not present time as a factor, and this might explain why PR/KB was higher compared to SB/CB at a higher fertility rate.

Figure 5. Effects of turfgrass cover percent on species x fertility x crumb rubber interaction on a trafficked system study.

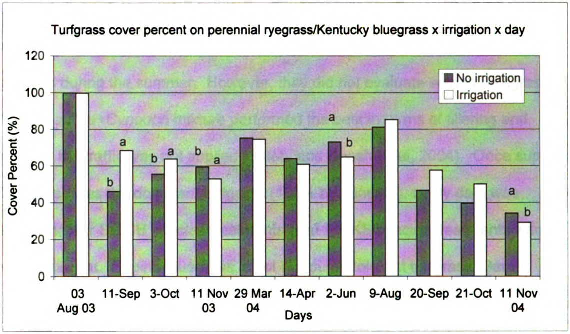


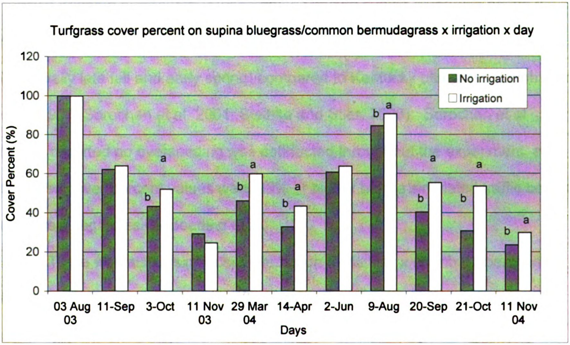


PR/KB treatments did not have to transition at all during the length of this experiment compared to SB/CB treatments (See below).

There was a species x irrigation x time interaction for turfgrass percent cover values (Figure 6). PR/KB species treatments tended to have higher values, regardless of irrigation scheme when compared to SB/CB species treatments. A possible reason, for PR/KB having higher values, is PR/KB treatments did not have to transition at all during the length of this experiment compared to SB/CB treatments. Common bermudagrass was the dominant grass in summer and fall (dormant) 2003, but then supina bluegrass became the dominant grass at the end of spring 2004 and for the rest of the experiment for those treatments. This transition could have influenced turfgrass cover percent ratings. Treatments receiving 50% ET returned had higher turfgrass cover percent values, and did not continue for more than six days without irrigation or precipitation. There were five significant dates for PR/KB species treatments compared to 7 significant dates for SB/CB species treatments. The five dates for PR/KB species treatments, two dates (11 Nov 03 and 11 Nov 04) were significant when the irrigation had been turned off for the season. The 7 dates for SB/CB species treatments, turfgrass cover percent on 11 Nov 04 was significant when the irrigation was turned off. In the beginning of the experiment, bermudagrass was the dominant grass for the SB/CB species treatments. Bermudagrass went dormant on 6 October 2003, and it never returned as the dominant species for the rest of the experiment regardless of overseeded or not. From this point on, supina bluegrass began to transition into the treatments. This might reflect the

Figure 6. Effects of turfgrass cover percent on species x irrigation x time interaction on a trafficked system study.



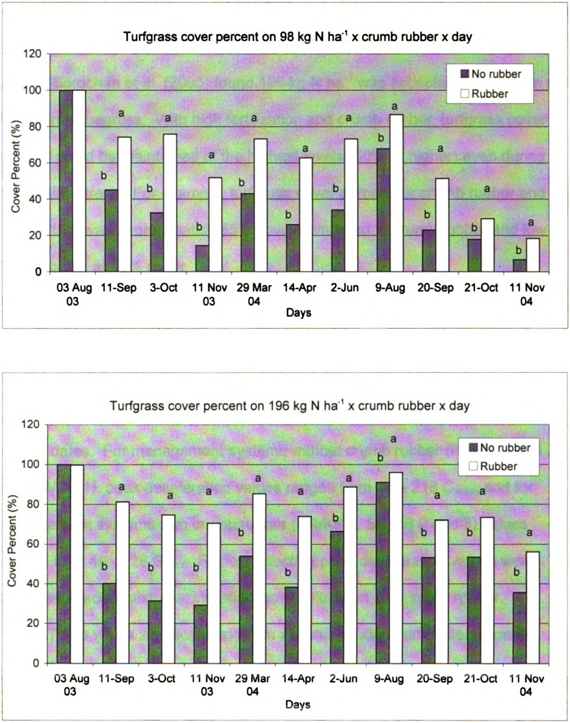


Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

importance of water in managing supina bluegrass. In Iowa, Kansas and Nebraska, Gaussoin et al., (2001) found in their overseeding studies that bermudagrass (alone, mixed with perennial ryegrass or overseeded) will not overwinter, but it provided a far better turfgrass cover than traditional cool season grasses during the summer. However, they did not evaluate supina bluegrass. In Iran, a *Poa+Cynodon* mixture performed the best in terms of tillering and rooting, but traffic was not applied (Salehi and Khosh-Khui, 2004). Once supina bluegrass was the dominant turfgrass (100% by June 04), every date was significant for SB/CB species treatments, and PR/KB species treatments were not significant. Supina bluegrass is not a drought tolerant turfgrass (Berner 1980; Leinhauer et al., 1997), consequently differences between no irrigation and irrigation with SB/CB species treatments were greater compared to the PR/KB species irrigated treatments. Research has shown supina bluegrass needs a higher fertility rate, more irrigation, and will be more aggressive in colder climates (especially late fall and early spring) compared to Kentucky bluegrass (Leinhauer et al. 1997; Sorochan et al. 2001; Steinke and Stier, 2003). Sorochan et al. (2001) reported no overseeding was conducted throughout the experiment, and turfgrass cover percent values were 98% or higher before simulated traffic began each year regardless of seeding ratio.

There was also a significant interaction for fertility x crumb rubber x time for turfgrass cover percent values (Figure 7). Regardless of fertility level, crumb rubber improved the consistency of the turfgrass stand. Regardless of species, at the low fertility level, turfgrass cover percent at the end of the experiment was

Figure 7. Effects of turfgrass cover percent on fertility x crumb rubber x time interaction on a trafficked system study.



Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

20% or less. If the fertilization was applied more evenly over time, it is possible these values would not have been as low. For this experiment, although there was an erratic fertilizer schedule and supina bluegrass has a shallow root system (Stier, 1999), fertility treatments for this experiment did not exceed 196 kg N ha^{-1} year^{-1}. Sorochan et al. (2005) found 196 kg N ha^{-1} was acceptable on a loam soil for supina bluegrass. With high fertilization and crumb rubber, turfgrass cover percent could be maintained at the highest levels (50% or higher) even during high traffic stress. For example, turfgrass cover percent for crumb rubber and high fertility was approximately 55% cover compared to crumb rubber and low fertility being at 18% cover.

Peak deceleration

Peak deceleration or surface hardness values for management systems are listed in Table 24. There were significant differences in peak deceleration values for each date except for 11 Nov 2003, and every system was significant across dates. For management systems without crumb rubber (PR/KB 1 and 3, and SB/CB 1), peak deceleration values ranged from 44 – 218 G_{max}, and for management systems with crumb rubber (PR/KB 2, SB/CB 2 and 3) values ranged from 49 - 128 G_{max}. Factors affecting peak deceleration values were turfgrass species mixtures, irrigation, core cultivation and crumb rubber.

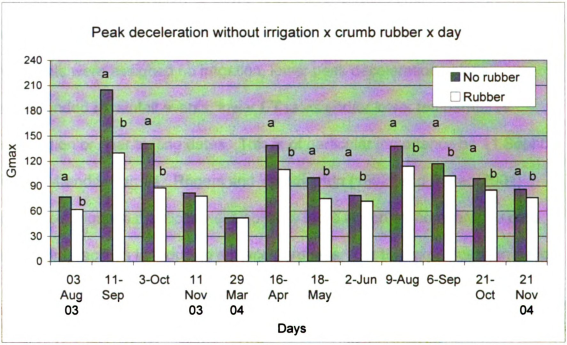
There was a significant irrigation x crumb rubber x time interaction for peak deceleration values (Figure 8). Any significant testing date produced a difference of 7 gravities ($_g$) or higher. Rogers and Waddington (1989) and Lundberg (2002) had significant differences of G_{max} at 7 $_g$ or less. An inverse

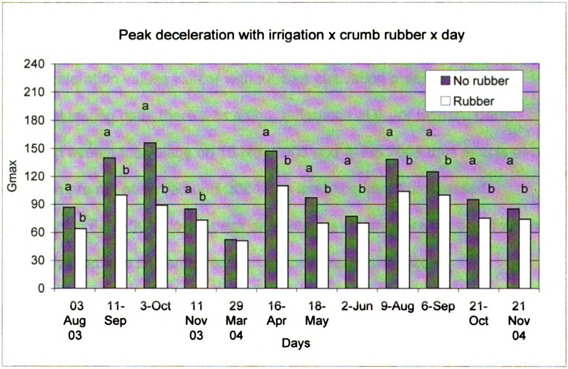
Table 24. Effects of management systems on peak deceleration using repeated measures at the Hancock Turfgrass Research Center.

	2003				2004							
System	11-Aug	11-Sep	3-Oct	11-Nov	29-Mar	16-Apr	18-May	2-Jun	9-Aug	6-Sep	21-Oct	21-Nov
	Gmax											
PR/KB 1	G 77 ab	A 218 a	BC 148 a	G 84	H 57 ab	BC 146 a	E 110 a	G 81 a	B 165 a	C 139 a	D 127 a	F 94 a
PR/KB 2	DE 58 c	A 101 c	AB 89 b	CD 71	E 48 c	A 108 b	CD 70 c	C 72 b	AB 95 c	A 96 d	BC 77 cd	C 72 d
PR/KB 3	D 89 a	AB 144 b	A 157 a	D 81	F 44 c	AB 148 a	D 88 b	E 67 b	BC 125 bc	C 116 bc	D 86 c	D 84 bc
SB/CB 1	E 75 abc	A 204 a	BC 143 a	E 81	F 61 a	BC 138 a	D 114 a	E 81 a	B 159 ab	C 131 ab	D 104 b	E 87 ab
SB/CB 2	DE 61 bc	A 128 b	C 84 b	C 81	E 50 bc	AB 112 b	C 76 bc	CD 73 ab	AB 118 c	B 106 cd	C 77 cd	C 77 cd
SB/CB 3	D 66 bc	AB 96 c	BC 87 b	CD 77	E 49 c	AB 100 b	CD 70 c	D 65 b	A 114 c	AB 95 d	CD 75 d	C 71 d
Days into Expt.	1	32	54	93	232	250	282	297	365	393	438	469
No. of Passes	0	56	82	112	0	24	64	80	0	46	112	146
Accum. Passes	0	56	82	112	112	136	176	192	192	238	304	338

Means preceded by the same uppercase letter (within rows) and means followed by the same lowercase letters (within columns) are not significantly different at $p > 0.05$. No letters across a row (management system) or down a column (date) means there is no significance at $p > 0.05$.

Figure 8. Effects of peak deceleration on irrigation x crumb rubber x time interaction on a trafficked system study.





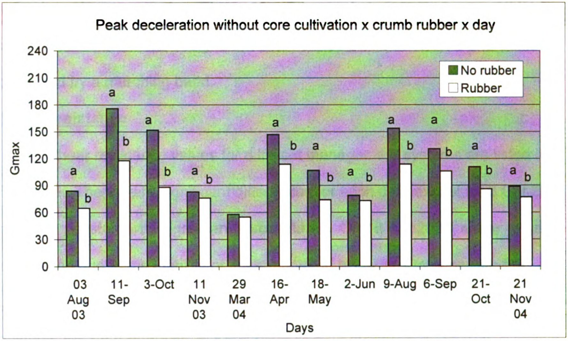
Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

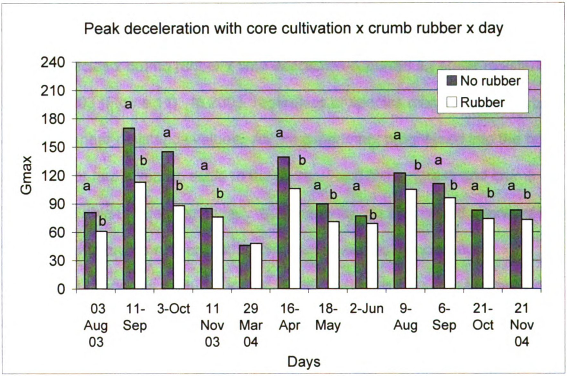
relationship of soil moisture and peak deceleration is consistent with Gramckow (1968) and Rogers et al. (1988). In Fall 03, crumb rubber alone was able to decrease peak deceleration values, (Rogers et al., 1998) and with the addition of supplemental irrigation, peak deceleration values were lowered further. When treatments were assigned no irrigation, lower peak deceleration values corresponded to rainfall events, lower ET rates and/or lower temperatures occurred on or near testing dates. This is of particular importance on 11 Sept 03, 16 Apr 04 and 9 Aug 04. Rogers and Waddington (1992) and Baker (2001) suggested irrigation practices were possibly more important compared to core cultivation practices in reducing surface hardness. For this experiment, irrigation practices were a daily to weekly event while core cultivation was a bi-yearly event.

A core cultivation x crumb rubber x time interaction occurred throughout the experiment for peak deceleration values (Figure 9). Crumb rubber lowered peak deceleration values with or without core cultivation present. On any significant testing date, there was a G_{max} difference at 6 $_g$ or higher. Core cultivation events took place on 15 Nov 2003 and 3 Jun 2004 thus effects of core cultivation are not observed until 2004. As the experiment progressed (especially in Fall 2004), lower peak deceleration values were observed when core cultivation was implemented with and without crumb rubber.

Similar to the irrigation x crumb rubber x time for peak deceleration interaction, crumb rubber reduced peak deceleration values, and core cultivation continued to lower values and provide more consistency to the playing surface.

Figure 9. Effects of peak deceleration on core cultivation x crumb rubber x time interaction on a trafficked system study.





Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

Furthermore, it was observed that crumb rubber was migrating into core cultivation holes which could potentially aid in stabilizing peak deceleration values and improve rooting (Figure 10). Rogers et al., (1996) observed this concept in experimental designs under simulated traffic conditions and traffic produced by a marching band.

Shear resistance

Shear resistance values for different management systems are listed in Table 25. There were significant differences for each date except for 3 Oct 2003, and every system was significant across dates. On 16 Apr 2004, shear values decreased due to the inability of the shear vane apparatus to penetrate the ground because of a lack of soil water. Shear resistance for management systems PR/KB 2 and SB/CB 3 improved as time progressed. Factors affecting shear resistance were species, fertility, irrigation and crumb rubber.

