# Chapter 1

## Impact of Cultural Practices and Traffic on a Sand Based Athletic Field

### Introduction

The combination of grass, maintenance, and condition of the root zone are essential components in determining if an athletic field will hold-up under game traffic, or if it will fail. The grass provides the cover of the field as well as added stability. If a field is used beyond its capacity, worn areas will occur, resulting in a lack of stability and decreased playing surface conditions. Worn areas and instability have been shown not only to reduce the playability and aesthetics of the field but also to increase field-related injuries (Harper *et al.,* 1984; Rogers *et al.,* 1988). The root zone is the source of nutrient and water for turfgrass growth and it provides for the stability of the grass plants by anchoring their roots (Beard, 1973).

An athletic field must provide firm footing, adequate resiliency on impact, and resistance to tearing during play. It must also drain well and resist compacting effects of severe traffic (Turgeon, 1996). This statement describes a combination of the two most commonly used athletic field root zones today. It describes the resistance to compaction of a sand based root zone and it describes the firm surface of an "existing" or native soil root zone-which is higher in silt + clay then a sand based field. Because both of these root zones have benefits for athletic traffic and may respond differently to treatments, this research was done on both types of root zones.

The benefits of using a sand based root zone for athletic field construction are that the macropore space provides for increased water, nutrient, and air movement, rapid drainage, and resistance to compaction (Bingaman and Kohnke, 1970; Brown and Duble, 1975; Adams, 1976; Blake, 1980). This allows for play in adverse conditions as well as potential for increased rooting and shoot growth. Unfortunately, sand based fields have less desirable characteristics as well. Not only can they be more expensive then a native soil field, but they can be unstable and the large macropore space provides for little plant available water holding capacity. Also, low clay and organic matter content provide little cation exchange capacity (Carrow *et al.,* 2001). As result, sand based root zones need to rely heavily on plant root systems for support (Adams and Jones 1979; Adams *et al.,* 1985). Therefore, choosing the proper grass species is very important, especially on a sand based athletic field. A grass with strong rooting and recuperative capabilities is essential. For these reasons a Kentucky bluegrass/perennial ryegrass mixture was used for this research. Kentucky bluegrass provided the dense system of rhizomes which anchor it to the root zone, thereby giving the field good recuperative potential. Perennial ryegrass provided rapid germination, high wear tolerance, and deep rooting (Beard, 1973).

The maintenance practices for this research consisted of twelve different treatments, compromised of three treatment factors each; mowing, fertility, and cultivation. Plots were mown either once or twice per week for the low and high treatment, respectively. These rates were chosen because they correlate with what is done on the majority of high school athletic fields in Michigan (Appendix

A). In addition, the high mowing frequency stays within the one-third rule-especially during the summer and early fall months-while the low mowing frequency does not. The one-third rule was based upon findings by Crider (1955). The one third rule defines that no more then one third of the plant should be removed at any one mowing: otherwise, imbalance between shoots and roots may impede growth (Turgeon, 1996). By using two different mowing frequencies, we can demonstrate the potential benefits of proper mowing practices.

The mowing height used was one inch lower then the average mowing height in Michigan (Appendix A); however, we chose it because it is within the preferred range for both Poa pratensis and Lolium perenne and because sand based fields are usually associated with highly maintained, irrigated fields, therefore, they can tolerate a lower mowing height.

The fertilizer was applied in accordance with the rates commonly used on Michigan athletic fields (Appendix A). A variety of these rates were used to determine if the rate of growth and development of the grass would differ at different rates when subjected to traffic. In addition, we investigated varying application frequencies within the low rate of nitrogen. This was investigated to determine if more frequent applications of nitrogen could potentially help compensate for the low nutrient holding capacity of the sand root zone.

Plots were cultivated with a hollow tine core aerifier at the end of each traffic season and in the spring when turfgrass growth and development is high; or plots were not cultivated at all. The frequencies of cultivation were chosen to represent what is commonly done on Michigan athletic fields (Appendix A). Although a sand root zone field is not likely to compact, some of the reasons for coring were to disrupt the root zone surface area. This is important to prevent a potential layering problem from occurring from the decomposition of organic matter from roots and clippings. The decomposing organic matter could seal the pore space at the root zone surface and this could eventually cause a layering problem leading to anaerobic conditions (Carrow 2001). This would result in decreased rooting and subsequently, decreased stability and decreased turf health and vigor (Harper, 1991)

All plots were subjected to simulated traffic using the Cady Traffic Simulator (CTS) or the Brinkman Traffic Simulator (BTS). The CTS was used in the second year because the wear from it is more representative of actual human traffic, it is much more intense then the traffic simulated by the BTS.

The results of this study will be used to quantify the relationship between cultural practices and turfgrass quality on two commonly used athletic field root zone types.

**Materials and Methods**

*Plot Construction*

Individual plots measured 2.7 m by 2.7 m. Beginning 20 May 1999, plots were established on a sand based root zone at the Hancock Turfgrass Research Center in East Lansing, Michigan (Table 1). Prior to seeding, the area had been treated with a starter fertilizer (13-25-12; 5 g phosphorus (P)/$m^{-2}$) and Siduron, a preemergent herbicide (Kansas City, MO 50% Siduron and 50% Inert ingredients, wettable powder) for control of grassy weeds. Siduron was applied at a rate of 10 g $m^{-2}$ The only other maintenance procedure necessary was one spray application of Confront (Indianapolis, IN 33% triclopyr, 12.1% clopyralid, liquid formulation) on 8 May 2001 at a rate of 024 ml $m^{-2}$ for control of broadleaf weeds.

Seed was an 85% Kentucky bluegrass (Varieties: Touchdown, Fairfax, SR2100, and Midnight), 15% perennial ryegrass mixture (ASP410, Michigan State Seed Co., Grand Ledge, MI). Kentucky bluegrass was used because it grows by rhizomes which give it good recuperative potential (Beard, 1973). Perennial ryegrass was used because it has good wear tolerance and rapid germination (Beard, 1973).

Seed was broadcast at a rate of 20 g $m^{-2}$ and the area was fertilized weekly for 5 weeks using a Lebanon Country Club 13-25-12 fertilizer (Lebanon, PA) at a rate of 5 g P $m^{-2}$. The field was mown for the first time on 18 June 1999 to a height of 3.2 cm using a Toro GTSF lawn mower (Toro Co., Minneapolis, MN). Once the field had filled in, (five weeks after seeding) it was mown each

Table 1. Particle-size analysis of sand root zone.

| Size class | (mm) | (µm) | mesh # | % Ret† | % Passing‡ |
|---|---|---|---|---|---|
| Fine gravel | 12.700-2.000 | 2000 | 10 | 0.4 | 99.6 |
| Very coarse sand | 2.000-1.000 | 1000 | 18 | 7.2 | 92.4 |
| Coarse sand | 1.000-0.500 | 500 | 35 | 31.7 | 60.7 |
| Medium sand | 0.500-0.250 | 250 | 60 | 44.2 | 16.5 |
| Fine sand | 0.250-0.100 | 106 | 140 | 10.4 | 6.1 |
| Very fine sand | 0.100-0.050 | 53 | 270 | 1.0 | 5.1 |
| Silt | 0.050-0.002 | | | 1.3 | 3.8 |
| Clay | < 0.002 | | | 3.8 | 0 |

† Indicates the percent by weight of soil particles remaining in each size class.

‡ Indicates the percent by weight of soil particles passing through each sieve.

week using a zero turn rotary mower at a setting of 3.8 cm. In addition, Lebanon Country Club 18-3-18 fertilizer (Lebanon, PA) was applied weekly for the next 10 weeks at a rate of 5 g N $m^{-2}$. Possibly due to the herbicide application, bare areas needed to be overseeded on 22 June, 12 July, and 11 August 1999.
In 2000, the entire area was overseeded with the same seed mix on May 11 at a rate of 15 g $m^{-2}$.

*Plot maintenance*

The experimental design for this study was a 2 x 3 x 2 (mowing x fertilizing x cultivating) randomized complete block design with three replications. The two levels of mowing consisted of mowing once per week (Low) or twice per week (High) at a height of 3.8 cm. The three levels of fertilizer consisted of 5 g N $m^{-2}$ applied five times per year for a total of 25 g N $m^{-2}$ $yr^{-1}$ (Low Infrequent), 2.5 g N $m^{-2}$ applied 8 times per year for a total of 25 g of N $m^{-2}$ $yr^{-1}$ (Low Frequent), or 5 g N $m^{-2}$ applied 7 times per year for a total of 35 g N $m^{-2}$ $yr^{-1}$ (High). The two levels of cultivating consisted of zero (Low) or two times per year (High). These treatments are outlined in Table 2.

Mowing treatments began the first week of May 2000 and 2001. All plots were mown to a height of 3.8 cm using a Toro zero turn mower (Toro Co., Minneapolis, MN) once per week. Plots mown at the high level were mown an additional time each week with a reel mower set at 3.8 cm.

Fertilizer treatments began for all plots receiving the low frequent fertility application on 26 October 1999. On 10 November 1999, a 10 g N $m^{-2}$ of urea

**Table 2. Treatment applications for the sandy soil athletic field study, 1999-2001.**

| Treatment | Mowing† (times/week$^{-1}$) | Fertilizer‡ (g N m$^{-2}$ year$^{-1}$) | Cultivation§ |
|---|---|---|---|
| 1 | 1 | 25(LIF) | No |
| 2 | 1 | 25(LIF) | Yes |
| 3 | 1 | 25(LF) | No |
| 4 | 1 | 25(LF) | Yes |
| 5 | 1 | 35(High) | No |
| 6 | 1 | 35(High) | Yes |
| 7 | 2 | 25(LIF) | No |
| 8 | 2 | 25(LIF) | Yes |
| 9 | 2 | 25(LF) | No |
| 10 | 2 | 25(LF) | Yes |
| 11 | 2 | 35(High) | No |
| 12 | 2 | 35(High) | Yes |

† The sandy soil study was mown at 3.8 cm.

‡ The fertilizer treatments consisted of low infrequent, low frequent, and high levels. LIF = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; LF = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

§ Cultivation consisted of spring and fall core cultivation.

**Table 3. Annual fertilizer† schedule for sandy soil athletic field study, 1999-2001.**

| Year | Date | Low Infrequent | Low Frequent | High |
|---|---|---|---|---|
| | | | *g N m$^{-2}$ application$^{-1}$* | |
| 1999 | 26 October | | 2.5 | |
| | 11 November‡ | 5.0 | 5.0 | 5.0 |
| | **Total g N m$^{-2}$/yr.** | 5.0 | 7.5 | 5.0 |
| 2000 | 01 May | -- | 2.5 | -- |
| | 20 May | 5.0 | 2.5 | 5.0 |
| | 10 June | -- | 2.5 | 5.0 |
| | 01 July | 5.0 | 2.5 | 5.0 |
| | 01 August | -- | 2.5 | 5.0 |
| | 01 September | 5.0 | 2.5 | 5.0 |
| | 18October† | 5.0 | 5.0 | 5.0 |
| | 18 November‡ | 5.0 | 5.0 | 5.0 |
| | **Total g N m$^{-2}$/yr.** | 25 | 25 | 35 |
| 2001 | 03 May | | 2.5 | |
| | 22 May | 5.0 | 2.5 | 5.0 |
| | 12 June | -- | 2.5 | 5.0 |
| | 03 July | 5.0 | 2.5 | 5.0 |
| | 02 August | -- | 2.5 | 5.0 |
| | 03 September | 5.0 | 2.5 | 5.0 |
| | 19 October† | 5.0 | 5.0 | 5.0 |
| | 20 November‡ | 5.0 | 5.0 | 5.0 |
| | **Total g N m$^{-2}$** | 25 | 25 | 35 |

† Scotts® ProTurf fertilizer 18-5-18

‡ Dormant fertilization using urea (46-0-0).