A species x crumb rubber x time interaction occurred for shear resistance values in 2003 (Figure 11). In 2003, regardless of species mixture, crumb rubber decreased shear resistance values. As the experiment progressed into the fall, crumb rubber had a year to settle to the surface, and the turfgrass and crumb rubber were able to “mesh together”. Subsequently, on 21 Oct and afterwards, treatments with crumb rubber produced higher shear resistance values independent of species mixture. Vanini (1995) observed the same tendency of crumb rubber needing a year to “mesh together” with the turfgrass community, before shear resistance values improved in a perennial ryegrass/Kentucky bluegrass mixture. When crumb rubber was applied in July 03, bermudagrass

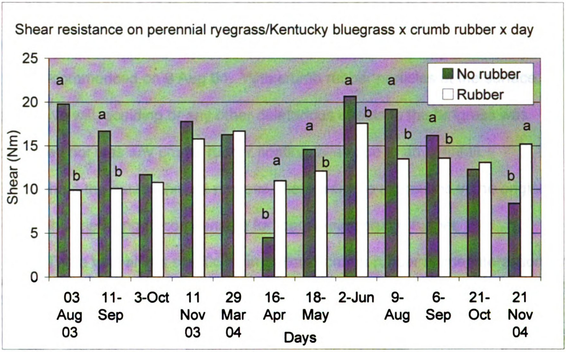
Figure 10. The effects of core cultivation and crumb rubber improving rooting by crumb rubber filling up a core cultivation hole and potentially preventing it from collapsing.

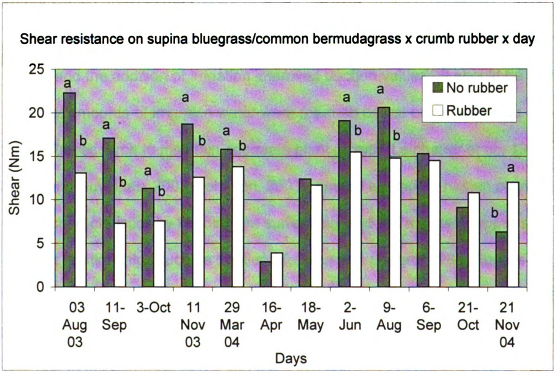
Table 25. Effects of management systems on shear resistance using repeated measures at the Hancock Turfgrass Research Center.

	2003				2004							
System	11-Aug	11-Sep	3-Oct	11-Nov	29-Mar	16-Apr	18-May	2-Jun	9-Aug	6-Sep	21-Oct	11-Nov
	Nm											
PR/KB 1	A 18.3 a	B 13.3 b	BC 10.7	A 19.3 a	A 17.0	C 7.0 a	B 13.0 b	A 19.7 b	A 17.5 ab	B 12.3 b	C 6.7 b	D 0 c
PR/KB 2	D 9.0 b	D 11.0 bc	D 11.0	A 17.3 a	ABC 14.7	D 8.3 a	CD 11.7 b	AB 15.0 c	BCD 12.3 c	BCD 12.3 b	A-D 13.0 a	BCD 12.3 ab
PR/KB 3	ABC 20.3 a	BC 19.7 a	E 10.3	BC 18.0 a	D 15.3	F 2.0 b	BC 18.0 a	A 22.7 a	AB 21.7 a	AB 22.0 a	C 16.7 a	DE 13.7 ab
SB/CB 1	A 21.7 a	C 12.7 bc	C 11.0	AB 19.3 a	AB 18.3	E 1.7 b	D 7.3 c	B 16.3 c	AB 18.7 ab	C 11.3 b	E 0 c	E 0 c
SB/CB 2	AB 12.3 b	EF 5.7 d	DE 7.7	AB 13.0 b	AB 13.7	F 1.7 b	ABC 11.7 b	A 14.7 c	ABC 12.0 c	BCD 10.7 b	EF 4.3 b	CDE 8.3 b
SB/CB 3	CDE 13.0 b	EF 9.3 c	F 7.7	CDE 13.0 b	BC 14.0	F 7.3 a	DE 12.7 b	A 18.7 b	ABC 17.3 b	AB 18.3 a	ABC 17.3 a	ABC 17.3 a
Days into Expt.	1	32	54	93	232	250	282	297	365	393	438	469
No. of Passes	0	56	82	112	0	24	64	80	0	46	112	146
Accum. Passes	0	56	82	112	112	136	176	192	192	238	304	338

Means preceded by the same uppercase letter (within rows) and means followed by the same lowercase letters (within columns) are not significantly different at $p > 0.05$. No letters across a row (management system) or down a column (date) means there is no significance at $p > 0.05$.

Figure 11. Effects of shear resistance on species x crumb rubber x time interaction on a trafficked system study.



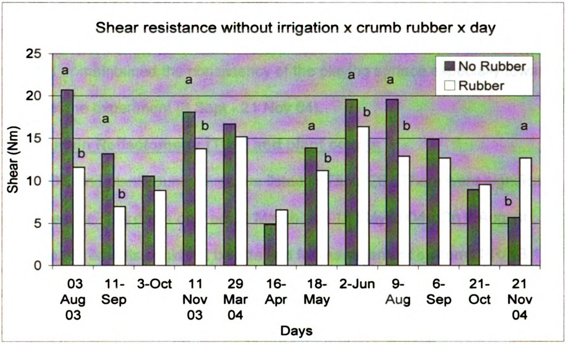


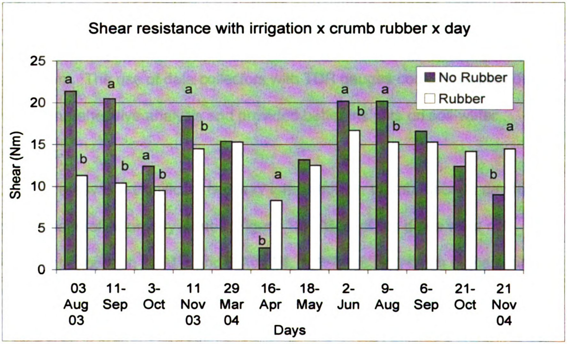
Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

was the dominant turfgrass, but supina bluegrass eventually became the dominant turfgrass stand. There were no observed adverse effects to the species treatments due to crumb rubber attracting heat to the surface. After a year, crumb rubber was no longer visible on the playing surface before the traffic regime commenced on 9 Aug 04. With crumb rubber particles at the surface, no excessive wilt, scalding or any other deleterious effects to the turfgrass was observed nor was any crumb rubber floating away due to any rainfall. Throughout the establishment process, there were no alterations in the original irrigation scheduling to compensate for topdressing crumb rubber.

There was also a significant irrigation x crumb rubber x time interaction for shear resistance values (Figure 12). In the beginning of the experiment, regardless of irrigation, crumb rubber lowered shear resistance values because it had not settled down to the soil surface. As the experiment progressed, crumb rubber "meshed together" with the turfgrass community, settled down to the soil surface, and the addition of irrigation improved traction values. It should be noted that amounts of irrigation water were returned based on 50% ET rate due to previous research to maintain adequate plant growth (Leinhauer et al., 1997; Bastug and Buyuktas, 2003, Johnson, 2003), and an attempt to hasten playing surface characteristics by keeping the surface dry and still maintain proper soil and plant relationships such as traction (Zebarth and Sheard, 1985, Rogers and Waddington, 1989) and surface hardness (Gramckow, 1968, Rogers et al., 1988, Rogers and Waddington, 1992). On 16 Apr 2004, traction values were much lower due to the hardness of the surface and the inability of the shearvane to

Figure 12. Effects of shear resistance on irrigation x crumb rubber x time interaction on a trafficked system study.





Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

penetrate the surface. Furthermore, shear values in crumb rubber treated plots were higher, and there was a significant difference when irrigation was returned. Although this reversed again on 18 May and 2 Jun 04 (probably due to in excess of 25 cm of rainfall in May 04), treatments with irrigation and/or crumb rubber improved or maintained the consistency of the playing surface especially towards the end of the experiment (6 Sept - 21 Nov 04).

Time Domain Reflectometry (TDR) and plant counts

TDR and plant count values are listed in Table 26. There were significant differences for TDR dates only on 29 March and 18 May 2004. On 6 August 2004, measurements could not be attained for management systems PR/KB 1 and SB/CB 1 due to dry conditions, and the inability of the probe to penetrate the ground. Factors affecting volumetric soil water content were turfgrass species mixtures, fertility and crumb rubber. Soil water volume changes continuously from day to day, and there were only eight measurement days throughout the experiment. The use of data collectors with TDR gauges could have provided a more comprehensive analysis and provided better insights on soil-water dynamics.

There was a significant two-way interaction for crumb rubber x day for time domain reflectometry values (Figure 13). Most of the dates were not significant except on 29 Mar and 9 Aug 04, both beginning dates of the spring and fall seasons. It would be assumed that ideal conditions (100% turfgrass cover percent, proper soil conditions with good porosity) existed before the beginning of the playing season. One possible reason for lower soil moisture

Table 26. Effects of management systems on time domain reflectometry and plant counts using repeated measures at the Hancock Turfgrass Research Center.

	2003		2004										
System	6-Aug	11-Nov	29-Mar	18-May	2-Jun	9-Aug	21-Oct	21-Nov	29-Mar	16-Apr	2-Jun	4-Aug	12-Nov
	v/v								plants * 100 cm^2				
PR/KB 1	AB 38	AB 37.8	A 39.8 a	BC 31.8 a	BC 34.5	—	C 30.5	C 30.5	A 156 ab	B 54 bc	A 130 a	A 156 abc	B 45 de
PR/KB 2	AB 36	A 40.1	AB 35.3 bc	AB 34.3 a	AB 34.1	C 20.3 b	B 31.4	B 32.3	A 181 a	B 83 abc	A 139 a	A 177 ab	B 83 bc
PR/KB 3	A 37	A 40.3	A 39.0 a	B 31.6 a	A 36.0	C 28.3 a	AB 32.6	AB 33.9	A 223 a	C 109 ab	B 160 a	A 215 a	C 109 ab
SB/CB 1	A 38	A 39.1	A 37.8 ab	BC 31.9 a	BC 31.4	—	C 30.5	AB 34.5	A 83 b	B 33 c	A 76 b	A 114 bcd	B 25 e
SB/CB 2	A 37	A 37.8	A 32.1 c	A 30.9 ab	A 33.9	B 22.3 b	A 31.9	A 31.8	A 210 a	C 76 abc	B 134 a	BC 89 d	C 63 cd
SB/CB 3	A 35	A 36.1	A 33.5 c	B 27.7 b	A 36.1	C 19.3 b	AB 30.9	A 34.1	168 a	121 a	130 a	130 bcd	139 a
Days into Expt.	0	93	232	282	297	362	438	469	232	250	297	360	460
No. of Passes	0	112	0	64	80	0	112	146	0	24	80	0	146
Accum. Passes	0	112	112	176	192	192	304	338	112	136	192	192	338

Means preceded by the same uppercase letter (within rows) and means followed by the same lowercase letters (within columns) are not significantly different at $p > 0.05$.
No letters across a row (management system) or down a column (date) means there is no significance.

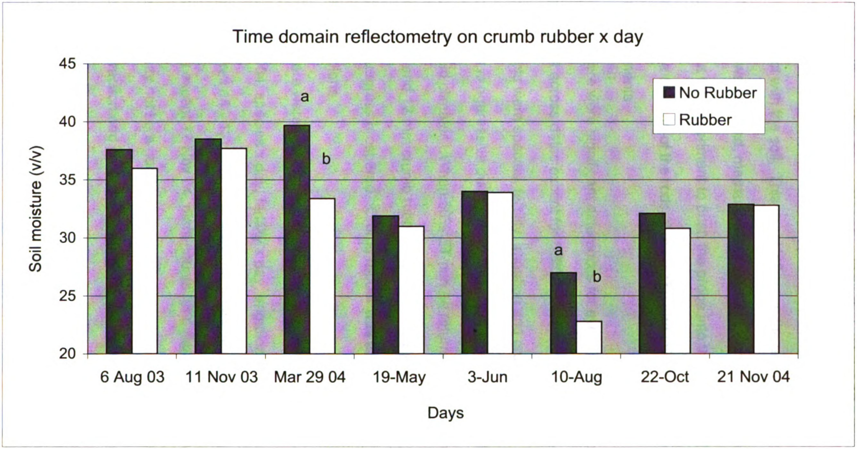


Figure 13. Effects of time domain reflectometry on crumb rubber x day interaction in 2003 and 2004. Letters above bars indicate significance between treatments on a particular date at $p < 0.05$.

values with crumb rubber values would be that at least 12 mm occupied space in the crumb rubber topdressing along the 76 mm probe, and the probe was not in full contact with the soil. This could influence the accuracy of the measurements. As traffic was applied, measurements were not significant. It was difficult throughout the experiment to push the probe into the ground; efforts to do so altered the spacing of the rods of the probe and influenced the accuracy of the measurements

There were significant differences for every date, and every system was significant across dates except for SB/CB 3 for plant counts. Factors affecting plant counts were species, fertility, irrigation and crumb rubber. Supina bluegrass is aggressive due to its stoloniferous growth habit and adaptation to cool, humid climates. When 50% ET can be returned, fertilization applied at 196 kg N ha^{-1} and 12 mm crumb rubber depth was applied to a sandy clay loam soil, supina bluegrass prospered. Crumb rubber was able to protect the crown tissue and/or stolons.