(46-0-0) dormant feeding was given to all plots. For the years 2000 and 2001, Scotts 18-5-18 fertilizer (Scotts, Marysville, OH) was applied 5, 7, or 8 times per year (Table 3).

Fertilizer was applied with a drop spreader unless all plots were to receive at least 2.5 g of N $m^{-2}$. In this case, a rotary spreader was used to apply the 2.5 g of N $m^{-2}$ and a drop spreader was used to apply the additional 2.5 g of N $m^{-2}$. Plots were cultivated on 9 May and 28 November 2000, and 9 May and 05 December 2001 using a 1.2 m Toro walking greens aerator (Toro Co., Minneapolis, MN) with 7.6 x 0.64 cm hollow tines.

*Traffic Simulation*

For traffic simulation, each 2.7 x 2.7 m plot was split in half. In 2000, one half of the plot received Brinkman traffic simulation and the other half received no traffic. In 2001, one half received Brinkman traffic simulation and one half received Cady traffic simulation. The same half received Brinkman traffic in 2000 and 2001.

<u>Brinkman Traffic Simulator</u>

All treatments were subjected to simulated traffic using the Brinkman Traffic Simulator (BTS) in 2000 and 2001. The BTS imposes both compactive and minimal tearing forces on the turf by using full rollers with metal cleats. Two passes with the BTS equal the number of cleat marks made between the hash marks and between the 40 yard lines during one NFL football game (Cockerham

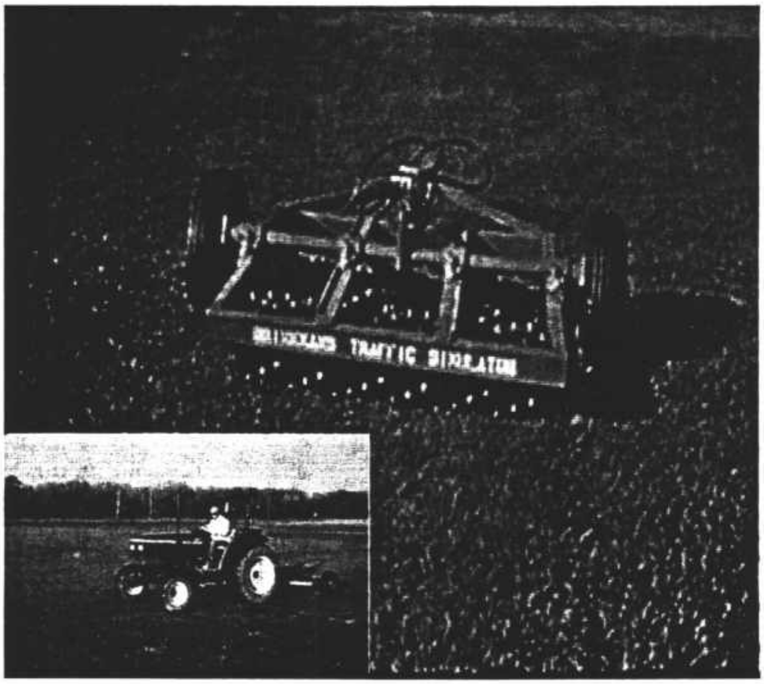

Figure 1. Brinkman Traffic Simulator

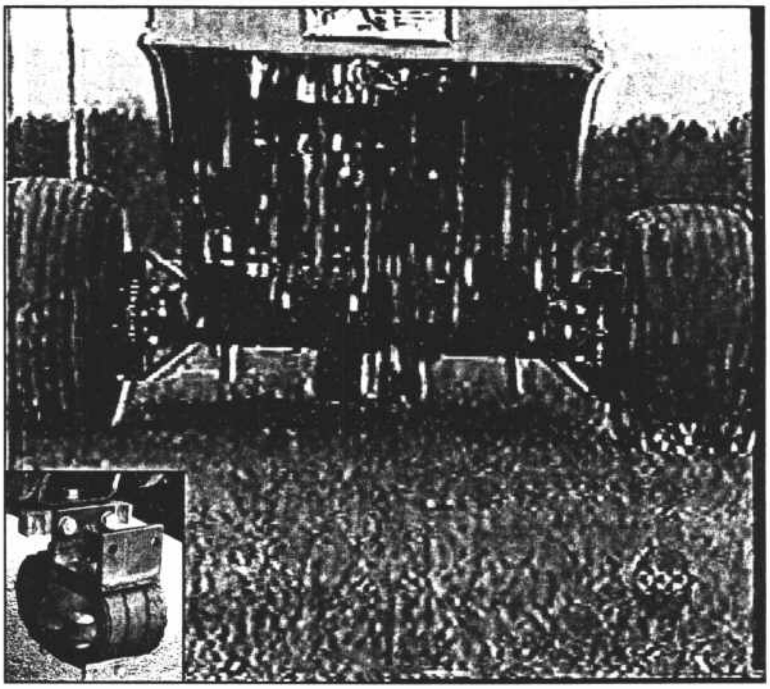

Figure 2. Cady Traffic Simulator

and Brinkman, 1990). For this research, two passes were made 2 times/week beginning on 24 August continuing through 16 November of 2000 and 27 August continuing through 19 November of 2001 for a total of 50 passes (25 games) each year.

Cady Traffic Simulator

All treatments were subjected to simulated traffic in 2001 using the Cady Traffic Simulator (CTS), which is a modified Jackobson core-aerifier that simulates traffic by imposing compactive and tearing forces on the turf. The CTS was recently built by Jack Cady for Michigan State University (Lansing, MI) because the wear from the BTS did not simulate actual human athletic traffic. The CTS uses recycled car tires with metal spikes to simulate the compactive and tearing forces being applied by a human foot (non-published data). The number of spike marks per square foot does not differ significantly from the BTS where two passes equal the cleat marks made between the hash marks of the 40 yard line during one National Football League game (Henderson, 2001, personal contact). Exact calibrations for the compaction and shearing effects of the CTS are currently underway. Cady traffic simulation took place on the half of the plot that was not trafficked by the Brinkman. Trafficking began 27 August continuing through 19 November for a total of 24 games for the 2001 season.

*Data Collection*

Turfgrass cover, color, quality, shear strength, and surface hardness ratings were made in September and October of 1999, and monthly from May through November of 2000 and 2001 for treatments trafficked by the BTS. Data was collected August through November 2001 for treatments trafficked by the CTS. The turfgrass cover ratings were based on a visual percent cover scale (0-100%). Beginning in 2001, density was also measured quantitatively by plant counts 100cm$^{-2}$. Quality and color were rated on a visual (1-9) scale. For quality ratings, a rating of one was given for dead or no turf, six for acceptable turf, and nine for excellent turf. For color, a rating of one was given for yellow or brown turf, six for acceptable turf color, and nine for dark green. Beginning in July of 2001, color was assessed using the Spectrum™ FieldScout chlorophyll meter (Spectrum Technologies, Inc., Plainfield, IL). Shear strength was measured using an Eijelkamp shear vane (Eijkelkamp, Giesbeck, The Netherlands) and beginning in August of 2001, shear strength was also assessed using the Shear Clegg (Dr. Baden Clegg Pty Ltd., Perth, Australia). Both tools were used because they measure different aspects of shear strength. The Eijkelkamp shear vane measures rotational shear strength, thereby effecting the plants and plant tillers. The shear/clegg measures lateral shear strength, thereby having more of an effect on plant displacement from the soil. Surface hardness was measured using a 2.5 kg Clegg Impact Hammer (Lafayette Instrument Co., Lafayette, IN).

## Results and Discussion

*Brinkman Traffic Simulator*

All data was analyzed as a factorial, randomized complete block design using the Agriculture and Resource Management program. Results and discussion are presented by maintenance practice and then subdivided by the effect each practice had on the evaluation criteria. Interaction results and discussion are at the end of the chapter. Because of variability within data collection devices and because statistical significance can contrast with actual significance, we designated surface hardness and shear strength measurements between treatments to be inconclusive if differences were less then 5 $g_{max}$ 5 Nm. Comparisons between treatments for plant count and percent cover ratings are listed in Appendix C. A cost analysis for each treatment is also listed in Appendix C.

## Mowing

*Plant counts*

Plots mown twice per week yielded 15-22 % higher plant counts then plots mown once per week beginning in July and continuing through November of 2001 (Table 4). The increase in plant counts for plots mown twice per week may have been because mowing, at the proper height and frequency stimulates shoot growth and tillering (Crider 1955; Juska, 1961). However, if more then 30% of the leaf blade of a plant is removed in a single mowing, then all, or nearly all, of

**Table 4. Significance of treatment effects and Brinkman traffic on plant counts (plants 100cm$^{-2}$)† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 5/08 | 6/04 | 7/19 | 8/25 | 10/01 | 10/15 | 10/29 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|---|---|---|
| Mowing | | | | | | | | | |
| 1x/week | 110.0 | 210.9 | 212.5 | 171.1 | 166.7 | 145.1 | 122.9 | 127.8 | 109.0 |
| 2x/week | 116.2 | 226.6 | 238.4 | 201.6 | 213.9 | 172.9 | 144.0 | 152.3 | 143.1 |
| Significance | ns | ns | * | ** | *** | *** | ** | ** | *** |
| Fertilization‡ | | | | | | | | | |
| Low infrequent | 105.1 | 201.0 | 213.5 | 178.5 | 182.3 | 149.7 | 126.7 | 133.3 | 111.5 |
| Low frequent | 127.4 | 239.9 | 230.6 | 191.0 | 186.8 | 160.1 | 133.0 | 148.3 | 121.2 |
| High | 106.8 | 215.3 | 232.3 | 189.6 | 201.7 | 167.4 | 140.6 | 138.5 | 145.5 |
| Significance | ns | * | ns | ns | ns | ns | ns | ns | ** |
| Cultivation | | | | | | | | | |
| 0x/yr$^{-1}$ | 116.2 | 224.1 | 225.9 | 185.9 | 192.1 | 165.1 | 129.4 | 140.1 | 131.0 |
| 2x/yr$^{-1}$ | 110.0 | 213.4 | 225.0 | 186.8 | 188.4 | 153.0 | 137.5 | 140.1 | 121.1 |
| Significance | ns | ns | ns | ns | ns | ns | ns | ns | Ns |
| # of Games | - | - | - | - | 10 | 15 | 19 | 22 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Ns Not significant at the 0.10 probability level.

† Plants were hand counted using three subsamples per treatment.

‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

the plants energy goes into shoot production and negligible amounts, if any go into root, rhizome, or tiller initiation (Crider, 1955). Thus, once traffic simulation began, the root systems of the plants mown once per week may not have been as strong as the root systems of the plants mown twice per week, because all of their energy was being put towards shoot development. Therefore, when put under stress, these plants were removed from the ground much more easily causing a decrease in plant counts. Between the rating dates of 01 and 15 October, there was a large drop in plant counts. This may have been because as traffic simulation continued, the optimal growth period for plant recovery was coming to an end.

**Turfgrass cover**

No differences were seen between mowing treatments in 2000. However, in 2001, mowing twice per week yielded a 2-12% increase in turfgrass cover ratings in every month except July and August (Tables 5 and 6). The year 2000 showed no differences in turfgrass cover with respect to mowing frequency. In 2001, plots mown twice per week had higher turfgrass cover ratings in May and again on 01 October through 16 November (although the June and September ratings are statistically significant, the June ratings of 90 and 92% and the September ratings of 96 and 98% for the low and high mow treatments respectively, were too close to accept statistical significance). From June through early August, plant growth was fairly slow because growing conditions were not optimal. As a result, differences between treatments were less obvious because less leaf tissue was being removed with each mowing, thus less stress

**Table 5. Significance of treatment effects and Brinkman traffic on turfgrass cover† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 1999-2000.**

| | 1999 | | | 2000 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9/15 | 10/15 | 11/15 | 5/15 | 6/15 | 7/15 | 8/15 | 9/15 | 10/13 | 10/20 | 10/27 | 11/15 |
| Mowing | | | | | | | | | | | | |
| 1x/week | 97 | 96 | 96 | 78 | 97 | 98 | 100 | 100 | 80 | 81 | 80 | 78 |
| 2x/week | 96 | 95 | 96 | 77 | 96 | 99 | 100 | 100 | 82 | 80 | 82 | 80 |
| Significance | na | na | na | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Fertilization‡ | | | | | | | | | | | | |
| Low infrequent | 95 | 94 | 95 | 72 | 95 | 97 | 100 | 100 | 72 | 74 | 73 | 72 |
| Low frequent | 97 | 97 | 97 | 86 | 99 | 99 | 100 | 100 | 85 | 84 | 84 | 83 |
| High | 96 | 95 | 95 | 75 | 97 | 99 | 100 | 100 | 86 | 83 | 85 | 83 |
| Significance | ns | ns | ns | *** | *** | *** | ns | ns | *** | *** | *** | *** |
| Cultivation | | | | | | | | | | | | |
| 0x/yr$^{-1}$ | 97 | 96 | 96 | 77 | 97 | 99 | 100 | 100 | 79 | 79 | 79 | 78 |
| 2x/yr$^{-1}$ | 96 | 95 | 96 | 78 | 96 | 98 | 100 | 100 | 82 | 81 | 82 | 80 |
| Significance | na | na | na | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| # of Games | - | - | - | - | - | - | - | 7 | 15 | 17 | 19 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
Na Not applicable, prior to treatment application.
† Turf cover was visually estimated on a percent (0-100%) scale.
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

**Table 6. Significance of treatment effects and Brinkman traffic on turfgrass cover† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001.**

| | 5/15 | 6/15 | 7/15 | 8/25 | 9/12 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mowing | | | | | | | | | | |
| 1x/week | 63 | 90 | 98 | 100 | 96 | 77 | 78 | 66 | 48 | 35 |
| 2x/week | 75 | 92 | 99 | 100 | 98 | 85 | 83 | 72 | 59 | 44 |
| Significance | *** | * | ns | ns | *** | *** | ** | *** | *** | *** |
| Fertilization‡ | | | | | | | | | | |
| Low infrequent | 55 | 88 | 97 | 100 | 97 | 77 | 76 | 64 | 47 | 36 |
| Low frequent | 81 | 93 | 100 | 100 | 97 | 81 | 79 | 69 | 51 | 36 |
| High | 72 | 92 | 99 | 100 | 98 | 85 | 86 | 75 | 63 | 46 |
| Significance | *** | *** | ** | ns | ns | *** | *** | *** | *** | *** |
| Cultivation | | | | | | | | | | |
| 0x/yr$^{-1}$ | 67 | 91 | 99 | 100 | 97 | 80 | 80 | 67 | 52 | 37 |
| 2x/yr$^{-1}$ | 71 | 91 | 99 | 100 | 97 | 82 | 81 | 72 | 56 | 42 |
| Significance | ns | ns | ns | ns | ns | ns | ns | ** | ** | *** |
| # of Games | - | - | - | - | 5 | 10 | 14 | 18 | 22 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
† Turf cover was visually estimated on a percent (0-100%) scale.
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

was put upon the plants. Therefore, mowing frequency effects on turfgrass cover really did not begin to show until turfgrass growth slowed and traffic simulation continued. At this time, plots mown twice per week had higher turfgrass cover ratings. These results mirror what was seen in plant count ratings. Thus, similar to plant counts, this effect most likely occurred as a result of a weakened root system.

**Surface hardness**

Statistical significance occurred for mowing once per week versus twice per week in May (50.7, 48.6), August (54.2, 57.5), and November (57.7, 56.0) of 2000 and June (43.3, 44.6) of 2001 (Tables 7 and 8). However, because the actual difference between surface hardness ratings was so small (less then 5 $G_{max}$), it is inconclusive as to whether or not mowing frequency had an effect on surface hardness characteristics. Rogers and Waddington (1990) also found that cutting height and biomass have little effect on surface hardness.

**Shear vane**

Statistical significance occurred for mowing once per week versus twice per week in August of 2000 (20.0, 21.4), and August (14.4, 14.8) and September of 2001 (18.7, 17.6) (Table 9 and 10). These results indicate there is an increase of shear strength following summer mowing. However, because the actual difference between shear strength ratings was so small, it is inconclusive as to whether or not mowing frequency had an effect on shear vane ratings. Previous research has shown that for treatment effects to be actually significant, the

**Table 7. Significance of treatment effects and Brinkman traffic on surface hardness ($G_{max}$)† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 1999-2000.**

| | 1999 | | 2000 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10/15 | 11/15 | 5/15 | 6/15 | 7/15 | 8/15 | 9/15 | 10/15 | 11/15 |
| Mowing | | | | | | | | | |
| 1x/week | 66.3 | 67.2 | 50.7 | 62.3 | 61.1 | 54.2 | 61.1 | 64.3 | 57.7 |
| 2x/week | 65.3 | 63.3 | 48.6 | 63.7 | 61.4 | 57.5 | 61.7 | 62.4 | 56.0 |
| Significance | na | na | ** | ns | ns | ** | ns | ns | ** |
| Fertilization‡ | | | | | | | | | |
| Low infrequent | 65.0 | 65.7 | 50.1 | 63.4 | 62.4 | 57.6 | 61.0 | 63.7 | 57.7 |
| Low frequent | 66.1 | 65.4 | 47.6 | 60.4 | 58.4 | 53.1 | 62.3 | 64.8 | 56.3 |
| High | 66.3 | 64.6 | 51.2 | 65.3 | 63.0 | 56.9 | 60.7 | 61.7 | 56.4 |
| Significance | ns | ns | *** | *** | *** | ** | ns | ns | ns |
| Cultivation | | | | | | | | | |
| $0x/yr^{-1}$ | 65.7 | 64.2 | 50.0 | 67.3 | 63.4 | 57.8 | 62.9 | 65.3 | 57.6 |
| $2x/yr^{-1}$ | 65.9 | 66.2 | 49.3 | 58.7 | 59.1 | 54.0 | 59.7 | 61.4 | 56.0 |
| Significance | na | na | ns | *** | *** | ** | *** | * | * |
| # of Games | - | - | - | - | - | - | 7 | 15 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
Na Not applicable, prior to treatment application.
† Surface hardness was measured using the Clegg Impact Soil Tester in gravity deceleration ($G_{max}$).
‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

**Table 8. Significance of treatment effects and Brinkman traffic on turfgrass surface hardness ($G_{max}$)† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001.**

| | 5/15 | 6/15 | 7/15 | 8/25 | 9/12 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mowing | | | | | | | | | | |
| 1x/week | 40.2 | 43.3 | 45.9 | 45.0 | 44.0 | 50.1 | 46.4 | 48.9 | 51.1 | 50.3 |
| 2x/week | 40.4 | 44.6 | 45.9 | 45.7 | 43.4 | 49.3 | 47.4 | 49.7 | 50.8 | 50.3 |
| Significance | ns | * | ns | ns | ns | ns | ns | ns | ns | ns |
| Fertilization‡ | | | | | | | | | | |
| Low infrequent | 40.9 | 44.8 | 46.8 | 45.0 | 43.8 | 51.7 | 46.8 | 49.6 | 52.1 | 50.6 |
| Low frequent | 39.7 | 43.0 | 45.3 | 46.0 | 44.4 | 48.6 | 47.1 | 49.4 | 50.6 | 49.7 |
| High | 40.3 | 44.1 | 45.7 | 45.1 | 43.0 | 48.8 | 46.9 | 48.8 | 50.1 | 50.6 |
| Significance | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Cultivation | | | | | | | | | | |
| $0x/yr^{-1}$ | 42.6 | 47.0 | 48.2 | 46.1 | 45.9 | 50.8 | 48.8 | 50.5 | 52.0 | 52.0 |
| $2x/yr^{-1}$ | 38.0 | 40.9 | 43.6 | 44.6 | 41.6 | 48.6 | 45.0 | 48.1 | 49.8 | 48.5 |
| Significance | *** | *** | *** | ns | *** | ns | *** | ** | * | *** |
| # of Games | - | - | - | - | 5 | 10 | 14 | 18 | 22 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
† Surface hardness was measured using the Clegg Impact Soil Tester in gravity deceleration ($G_{max}$).
‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

**Table 9. Significance of treatment effects and Brinkman traffic on turfgrass Eijelkamp shear strength (Nm)† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 1999-2000.**

| | 1999 | | 2000 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10/15 | 11/15 | 5/15 | 6/15 | 7/15 | 8/15 | 9/15 | 10/15 | 11/15 |
| Mowing | | | | | | | | | |
| 1x/week | 13.5 | 14.4 | 17.4 | 19.0 | 17.9 | 20.0 | 22.6 | 24.1 | 15.3 |
| 2x/week | 13.7 | 14.2 | 16.8 | 19.2 | 18.4 | 21.4 | 22.5 | 24.4 | 16.0 |
| Significance | na | na | ns | ns | ns | * | ns | ns | ns |
| Fertilization‡ | | | | | | | | | |
| Low infrequent | 13.0 | 13.2 | 16.7 | 19.4 | 17.8 | 20.0 | 22.2 | 22.2 | 14.9 |
| Low frequent | 13.7 | 16.1 | 16.6 | 18.1 | 18.1 | 21.6 | 23.5 | 26.4 | 17.2 |
| High | 14.1 | 13.7 | 18.0 | 20.0 | 18.5 | 20.2 | 22.1 | 24.1 | 14.9 |
| Significance | ns | ns | ns | ** | ns | ns | ns | *** | * |
| Cultivation | | | | | | | | | |
| 0x/yr$^{-1}$ | 13.8 | 14.1 | 17.8 | 20.4 | 19.1 | 21.7 | 23.3 | 25.0 | 15.2 |
| 2x/yr$^{-1}$ | 13.4 | 14.6 | 16.4 | 17.8 | 17.1 | 19.5 | 21.9 | 23.4 | 16.1 |
| Significance | na | na | ** | *** | *** | ** | ** | ns | ns |
| # of Games | - | - | - | - | - | - | 7 | 15 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
Na Not applicable, prior to treatment application.
† Shear strength was measured using the Eijelkamp Shear vane in Newton meters (Nm).
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