There were four significant two-way interactions for plant counts all across time in 2004; species x day, fertility x day, irrigation x day, and crumb rubber x day (Figures 14 - 17). For species x day interaction, although all dates were significant except 12 Nov 04, plant counts for different grasses were measured, yet this may not be a good indication of surface performance. Turfgrass cover percent, traction and peak deceleration must be considered along with the type of species in order to ascertain the best playing surface. If the experimental plot was consistently the same turfgrass mixture then this could be a good indicator

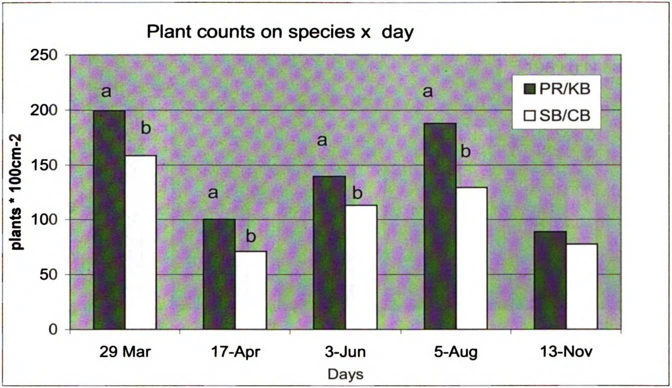


Figure 14. Effects of plant counts on species x day interaction on a trafficked management system study during the 2004 spring and fall playing seasons. Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

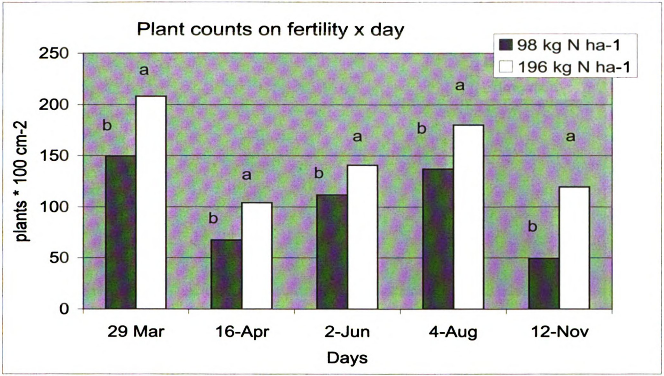


Figure 15. Effects of plant counts on fertility x day interaction on a trafficked management system study during the 2004 spring and fall playing seasons. Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

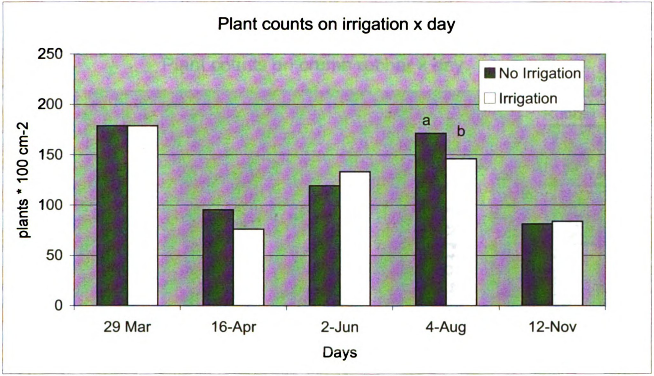


Figure 16. Effects of plant counts on irrigation x day interaction on a trafficked management system study during the 2004 spring and fall playing seasons. Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

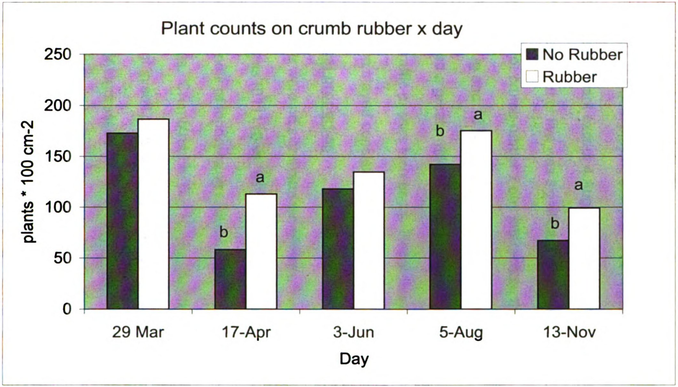


Figure 17. Effects of plant counts on crumb rubber x day interaction on a trafficked management system study during the 2004 spring and fall playing seasons. Letters above bars indicate significance between treatments on that date at $p < 0.05$ level.

of performance of the playing surface. As mentioned, PR/KB treatments did not have to transition from one grass to the other as did SB/CB through the first half of the experiment. On the last testing date, there was no significant difference. For fertility x day interaction, all dates were significant. Regardless of time of year, a higher fertility rate can produce more plants regardless of turfgrass species however, other playing surface characteristics must be considered when ascertaining the best playing surface. For irrigation x day interaction, all dates were not significant except 4 Aug 04. Although the interaction was significant, only one date out of five was significant, and the result appears to be an anomaly. For crumb rubber x day interaction, three of five dates were significant, 16 Apr, 4 Aug and 12 Nov 04. As the experiment extended into 2004, crumb rubber played a greater role in maintaining more plants at the surface as the number of traffic passes increased. Regardless of turfgrass mixture, this phenomenon stayed consistent

Soil physical properties

There were no significant differences in soil physical properties comparing two treatments (011110 vs. 011111) and (100100 and 100101) in Table 27. One possible benefit of topdressing crumb rubber would be maintaining the integrity of the soil pores. Crumb rubber is a soil amendment that has demonstrated improvement in soil physical properties and turfgrass cover when tilled into the soil profile or topdressed (Vanini, 1995, Rogers et al, 1998, Baker et al., 2001, Boniak et al., 2001 and Chong et al., 2001). Baker et al. (2001) researched soil physical properties of crumb rubber mixed with sand and then topdressed onto

Table 27. Crumb rubber treatment effects on two treatments on 23 November, 2004 at the Hancock Turfgrass Research Center, East Lansing, MI.

Treatment Code	011110	011111	100100	100101	p - value
Parameters					
Calculated Porosity	32.7	35.7	33.8	31.1	0.900
Bulk Density	1.78	1.7	1.75	1.82	0.895
Total Porosity	42.1	44.3	41.3	36.4	0.373
-2 kPa	34.0	36.3	35.4	31.0	0.422
- 4 kPa	34.2	36.5	34.8	30.6	0.449
- 7 kPa	33.3	35.6	33.9	29.4	0.424
-10 kPa	32.2	34.6	32.8	28.2	0.409
- 33 kPa	28.5	31.0	29.7	25.0	0.461
- 100 kPa	27.9	30.5	29.1	24.4	0.509
Saturated Hydraulic Cond.	4.22	2.03	1.82	15.77	0.345

011110 - Perennial ryegrass/Kentucky bluegrass, high fertility, irrigation at 50% ET returned, oversedding, core cultivation and no crumb rubber

011111 - Perennial ryegrass/Kentucky bluegrass, high fertility, irrigation at 50% ET returned, oversedding, core cultivation and crumb rubber

100100 - Supina bluegrass/common bermudagrass, low fertility, no supplemental irrigation, overseeding, no core cultivation, and no crumb rubber.

100101 - Supina bluegrass/common bermudagrass, low fertility, no supplemental irrigation, overseeding, no core cultivation, and crumb rubber.

sand in the laboratory. They observed a decrease in bulk density, capillary porosity (micropores), and peak deceleration and an increase in total porosity and air-filled porosity (macropores) as crumb rubber levels increased for topdressing. In recreational turf, the top 2-3 cm was considered the most compacted area (O'Neil and Carrow, 1982). However, for this experiment, in sampling the cores, the top 2-3 cm were removed thereby the data did not produce results similar to previous research, and therefore, it was not significant. Perhaps better sampling methods in the field could be implemented to ascertain any possible differences.

Ranking system

Rank of playing surface characteristics, based on F-values, is listed in Table 28. Based on a 4-point system (1 = lowest, 4 = highest) from Tables 21 and 22, each playing surface characteristic had four factors that contributed to the statistical analysis. Each factor was ranked based on F value order, regardless of significance. The higher the F value (the lower the P value), the less variability there is in the analysis. The ranking from highest to lowest consisted of crumb rubber, fertility, turfgrass species mixtures, irrigation, core cultivation and overseeding.

Larsen et al., (2004) made conclusions from F values, and found the highest F values were associated with ground cover before the start of a playing season and the zone on the field. For this experiment, although time of the year (day) had the highest F value for all playing surface parameters except for turfgrass cover percent, the focus of the results is on which factors were

Table 28. Rank of F values for playing surface characteristics based on a 4-point scheme.

Playing surface parameter	Species	Fertility	Irrigation	Overseeding	Core Cultivation	Crumb Rubber
Turfgrass cover percent	2	3	1	NF	NF	4
Peak deceleration	1	NF	2	NF	3	4
Shear resistance	1	4	2	NF	NF	3
Volumetric soil water content	3	1	2	NF	NF	4
Plant counts	3	4	1	NF	NF	2
	10	12	8	0	3	17

4 point system (4 = highest, 1 = lowest), NF - Non Factor

important or which factor dominated. Crumb rubber amassed the most points based on this arbitrary system. From the interactions, crumb rubber played a role in turfgrass cover percent, peak deceleration, and traction for the conditions of this experiment.

This ranking provided a guide based on the conditions of the experiment, and it suggested subsequent research to be initiated in the future. The FFD was not designed to make recommendations; it was designed to identify (the) factor(s) driving a system (Kuehl, 2000).

CONCLUSIONS

In terms of playing surface parameters, SB/CB 3 management system, with one of the highest inputs for this experiment, performed the best over time. It had the highest turfgrass cover percent at the end of the experiment, and it had the least amount of fluctuations in peak deceleration, shear resistance and plant count values across time. By combining different factors/cultural practices, and by taking best management practices from different research, supina bluegrass (Berner, 1980; Leinhauer et al 1997; Sorochan et al., 2001), fertility (Sorochan et al., 2005), and topdressing crumb rubber (Rogers et al., 1998; Baker et al., 2001), the best playing surface, for the conditions of this experiment, were produced. Even though all the systems had the same amount of time and inputs to establish, lack of cultural practices (only 98 kg N ha-1, no irrigation, core cultivation and crumb rubber) altered the playing surface, such as PR/KB 1 and SB/CB 1 management systems. This should also be noted by budget administrators.

Due to the experimental design, management systems were explored to define the most relevant cultural practices for each playing surface characteristic for sports fields. The highest F values for each playing surface characteristic were ranked arbitrarily to ascertain differences. When adding all the playing surface characteristics F-values together crumb rubber, fertility, species, irrigation, core cultivation and overseeding had the following order from highest to lowest. Crumb rubber provided a protective layer that stabilized surface hardness values and promoted turfgrass vigor via traction and plant counts.

Interactions were primarily focused around surface hardness, traction, and turfgrass cover percent with crumb rubber playing a role most of the time. For the conditions of this experiment, crumb rubber demonstrated the ability to override or enhance other factors/cultural practices, regardless of maintenance level.

Having the management schemes within the experiment of the FFD, the data suggests the importance of a sports field manager having a year-round management philosophy as opposed to re-establishing a sports field in between playing seasons. This data will hopefully prompt administrators to consider the importance of budgeting for year-round cultural practices.

Future research possibilities with crumb rubber include investigating soil physical properties of the top 5 cm of a native soil site, balancing crumb rubber and irrigation relationships in regards to playing surface characteristics and water conservation, evaluating organic matter accumulation at the surface, and bridging the gap between biomechanical (athlete) and agronomic relationships. In essence, what is the relationship between playing surface data, the athlete, and the role crumb rubber plays?

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APPENDICES

Appendix A – Weather data for the system study

Days of Exp.	Date	Min Temp (°C)	Max Temp (°C)	Relative Humid. (%)	Rainfall (cm)	ET (cm)
	5/1/03	11.3	17.0	107.8	2.8	0.2
	5/2/03	7.2	14.0	98.2	1.1	0.3
	5/3/03	2.0	16.5	75.5	0.0	0.4
	5/4/03	2.7	18.1	99.9	0.0	0.4
	5/5/03	10.6	21.2	99.4	0.8	0.3
	5/6/03	11.2	23.5	100.0	0.1	0.4
	5/7/03	7.8	18.7	100.0	0.1	0.2
	5/8/03	9.4	16.0	100.0	0.0	0.2
	5/9/03	7.8	22.1	87.8	0.9	0.4
	5/10/03	14.0	24.1	100.0	0.0	0.3
	5/11/03	9.6	23.2	99.9	0.2	0.2
	5/12/03	6.4	9.9	95.6	0.8	0.1
	5/13/03	5.4	19.2	82.4	0.1	0.5
	5/14/03	3.6	21.8	92.0	0.0	0.4
	5/15/03	9.6	20.3	85.9	0.6	0.2
	5/16/03	10.8	19.0	100.0	0.0	0.2
	5/17/03	10.4	21.2	107.0	0.0	0.3
	5/18/03	9.6	21.5	100.0	0.0	0.4
	5/19/03	13.5	22.5	98.6	0.0	0.4
	5/20/03	13.2	22.4	97.1	0.2	0.2
	5/21/03	4.7	14.9	86.3	0.0	0.4
	5/22/03	2.7	18.3	89.9	0.0	0.5
	5/23/03	5.9	18.6	77.9	0.0	0.3
	5/24/03	8.3	14.7	100.0	0.1	0.1
	5/25/03	7.2	18.5	108.0	0.0	0.3
	5/26/03	8.7	18.9	106.9	0.0	0.3
	5/27/03	6.5	20.5	100.0	0.0	0.3
	5/28/03	7.5	24.8	104.1	0.1	0.4
	5/29/03	12.1	24.5	97.0	0.2	0.4
	5/30/03	8.1	20.3	100.0	0.1	0.2
	5/31/03	9.4	18.5	107.5	1.8	0.1
	Average	8.3	19.5	96.9	0.3	0.3
	Total				10.0	9.2
	6/1/03	4.2	18.0	96.8	0.0	0.4
	6/2/03	5.2	21.9	96.9	0.0	0.4
	6/3/03	12.7	21.9	88.8	0.0	0.3

6/4/03	10.2	18.5	77.8	0.3	0.2
6/5/03	10.3	20.0	108.0	0.2	0.3
6/6/03	7.9	23.7	97.8	0.0	0.4
6/7/03	14.5	24.3	86.9	0.0	0.4
6/8/03	12.0	24.8	100.0	0.4	0.3
6/9/03	12.5	21.5	100.0	0.2	0.3
6/10/03	10.7	22.4	100.0	0.0	0.3
6/11/03	18.6	21.6	100.0	0.0	0.3
6/12/03	13.7	21.9	100.0	0.3	0.2
6/13/03	13.3	22.6	109.1	0.0	0.2
6/14/03	12.3	26.2	108.5	0.0	0.4
6/15/03	14.6	26.4	99.5	0.0	0.5
6/16/03	10.4	26.1	77.6	0.0	0.6
6/17/03	15.9	26.1	75.9	0.0	0.4
6/18/03	15.9	28.9	106.9	0.0	0.5
6/19/03	14.5	29.2	93.2	0.4	0.6
6/20/03	7.4	23.7	96.1	0.0	0.5
6/21/03	9.0	26.8	99.7	0.0	0.5
6/22/03	11.3	28.0	97.1	0.0	0.5
6/23/03	12.1	30.4	95.4	0.0	0.6
6/24/03	15.3	30.8	94.1	0.0	0.5
6/25/03	19.8	32.4	81.8	0.0	0.6
6/26/03	17.7	32.5	79.7	2.2	0.4
6/27/03	12.9	25.2	93.6	0.0	0.5
6/28/03	16.5	25.7	86.3	0.3	0.4
6/29/03	16.2	26.5	100.0	0.1	0.4
6/30/03	13.4	27.8	100.0	0.0	0.5
Average	12.7	25.2	94.9	0.1	0.4
Total				4.2	12.3
7/1/03	13.8	28.3	100.0	0.0	0.5
7/2/03	13.9	29.2	100.0	0.0	0.4
7/3/03	15.3	31.4	100.0	0.0	0.5
7/4/03	21.2	31.5	90.9	0.3	0.5
7/5/03	20.2	30.8	100.0	1.3	0.4
7/6/03	16.3	29.5	107.8	0.0	0.4
7/7/03	19.7	29.7	100.0	1.5	0.4
7/8/03	20.9	29.8	98.0	0.2	0.4
7/9/03	16.9	25.1	100.0	0.5	0.4
7/10/03	19.2	26.1	98.1	0.0	0.3
7/11/03	15.1	25.9	100.0	0.3	0.2
7/12/03	14.0	24.5	100.0	0.0	0.4
7/13/03	12.4	27.2	100.4	0.0	0.5