**Table 10. Significance of treatment effects and Brinkman traffic on turfgrass Eijelkamp shear strength† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001.**

| | 5/15 | 6/15 | 7/15 | 8/25 | 9/12 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mowing | | | | | | | | | | |
| 1x/week | 26.0 | 21.2 | 20.3 | 14.4 | 18.7 | 17.6 | 17.0 | 18.1 | 13.4 | 12.1 |
| 2x/week | 25.9 | 21.4 | 20.7 | 14.8 | 17.6 | 17.3 | 16.8 | 17.3 | 13.0 | 11.7 |
| Significance | ns | ns | ns | * | ** | ns | ns | ns | ns | ns |
| Fertilization‡ | | | | | | | | | | |
| Low infrequent | 23.6 | 20.7 | 19.9 | 14.4 | 18.3 | 16.9 | 16.1 | 17.7 | 13.0 | 11.7 |
| Low frequent | 27.3 | 22.1 | 20.9 | 14.8 | 18.2 | 17.6 | 17.0 | 18.0 | 13.5 | 11.9 |
| High | 26.9 | 21.1 | 20.6 | 14.7 | 17.9 | 17.8 | 17.6 | 17.3 | 13.1 | 12.1 |
| Significance | ns | ns | ns | ns | ns | * | ** | ns | ns | ns |
| Cultivation | | | | | | | | | | |
| 0x/yr$^{-1}$ | 26.4 | 22.4 | 21.3 | 15.2 | 18.4 | 17.2 | 17.0 | 17.1 | 13.1 | 12.0 |
| 2x/yr$^{-1}$ | 25.5 | 20.3 | 19.6 | 14.0 | 17.9 | 17.7 | 16.9 | 18.3 | 13.3 | 11.8 |
| Significance | ns | *** | *** | *** | ns | ns | ns | ** | ns | ns |
| # of Games | - | - | - | - | 5 | 10 | 14 | 18 | 22 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
† Shear strength was measured using the Eijelkamp Shear vane in Newton meters (Nm).
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

difference between ratings should be greater then 5 Nm (Stier and Rogers, 2001).

**Shear clegg**

Although plots mown once per week had statistically higher shear/clegg ratings then plots mown twice per week, (23.5 vs. 20.4), further research is warranted to make any definite conclusions. Given this effect only occurred at this rating date, the differences between ratings was very small, and that plant counts and turfgrass cover were higher on plots mown twice per week (Tables 4 and 6), the reason for differences is most likely chance by sampling location rather then mowing frequency (Table 11).

**Quality**

Mowing once per week had a higher quality rating then mowing twice per week in July of 2000. Although these ratings were statistically significant, the actual ratings of 7.8 and 7.6 for the low and high mowing frequencies respectively, did not differ enough to warrant discussion of cultivation effects on turfgrass quality for this date. Because the ratings were qualitative and only occurred once, the difference was probably incidental.

However, mowing twice per week had a higher quality rating then mowing once per week from November 2000 through June of 2001 and again on 01 October through November 2001 (Tables 12 and 13). This effect probably occurred because the increased mowing frequency caused the older leaf tissue to be removed and newer leaf tissue to emerge. Thus mowing, in combination

**Table 11. Significance of treatment effects and Brinkman traffic on turfgrass Clegg/shear strength (Nm)[†] on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001.**

| | 9/12 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 22.4 | 30.5 | 22.6 | 23.5 | 27.8 | 27.4 |
| 2x/week | 21.5 | 30.2 | 22.6 | 20.4 | 27.7 | 26.4 |
| Significance | ns | ns | ns | *** | ns | ns |
| Fertilization[‡] | | | | | | |
| Low infrequent | 23.2 | 32.6 | 24.4 | 23.4 | 28.5 | 26.9 |
| Low frequent | 22.3 | 29.2 | 22.6 | 21.9 | 27.7 | 27.4 |
| High | 20.4 | 29.3 | 20.8 | 20.5 | 27.0 | 26.4 |
| Significance | ns | ** | ns | * | ns | ns |
| Cultivation | | | | | | |
| 0x/yr$^{-1}$ | 21.0 | 31.5 | 23.1 | 21.1 | 27.5 | 27.3 |
| 2x/yr$^{-1}$ | 22.9 | 29.2 | 22.1 | 22.8 | 27.9 | 26.5 |
| Significance | ns | ** | ns | ns | ns | ns |
| # of Games | 5 | 10 | 14 | 18 | 22 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
† Shear strength was measured using the shear/clegg in Newton meters.
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

**Table 12. Significance of treatment effects and Brinkman traffic on turfgrass quality† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 1999-2000.**

| | 1999 | | 2000 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10/15 | 11/15 | 5/15 | 6/15 | 7/15 | 8/15 | 9/15 | 10/15 | 11/15 |
| Mowing | | | | | | | | | |
| 1x/week | 6.8 | 6.2 | 5.9 | 7.8 | 7.8 | 7.3 | 7.5 | 6.3 | 6.4 |
| 2x/week | 6.4 | 5.9 | 5.8 | 8.0 | 7.6 | 7.3 | 7.3 | 6.5 | 7.2 |
| Significance | na | na | ns | ns | ** | ns | ns | ns | *** |
| Fertilization‡ | | | | | | | | | |
| Low infrequent | 6.3 | 6.0 | 5.3 | 7.5 | 7.1 | 6.8 | 7.0 | 5.6 | 6.3 |
| Low frequent | 7.0 | 6.4 | 6.6 | 8.5 | 7.9 | 7.5 | 7.3 | 6.6 | 6.9 |
| High | 6.6 | 5.8 | 5.5 | 7.8 | 8.1 | 7.7 | 7.9 | 6.9 | 7.2 |
| Significance | *** | *** | *** | *** | *** | ns | *** | *** | *** |
| Cultivation | | | | | | | | | |
| 0x/yr$^{-1}$ | 6.7 | 6.0 | 5.9 | 7.9 | 7.7 | 7.3 | 7.4 | 6.3 | 6.7 |
| 2x/yr$^{-1}$ | 6.6 | 6.1 | 5.8 | 7.9 | 7.7 | 7.3 | 7.4 | 6.5 | 6.8 |
| Significance | na | na | ns | ns | ns | ns | ns | ns | ns |
| # of Games | - | - | - | - | - | - | 7 | 15 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
Na Not applicable, prior to treatment application.
† Quality was rated visually on a 1-9 scale: 1=necrotic turf/bare soil, 9=dense, uniform turf with acceptable color (color ≥ 5).
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

**Table 13. Significance of treatment effects and Brinkman traffic on turfgrass quality† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001.**

| | 5/15 | 6/15 | 7/15 | 8/25 | 9/12 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mowing | | | | | | | | | | |
| 1x/week | 6.6 | 7.1 | 8.0 | 8.6 | 8.5 | 7.0 | 6.6 | 6.3 | 5.1 | 5.5 |
| 2x/week | 7.1 | 7.6 | 8.0 | 8.7 | 8.5 | 7.5 | 7.0 | 7.0 | 6.3 | 6.3 |
| Significance | *** | *** | ns | ns | ns | *** | *** | *** | *** | *** |
| Fertilization‡ | | | | | | | | | | |
| Low infrequent | 6.4 | 7.0 | 8.0 | 8.8 | 8.5 | 6.9 | 6.3 | 6.0 | 5.3 | 5.8 |
| Low frequent | 7.2 | 7.4 | 8.0 | 8.6 | 8.5 | 6.9 | 6.5 | 6.5 | 5.4 | 5.3 |
| High | 7.0 | 7.7 | 8.0 | 8.6 | 8.5 | 7.9 | 7.6 | 7.5 | 6.4 | 6.5 |
| Significance | *** | *** | ns | ns | ns | *** | *** | *** | *** | *** |
| Cultivation | | | | | | | | | | |
| 0x/yr$^{-1}$ | 6.8 | 7.3 | 8.0 | 8.6 | 8.5 | 7.2 | 6.6 | 6.4 | 5.7 | 5.8 |
| 2x/yr$^{-1}$ | 7.0 | 7.4 | 8.0 | 8.7 | 8.5 | 7.3 | 7.0 | 6.8 | 5.7 | 6.0 |
| Significance | ns | ns | ns | ns | ns | ns | ** | ** | ns | ns |
| # of Games | - | - | - | - | 5 | 10 | 14 | 18 | 22 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
† Quality was rated visually on a 1-9 scale: 1=necrotic turf/bare soil, 9=dense, uniform turf with acceptable color (color ≥ 5).
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

with traffic, likely stimulated more growth, resulting in greater turfgrass cover (Table 4 and 6), which provided a more uniform turf appearance. There was probably no significance between treatments during July, August, and mid-September because traffic simulation had not begun.

## Color

Although statistical significance occurred between color ratings in August (7.2, 6.8), September (7.4, 7.7), and October of 2000 (6.2, 6.5), and June (7.3, 7.6) and November (4.3, 4.6) of 2001 the actual difference between ratings is not enough to warrant further discussion or acceptation of statistical significance (Tables 14 and 15). However, the 15 November 2000 (7.0, 7.7), and the July (7.1, 7.7), August (7.8, 8.2) and September 2001 (6.6, 7.2) ratings varied enough to warrant discussion (color ratings taken after June of 2001 were done quantitatively with the Spectrum™ FieldScout chlorophyll meter--Spectrum Technologies, Inc., Plainfield, IL). In November of 2000 and July, August, and September of 2001, color ratings were higher for plots mown twice per week. The ratings may have been higher for these plots on these dates because the increased mowing frequency caused the older leaf tissue to be removed and newer leaf tissue to emerge; thereby causing the color to appear darker.

## Fertilization

*Plant counts*

**Table 14. Significance of treatment effects and Brinkman traffic on turfgrass color† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 1999-2000.**

| | 1999 | | 2000 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10/15 | 11/15 | 5/15 | 6/15 | 7/15 | 8/15 | 9/15 | 10/15 | 11/15 |
| Mowing | | | | | | | | | |
| 1x/week | 6.6 | 6.3 | 6.3 | 7.9 | 7.1 | 7.2 | 7.7 | 6.2 | 7.0 |
| 2x/week | 6.6 | 6.3 | 6.2 | 8.0 | 7.2 | 6.8 | 7.4 | 6.5 | 7.7 |
| Significance | na | na | ns | ns | ns | ** | ** | ** | *** |
| Fertilization‡ | | | | | | | | | |
| Low infrequent | 6.3 | 6.0 | 5.6 | 7.8 | 6.8 | 6.3 | 7.3 | 5.8 | 6.9 |
| Low frequent | 7.3 | 6.8 | 7.3 | 8.3 | 7.0 | 7.2 | 7.4 | 6.5 | 7.6 |
| High | 6.3 | 6.0 | 5.9 | 7.8 | 7.6 | 7.5 | 8.0 | 6.8 | 7.5 |
| Significance | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Cultivation | | | | | | | | | |
| $0x/yr^{-1}$ | 6.6 | 6.3 | 6.3 | 8.0 | 7.1 | 6.9 | 7.5 | 6.4 | 7.3 |
| $2x/yr^{-1}$ | 6.7 | 6.3 | 6.3 | 8.0 | 7.2 | 7.1 | 7.7 | 6.4 | 7.4 |
| Significance | na | na | ns | ns | ns | ns | * | ns | ns |
| # of Games | - | - | - | - | - | - | 7 | 15 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
Na Not applicable, prior to treatment application.
† Color was rated visually on a 1-9 scale: 1 = dead/no turf, 9 = uniform dark green turf.
‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