	7/14/03	14.0	28.2	100.0	0.0	0.5
	7/15/03	18.0	28.2	86.8	0.0	0.3
	7/16/03	14.5	26.7	84.3	0.0	0.6
	7/17/03	15.0	28.1	96.8	0.1	0.4
	7/18/03	16.5	27.3	69.1	0.0	0.6
	7/19/03	12.3	26.1	85.7	0.0	0.5
	7/20/03	15.4	26.7	81.8	0.2	0.4
	7/21/03	17.8	25.2	106.5	0.3	0.2
	7/22/03	15.4	24.2	100.0	0.0	0.4
	7/23/03	14.6	24.4	100.0	0.0	0.4
	7/24/03	12.2	26.1	101.3	0.0	0.4
	7/25/03	12.1	27.7	100.0	0.0	0.5
	7/26/03	18.7	27.8	88.6	0.0	0.3
	7/27/03	23.0	29.7	82.3	0.0	0.4
	7/28/03	16.1	28.9	100.0	0.0	0.4
	7/29/03	10.8	27.2	100.0	0.0	0.5
	7/30/03	13.6	28.2	100.0	0.0	0.5
	7/31/03	14.0	28.6	100.0	0.0	0.4
	Average	15.9	27.7	96.1	0.1	0.4
	Total				4.6	13.0
	8/1/03	16.2	29.2	99.6	0.2	0.3
	8/2/03	13.7	26.5	103.7	0.1	0.4
	8/3/03	18.6	26.5	100.0	0.0	0.2
	8/4/03	14.1	27.0	108.7	0.3	0.4
	8/5/03	15.5	26.6	107.5	0.1	0.4
	8/6/03	17.4	27.3	100.0	0.0	0.4
	8/7/03	17.0	27.6	102.4	0.4	0.4
	8/8/03	18.2	26.8	108.3	0.0	0.3
	8/9/03	15.6	23.9	99.4	0.0	0.3
	8/10/03	16.7	26.3	100.0	0.0	0.3
1	8/11/03	15.9	26.4	100.0	0.0	0.3
2	8/12/03	18.8	25.0	100.0	0.0	0.3
3	8/13/03	16.3	28.8	106.8	0.0	0.4
4	8/14/03	17.8	31.1	107.5	0.0	0.4
5	8/15/03	22.0	31.0	100.0	0.0	0.4
6	8/16/03	21.2	29.8	100.0	1.2	0.3
7	8/17/03	14.4	25.8	100.0	0.0	0.4
8	8/18/03	10.2	27.6	103.1	0.0	0.4
9	8/19/03	12.7	28.0	100.8	0.0	0.5
10	8/20/03	14.7	29.8	100.0	0.0	0.5
11	8/21/03	18.4	34.0	97.9	0.0	0.5
12	8/22/03	19.0	33.8	93.7	0.3	0.6

13	8/23/03	15.6	27.3	81.1	0.0	0.5
14	8/24/03	13.3	26.5	90.1	0.0	0.3
15	8/25/03	20.2	29.3	91.6	0.0	0.4
16	8/26/03	19.0	30.8	100.0	0.9	0.4
17	8/27/03	18.0	30.2	103.6	0.0	0.4
18	8/28/03	11.9	28.4	100.0	0.0	0.5
19	8/29/03	20.7	28.7	96.1	0.6	0.3
20	8/30/03	11.4	26.5	91.9	0.0	0.4
21	8/31/03	11.7	22.4	99.5	0.0	0.3
	Average	16.3	28.0	99.8	0.1	0.4
	Total				3.9	12.0
22	9/1/03	13.9	22.0	100.0	0.2	0.1
23	9/2/03	15.1	24.7	100.0	0.4	0.4
24	9/3/03	11.2	25.0	107.0	0.0	0.3
25	9/4/03	13.5	24.8	89.2	0.0	0.3
26	9/5/03	8.6	22.1	100.0	0.0	0.3
27	9/6/03	7.3	25.6	100.0	0.0	0.4
28	9/7/03	14.8	28.6	98.0	0.0	0.4
29	9/8/03	14.8	28.5	107.2	0.0	0.3
30	9/9/03	14.0	27.0	108.1	0.0	0.3
31	9/10/03	10.6	27.1	100.0	0.0	0.4
32	9/11/03	15.5	27.1	108.0	0.0	0.4
33	9/12/03	14.4	27.0	100.0	0.0	0.4
34	9/13/03	16.3	27.8	85.5	0.0	0.4
35	9/14/03	16.3	27.4	105.0	0.0	0.2
36	9/15/03	14.9	23.9	100.0	0.6	0.3
37	9/16/03	9.7	25.2	95.4	0.0	0.3
38	9/17/03	12.2	27.9	99.2	0.0	0.4
39	9/18/03	11.5	27.4	100.0	0.0	0.4
40	9/19/03	13.7	23.5	100.0	0.0	0.2
41	9/20/03	8.0	20.9	96.0	0.0	0.3
42	9/21/03	5.0	22.2	100.0	0.0	0.3
43	9/22/03	14.3	22.0	100.0	3.5	0.1
44	9/23/03	10.6	19.3	100.0	0.1	0.2
45	9/24/03	9.3	19.0	85.0	0.0	0.2
46	9/25/03	7.5	18.6	95.3	1.3	0.2
47	9/26/03	3.4	18.6	106.5	0.0	0.2
48	9/27/03	11.9	18.0	100.0	0.4	0.2
49	9/28/03	8.1	16.5	100.0	0.3	0.2
50	9/29/03	5.3	12.9	99.7	0.0	0.2
51	9/30/03	5.1	11.7	89.6	0.0	0.2
	Average	11.2	23.1	99.2	0.2	0.3

	Total				6.6	8.3
52	10/1/03	5.1	10.1	86.6	0.0	0.1
53	10/2/03	0.2	11.2	100.0	0.0	0.2
54	10/3/03	2.4	11.0	82.2	0.3	0.1
55	10/4/03	3.5	10.7	100.0	0.3	0.1
56	10/5/03	-1.2	12.3	100.0	0.0	0.2
57	10/6/03	-1.3	14.9	100.0	0.0	0.2
58	10/7/03	1.7	22.6	100.0	0.0	0.3
59	10/8/03	11.5	26.0	97.1	0.0	0.3
60	10/9/03	8.7	25.9	104.9	0.0	0.2
61	10/10/03	8.1	24.2	106.3	0.0	0.2
62	10/11/03	11.6	25.0	107.4	0.0	0.2
63	10/12/03	10.9	24.1	91.8	0.1	0.3
64	10/13/03	4.7	21.3	100.0	0.0	0.2
65	10/14/03	8.8	21.2	78.3	1.5	0.2
66	10/15/03	5.9	14.4	88.9	0.8	0.2
67	10/16/03	2.3	13.8	90.3	0.0	0.2
68	10/17/03	-1.0	12.2	96.6	0.0	0.1
69	10/18/03	5.8	17.1	73.1	0.0	0.2
70	10/19/03	4.3	17.4	95.4	0.0	0.2
71	10/20/03	5.7	26.0	98.4	0.0	0.3
72	10/21/03	10.4	25.6	71.3	0.0	0.3
73	10/22/03	4.9	10.9	93.4	0.0	0.1
74	10/23/03	-1.9	8.5	98.1	0.0	0.1
75	10/24/03	0.4	13.9	91.1	0.0	0.1
76	10/25/03	6.3	13.0	100.0	1.1	0.1
77	10/26/03	7.2	11.0	90.2	0.1	0.1
78	10/27/03	3.8	8.3	100.0	0.0	0.1
79	10/28/03	3.4	8.5	86.7	0.3	0.1
80	10/29/03	4.3	8.6	95.1	0.3	0.1
81	10/30/03	5.1	18.1	99.2	0.0	0.2
82	10/31/03	13.9	22.0	84.9	0.1	0.2
	Average	5.0	16.4	93.8	0.2	0.2
	Total				4.9	5.4
83	11/1/03	9.4	20.1	97.8	0.0	0.1
84	11/2/03	8.6	12.3	108.9	2.6	0.0
85	11/3/03	6.6	11.8	109.7	2.1	0.0
86	11/4/03	5.8	21.5	110.0	0.3	0.2
87	11/5/03	5.6	21.4	100.0	1.5	0.1
88	11/6/03	3.1	8.0	90.3	0.0	0.1
89	11/7/03	-1.4	7.0	86.1	0.0	0.1

90	11/8/03	-5.6	2.9	81.7	0.0	0.1
91	11/9/03	-9.1	4.5	100.0	0.0	0.1
92	11/10/03	-4.2	8.7	99.0	0.0	0.1
93	11/11/03	4.6	12.7	108.0	0.5	0.0
94	11/12/03	2.6	15.7	100.0	0.0	0.1
95	11/13/03	-0.1	14.8	69.3	0.1	0.5
96	11/14/03	-1.9	7.3	85.9	0.0	0.1
97	11/15/03	3.8	7.4	68.7	0.1	0.1
98	11/16/03	3.7	6.7	107.9	0.1	0.0
99	11/17/03	6.1	10.7	109.1	0.0	0.0
100	11/18/03	7.6	15.4	101.9	1.9	0.1
101	11/19/03	6.6	15.8	100.0	1.5	0.1
102	11/20/03	0.1	15.4	100.0	0.0	0.1
103	11/21/03	6.1	14.2	94.0	0.0	0.1
104	11/22/03	3.1	9.8	92.8	0.0	0.1
105	11/23/03	9.7	17.8	92.5	0.0	0.1
106	11/24/03	-4.1	17.3	100.0	1.8	0.2
107	11/25/03	-4.1	2.2	88.0	0.0	0.1
108	11/26/03	1.2	8.2	80.6	0.0	0.1
109	11/27/03	-0.9	6.9	91.4	0.0	0.0
110	11/28/03	1.4	6.4	100.0	0.0	0.0
111	11/29/03	-0.7	2.2	92.9	0.2	0.1
112	11/30/03	-1.1	9.2	82.8	0.0	0.1
	Average	2.1	11.1	95.0	0.4	0.1
	Total				12.6	2.8
113	12/1/03	0.3	9.3	70.0	0.0	0.2
114	12/2/03	-3.3	2.4	65.9	0.0	0.1
115	12/3/03	-7.5	3.5	88.3	0.0	0.1
116	12/4/03	-3.4	6.2	86.5	0.0	0.1
117	12/5/03	0.0	4.4	66.2	0.0	0.1
118	12/6/03	-3.3	2.6	100.0	0.0	0.0
119	12/7/03	-8.9	0.7	90.7	0.0	0.0
120	12/8/03	-3.1	3.3	92.7	0.0	0.1
121	12/9/03	1.1	3.7	101.6	0.0	0.0
122	12/10/03	3.4	8.2	105.8	0.7	0.0
123	12/11/03	-2.6	7.9	94.7	0.4	0.1
124	12/12/03	-6.4	-2.3	95.6	0.0	0.0
125	12/13/03	-12.0	-1.5	100.0	0.0	0.0
126	12/14/03	-3.8	-0.9	92.9	0.0	0.0
127	12/15/03	-4.1	-0.1	100.0	0.0	0.0
128	12/16/03	-1.9	5.7	91.3	0.2	0.1
129	12/17/03	-3.5	2.2	100.0	0.0	0.0

130	12/18/03	-2.8	-0.6	95.9	0.0	0.0
131	12/19/03	-2.9	-0.8	98.4	0.0	0.0
132	12/20/03	-7.8	-1.2	91.7	0.0	0.0
133	12/21/03	-3.4	6.1	70.4	0.0	0.2
134	12/22/03	4.1	6.6	86.3	0.0	0.1
135	12/23/03	1.5	6.2	100.0	0.8	0.0
136	12/24/03	-1.4	2.3	97.7	0.1	0.0
137	12/25/03	-2.7	-0.3	109.6	0.0	0.0
138	12/26/03	-8.6	4.3	107.5	0.1	0.0
139	12/27/03	-7.5	7.4	103.2	0.0	0.1
140	12/28/03	1.6	8.3	74.3	0.1	0.1
141	12/29/03	4.8	8.7	100.2	1.1	0.0
142	12/30/03	-0.8	4.9	95.6	0.1	0.1
143	12/31/03	-1.9	6.8	70.6	0.0	0.2
	Average	-2.8	3.7	91.7	0.1	0.1
	Total				3.6	1.8
144	1/1/04	-6.0	2.3	100.0	0.0	0.0
145	1/2/04	1.3	11.2	100.0	0.6	0.1
146	1/3/04	5.6	14.8	94.2	0.0	0.1
147	1/4/04	-3.4	5.7	80.2	0.0	0.1
148	1/5/04	-5.4	-2.7	100.0	0.0	0.0
149	1/6/04	-13.0	-3.6	95.9	0.0	0.1
150	1/7/04	-13.3	-6.8	94.4	0.0	0.0
151	1/8/04	-16.1	-3.9	97.5	0.0	0.0
152	1/9/04	-14.1	-5.2	88.5	0.0	0.0
153	1/10/04	-17.0	-7.9	93.9	0.0	0.0
154	1/11/04	-8.4	1.8	80.6	0.0	0.1
155	1/12/04	-0.2	2.9	93.1	0.0	0.1
156	1/13/04	-4.5	1.8	84.6	0.0	0.1
157	1/14/04	-11.1	-4.0	84.8	0.0	0.0
158	1/15/04	-14.5	-4.0	87.8	0.0	0.1
159	1/16/04	-16.1	-9.2	76.6	0.0	0.1
160	1/17/04	-10.1	-3.4	84.6	0.0	0.1
161	1/18/04	-9.8	-0.5	89.2	0.0	0.1
162	1/19/04	-10.4	-6.5	86.3	0.0	0.1
163	1/20/04	-14.2	-6.6	98.6	0.0	0.0
164	1/21/04	-16.1	-3.6	95.3	0.0	0.0
165	1/22/04	-14.5	0.5	86.6	0.0	0.1
166	1/23/04	-17.6	-10.5	89.0	0.0	0.0
167	1/24/04	-15.1	-9.9	100.0	0.0	0.0
168	1/25/04	-23.6	-8.8	91.4	0.0	0.0
169	1/26/04	-10.7	-7.9	73.9	0.0	0.1

170	1/27/04	-9.2	-6.0	106.5	0.0	0.0
171	1/28/04	-8.4	-3.9	96.4	0.0	0.1
172	1/29/04	-16.7	-6.6	82.6	0.0	0.1
173	1/30/04	-16.6	-9.8	90.3	0.0	0.0
174	1/31/04	-12.8	-5.5	95.0	0.0	0.1
	Average	-11.0	-3.1	90.9	0.0	0.0
	Total				0.7	1.4
175	2/1/04	-10.7	-3.3	100.0	0.0	0.1
176	2/2/04	-9.1	0.0	100.0	0.0	0.1
177	2/3/04	-0.7	2.0	108.4	0.3	0.0
178	2/4/04	-10.3	0.3	91.0	0.0	0.1
179	2/5/04	-15.4	-2.8	96.2	0.0	0.0
180	2/6/04	-3.7	-0.1	107.6	0.0	0.0
181	2/7/04	-6.6	-0.6	97.8	0.0	0.1
182	2/8/04	-17.1	-2.3	95.4	0.0	0.1
183	2/9/04	-6.5	1.7	90.4	0.1	0.1
184	2/10/04	-4.4	-1.1	93.6	0.0	0.1
185	2/11/04	-11.4	-1.2	100.0	0.0	0.1
186	2/12/04	-6.8	-0.7	100.0	0.0	0.0
187	2/13/04	-4.7	-1.2	87.9	0.0	0.1
188	2/14/04	-5.2	0.3	89.0	0.0	0.1
189	2/15/04	-16.6	-2.2	81.8	0.0	0.1
190	2/16/04	-21.9	-4.6	91.6	0.0	0.1
191	2/17/04	-10.3	1.1	94.8	0.0	0.1
192	2/18/04	-10.6	1.8	100.0	0.0	0.1
193	2/19/04	-4.5	6.4	100.0	0.0	0.1
194	2/20/04	1.9	6.2	96.3	0.4	0.1
195	2/21/04	-1.4	5.8	100.0	0.1	0.1
196	2/22/04	-1.0	4.7	90.8	0.0	0.1
197	2/23/04	-0.4	3.7	89.5	0.0	0.1
198	2/24/04	-2.9	0.9	107.7	0.0	0.0
199	2/25/04	-9.4	3.0	100.0	0.1	0.1
200	2/26/04	-8.1	3.7	101.3	0.0	0.1
201	2/27/04	-5.9	7.9	100.0	0.0	0.1
202	2/28/04	-6.1	9.8	74.3	0.0	0.2
203	2/29/04	1.1	13.2	81.4	0.0	0.2
	Average	-7.2	1.8	95.4	0.0	0.1
	Total				1.2	2.1
204	3/1/04	2.4	13.1	82.6	0.5	0.1
205	3/2/04	5.5	11.5	91.0	0.7	0.1
206	3/3/04	3.4	6.6	98.8	0.0	0.1

207	3/4/04	3.9	9.1	100.0	0.1	0.1
208	3/5/04	4.9	18.4	108.5	2.4	0.2
209	3/6/04	0.5	12.4	91.7	0.0	0.2
210	3/7/04	0.4	5.6	97.4	0.3	0.1
211	3/8/04	-1.4	2.2	93.6	0.0	0.1
212	3/9/04	-1.9	4.9	100.0	0.0	0.2
213	3/10/04	-5.1	8.4	100.0	0.0	0.2
214	3/11/04	-1.6	7.9	100.0	0.1	0.1
215	3/12/04	-7.1	-1.5	83.2	0.0	0.1
216	3/13/04	-10.2	4.4	95.4	0.0	0.2
217	3/14/04	-1.1	5.6	76.4	0.1	0.2
218	3/15/04	-1.4	3.9	78.3	0.0	0.2
219	3/16/04	-3.3	2.7	83.1	0.0	0.1
220	3/17/04	-4.9	-0.1	98.1	0.0	0.1
221	3/18/04	-1.9	3.8	100.0	0.1	0.1
222	3/19/04	-1.3	7.6	109.1	0.1	0.1
223	3/20/04	3.3	14.0	100.0	0.9	0.2
224	3/21/04	-3.2	12.8	78.6	0.0	0.4
225	3/22/04	-8.8	0.8	80.6	0.0	0.2
226	3/23/04	-2.5	11.7	60.2	0.0	0.4
227	3/24/04	3.7	11.4	75.4	0.4	0.1
228	3/25/04	8.8	18.4	84.7	0.8	0.2
229	3/26/04	13.1	17.0	96.3	0.8	0.1
230	3/27/04	10.9	16.6	106.6	0.0	0.1
231	3/28/04	6.8	17.0	100.0	0.0	0.2
232	3/29/04	8.5	17.2	100.0	0.1	0.2
233	3/30/04	6.1	14.6	104.9	0.0	0.2
234	3/31/04	2.5	10.4	100.0	0.0	0.2
	Average	0.9	9.3	92.7	0.2	0.2
	Total				7.2	5.0
235	4/1/04	1.5	10.1	84.7	0.0	0.3
236	4/2/04	3.7	14.9	63.5	0.0	0.4
237	4/3/04	2.2	14.8	78.8	0.0	0.3
238	4/4/04	-0.9	8.4	78.0	0.1	0.4
239	4/5/04	-4.9	7.5	79.5	0.0	0.3
240	4/6/04	-1.3	15.0	66.8	0.0	0.2
241	4/7/04	2.6	16.2	93.0	0.0	0.3
242	4/8/04	5.8	15.9	73.8	0.1	0.2
243	4/9/04	0.9	11.3	88.2	0.0	0.2
244	4/10/04	0.1	10.9	89.1	0.0	0.2
245	4/11/04	0.5	9.3	90.5	0.0	0.2
246	4/12/04	-0.5	9.0	99.0	0.0	0.2

247	4/13/04	1.4	10.6	82.6	0.0	0.3
248	4/14/04	0.4	15.9	71.0	0.0	0.4
249	4/15/04	3.6	20.3	77.6	0.0	0.4
250	4/16/04	7.7	24.9	72.4	0.0	0.5
251	4/17/04	15.2	25.1	73.2	0.2	0.4
252	4/18/04	13.8	29.5	92.3	0.0	0.6
253	4/19/04	14.8	28.8	52.6	0.0	0.8
254	4/20/04	2.3	16.3	95.2	0.0	0.3
255	4/21/04	8.1	22.4	98.1	0.1	0.4
256	4/22/04	5.0	20.7	96.8	0.0	0.4
257	4/23/04	3.0	17.5	95.5	0.0	0.4
258	4/24/04	3.6	17.4	71.7	0.0	0.4
259	4/25/04	7.4	22.1	88.8	0.5	0.4
260	4/26/04	6.5	20.5	96.1	0.0	0.5
261	4/27/04	0.4	15.3	98.7	0.0	0.3
262	4/28/04	-0.9	23.3	62.9	0.0	0.6
263	4/29/04	16.7	25.7	60.9	0.0	0.7
264	4/30/04	14.3	25.8	95.8	0.0	0.3
	Average	4.4	17.5	82.2	0.0	0.4
	Total				0.9	11.0
265	5/1/04	7.1	20.0	107.6	1.5	0.1
266	5/2/04	3.2	9.9	100.0	1.3	0.2
267	5/3/04	-0.3	10.0	81.0	0.0	0.3
268	5/4/04	-0.7	17.1	94.5	0.0	0.3
269	5/5/04	5.3	16.9	89.1	0.1	0.4
270	5/6/04	7.1	27.0	70.1	0.0	0.5
271	5/7/04	9.3	26.0	64.1	0.0	0.6
272	5/8/04	5.9	19.9	93.3	0.4	0.3
273	5/9/04	12.4	26.8	108.0	1.3	0.4
274	5/10/04	16.7	28.1	99.9	1.6	0.5
275	5/11/04	13.4	26.9	108.4	1.3	0.3
276	5/12/04	16.8	28.2	100.0	0.0	0.5
277	5/13/04	18.3	28.6	92.7	0.2	0.4
278	5/14/04	18.6	25.6	105.3	1.0	0.2
279	5/15/04	7.3	19.0	97.8	0.3	0.2
280	5/16/04	2.7	19.7	104.8	0.0	0.4
281	5/17/04	10.7	25.2	100.0	0.5	0.4
282	5/18/04	16.7	25.0	107.0	1.3	0.3
283	5/19/04	9.8	22.1	100.0	0.0	0.4
284	5/20/04	12.9	25.3	92.0	0.1	0.3
285	5/21/04	12.4	25.1	93.4	3.1	0.2
286	5/22/04	13.3	27.2	109.6	2.1	0.3

287	5/23/04	14.6	27.4	109.4	4.2	0.3
288	5/24/04	11.8	26.1	90.8	2.1	0.3
289	5/25/04	10.1	16.3	100.0	0.7	0.1
290	5/26/04	11.3	17.3	108.0	0.0	0.2
291	5/27/04	5.6	21.1	107.0	0.0	0.3
292	5/28/04	8.7	21.6	98.9	0.0	0.4
293	5/29/04	6.7	17.0	100.5	0.0	0.3
294	5/30/04	11.4	21.7	87.8	0.0	0.4
295	5/31/04	14.0	23.7	109.5	1.3	0.3
	Average	10.1	22.3	97.8	0.8	0.3
	Total				24.2	9.9
296	6/1/04	13.2	22.8	91.6	0.0	0.5
297	6/2/04	13.9	22.7	95.8	0.0	0.3
298	6/3/04	9.5	21.6	102.9	0.0	0.4
299	6/4/04	7.6	21.9	97.9	0.0	0.5
300	6/5/04	8.5	23.6	99.2	0.0	0.5
301	6/6/04	14.8	25.3	80.7	0.0	0.4
302	6/7/04	17.8	28.5	89.0	0.0	0.5
303	6/8/04	19.9	31.5	95.0	0.0	0.5
304	6/9/04	20.2	31.7	88.0	1.0	0.5
305	6/10/04	14.2	28.6	109.4	0.7	0.2
306	6/11/04	10.9	16.6	109.1	2.3	0.1
307	6/12/04	11.9	22.9	72.6	0.4	0.5
308	6/13/04	17.8	28.3	100.0	0.0	0.5
309	6/14/04	17.4	28.6	107.1	2.2	0.3
310	6/15/04	14.9	26.6	108.2	0.0	0.4
311	6/16/04	17.5	26.2	92.8	0.0	0.3
312	6/17/04	19.9	26.7	109.1	0.0	0.2
313	6/18/04	18.4	27.0	100.0	0.2	0.4
314	6/19/04	11.7	25.7	73.4	0.0	0.7
315	6/20/04	8.4	21.1	100.0	0.0	0.4
316	6/21/04	11.8	21.5	86.5	0.0	0.3
317	6/22/04	14.0	21.3	107.6	0.7	0.3
318	6/23/04	10.9	25.4	95.6	0.0	0.5
319	6/24/04	12.8	24.5	100.0	0.8	0.4
320	6/25/04	7.7	20.0	100.0	0.0	0.4
321	6/26/04	10.3	21.1	87.1	0.0	0.5
322	6/27/04	11.1	22.6	93.7	0.0	0.4
323	6/28/04	13.5	22.6	98.7	0.1	0.4
324	6/29/04	12.4	25.8	89.2	0.0	0.5
325	6/30/04	15.7	27.8	85.4	0.0	0.5
	Average	13.6	24.7	95.5	0.3	0.4

	Total				8.5	12.2
326	7/1/04	17.8	28.2	85.2	0.0	0.6
327	7/2/04	14.2	28.2	87.7	0.0	0.5
328	7/3/04	14.6	27.8	93.5	0.0	0.5
329	7/4/04	20.0	27.9	107.2	0.8	0.3
330	7/5/04	16.4	25.0	100.0	0.1	0.3
331	7/6/04	15.5	29.1	100.9	0.0	0.5
332	7/7/04	19.5	29.6	108.6	1.5	0.4
333	7/8/04	14.8	21.9	98.5	0.0	0.3
334	7/9/04	11.4	24.3	97.2	0.0	0.4
335	7/10/04	17.6	28.7	100.0	0.0	0.4
336	7/11/04	17.7	28.9	106.2	0.0	0.5
337	7/12/04	19.6	28.9	100.0	0.8	0.3
338	7/13/04	19.6	29.2	109.2	0.0	0.4
339	7/14/04	17.4	29.1	100.0	1.4	0.4
340	7/15/04	16.2	26.1	90.3	0.0	0.5
341	7/16/04	13.2	27.5	96.6	0.0	0.4
342	7/17/04	16.7	25.6	109.1	0.6	0.3
343	7/18/04	16.0	26.0	102.0	0.0	0.4
344	7/19/04	14.5	26.4	108.1	0.0	0.4
345	7/20/04	17.6	29.0	97.0	0.0	0.4
346	7/21/04	19.2	30.7	106.6	0.0	0.4
347	7/22/04	20.9	30.5	108.2	1.9	0.4
348	7/23/04	13.2	29.6	93.5	0.0	0.6
349	7/24/04	10.2	22.1	100.0	0.0	0.4
350	7/25/04	13.9	22.7	84.9	0.0	0.4
351	7/26/04	14.0	23.0	93.3	0.0	0.4
352	7/27/04	14.0	21.8	100.1	1.1	0.2
353	7/28/04	12.3	27.4	107.8	0.2	0.4
354	7/29/04	14.3	26.5	100.0	0.0	0.4
355	7/30/04	16.0	25.2	107.3	0.0	0.2
356	7/31/04	18.4	26.7	107.9	0.1	0.4
	Average	16.0	26.9	100.2	0.3	0.4
	Total				8.4	12.3
357	8/1/04	13.4	28.0	106.7	0.0	0.5
358	8/2/04	19.5	30.4	100.0	0.0	0.5
359	8/3/04	17.9	29.5	108.3	0.7	0.4
360	8/4/04	15.0	29.0	107.0	2.0	0.3
361	8/5/04	14.1	23.3	90.5	0.0	0.4
362	8/6/04	11.1	23.8	89.0	0.0	0.4
363	8/7/04	11.0	24.2	100.0	0.0	0.4