**Table 15. Significance of treatment effects and Brinkman traffic on turfgrass color† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001.**

| | 5/15 | 6/15 | 7/15 | 8/25 | 9/12 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mowing | | | | | | | | | | |
| 1x/week | 6.9 | 7.3 | 7.1 | 7.8 | 6.6 | 6.7 | 6.3 | 5.8 | 4.5 | 4.3 |
| 2x/week | 7.1 | 7.6 | 7.7 | 8.2 | 7.2 | 7.2 | 6.6 | 6.0 | 4.7 | 4.6 |
| Significance | ns | *** | ** | *** | *** | ns | ns | Ns | ns | *** |
| Fertilization‡ | | | | | | | | | | |
| Low infrequent | 6.5 | 7.0 | 7.1 | 7.8 | 6.9 | 6.3 | 5.9 | 5.4 | 4.3 | 4.3 |
| Low frequent | 7.3 | 7.5 | 7.1 | 8.0 | 6.7 | 7.0 | 6.5 | 6.0 | 4.3 | 4.2 |
| High | 7.2 | 7.8 | 7.9 | 8.2 | 7.1 | 7.7 | 7.0 | 6.3 | 5.2 | 4.9 |
| Significance | *** | *** | *** | ns | ns | *** | *** | ** | ** | *** |
| Cultivation | | | | | | | | | | |
| $0x/yr^{-1}$ | 6.9 | 7.5 | 7.3 | 7.9 | 6.9 | 6.8 | 6.3 | 5.8 | 4.4 | 4.4 |
| $2x/yr^{-1}$ | 7.1 | 7.4 | 7.4 | 8.1 | 7.0 | 7.1 | 6.5 | 6.0 | 4.8 | 4.5 |
| Significance | ** | ns | ns | ns | ns | ns | ns | Ns | ns | ns |
| # of Games | - | - | - | - | 5 | 10 | 14 | 18 | 22 | 25 |

*,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not significant at the 0.10 probability level.
† October 2000 through June 2001 color was rated visually on a 1-9 scale: 1 = dead/no turf, 9 = uniform dark green turf. July through November 2001 color was rated using the Spectrum™ FieldScout chlorophyll meter (Spectrum Technologies, Inc., Plainfield, IL).
‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

Fertilizing at the low frequent (LF) rate gave a 16 % increase in plant counts over fertilizing at the low infrequent (LIF) rate in June of 2001. Fertilizing at the high (HF) rate of fertilizer yielded a 24 % increase in plant counts over theLIF rate of fertilizer on 16 November 2001 (Table 4). The reason the LF rate of fertilizer showed an increase in plant counts over plants fertilized at the LIF level in June of 2001 could be because the plants in the LF fertilizer regime were getting the nitrogen needed for growth more frequently. Although plots in the LIF regime were getting more nutrients per application, they were not getting the nutrients as frequently (plots in the LIF regime had 1 application, plots in the LF regime had 4 applications and plots in the HF regime had 2 applications). Thus, the LIF level of fertilizer may provide enough annual nitrogen, but in a sand rootzone, the nutrients are not held in the soil long enough to be readily available for plant absorption (Rogers *et al.,* 1996).

In November, continued traffic simulation caused the variance between treatments to lessen. By the last rating date, only plants receiving the HF level of fertilizer had higher plant counts then plants receiving the LIF regime (Table 4). Plants in the LF fertilizer regime had higher plant counts then plants in the LIF regime however, the difference was not significant. The reason plant counts were highest in the high fertilizer regime could be because plants needed more nutrients with each application to withstand the wear. In addition, by the end of traffic simulation, plants in the HF fertilizer regime only had one less fertilizer application. Because application frequencies were similar by the 16 November

2001 rating date, the increase in plant counts could most likely be due to fertilizer amount rather then fertilizer frequency.

**Turfgrass cover**

In May and June of 2000, fertilizing at the LF rate had a higher turfgrass cover rating then fertilizing at either the low infrequent or HF rate. Also in June of 2000, the HF rate of fertilizer gave a higher turf cover rating then the LIF rate of fertilizer. This occurred again on 01 October of 2001. Both the LF and HF rate of fertilizer gave higher turfgrass cover ratings then the LIF rate in July and 13 October through 15 November of 2000 and again in May and June of 2001. Fertilizing at the LF rate yielded higher turf cover ratings then just the LIF rate in July of 2001. The HF rate of fertilizer gave higher turfgrass cover ratings then either of the other two fertilizer levels beginning on 15 October and continuing through 16 November 2001 (Tables 5 and 6).

Although statistical significance occurred for fertilizing at the LIF, LF and HF rate in June (95, 99, 97) and July (97, 99, 99) of 2000 and June (88, 93, 92) and July of 2001 (97, 100, 99), the actual difference in qualitative ratings of turfgrass cover between treatments on these dates do not vary enough to warrant further discussion or acceptation of statistical significance.

In May of 2000, the LF level of fertilizer increased turfgrass cover by at least 9% over either of the other two levels most likely because plots in this regime were the only ones to receive fertilizer by this rating date. Therefore, these plots appeared denser. After all plots received an application, the effect diminished.

On 13 October 2000 and continuing through 15 May 2001 both the LF and the HF level of fertilizer yielded a 9-26% increase in turfgrass ratings then the LIF rate of fertilizer. The reason both levels of fertilizer were more effective at increasing density then the LIF level could be because for both of these levels, nutrients were provided on a fairly frequent basis. Given this, perhaps fertilizing at the LF rate is just as beneficial to the plant as fertilizing at the HF rate. The lesser amount, yet higher frequency of application in the LF fertilizer regime may have provided plants with adequate available nutrients so they were just as healthy as plants fertilized at the HF level. Therefore, fertilizing at the low rate is enough for annual nitrogen requirements; however, because this study was on a sand based rootzone, the light and more frequent fertilizer applications are necessary.

This effect was somewhat modified in 01 October 2001, when the HF fertilizer level increased turfgrass cover by 8% over the LIF fertilizer levels. Continuing with this effect, beginning on the next rating date and continuing through the rest of traffic simulation, the HF fertilizer level had higher turfgrass cover ratings then either of the other fertilizer levels. The reason the effect of fertilizer level was modified from 2000 may be because a half-pound of nitrogen per application did not provide enough nutrients for plants in the second year of intense traffic. Similar results were also found for the Cady traffic simulation.

This data shows that by fertilizing at the HF rate, the turfgrass will at least appear to be denser for an additional 30 passes.

**Surface Hardness**

Fertilizing at the LF rate yielded a lower surface hardness then fertilizing at either the HF or LIF rate in May through August of 2000 (Tables 7 and 8). The LF rate of fertilizer yielded lower surface hardness ratings on these dates because the higher frequency of fertilizer application may have caused plants in this regime to have increased shoot growth (Juska, 1967; Johnston, 1984). The increased shoot growth provided for a slight increase in turfgrass cover, which previous research has shown to have an inverse relationship with surface hardness (Rogers *et al.,* 1988). This could have caused a slight decrease in surface hardness ratings. However, once traffic began these effects were indiscernible.

**Shear vane**

Statistical significance occurred for the LIF, LF, and HF fertilizer levels in June of 2000 (19.4, 18.1 and 20.0), 01 October (16.9, 17.6, and 17.8) and 15 October of 2001 (16.1, 17.0, and 17.6) (Tables 9 and 10). However, because the actual difference between shear strength ratings were so small, it is inconclusive whether or not fertilizer rate and frequency had an effect on shear vane ratings.

However, the October and November 2000 ratings did vary enough to show a slight trend. In October, the LF fertilizer had higher shear strength ratings then the LIF level and in November the LF level had higher ratings then either of the other fertilizer levels. This could be because plots in the LF and HF fertilizer regime had higher turfgrass cover over plots in the LIF fertilizer regime (Table 5). In addition, the increased frequency of fertilizer application potentially increased rooting and shoot growth (Kussow, 2000; Bredakis and Roberts, 1959). Therefore, when rotational shear strength was measured, plants in the LF regime yielded higher ratings (Tables 9 and 10). These results are supported by previous athletic turfgrass research which has demonstrated that increased turf cover leads to increased rooting (Rogers *et al.,* 1988) and that rooting has a considerable effect on turfgrass shear strength-especially in sand root zones (Chen *et al.,* 1980). Thus, plants in the LF fertilizer regime benefited from fertilizer being supplied on a frequent basis; the overall health of these plants was maintained, even at lower nitrogen levels.

**Shear/clegg**

Fertilizing at the LIF rate gave a higher shear strength rating then fertilizing at either the LF or the HF rate of fertilizer on 01 October 2001 and a higher shear strength ratings then fertilizing at the HF rate on 26 October 2001 (Table 11). Although the LIF rate of fertilizer had increased shear/clegg ratings for two sampling dates, the increase was minimal. However, a possible reason for the LIF fertilizer rate having higher shear strength ratings may be because of increased rooting and shoot growth (Bredakis and Roberts, 1959; Juska, 1967).

The reason the shear/clegg ratings showed different statistical significance between fertilizer treatments then the shear vane could be because the shear/clegg measures lateral shear strength, which is more of a reflection on rooting depth while the shear vane measures rotational shear strength, which is more of a reflection on plant and plant tiller tensile strength.

## Quality

Fertilizer levels had a significant effect on quality ratings at almost all of the ratings dates (Tables 12 and 13). However, there was little consistancy between ratings. At times, the LIF had the highest ratings, but the majority of the time, either the LF or the HF rate of fertilizer had higher ratings. This was probably due to the increased frequency of applications for both of these levels over the LIF level; quality ratings were often taken shortly after fertilizer applications. In addition, in Michigan, October is typically the end of the optimal growing season for cool season turfgrasses and any additional nutrients would improve turfgrass growing conditions-especially considering that these plants were being grown in a sand rootzone (Baker and Jung, 1968). As a result, plants receiving more fertilizer appeared to be healthier.

## Color

Similar to quality ratings, fertilizer level almost always had an effect on turfgrass color (Table 14 and 15). Most frequently, the HF fertilizer level rating was similar to the LF level and higher then the LIF level. This could be because plants were getting more of the nutrients they needed when they needed them-especially considering that these plants were being grown in a sand rootzone. In Michigan, October is typically the end of the optimal growing season for cool season turfgrasses. Therefore, any additional nutrients will improve turfgrass growing conditions, thereby making the plants appear healthier and more vibrant (Baker and Jung, 1968). Plots fertilized at the LIF level had lower color ratings because although they received as much fertilizer per application as did plots at the HF level, the accumulated amount and frequency was lower. In addition, plots fertilized at the LF and HF level received fertilizer more frequently then plots fertilized at the LIF level. Hence, when color ratings were taken, these plots had usually just received a fertilizer application (Table 3).

## Cultivation

### *Plant counts*

Cultivation had no effect of plant counts throughout the study (Table 4). Cultivation did not have an effect on plant counts because the study was on a three-year old, sand based root zone field. The field was probably not compacted enough to effect turfgrass growth; therefore, differences in plant counts were not significant. In addition, cultivation was done at the end of traffic simulation and again in the early spring. Thus, when plant counts were taken, almost four months had passed since the plots had been cultivated. Therefore, any long-term cultivation benefits were not attained for an increase in plant counts.

## Turfgrass cover

Statistical significance occurred between cover ratings on 26 October (67 and 72%), 09 November (52 and 56%) and the 16 November of 2001 (37 and 42%) for the low and high cultivation frequencies respectively (Tables 5 and 6). However, because the difference between ratings was minimal, it is inconclusive as to whether or not cultivation had an effect on turfgrass cover.

Consequently, because the ratings were qualitative, the effect only occurred once, and the variance did not show in plant counts (Table 4), the difference was probably incidental. However, more investigation is warranted because this data, although weak, does show the potential for cultivation frequency to extend turfgrass cover for at least an additional 6 traffic applications.

## Surface Hardness

Cultivating twice per year decreased surface hardness from June through November of 2000 and again in May through July, September, and 15 October through November of 2001 (Tables 5 and 6). This effect was seen because cultivation directly affects soil conditions; therefore it has the potential to greatly influence surface characteristics, as it did on these rating dates. This result was also seen on *Poa pratensis* and *Festuca arundinacea* in a study done by Rogers and Waddington (1990). However, by November 2000 and 26 October 2001, although statistically significant, the difference in ratings between treatments was minimal; this could be because the effects of traffic made the soil conditions more uniform. These results potentially show that for 2000, surface hardness can be lowered by cultivating twice per year for an additional 25 games and, for 2001, surface hardness conditions can be lowered for an additional 10 games.

**Shear vane**

Statistical significance occurred between shear strength ratings in May through September 2000 and June through August 2001 (Tables 9 and 10). However because the difference between ratings was small, it is inconclusive as to whether or not cultivation frequency effects shear vane ratings. Previous research has shown that for treatment effects to be truly significant, the difference between ratings should be greater then five (Stier and Rogers, 2001).

Even though differences between treatments were small, more research is warranted because it does appear that cultivation does lower shear strength until traffic simulation begins. This trend was seen at every rating date with the exception of 26 October 2001. However, these ratings were also too similar to regard as truly being significant.

**Shear/clegg**

Statistical significance occurred between shear/clegg ratings on 01 October 2001 (31.5 and 29.2) for the low and high cultivation frequencies respectively (Table 11). However, because the difference between ratings was minimal, it is inconclusive if cultivation frequency had and effect on shear/clegg ratings.

However, more investigation is warranted because this occurrence although weak, supports the theory also found in the Cady and native soil results' shear vane ratings that cultivating lowers shear strength.

**Quality**

Although statistical significance occurred for quality ratings between plots cultivated twice per year versus not cultivated on 15 October (6.6, 7.0), and 26 October of 2001 (7.4, 7.8), the actual difference between numbers for qualitative quality ratings is not enough to warrant further discussion or acceptation of statistical significance (Table 13).

**Color**

Although statistical significance occurred for color ratings between plots cultivated twice per year versus not cultivated in September of 2000 (7.5, 7.7), and May of 2001 (6.9, 7.1), the actual difference between numbers for qualitative color ratings is not enough to warrant further discussion or acceptation of statistical significance (Tables 14 and 15).

**Mowing x Fertilization Interaction**

In August of 2001, plots mown once per week had higher shear strength ratings if they were fertilized at the LF level then if they were fertilized at either the LIF or the HF level. If plots were mown twice per week, fertilizer rate and frequency did not have an effect. However, the difference between ratings was minimal and this was the only date that this effect occurred (Table 16).

**Table 16. Significance of the interaction of mowing frequency, fertilizing rate and frequency and Brinkman traffic on turfgrass Eijelkamp shear strength† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/15 |
|---|---|
| Mowing x Fertilizing‡ | |
| 1x/week, Low infrequent | 13.9 |
| 1x/week, Low frequent | 15.1 |
| 1x/week, High | 14.3 |
| 2x/week, Low infrequent | 14.8 |
| 2x/week, Low frequent | 14.6 |
| 2x/week, High | 15.0 |
| $LSD_{(0.05)}$ | 0.7 |
| # of Passes | - |

† Shear strength was measured using the Eijelkamp Shear Vane in Newton meters (Nm).
‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

### Mowing x Cultivation Interaction

If plots were mown once per week, cultivation lowered shear vane and surface hardness ratings. If plots were mown twice per week cultivation increased quality and shear/clegg ratings. However, the differences between ratings were minimal and these ratings were isolated (Table 17).

### Fertilization x Cultivation Interaction

In August of 2001, not cultivated had higher shear vane ratings if they were fertilized at the HF level, as compared to the other two levels of fertilizer. However, if plots were cultivated, plots fertilized at the HF level had lower shear vane ratings then plots fertilized at the other two fertilizer levels. However, difference between ratings was minimal and these ratings were all isolated (Table 18). In terms of shear/clegg ratings, plots fertilized at the LIF level and cultivated twice per year had higher shear/clegg ratings if they were fertilized at the same level and not cultivated. If plots were fertilized at either of the other two levels, cultivating twice per year yielded lower shear/clegg ratings-although not significantly lower. However, similar to the shear vane ratings, differences between ratings were minimal and this was an isolated observation (Table 18).

### Mowing x Fertilization x Cultivation

A three-way interaction occurred for turfgrass cover ratings on 16 November 2001. This interaction shows that cultivation by itself does not lead to increased turfgrass cover late in the season. However, cultivation seems to act

**Table 17. Significance of the interaction of mowing, cultivating, and Brinkman traffic on turfgrass Eijelkamp and Clegg/shear shear strength†‡, surface hardness§, and quality¶ on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2000-01.**

| | Shear Vane (Nm) | Surface Hardness ($G_{max}$) | Quality | Shear/Clegg (Nm) |
|---|---|---|---|---|
| | 2000 | | 2001 | |
| | 8/15 | 10/15 | 10/15 | 10/26 |
| Mowing x Cultivating | | | | |
| 1x/week, Low | 21.8 | 69.1 | 6.6 | 23.6 |
| 1x/week, High | 17.7 | 59.6 | 6.5 | 23.5 |
| 2x/week, Low | 21.6 | 61.5 | 6.7 | 18.6 |
| 2x/week, High | 21.3 | 63.3 | 7.4 | 22.1 |
| $LSD_{(0.05)}$ | 2.6 | 6.4 | 0.6# | 2.4†† |
| # of Games | - | 15 | 15 | 19 |

† Shear strength was measured using the Eijelkamp Shear Vane in Newton meters (Nm).
‡ Shear strength was also measured using the shear/clegg in Newton meters.
§ Surface hardness was measured using the Clegg Impact Soil Tester in gravity deceleration ($G_{max}$).
¶ Quality was rated visually on a 1-9 scale: 1=necrotic turf/bare soil, 9=dense, uniform turf with acceptable color (color ≥ 5).
# Significant to the 0.01 value.
†† Significant to the 0.10 value.

**Table 18. Significance of the interaction of fertilizing, cultivating, and Brinkman traffic on turfgrass Eijelkamp and Clegg/shear shear strength†‡ on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | Shear Vane (Nm) | Shear/Clegg (Nm) |
|---|---|---|
| | 8/15 | 11/9 |
| Fertilizing§ x Cultivating | | |
| Low infrequent, Low | 14.6 | 26.2 |
| Low frequent, Low | 15.3 | 28.6 |
| High, Low | 15.8 | 27.8 |
| Low infrequent, High | 14.2 | 30.9 |
| Low frequent, High | 14.3 | 26.8 |
| High, High | 13.6 | 26.2 |
| $LSD_{(0.05)}$ | 0.7 | 3.3 |
| # of Games | - | 22 |

† Shear strength was measured using the Eijelkamp Shear Vane in Newton meters (Nm).
‡ Shear strength was also measured using the shear/clegg in Newton meters.
§ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

as a catalyst for mowing and/or fertilizing applications to increase turfgrass cover. Thus, cultivation, in combination with either the low mow/HF fertilizer treatment or the high mow/LF or HF fertilizer treatment, did increase turfgrass cover. Furthermore, if both mowing and fertilizing are applied at the high rate, there is not an increase in turfgrass cover. This is likely a result of the environmental and plant limitations. A three-way interaction also occurred for other ratings throughout the study. However, each of the observations were isolated, thus, no trend can be made (Table 19).

## Treatment Comparisons

The highest and lowest level treatment regimes were compared to quantify the number of additional games gained from increased inputs. In addition, fertilizer regimes were compared to quantify the number of additional games gained from the varying fertilizer inputs (Appendix D).

**Table 19. Significance of the interaction of mowing, fertilizing, cultivating, and Brinkman traffic on turfgrass cover[†], Eijelkamp shear strength[‡], quality[§], plant count[¶], and surface hardness[#] on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 1999-2001**

| | Cover | Shear Vane (Nm) | Shear Vane (Nm) | | Surface Hardness ($G_{max}$) | Plant Count (plants $100cm^{-2}$) | Cover | Quality |
|---|---|---|---|---|---|---|---|---|
| | 2000 | | 2001 | | | | | |
| | 7/15 | 9/15 | 8/15 | 10/15 | 10/15 | 10/01 | 11/16 | 11/16 |
| Mowing x Fertilizing[††] x Cultivating | | | | | | | | |
| 1x/week, Low infrequent, Low | 98.3 | 21.8 | 13.7 | 16.2 | 45.2 | 143.1 | 30.0 | 4.8 |
| 1x/week, Low infrequent, High | 95.0 | 22.9 | 14.2 | 16.2 | 49.0 | 155.6 | 33.3 | 5.8 |
| 1x/week, Low frequent, Low | 98.7 | 23.1 | 15.6 | 16.7 | 49.7 | 175.0 | 33.3 | 5.3 |
| 1x/week, Low frequent, High | 99.7 | 22.9 | 14.6 | 17.3 | 44.6 | 165.3 | 30.0 | 4.8 |
| 1x/week, High, Low | 99.0 | 23.8 | 15.8 | 18.3 | 48.2 | 179.2 | 36.7 | 5.7 |
| 1x/week, High, High. | 100.0 | 21.3 | 12.9 | 17.5 | 41.8 | 181.9 | 46.7 | 6.3 |
| 2x/week, Low infrequent, Low | 97.0 | 24.0 | 15.4 | 16.3 | 51.6 | 245.8 | 35.0 | 6.3 |
| 2x/week, Low infrequent, High | 97.0 | 20.0 | 14.2 | 15.8 | 41.4 | 184.7 | 45.0 | 6.2 |
| 2x/week, Low frequent, Low | 99.0 | 25.4 | 15.1 | 17.8 | 49.8 | 201.4 | 36.7 | 5.5 |
| 2x/week, Low frequent, High | 99.7 | 22.7 | 14.1 | 16.2 | 44.2 | 205.6 | 45.0 | 5.7 |
| 2x/week, High, Low | 99.3 | 21.6 | 15.8 | 16.5 | 48.4 | 208.3 | 50.0 | 6.8 |
| 2x/week, High, High | 99.0 | 21.6 | 14.2 | 18.2 | 49.1 | 237.5 | 50.0 | 7.0 |
| $LSD_{(0.10)}$ | 1.8 | 2.7 | 1.0[‡‡] | 1.6 | 8.6[§§] | 37.0 | 8.5[‡‡] | 0.7 |
| # of Games | - | 7 | - | 15 | 15 | 10 | 25 | 25 |

[†] Turf cover was visually estimated on a percent (0-100%) scale.
[‡] Shear strength was measured using the Eijelkamp Shear Vane in Newton meters (Nm).
[§] Quality was rated visually on a 1-9 scale: 1=necrotic turf/bare soil, 9=dense, uniform turf with acceptable color (color ≥ 5).
[¶] Plants were hand counted using three subsamples per treatment.
[#] Surface hardness was measured using the Clegg Impact Soil Tester in gravity deceleration ($G_{max}$).
[††] Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.
[‡‡] Significant at the 0.05 probability level.
[§§] Significant at the 0.01 probability level.