364	8/8/04	14.0	24.7	100.0	0.0	0.4
365	8/9/04	15.4	26.8	100.0	0.0	0.4
366	8/10/04	17.3	26.3	100.0	0.0	0.3
367	8/11/04	14.1	19.5	100.0	1.0	0.2
368	8/12/04	10.7	16.7	100.0	0.0	0.2
369	8/13/04	13.2	21.1	100.0	0.0	0.3
370	8/14/04	13.1	21.1	104.2	0.0	0.4
371	8/15/04	9.6	22.7	106.5	0.0	0.4
372	8/16/04	10.2	23.8	108.5	0.0	0.4
373	8/17/04	13.5	23.9	100.0	0.0	0.3
374	8/18/04	16.9	24.9	100.0	0.0	0.2
375	8/19/04	14.3	25.1	84.5	0.0	0.5
376	8/20/04	11.2	22.3	99.9	0.0	0.2
377	8/21/04	10.2	20.9	88.2	0.0	0.4
378	8/22/04	8.0	24.9	100.0	0.0	0.4
379	8/23/04	18.7	24.7	90.4	0.0	0.2
380	8/24/04	13.3	27.5	100.0	0.0	0.4
381	8/25/04	20.9	28.9	100.0	0.0	0.4
382	8/26/04	19.7	29.0	102.3	0.7	0.4
383	8/27/04	22.8	30.9	100.0	0.0	0.4
384	8/28/04	19.9	30.8	107.6	1.7	0.3
385	8/29/04	14.9	20.9	109.0	2.0	0.1
386	8/30/04	11.8	22.0	100.9	0.0	0.3
387	8/31/04	11.1	25.2	107.8	0.0	0.3
	Average	14.4	24.9	100.4	0.3	0.3
	Total				8.2	10.5
388	9/1/04	12.7	26.9	100.0	0.0	0.4
389	9/2/04	14.9	27.3	100.4	0.0	0.4
390	9/3/04	17.0	28.0	107.2	0.0	0.3
391	9/4/04	15.4	28.5	108.6	0.0	0.4
392	9/5/04	19.1	28.6	110.2	0.5	0.3
393	9/6/04	19.2	29.0	97.9	0.0	0.4
394	9/7/04	15.0	28.7	100.0	1.4	0.4
395	9/8/04	12.9	23.5	100.0	0.0	0.3
396	9/9/04	12.6	22.2	100.0	0.0	0.4
397	9/10/04	9.8	25.2	106.8	0.0	0.4
398	9/11/04	12.0	26.2	99.8	0.0	0.4
399	9/12/04	14.6	28.6	106.6	0.0	0.4
400	9/13/04	13.9	28.4	100.5	0.0	0.4
401	9/14/04	18.0	28.9	98.5	0.0	0.4
402	9/15/04	18.2	28.2	96.5	0.0	0.4
403	9/16/04	19.2	28.2	94.9	0.6	0.4

404	9/17/04	11.0	22.1	92.0	0.0	0.3
405	9/18/04	8.7	22.3	100.0	0.0	0.3
406	9/19/04	7.1	22.4	106.7	0.0	0.3
407	9/20/04	8.8	25.1	107.6	0.0	0.3
408	9/21/04	8.7	27.4	98.3	0.0	0.4
409	9/22/04	8.6	29.3	100.0	0.0	0.4
410	9/23/04	10.4	29.2	105.6	0.0	0.3
411	9/24/04	15.8	28.7	92.8	0.0	0.3
412	9/25/04	12.5	26.3	93.4	0.0	0.2
413	9/26/04	8.3	22.7	100.0	0.0	0.3
414	9/27/04	6.2	24.0	106.9	0.0	0.3
415	9/28/04	11.5	23.6	97.7	0.3	0.2
416	9/29/04	7.6	14.0	99.1	0.4	0.0
417	9/30/04	4.0	21.7	107.7	0.0	0.3
	Average	12.5	25.8	101.2	0.1	0.3
	Total				3.2	9.6
418	10/1/04	7.0	21.9	94.7	0.0	0.3
419	10/2/04	7.3	21.5	100.0	0.3	0.3
420	10/3/04	1.9	17.6	100.0	0.0	0.2
421	10/4/04	8.4	17.7	77.1	0.0	0.3
422	10/5/04	-2.0	13.8	100.0	0.0	0.2
423	10/6/04	4.3	22.4	80.7	0.0	0.3
424	10/7/04	9.7	23.7	75.6	0.0	0.3
425	10/8/04	12.1	23.3	75.9	0.0	0.2
426	10/9/04	11.3	22.3	86.2	1.1	0.3
427	10/10/04	4.7	18.3	96.4	0.0	0.2
428	10/11/04	1.9	16.3	107.5	0.0	0.2
429	10/12/04	1.5	16.1	107.6	0.0	0.1
430	10/13/04	5.8	16.6	100.0	0.0	0.1
431	10/14/04	10.4	16.5	107.9	0.0	0.1
432	10/15/04	10.0	15.4	106.5	1.0	0.1
433	10/16/04	3.7	10.9	100.0	1.0	0.1
434	10/17/04	3.7	6.4	100.0	0.1	0.1
435	10/18/04	2.4	8.6	99.4	0.0	0.1
436	10/19/04	6.5	9.6	99.1	0.0	0.1
437	10/20/04	8.1	11.3	100.0	0.0	0.1
438	10/21/04	8.3	11.5	108.0	0.0	0.0
439	10/22/04	8.2	13.4	99.6	0.0	0.1
440	10/23/04	10.1	13.9	99.8	0.3	0.1
441	10/24/04	11.1	16.7	99.5	0.6	0.1
442	10/25/04	3.1	20.1	107.8	0.0	0.2
443	10/26/04	6.4	20.3	100.0	0.0	0.2

444	10/27/04	10.6	15.9	100.0	0.0	0.1
445	10/28/04	7.9	15.7	104.7	0.0	0.1
446	10/29/04	11.1	20.8	108.7	1.1	0.1
447	10/30/04	13.6	21.5	97.7	0.0	0.1
448	10/31/04	9.0	13.7	87.6	0.0	0.2
	Average	7.0	16.6	97.7	0.2	0.2
	Total				5.7	4.7
449	11/1/04	1.0	9.9	95.3	0.0	0.1
450	11/2/04	6.7	8.6	109.6	2.1	0.0
451	11/3/04	1.5	7.9	97.4	0.0	0.1
452	11/4/04	2.4	7.5	100.0	1.4	0.0
453	11/5/04	2.7	11.0	73.3	0.0	0.2
454	11/6/04	4.4	16.3	84.0	0.0	0.2
455	11/7/04	8.1	15.3	85.6	0.0	0.2
456	11/8/04	-1.6	9.7	82.3	0.0	0.1
457	11/9/04	-4.5	6.1	93.8	0.0	0.1
458	11/10/04	0.7	15.8	74.6	0.0	0.2
459	11/11/04	3.2	14.6	92.0	0.0	0.1
460	11/12/04	-2.9	6.7	90.4	0.0	0.1
461	11/13/04	-3.7	6.6	96.7	0.0	0.1
462	11/14/04	-6.3	11.9	100.0	0.0	0.1
463	11/15/04	-3.6	9.0	94.1	0.0	0.1
464	11/16/04	5.1	10.1	98.8	0.1	0.0
465	11/17/04	9.5	12.8	109.2	0.2	0.0
466	11/18/04	11.9	16.4	111.4	0.0	0.1
467	11/19/04	7.2	15.2	107.6	0.6	0.0
468	11/20/04	8.3	13.6	110.5	0.2	0.0
469	11/21/04	4.1	10.5	90.9	0.0	0.1
	Average	2.6	11.2	95.1	0.2	0.1
	Total				4.5	1.7

Appendix B – Evapotranspiration (ET), rainfall and irrigation schedule for system study.

* Day Before, ET, Total Rainfall, Leftover and 50% ET all reported in cm.

Day	2003 Date	* Day Before	ET	Total	Rainfall	Leftover	50% ET	Seconds of Water
6	16-Aug	0.00	**-0.28**	-0.28	**1.17**	0.89	**0.00**	**0**
7	17-Aug	0.89	**-0.38**	0.51	**0.00**	0.51	**0.00**	**0**
8	18-Aug	0.51	**-0.43**	0.08	**0.00**	0.08	**0.00**	**0**
9	19-Aug	0.08	**-0.46**	-0.38	**0.00**	-0.38	**0.00**	**0**
10	20-Aug	-0.38	**-0.51**	-0.89	**0.00**	-0.89	**-0.45**	**38**
11	21-Aug	0.00	**-0.48**	-0.48	**0.25**	-0.23	**-0.11**	**10**
12	22-Aug	0.00	**-0.58**	-0.58	**0.00**	-0.58	**0.00**	**0**
13	23-Aug	-0.58	**-0.51**	-1.09	**0.00**	-1.09	**-0.55**	**47**
14	24-Aug	0.00	**-0.41**	-0.41	**0.00**	-0.41	**-0.20**	**18**
15	25-Aug	0.00	**-0.71**	-0.71	**0.91**	0.20	**0.00**	**0**
16	26-Aug	0.20	**-0.61**	-0.41	**0.20**	-0.21	**0.00**	**0**
17	27-Aug	-0.21	**-0.43**	-0.64	**0.00**	-0.64	**-0.32**	**27**
18	28-Aug	0.00	**-0.46**	-0.46	**0.00**	-0.46	**0.00**	**0**
19	29-Aug	-0.46	**-0.30**	-0.76	**0.56**	-0.20	**0.00**	**0**
20	30-Aug	-0.20	**-0.41**	-0.61	**0.00**	-0.61	**-0.30**	**26**
21	31-Aug	0.00	**-0.25**	-0.25	**0.00**	-0.25	**0.00**	**0**
22	1-Sep	-0.25	**-0.38**	-0.63	**0.53**	-0.10	**0.00**	**0**
23	2-Sep	-0.10	**-0.38**	-0.48	**0.00**	-0.48	**0.00**	**0**
24	3-Sep	-0.48	**-0.30**	-0.78	**0.00**	-0.78	**-0.39**	**34**
25	4-Sep	0.00	**-0.33**	-0.33	**0.00**	-0.33	**0.00**	**0**
26	5-Sep	-0.33	**-0.33**	-0.66	**0.00**	-0.66	**0.00**	**0**
27	6-Sep	-0.66	**-0.38**	-1.04	**0.00**	-1.04	**0.00**	**0**
28	7-Sep	-1.04	**-0.38**	-1.42	**0.00**	-1.42	**-0.71**	**61**
29	8-Sep	0.00	**-0.33**	-0.33	**0.00**	-0.33	**-0.17**	**14**
30	9-Sep	0.00	**-0.33**	-0.33	**0.00**	-0.33	**0.00**	**0**
31	10-Sep	-0.33	**-0.36**	-0.69	**0.00**	-0.69	**-0.35**	**30**
32	11-Sep	0.00	**-0.36**	-0.36	**0.00**	-0.36	**-0.18**	**15**
33	12-Sep	0.00	**-0.38**	-0.38	**0.00**	-0.38	**0.00**	**0**
34	13-Sep	-0.38	**-0.41**	-0.79	**0.00**	-0.79	**0.00**	**0**
35	14-Sep	-0.79	**-0.20**	-0.99	**0.56**	-0.43	**-0.22**	**18**
36	15-Sep	0.00	**-0.33**	-0.33	**0.00**	-0.33	**-0.17**	**14**
37	16-Sep	0.00	**-0.33**	-0.33	**0.00**	-0.33	**-0.17**	**14**
38	17-Sep	0.00	**-0.36**	-0.36	**0.00**	-0.36	**-0.18**	**14**
39	18-Sep	0.00	**-0.36**	-0.36	**0.00**	-0.36	**-0.18**	**14**
40	19-Sep	0.00	**-0.20**	-0.20	**0.00**	-0.20	**0.00**	**0**
41	20-Sep	-0.20	**-0.30**	-0.50	**0.00**	-0.50	**0.00**	**0**

42	21-Sep	-0.50	**-0.28**	-0.78	**0.00**	-0.78	**0.00**	**0**
43	22-Sep	-0.78	**-0.13**	-0.91	**3.51**	2.60	**0.00**	**0**
44	23-Sep	2.60	**-0.20**	2.40	**0.00**	2.40	**0.00**	**0**
45	24-Sep	2.40	**-0.20**	2.20	**1.30**	3.50	**0.00**	**0**
46	25-Sep	3.50	**-0.18**	3.32	**0.00**	3.32	**0.00**	**0**
47	26-Sep	3.32	**-0.18**	3.14	**0.33**	3.47	**0.00**	**0**
48	27-Sep	3.47	**-0.20**	3.27	**0.08**	3.35	**0.00**	**0**
49	28-Sep	3.35	**-0.18**	3.17	**0.20**	3.37	**0.00**	**0**
50	29-Sep	3.37	**-0.15**	3.22	**0.00**	3.22	**0.00**	**0**
51	30-Sep	3.22	**-0.15**	3.07	**0.03**	3.10	**0.00**	**0**
52	1-Oct	3.10	**-0.13**	2.97	**0.00**	2.97	**0.00**	**0**
53	2-Oct	2.97	**-0.20**	2.77	**0.00**	2.77	**0.00**	**0**
54	3-Oct	2.77	**-0.13**	2.64	**0.66**	3.30	**0.00**	**0**
55	4-Oct	3.30	**-0.13**	3.17	**0.00**	3.17	**0.00**	**0**
56	5-Oct	3.17	**-0.18**	2.99	**0.00**	2.99	**0.00**	**0**
57	6-Oct	2.99	**-0.18**	2.81	**0.00**	2.81	**0.00**	**Starting at 0**
58	7-Oct	0.00	**-0.25**	-0.25	**0.00**	-0.25	**0.00**	**0**
59	8-Oct	-0.25	**-0.28**	-0.53	**0.00**	-0.53	**-0.27**	**23**
60	9-Oct	0.00	**-0.20**	-0.20	**0.00**	-0.20	**0.00**	**0**
61	10-Oct	-0.20	**-0.20**	-0.40	**0.00**	-0.40	**0.00**	**0**
62	11-Oct	-0.40	**-0.23**	-0.63	**0.00**	-0.63	**0.00**	**0**
63	12-Oct	-0.63	**-0.33**	-0.96	**0.08**	-0.88	**-0.44**	**38**
64	13-Oct	0.00	**-0.23**	-0.23	**0.00**	-0.23	**0.00**	**0**
65	14-Oct	-0.23	**-0.15**	-0.38	**2.36**	1.98	**0.00**	**0**
66	15-Oct	1.98	**-0.23**	1.75	**0.00**	1.75	**0.00**	**0**
67	16-Oct	1.75	**-0.15**	1.60	**0.00**	1.60	**0.00**	**0**
68	17-Oct	1.60	**-0.13**	1.47	**0.00**	1.47	**0.00**	**0**
69	18-Oct	1.47	**-0.23**	1.24	**0.00**	1.24	**0.00**	**Starting at 0**
70	19-Oct	0.00	**-0.18**	-0.18	**0.00**	-0.18	**0.00**	**0**
71	20-Oct	-0.18	**-0.30**	-0.48	**0.00**	-0.48	**-0.24**	**21**
72	21-Oct	0.00	**-0.33**	-0.33	**0.00**	-0.33	**0.00**	**0**
73	22-Oct	-0.33	**-0.13**	-0.46	**0.00**	-0.46	**0.00**	**0**
74	23-Oct	-0.46	**-0.08**	-0.54	**0.00**	-0.54	**0.00**	**0**
75	24-Oct	-0.54	**-0.13**	-0.67	**0.00**	-0.67	**0.00**	**Irrigation Off**
76	25-Oct	-0.67	**-0.05**	-0.72	**1.12**	0.40	**0.00**	
77	26-Oct	0.40	**-0.10**	0.30	**0.05**	0.35	**0.00**	
78	27-Oct	0.35	**-0.05**	0.30	**0.00**	0.30	**0.00**	
79	28-Oct	0.30	**-0.08**	0.22	**0.30**	0.52	**0.00**	
80	29-Oct	0.52	**-0.05**	0.47	**0.25**	0.72	**0.00**	
81	30-Oct	0.72	**-0.20**	0.52	**0.00**	0.52	**0.00**	
82	31-Oct	0.52	**-0.15**	0.37	**0.05**	0.42	**0.00**	

83	1-Nov	0.42	**-0.13**	0.29	**0.00**	0.29	**0.00**
84	2-Nov	0.29	**-0.03**	0.26	**2.62**	2.88	**0.00**
85	3-Nov	2.88	**0.00**	2.88	**2.13**	5.01	**0.00**
86	4-Nov	5.01	**-0.15**	4.86	**0.28**	5.14	**0.00**
87	5-Nov	5.14	**-0.10**	5.04	**1.47**	6.51	**0.00**
88	6-Nov	6.51	**-0.10**	6.41	**0.00**	6.41	**0.00**
89	7-Nov	6.41	**-0.13**	6.28	**0.00**	6.28	**0.00**
90	8-Nov	6.28	**-0.10**	6.18	**0.00**	6.18	**0.00**
91	9-Nov	6.18	**-0.08**	6.10	**0.00**	6.10	**0.00**
92	10-Nov	6.10	**-0.08**	6.02	**0.00**	6.02	**0.00**

Day	2004 Date	Day Before	**ET**	Total	**Rainfall**	Leftover	**50% ET**	**Seconds of Water**
245	11-Apr	0.00	**-0.15**	-0.15	**0.00**	-0.15	**0.00**	**0**
246	12-Apr	-0.15	**-0.20**	-0.35	**0.00**	-0.35	**-0.18**	**15**
250	16-Apr			**1.27 cm added to all plots after data**				
251	17-Apr	0.00	**-0.41**	-0.41	**0.18**	-0.23	**0.00**	**0**
252	18-Apr	-0.23	**-0.56**	-0.79	**0.00**	-0.79	**-0.40**	**35**
253	19-Apr	0.00	**-0.76**	-0.76	**0.00**	-0.76	**0.00**	**0**
254	20-Apr	-0.76	**-0.28**	-1.04	**0.08**	-0.96	**0.00**	**0**
255	21-Apr	-0.96	**-0.20**	-1.16	**0.03**	-1.13	**-0.57**	**50**
256	22-Apr	0.00	**-0.41**	-0.41	**0.00**	-0.41	**-0.20**	**17**
257	23-Apr	0.00	**-0.36**	-0.36	**0.00**	-0.36	**0.00**	**0**
258	24-Apr	-0.36	**-0.38**	-0.74	**0.00**	-0.74	**0.00**	**0**
259	25-Apr	-0.74	**-0.38**	-1.12	**0.48**	-0.64	**-0.32**	**28**
260	26-Apr	0.00	**-0.46**	-0.46	**0.00**	-0.46	**0.00**	**0**
261	27-Apr	-0.46	**-0.33**	-0.79	**0.00**	-0.79	**-0.39**	**35**
262	28-Apr	0.00	**-0.61**	-0.61	**0.00**	-0.61	**-0.30**	**26**
263	29-Apr	0.00	**-0.71**	-0.71	**0.00**	-0.71	**-0.36**	**30**
264	30-Apr	0.00	**-0.25**	-0.25	**0.05**	-0.20	**0.00**	**0**
265	1-May	-0.20	**-0.10**	-0.30	**1.70**	1.40	**0.00**	**0**
266	2-May	1.40	**-0.15**	1.25	**1.07**	2.32	**0.00**	**0**
267	3-May	2.32	**-0.28**	2.04	**0.00**	2.04	**0.00**	**0**
268	4-May	2.04	**-0.33**	1.71	**0.00**	1.71	**0.00**	**0**
269	5-May	1.71	**-0.41**	1.30	**0.05**	1.35	**0.00**	**0**
270	6-May	1.35	**-0.46**	0.89	**0.00**	0.89	**0.00**	**0**
271	7-May	0.89	**-0.58**	0.31	**0.03**	0.34	**0.00**	**0**
272	8-May	0.34	**-0.30**	0.04	**0.33**	0.37	**0.00**	**0**
273	9-May	0.37	**-0.41**	-0.04	**1.52**	1.48	**0.00**	**0**
274	10-May	1.48	**-0.48**	1.00	**2.57**	3.57	**0.00**	**0**
275	11-May	3.57	**-0.30**	3.27	**0.05**	3.32	**0.00**	**0**
276	12-May	3.32	**-0.46**	2.86	**0.00**	2.86	**0.00**	**0**

277	13-May	2.86	**-0.38**	2.48	**0.20**	2.68	**0.00**	**0**
278	14-May	2.68	**-0.23**	2.45	**1.22**	3.67	**0.00**	**0**
279	15-May	3.67	**-0.20**	3.47	**0.00**	3.47	**0.00**	**0**
280	16-May	3.47	**-0.38**	3.09	**0.00**	3.09	**0.00**	**0**
281	17-May	3.09	**-0.41**	2.68	**0.48**	3.16	**0.00**	**0**
282	18-May	3.16	**-0.25**	2.91	**1.35**	4.26	**0.00**	**0**
283	19-May	4.26	**-0.43**	3.83	**0.00**	3.83	**0.00**	**0**
284	20-May	3.83	**-0.30**	3.53	**0.15**	3.68	**0.00**	**0**
285	21-May	3.68	**-0.20**	3.48	**4.19**	7.67	**0.00**	**0**
286	22-May	7.67	**-0.30**	7.37	**1.17**	8.54	**0.00**	**0**
287	23-May	8.54	**-0.25**	8.29	**6.07**	14.36	**0.00**	**0**
288	24-May	14.36	**-0.33**	14.03	**0.00**	14.03	**0.00**	**0**
289	25-May	14.03	**-0.13**	13.90	**0.71**	14.61	**0.00**	**0**
290	26-May	14.61	**-0.20**	14.41	**0.00**	14.41	**0.00**	**0**
291	27-May	14.41	**-0.28**	14.13	**0.00**	14.13	**0.00**	**0**
292	28-May	14.13	**-0.38**	13.75	**0.00**	13.75	**0.00**	**0**
293	29-May	13.75	**-0.25**	13.50	**0.00**	13.50	**0.00**	**0**
294	30-May	13.50	**-0.41**	13.09	**0.84**	13.93	**0.00**	**0**
295	31-May	13.93	**-0.30**	13.63	**0.48**	14.11	**0.00**	**0**
296	1-Jun	14.11	**-0.48**	13.63	**0.00**	13.63	**0.00**	**0**
297	2-Jun	13.63	**-0.30**	13.33	**0.00**	13.33	**0.00**	**Starting at** **0**
298	3-Jun	0.00	**-0.41**	-0.41	**0.00**	-0.41	**-0.20**	**17**
299	4-Jun	0.00	**-0.46**	-0.46	**0.00**	-0.46	**0.00**	**0**
300	5-Jun	-0.46	**-0.46**	-0.92	**0.00**	-0.92	**0.00**	**0**
301	6-Jun	-0.92	**-0.43**	-1.35	**0.00**	-1.35	**-0.67**	**58**
302	7-Jun	0.00	**-0.53**	-0.53	**0.00**	-0.53	**-0.27**	**24**
303	8-Jun	0.00	**-0.53**	-0.53	**0.00**	-0.53	**-0.27**	**24**
304	9-Jun	0.00	**-0.48**	-0.48	**1.02**	0.54	**0.00**	**0**
305	10-Jun	0.54	**-0.18**	0.36	**0.84**	1.20	**0.00**	**0**
306	11-Jun	1.20	**-0.05**	1.15	**2.11**	3.26	**0.00**	**0**
307	12-Jun	3.26	**-0.51**	2.75	**0.41**	3.16	**0.00**	**0**
308	13-Jun	3.16	**-0.46**	2.70	**0.48**	3.18	**0.00**	**0**
309	14-Jun	3.18	**-0.30**	2.88	**1.75**	4.63	**0.00**	**0**
310	15-Jun	4.63	**-0.41**	4.22	**0.00**	4.22	**0.00**	**0**
311	16-Jun	4.22	**-0.41**	3.81	**0.00**	3.81	**0.00**	**0**
312	17-Jun	3.81	**-0.20**	3.61	**0.20**	3.81	**0.00**	**0**
313	18-Jun	3.81	**-0.41**	3.40	**0.00**	3.40	**0.00**	**0**
314	19-Jun	3.40	**-0.66**	2.74	**0.03**	2.77	**0.00**	**0**
315	20-Jun	2.77	**-0.69**	2.08	**0.00**	2.08	**0.00**	**0**
316	21-Jun	2.08	**-0.25**	1.83	**0.76**	2.59	**0.00**	**0**
317	22-Jun	2.59	**-0.30**	2.29	**0.00**	2.29	**0.00**	**0**
318	23-Jun	2.29	**-0.51**	1.78	**0.46**	2.24	**0.00**	**0**

319	24-Jun	2.24	**-0.38**	1.86	**0.36**	2.22	**0.00**	**0**
320	25-Jun	2.22	**-0.41**	1.81	**0.00**	1.81	**0.00**	**0**
								Starting at
321	26-Jun	1.81	**-0.48**	1.33	**0.00**	1.33	**0.00**	**0**
322	27-Jun	0.00	**-0.43**	-0.43	**0.00**	-0.43	**-0.21**	**19**
323	28-Jun	0.00	**-0.43**	-0.43	**0.08**	-0.35	**-0.18**	**15**
324	29-Jun	0.00	**-0.53**	-0.53	**0.00**	-0.53	**-0.27**	**24**
325	30-Jun	0.00	**-0.53**	-0.53	**0.00**	-0.53	**-0.27**	**24**
326	1-Jul	0.00	**-0.56**	-0.56	**0.00**	-0.56	**-0.28**	**24**
327	2-Jul	0.00	**-0.51**	-0.51	**0.00**	-0.51	**0.00**	**0**
328	3-Jul	-0.51	**-0.51**	-1.02	**0.00**	-1.02	**0.00**	**0**
329	4-Jul	-1.02	**-0.28**	-1.30	**0.81**	-0.49	**-0.24**	**22**
330	5-Jul	0.00	**-0.30**	-0.30	**0.00**	-0.30	**-0.15**	**13**
331	6-Jul	0.00	**-0.48**	-0.48	**0.51**	0.03	**0.00**	**0**
332	7-Jul	0.03	**-0.43**	-0.40	**1.02**	0.62	**0.00**	**0**
333	8-Jul	0.62	**-0.28**	0.34	**0.74**	1.08	**30 sec. added in error**	
334	9-Jul	0.00	**-0.43**	-0.43	**0.00**	-0.43	**0.00**	**0**
335	10-Jul	-0.43	**-0.43**	-0.86	**0.00**	-0.86	**0.00**	**0**
336	11-Jul	-0.86	**-0.46**	-1.32	**0.79**	-0.53	**0.00**	**0**
337	12-Jul	-0.53	**-0.30**	-0.83	**0.03**	-0.80	**-0.40**	**34**
338	13-Jul	0.00	**-0.41**	-0.41	**1.37**	0.96	**0.00**	**0**
339	14-Jul	0.96	**-0.41**	0.55	**0.00**	0.55	**0.00**	**0**
340	15-Jul	0.55	**-0.53**	0.02	**0.00**	0.02	**0.00**	**0**
341	16-Jul	0.02	**-0.41**	-0.39	**0.53**	0.14	**0.00**	**0**
342	17-Jul	0.14	**-0.30**	-0.16	**0.10**	-0.06	**0.00**	**0**
343	18-Jul	-0.06	**-0.43**	-0.49	**0.00**	-0.49	**0.00**	**0**
344	19-Jul	-0.49	**-0.38**	-0.87	**0.00**	-0.87	**-0.43**	**38**
345	20-Jul	0.00	**-0.43**	-0.43	**0.00**	-0.43	**0.00**	**0**
346	21-Jul	-0.43	**-0.41**	-0.84	**1.88**	1.04	**0.00**	**0**
347	22-Jul	1.04	**-0.43**	0.61	**0.00**	0.61	**37 sec. added in error**	
348	23-Jul	0.00	**-0.56**	-0.56	**0.00**	-0.56	**0.00**	**0**
349	24-Jul	-0.56	**-0.41**	-0.97	**0.00**	-0.97	**0.00**	**0**
350	25-Jul	-0.97	**-0.43**	-1.40	**0.00**	-1.40	**-0.71**	**61**
351	26-Jul	0.00	**-0.36**	-0.36	**0.00**	-0.36	**0.00**	**0**
352	27-Jul	-0.36	**-0.18**	-0.54	**1.24**	0.70	**0.00**	**0**
353	28-Jul	0.70	**-0.38**	0.32	**0.03**	0.35	**0.00**	**0**
354	29-Jul	0.35	**-0.36**	-0.01	**0.00**	-0.01	**0.00**	**0**
355	30-Jul	-0.01	**-0.18**	-0.19	**0.05**	-0.14	**0.00**	**0**
356	31-Jul	-0.14	**-0.38**	-0.52	**0.00**	-0.52	**0.00**	**0**
357	1-Aug	-0.52	**-0.46**	-0.98	**0.00**	-0.98	**-0.49**	**45**
358	2-Aug	0.00	**-0.46**	-0.46	**0.66**	0.20	**0.00**	**0**
359	3-Aug	0.20	**-0.43**	-0.23	**0.00**	-0.23	**0.00**	**0**