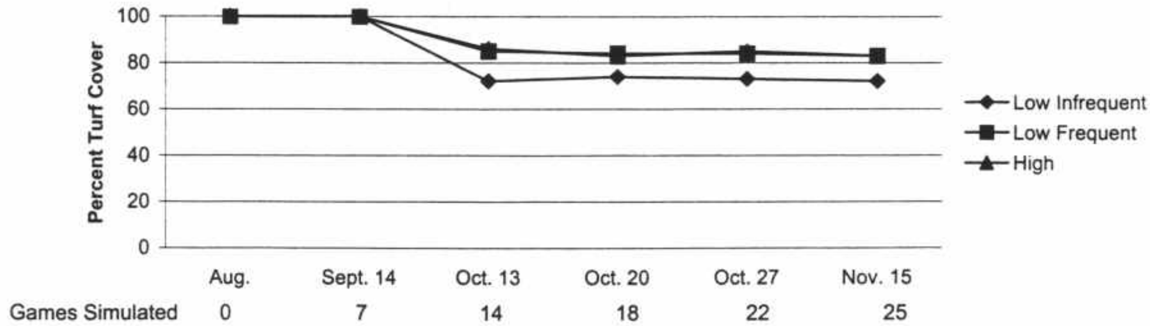


Figure 3. Effect of fertilizer and Brinkman traffic on turfgrass cover over time, East Lansing Michigan, 2000

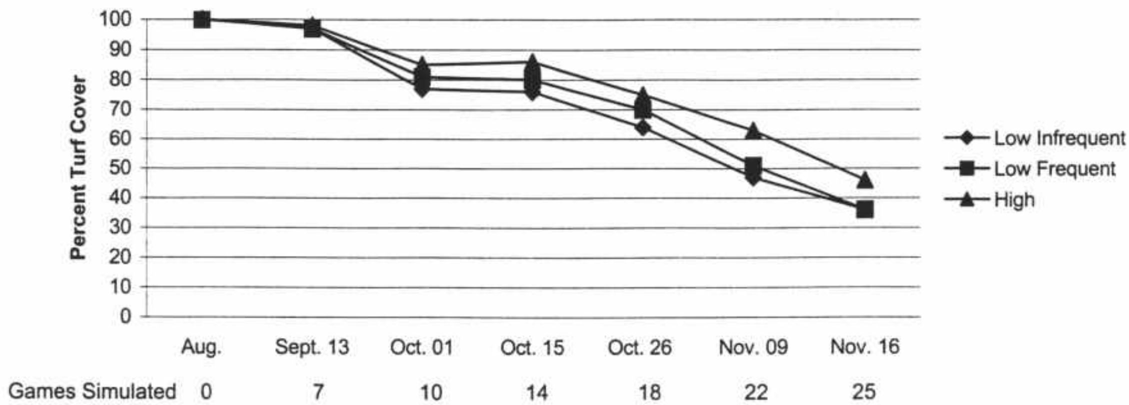


Figure 4. Effect of fertilizing and Brinkman traffic on turfgrass cover over time, East Lansing, MI, 2001

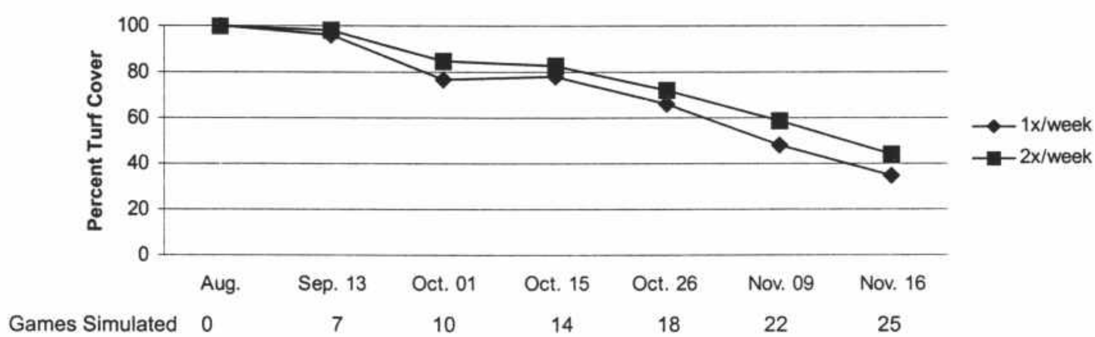


Figure 5. Effect of mowing and Brinkman traffic on turfgrass cover over time, East Lansing Michigan, 2001

## Results and Discussion

*Cady Traffic Simulator*

Results and discussion are divided by maintenance practice and then subdivided by the effect each practice had on the evaluation criteria. Interaction results and discussion are at the end. We designated surface hardness measurements between treatments to be inconclusive if differences were less then 5 $g_{max}$. In general, ratings decreased faster with the Cady traffic simulator as opposed to the Brinkman traffic simulator. The only exceptions were shear strength ratings, which remained similar and surface hardness ratings, which increased. Comparisons between treatments for plant count and percent cover ratings are listed in Appendix C. A cost analysis for each treatment is also listed in Appendix C.

## Mowing

*Plant counts*

Plots mown twice per week gave a 9-15 % increase in plant counts over plots mown once per week on August through 15 October 2001 and again on 09 November 2001 (Table 20). The higher number of plant counts may have occurred at the high mowing level because mowing, at the proper height and frequency, stimulates shoot growth and tillering (Juska, 1961; Crider, 1955). Thus, the increased mowing frequency resulted in increased tillering and shoot production causing an increase in plant counts. Furthermore, if more then 30% of the leaf blade of a plant is removed in a single mowing, the all or nearly all of the plants energy goes into shoot production and negligible amounts, if any go

**Table 20. Significance of treatment effects and Cady traffic on plant counts[†] on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/25 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 171.1 | 163.0 | 115.1 | 97.7 | 80.3 | 57.9 |
| 2x/week | 201.6 | 188.4 | 129.4 | 103.9 | 88.7 | 69.9 |
| Significance | ** | *** | * | ns | * | ns |
| Fertilization[‡] | | | | | | |
| Low infrequent | 178.5 | 148.3 | 103.5 | 93.8 | 79.2 | 64.2 |
| Low frequent | 191.0 | 185.8 | 129.2 | 99.0 | 80.2 | 66.7 |
| High | 189.6 | 193.1 | 134.0 | 109.7 | 94.1 | 60.8 |
| Significance | ns | *** | *** | ns | ns | ns |
| Cultivation | | | | | | |
| $0x/yr^{-1}$ | 185.9 | 181.9 | 119.2 | 98.2 | 83.1 | 58.3 |
| $2x/yr^{-1}$ | 186.8 | 169.4 | 125.2 | 103.5 | 85.9 | 69.4 |
| Significance | ns | ns | ns | ns | ns | ns |
| # of Passes | - | 20 | 30 | 38 | 44 | 50 |

*, **, *** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Ns Not Significant at the 0.10 probability level.

[†] Plant counts were hand counted using three subsamples per treatment.

[‡] Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

into root, rhizome, or tiller initiation (Crider, 1955). As a result, it follows that once traffic simulation began, the root systems of the plants mown once per week may have been weaker then the root systems of the plants mown twice per week, because all of their energy was probably being put towards shoot development as opposed to tillering. Therefore, when subjected to traffic simulation, plants were removed from the ground much more easily causing a decrease in plant counts.

**Turfgrass cover**

Plots mown twice per week yielded at least a 3% increase in turfgrass cover over plots mown once per week on 01 October and 09 and 16 November 2001 (Table 21). These results mirror what was seen in plant count ratings. Thus, similar to plant counts, this effect most likely occurred as a result of a weakened root system. As a result, it follows that when subjected to traffic simulation, plants were removed from the ground much more easily causing a decrease in plant counts and visual decrease in turfgrass cover (Table 20). Between the rating dates of 01 and 15 October, there was a drop in turfgrass cover ratings in plots mown twice per week. This may have been because the optimal growth period for recovery worsened while traffic simulation continued. Finally, although statistically significant the 16 November ratings of 12 and 15% for the low and high mowing frequencies respectively, did not differ enough to warrant discussion or acceptation of statistical significance.

**Table 21. Significance of treatment effects and Cady traffic on turfgrass cover† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/25 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 100 | 49 | 43 | 30 | 14 | 12 |
| 2x/week | 100 | 58 | 48 | 32 | 22 | 15 |
| Significance | ns | *** | ns | ns | *** | * |
| Fertilization‡ | | | | | | |
| Low infrequent | 100 | 50 | 42 | 28 | 17 | 13 |
| Low frequent | 100 | 52 | 43 | 31 | 18 | 13 |
| High | 100 | 60 | 51 | 35 | 20 | 15 |
| Significance | ns | *** | ** | *** | ns | ns |
| Cultivation | | | | | | |
| $0x/yr^{-1}$ | 100 | 52 | 44 | 31 | 17 | 13 |
| $2x/yr^{-1}$ | 100 | 56 | 47 | 31 | 19 | 14 |
| Significance | ns | ** | ns | ns | ns | ns |
| # of Passes | - | 20 | 30 | 38 | 44 | 50 |

*, **, *** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Ns Not Significant at the 0.10 probability level.

†Turf cover was visually estimated on a percent (0-100%) scale.

‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

## Surface hardness

Mowing frequency did not have an effect on surface hardness ratings at any of the data collection dates (Table 22). If the field was severely compacted or if mowing frequency resulted in major differences in turfgrass cover, then mowing frequency may have an effect on surface hardness ratings. However, because this study was conducted on a three-year old sand based root zone field, compaction was not a major issue. In addition, although mowing frequency increased plant counts (Table 20), the increase was not so vast that it affected the surface conditions of the soil. Thus, mowing frequency did not have an effect on surface hardness ratings.