360	4-Aug	-0.23	**-0.28**	-0.51	**2.01**	1.50	**0.00**	**0**
361	5-Aug	1.50	**-0.41**	1.09	**0.00**	1.09	**0.00**	**0**
362	6-Aug	1.09	**-0.43**	0.66	**0.00**	0.66	**0.00**	**0**
363	7-Aug	0.66	**-0.41**	0.25	**0.00**	0.25	**0.00**	**0**
364	8-Aug	0.25	**-0.36**	-0.11	**0.00**	-0.11	**0.00**	**0**
365	9-Aug	-0.11	**-0.41**	-0.52	**0.00**	-0.52	**-0.26**	**24**
366	10-Aug	0.00	**-0.30**	-0.30	**0.15**	-0.15	**0.00**	**0**
367	11-Aug	-0.15	**-0.23**	-0.38	**0.84**	0.46	**0.00**	**0**
368	12-Aug	0.46	**-0.15**	0.31	**0.00**	0.31	**0.00**	**0**
369	13-Aug	0.31	**-0.25**	0.06	**0.03**	0.09	**0.00**	**0**
370	14-Aug	0.09	**-0.36**	-0.27	**0.00**	-0.27	**0.00**	**0**
371	15-Aug	-0.27	**-0.41**	-0.68	**0.00**	-0.68	**-0.34**	**31**
372	16-Aug	0.00	**-0.38**	-0.38	**0.00**	-0.38	**-0.19**	**17**
373	17-Aug	0.00	**-0.28**	-0.28	**0.00**	-0.28	**0.00**	**0**
374	18-Aug	-0.28	**-0.20**	-0.48	**0.00**	-0.48	**-0.24**	**20**
375	19-Aug	0.00	**-0.48**	-0.48	**0.00**	-0.48	**0.00**	**0**
376	20-Aug	-0.48	**-0.20**	-0.68	**0.00**	-0.68	**0.00**	**0**
377	21-Aug	-0.68	**-0.41**	-1.09	**0.00**	-1.09	**0.00**	**0**
378	22-Aug	-1.09	**-0.38**	-1.47	**0.00**	-1.47	**-0.73**	**63**
379	23-Aug	0.00	**-0.23**	-0.23	**0.00**	-0.23	**0.00**	**0**
380	24-Aug	-0.23	**-0.38**	-0.61	**0.00**	-0.61	**0.00**	**0**
381	25-Aug	-0.61	**-0.38**	-0.99	**0.74**	-0.25	**0.00**	**0**
382	26-Aug	-0.25	**-0.36**	-0.61	**0.00**	-0.61	**-0.30**	**26**
383	27-Aug	0.00	**-0.43**	-0.43	**0.00**	-0.43	**0.00**	**0**
384	28-Aug	-0.43	**-0.25**	-0.68	**1.73**	1.05	**0.00**	**0**
385	29-Aug	1.05	**-0.10**	0.95	**2.01**	2.96	**0.00**	**0**
386	30-Aug	2.96	**-0.33**	2.63	**0.00**	2.63	**0.00**	**0**
387	31-Aug	2.63	**-0.33**	2.30	**0.00**	2.30	**0.00**	**0**
388	1-Sep	2.30	**-0.25**	2.05	**0.00**	2.05	**Starting at 0**	
389	2-Sep	0.00	**-0.38**	-0.38	**0.00**	-0.38	**-0.19**	**15**
390	3-Sep	0.00	**-0.33**	-0.33	**0.00**	-0.33	**0.00**	**0**
391	4-Sep	-0.33	**-0.36**	-0.69	**0.53**	-0.16	**0.00**	**0**
392	5-Sep	-0.16	**-0.28**	-0.44	**0.00**	-0.44	**0.00**	**0**
393	6-Sep	-0.44	**-0.41**	-0.85	**1.40**	0.55	**0.00**	**0**
394	7-Sep	0.55	**-0.41**	0.14	**0.03**	0.17	**0.00**	**0**
395	8-Sep	0.17	**-0.28**	-0.11	**0.00**	-0.11	**0.00**	**0**
396	9-Sep	-0.11	**-0.36**	-0.47	**0.00**	-0.47	**0.00**	**0**
397	10-Sep	-0.47	**-0.36**	-0.83	**0.00**	-0.83	**-0.41**	**33**
398	11-Sep	0.00	**-0.36**	-0.36	**0.00**	-0.36	**0.00**	**0**
399	12-Sep	-0.36	**-0.36**	-0.72	**0.00**	-0.72	**0.00**	**0**
400	13-Sep	-0.72	**-0.36**	-1.08	**0.00**	-1.08	**-0.54**	**46**
401	14-Sep	0.00	**-0.38**	-0.38	**0.00**	-0.38	**0.00**	**0**
402	15-Sep	-0.38	**-0.38**	-0.76	**0.00**	-0.76	**-0.38**	**32**

403	16-Sep	0.00	**-0.43**	-0.43	**0.58**	0.15	**0.00**	**0**
404	17-Sep	0.15	**-0.30**	-0.15	**0.00**	-0.15	**0.00**	**0**
405	18-Sep	-0.15	**-0.30**	-0.45	**0.00**	-0.45	**0.00**	**0**
406	19-Sep	-0.45	**-0.28**	-0.73	**0.00**	-0.73	**0.00**	**0**
407	20-Sep	-0.73	**-0.28**	-1.01	**0.00**	-1.01	**-0.50**	**44**
408	21-Sep	0.00	**-0.33**	-0.33	**0.00**	-0.33	**-0.16**	**15**
409	22-Sep	0.00	**-0.36**	-0.36	**0.00**	-0.36	**0.00**	**0**
410	23-Sep	-0.36	**-0.33**	-0.69	**0.00**	-0.69	**-0.34**	**29**
411	24-Sep	0.00	**-0.30**	-0.30	**0.00**	-0.30	**-0.15**	**13**
412	25-Sep	0.00	**-0.20**	-0.20	**0.00**	-0.20	**0.00**	**0**
413	26-Sep	-0.20	**-0.28**	-0.48	**0.00**	-0.48	**-0.24**	**20**
414	27-Sep	0.00	**-0.28**	-0.28	**0.00**	-0.28	**-0.14**	**8**
415	28-Sep	0.00	**-0.18**	-0.18	**0.38**	0.20	**0.00**	**0**
416	29-Sep	0.20	**-0.23**	-0.03	**0.38**	0.35	**0.00**	**0**
417	30-Sep	0.35	**-0.20**	0.15	**0.00**	0.15	**0.00**	**0**
418	1-Oct	0.15	**-0.25**	-0.10	**0.00**	-0.10	**0.00**	**0**
419	2-Oct	-0.10	**-0.25**	-0.35	**0.00**	-0.35	**0.00**	**0**
420	3-Oct	-0.35	**-0.25**	-0.60	**0.00**	-0.60	**-0.30**	**25**
421	4-Oct	0.00	**-0.25**	-0.25	**0.00**	-0.25	**0.00**	**0**
422	5-Oct	-0.25	**-0.25**	-0.50	**0.00**	-0.50	**-0.25**	**22**
423	6-Oct	0.00	**-0.30**	-0.30	**0.00**	-0.30	**-0.15**	**13**
424	7-Oct	0.00	**-0.28**	-0.28	**0.00**	-0.28	**-0.14**	**12**
425	8-Oct	0.00	**-0.23**	-0.23	**0.48**	0.25	**0.00**	**0**
426	9-Oct	0.25	**-0.33**	-0.08	**0.58**	0.50	**0.00**	**0**
427	10-Oct	0.50	**-0.23**	0.27	**0.00**	0.27	**0.00**	**0**
428	11-Oct	0.27	**-0.18**	0.09	**0.00**	0.09	**0.00**	**0**
429	12-Oct	0.09	**-0.15**	-0.06	**0.00**	-0.06	**0.00**	**0**
430	13-Oct	-0.06	**-0.13**	-0.19	**0.03**	-0.16	**-0.08**	**7**
431	14-Oct	-0.16	**-0.13**	-0.29	**0.00**	-0.29	**0.00**	**0**
432	15-Oct	-0.29	**-0.05**	-0.34	**1.42**	1.08	**0.00**	**0**
433	16-Oct	1.08	**-0.08**	1.00	**0.61**	1.61	**0.00**	**0**
434	17-Oct	1.61	**-0.05**	1.56	**0.05**	1.61	**0.00**	**0**
435	18-Oct	1.61	**-0.05**	1.56	**0.00**	1.56	**0.00**	**0**
436	19-Oct	1.56	**-0.05**	1.51	**0.00**	1.51	**0.00**	**0**
437	20-Oct	1.51	**-0.05**	1.46	**0.00**	1.46	**0.00**	**0**
438	21-Oct	1.46	**-0.03**	1.43	**0.00**	1.43	**0.00**	**0**
439	22-Oct	1.43	**-0.08**	1.35	**0.00**	1.35	**0.00**	**0**
440	23-Oct	1.35	**-0.05**	1.30	**0.97**	2.27	**0.00**	**0**
441	24-Oct	2.27	**-0.08**	2.19	**0.00**	2.19	**0.00**	**0**
442	25-Oct	2.19	**-0.15**	2.04	**0.00**	2.04	**0.00**	**Irrigation Off**
443	26-Oct	2.04	**-0.15**	1.89	**0.00**	1.89	**0.00**	
444	27-Oct	1.89	**-0.08**	1.81	**0.00**	1.81	**0.00**	

445	28-Oct	1.81	**-0.10**	1.71	**0.00**	1.71	**0.00**
446	29-Oct	1.71	**-0.08**	1.63	**1.09**	2.72	**0.00**
447	30-Oct	2.72	**-0.10**	2.62	**0.00**	2.62	**0.00**
448	31-Oct	2.62	**-0.15**	2.47	**0.00**	2.47	**0.00**
449	1-Nov	2.47	**-0.05**	2.42	**1.12**	3.54	**0.00**
450	2-Nov	3.54	**0.00**	3.54	**0.94**	4.48	**0.00**
451	3-Nov	4.48	**-0.05**	4.43	**0.00**	4.43	**0.00**
452	4-Nov	4.43	**0.00**	4.43	**1.42**	5.85	**0.00**
453	5-Nov	5.85	**-0.20**	5.65	**0.00**	5.65	**0.00**
454	6-Nov	5.65	**-0.20**	5.45	**0.00**	5.45	**0.00**
455	7-Nov	5.45	**-0.18**	5.27	**0.00**	5.27	**0.00**
456	8-Nov	5.27	**-0.15**	5.12	**0.00**	5.12	**0.00**
457	9-Nov	5.12	**-0.05**	5.07	**0.00**	5.07	**0.00**
458	10-Nov	5.07	**-0.23**	4.84	**0.00**	4.84	**0.00**
459	11-Nov	4.84	**-0.13**	4.71	**0.00**	4.71	**0.00**
460	12-Nov	4.71	**-0.08**	4.63	**0.00**	4.63	**0.00**
461	13-Nov	4.63	**-0.08**	4.55	**0.00**	4.55	**0.00**
462	14-Nov	4.55	**-0.08**	4.47	**0.00**	4.47	**0.00**
463	15-Nov	4.47	**-0.05**	4.42	**0.00**	4.42	**0.00**
464	16-Nov	4.42	**-0.03**	4.39	**0.05**	4.44	**0.00**
465	17-Nov	4.44	**-0.03**	4.41	**0.15**	4.56	**0.00**
466	18-Nov	4.56	**-0.05**	4.51	**0.00**	4.51	**0.00**
467	19-Nov	4.51	**-0.03**	4.48	**0.61**	5.09	**0.00**
468	20-Nov	5.09	**0.00**	5.09	**0.23**	5.32	**0.00**
469	21-Nov	5.32	**-0.10**	5.22	**0.00**	5.22	**0.00**

Appendix C – Traffic summary for system study

Day	Date	Fall 2003 # of Passes	Total Passes
1	11-Aug	2	2
2	12-Aug	2	4
3	13-Aug	2	6
4	14-Aug	2	8
5	15-Aug	2	10
7	17-Aug	2	12
8	18-Aug	2	14
9	19-Aug	2	16
10	20-Aug	2	18
11	21-Aug	2	20
12	22-Aug	2	22
16	26-Aug	4	26
17	27-Aug	4	30
18	28-Aug	4	34
19	29-Aug	2	36
22	1-Sep	4	40
23	2-Sep	2	42
26	5-Sep	4	46
30	9-Sep	4	50
31	10-Sep	2	52
32	11-Sep	4	56
33	12-Sep	2	58
36	15-Sep	2	60
37	16-Sep	2	62
39	18-Sep	4	66
44	23-Sep	2	68
46	25-Sep	4	72
50	29-Sep	4	76
52	1-Oct	2	78
53	2-Oct	2	80
54	3-Oct	2	82
57	6-Oct	2	84
58	7-Oct	2	86
60	9-Oct	4	90
61	10-Oct	2	92
64	13-Oct	2	94
65	14-Oct	2	96
66	15-Oct	2	98
67	16-Oct	2	100
68	17-Oct	2	102
72	21-Oct	4	106
74	23-Oct	4	110
75	24-Oct	2	112

Day	Date	Spring 2004 # of Passes	Total Passes
234	31-Mar	4	116
236	2-Apr	2	118
239	5-Apr	4	122
240	6-Apr	2	124
241	7-Apr	2	126
242	8-Apr	2	128
243	9-Apr	2	130
246	12-Apr	2	132
250	16-Apr	4	136
253	19-Apr	4	140
255	21-Apr	2	142
257	23-Apr	4	146
260	26-Apr	4	150
262	28-Apr	4	154
264	30-Apr	2	156
267	3-May	2	158
268	4-May	4	162
271	7-May	4	166
275	11-May	4	170
276	12-May	4	174
278	14-May	4	178
281	17-May	2	180
284	20-May	4	184
285	21-May	4	188
290	26-May	4	192
292	28-May	4	196

Day	Date	Fall 2004 # of Passes	Total Passes
372	16-Aug	4	200
373	17-Aug	4	204
374	18-Aug	4	208
375	19-Aug	4	212
376	20-Aug	4	216
380	24-Aug	4	220
381	25-Aug	2	222
382	26-Aug	2	224
383	27-Aug	4	228
387	31-Aug	4	232
389	2-Sep	4	236
390	3-Sep	2	238
393	6-Sep	4	242
395	8-Sep	2	244
396	9-Sep	4	248
401	14-Sep	4	252
402	15-Sep	2	254
404	17-Sep	4	258

407	20-Sep	2	260
409	22-Sep	4	264
411	24-Sep	2	266
414	27-Sep	2	268
415	28-Sep	2	270
417	30-Sep	2	272
418	1-Oct	2	274
421	4-Oct	4	278
424	7-Oct	4	282
425	8-Oct	4	286
428	11-Oct	2	288
429	12-Oct	2	290
430	13-Oct	2	292
431	14-Oct	4	296
436	19-Oct	4	300
437	20-Oct	2	302
438	21-Oct	2	304
443	26-Oct	4	308
444	27-Oct	4	312
445	28-Oct	4	316
450	2-Nov	2	318
451	3-Nov	4	322
452	4-Nov	4	326
453	5-Nov	2	328
457	9-Nov	4	332
458	10-Nov	2	334
459	11-Nov	4	338