## Shear vane

Mowing frequency did not have an effect on turfgrass shear strength except on 16 November 2001 when mowing once per week gave a higher shear vane reading then mowing twice per week (Table 23). This effect was probably seen because at the time of data collection, plants counts per unit area were 57.9 and 69.9 and shear vane ratings were 12.7 and 13.4, for plants mown once per week and twice per week respectively. Because there was such little turfgrass cover, getting an accurate rating was nearly impossible and, although the Eijelkamp shear vane ratings were statistically significant, the differences between ratings was so small, it is inconclusive if mowing frequency had an effect on shear vane ratings. Previous research has shown that for treatment effects to be truly significant, the difference between ratings should be greater

**Table 22. Significance of treatment effects and Cady traffic on surface hardness† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/25 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 47.7 | 51.9 | 43.2 | 54.6 | 64.9 | 61.5 |
| 2x/week | 47.9 | 50.8 | 43.7 | 55.6 | 64.4 | 61.9 |
| Significance | ns | ns | ns | ns | ns | ns |
| Fertilization‡ | | | | | | |
| Low infrequent | 48.4 | 51.8 | 44.2 | 54.1 | 65.4 | 61.7 |
| Low frequent | 47.3 | 49.4 | 44.5 | 55.0 | 64.8 | 62.1 |
| High | 47.8 | 52.7 | 41.6 | 56.3 | 63.8 | 61.3 |
| Significance | ns | ** | ns | ns | ns | ns |
| Cultivation | | | | | | |
| 0x/yr$^{-1}$ | 50.9 | 54.0 | 44.9 | 56.4 | 65.2 | 61.8 |
| 2x/yr$^{-1}$ | 44.7 | 48.6 | 42.0 | 53.9 | 64.1 | 61.6 |
| Significance | *** | *** | ** | ** | ns | ns |
| # of Passes | - | 20 | 30 | 38 | 44 | 50 |

*, **, *** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not Significant at the 0.10 probability level.
† Surface hardness was measured using the Clegg Impact Soil Tester in gravity deceleration ($G_{max}$).
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

**Table 23. Significance of treatment effects and Cady traffic on Eijelkamp shear strength† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/25 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 18.6 | 19.1 | 18.8 | 18.4 | 14.2 | 13.4 |
| 2x/week | 21.4 | 18.8 | 18.6 | 18.0 | 13.8 | 12.7 |
| Significance | ns | ns | ns | ns | ns | ** |
| Fertilization‡ | | | | | | |
| Low infrequent | 18.9 | 19.5 | 18.8 | 19.2 | 14.3 | 12.8 |
| Low frequent | 18.7 | 19.1 | 18.9 | 17.6 | 13.6 | 13.5 |
| High | 22.5 | 18.3 | 18.3 | 17.8 | 13.9 | 12.8 |
| Significance | ns | ns | ns | * | ns | ns |
| Cultivation | | | | | | |
| 0x/yr$^{-1}$ | 21.9 | 19.1 | 19.1 | 18.3 | 14.8 | 13.9 |
| 2x/yr$^{-1}$ | 18.1 | 18.8 | 18.2 | 18.1 | 13.1 | 12.2 |
| Significance | ns | ns | ns | ns | *** | *** |
| # of Passes | - | 20 | 30 | 38 | 44 | 50 |

*, **, *** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.
Ns Not Significant at the 0.10 probability level.
† Shear strength was measured using the Eijelkamp Shear vane in Newton meters (Nm).
‡ Low infrequent fertilizer = 25 g N m$^{-2}$ year$^{-1}$ with 5 applications; Low frequent = 25 g N m$^{-2}$ year$^{-1}$ with 8 applications; High = 35 g N m$^{-2}$ year$^{-1}$ with 7 applications.

then five (Stier and Rogers, 2001). In addition because this was the only date that this difference occurred, the reason for differences is most likely chance by sampling location.

**Shear clegg**

Plots mown twice per week yielded higher shear/clegg ratings then plots mown only once per week on 25 August 2001 (Table 24). Plots mown twice per week may have had higher shear/clegg ratings because of higher numbers of plant counts (Table 20). Although August was the first date that the shear/clegg was used, this data implies that mowing twice per week increases the lateral shear strength of the grass. The reason there were no significant differences for shear vane readings for this date may be because the shear vane measures rotational shear strength and the shear/clegg measures lateral shear strength.

**Quality**

Mowing twice per week gave higher quality ratings then mowing once per week beginning 01 October and continuing through 16 November 2001 (Table 25). This effect may have been because the increased mowing frequency caused the older leaf tissue to be removed and newer leaf tissue to emerge. This caused the plants to appear healthier and more vibrant in color. In addition, because there were more plants per unit area (Table 20) in plots mown twice per week, individual plant damage (i.e. necrosis) was less noticeable and the quality to appeared higher. Furthermore, because this effect appeared after traffic

**Table 24. Significance of treatment effects and Cady traffic on Clegg/shear strength† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/25 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 20.5 | 37.4 | 29.3 | 25.1 | 32.0 | 28.6 |
| 2x/week | 25.9 | 36.5 | 32.6 | 25.6 | 31.0 | 29.2 |
| Significance | *** | ns | ns | Ns | ns | ns |
| Fertilization‡ | | | | | | |
| Low infrequent | 25.7 | 38.9 | 33.6 | 24.0 | 32.5 | 30.8 |
| Low frequent | 22.9 | 36.1 | 32.1 | 27.8 | 28.7 | 30.0 |
| High | 20.9 | 35.9 | 27.2 | 24.3 | 33.3 | 26.0 |
| Significance | * | ns | ** | Ns | ns | ** |
| Cultivation | | | | | | |
| $0x/yr^{-1}$ | 22.7 | 38.7 | 30.5 | 23.8 | 33.2 | 29.6 |
| $2x/yr^{-1}$ | 23.7 | 35.3 | 31.4 | 26.9 | 29.8 | 28.2 |
| Significance | ns | ns | ns | * | * | ns |
| # of Passes | - | 20 | 30 | 38 | 44 | 50 |

*, **, *** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Ns Not Significant at the 0.10 probability level.

† Shear strength was measured using the shear/clegg in Newton meters (Nm).

‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

**Table 25. Significance of treatment effects and Cady traffic on turfgrass quality† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/25 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 8.6 | 3.9 | 3.7 | 3.4 | 1.9 | 2.5 |
| 2x/week | 8.7 | 4.6 | 4.2 | 3.8 | 2.5 | 3.0 |
| Significance | ns | ** | ** | *** | *** | *** |
| Fertilization‡ | | | | | | |
| Low infrequent | 8.8 | 4.0 | 3.6 | 3.3 | 2.0 | 2.7 |
| Low frequent | 8.6 | 3.9 | 3.8 | 3.6 | 2.2 | 2.4 |
| High | 8.6 | 4.8 | 4.4 | 3.9 | 2.4 | 3.0 |
| Significance | ns | ** | *** | *** | * | ** |
| Cultivation | | | | | | |
| $0x/yr^{-1}$ | 8.6 | 4.1 | 3.7 | 3.3 | 2.1 | 2.6 |
| $2x/yr^{-1}$ | 8.7 | 4.4 | 4.2 | 3.8 | 2.3 | 2.8 |
| Significance | ns | ns | ** | *** | ns | ns |
| # of Passes | - | 20 | 30 | 38 | 44 | 50 |

*, **, *** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Ns Not Significant at the 0.10 probability level.

†Quality was rated visually on a 1-9 scale: 1=necrotic turf/bare soil, 9=dense, uniform turf with acceptable color (color $\geq$ 5).

‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

simulation began, this data implies that mowing, in combination with traffic, stimulated higher wear tolerance and more growth, which resulted in greater turfgrass cover (Tables 20 and 21). This provided for a more uniform turf appearance, which resulted in greater turfgrass quality ratings.

### Color

Mowing twice per week gave a higher color rating then mowing once per week in August of 2001 and again 15 October through 09 November 2001 (Table 26). Similar to quality ratings, plots mown twice per week may have had higher color ratings because the increased mowing frequency allowed older leaf tissue to be removed and newer leaf tissue to emerge and because the higher amount of plants per unit area (Table 20) caused individual plant damage to become (i.e. necrosis) less noticeable. In addition, by the end of traffic simulation, the environmental conditions were no longer optimal for turfgrass growth. This resulted in slow growth and slow recovery from damage. This could be why at the last rating date, there were no longer differences in turfgrass color.

### Fertilization

#### *Plant counts*

Plots fertilized at either the low frequent (LF) or high (HF) rate of fertilizer gave at least a 20% increase in higher plant counts over plots fertilized at the low infrequent (LIF) rate of fertilizer on 01 and 15 October 2001 (Table 20). This effect could have resulted because in Michigan, October is typically the end of

**Table 26. Significance of treatment effects and Cady traffic on turfgrass color† on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | 8/25 | 10/01 | 10/15 | 10/26 | 11/09 | 11/16 |
|---|---|---|---|---|---|---|
| Mowing | | | | | | |
| 1x/week | 7.8 | 4.9 | 4.6 | 4.3 | 3.1 | 3.3 |
| 2x/week | 8.2 | 5.2 | 4.9 | 4.6 | 3.4 | 3.4 |
| Significance | ** | ns | * | *** | *** | ns |
| Fertilization‡ | | | | | | |
| Low infrequent | 7.8 | 4.5 | 4.4 | 4.3 | 3.3 | 3.4 |
| Low frequent | 8.0 | 5.0 | 4.6 | 4.3 | 3.2 | 3.2 |
| High | 8.2 | 5.8 | 5.3 | 4.8 | 3.3 | 3.4 |
| Significance | ns | *** | *** | *** | ns | ns |
| Cultivation | | | | | | |
| $0x/yr^{-1}$ | 7.9 | 5.0 | 4.7 | 4.4 | 3.3 | 3.3 |
| $2x/yr^{-1}$ | 8.1 | 5.2 | 4.8 | 4.5 | 3.3 | 3.4 |
| Significance | ns | ns | ns | Ns | ns | ns |
| # of Passes | - | 20 | 30 | 38 | 44 | 50 |

*, **, *** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Ns Not Significant at the 0.10 probability level.

†Color was rated using the Spectrum™ FieldScout chlorophyll meter (Spectrum Technologies, Inc., Plainfield, IL).

‡ Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.

the optimal growing season for cool season turfgrasses. Therefore, any additional nutrients would probably improve turfgrass growing conditions-especially considering that these plants were being grown in a sand rootzone (Baker and Jung, 1968). Given this, perhaps fertilizing at the LF rate is just as beneficial to the plant as fertilizing at the HF rate. The lesser amount, yet higher frequency of application in the LF fertilizer regime may have provided plants with adequate available nutrients so they were just as hardy as plants fertilized at the HF level (Johnston, 1984). Furthermore, by 01 October 2001 traffic had been applied for just over a month (20 passes). Thus, fertilizing at the LF or HF rate proved to extend the amount of plants per unit area for an additional 2 weeks (8 passes). However, with continued traffic (after 30 passes) the effects of fertilizer rate and frequency were no longer significant.

**Turfgrass cover**

Plots fertilized at the HF rate gave at least an 8% increase in turfgrass cover ratings over plots fertilized at either the LIF or the LF rate on 01 and 15 October 2001. On 26 October 2001, plots receiving the HF rate of fertilizer had a 7% increase in turfgrass cover over the plots receiving the LIF rate of fertilizer (Table 21). The reason plots fertilized at the HF level appeared to have higher turfgrass cover then plots fertilized at either the LIF or LF levels on 01 and 15 October may be because October is typically the end of the optimal growing season for cool season turfgrasses. Therefore, and additional nutrients would help increase turfgrass growth-especially considering that these plants were being grown in a sand rootzone. Perhaps the HF level of fertilizer appeared to have higher turfgrass cover ratings because there were more nutrients available for the plants. Plots fertilized at the HF rate had, cumulatively, 25 g N $m^{-2}$ while plots fertilized at either of the other two levels had only 15 g N $m^{-2}$. Perhaps at the ratings dates, plots fertilized at the LIF and the LF levels were deficient in nutrients which caused the plants to have decreased shoot density, and also a decrease in recuperative potential (Kussow, 2000). However, the plant count data indicates that both the HF and the LF fertilizer levels were equal in terms of quantitative density ratings. Therefore, more research is warranted to determine if both levels of fertilizer equally support increased turfgrass growth.

By the 26 October rating date, plots at the LF level had the same turfgrass cover ratings as plots fertilized at the HF level while plots fertilized at the LIF level had lower turfgrass cover ratings then both of these plots. This occurrence may have been influenced by the fact that all plots had just gotten a 5 g N $m^{-2}$ application so plots at the HF fertilizer level had, cumulatively, 30 g N $m^{-2}$ while plots at the LIF level and LF fertilizer level had, cumulatively, 20 g N $m^{-2}$. However, plots fertilized at the LIF level had only 4 applications while plots at the LF had 7 and plots at the HF level had 6. The fact that all plots just had an equal amount of nitrogen applied coupled with the increased frequency of application of fertilizer for the LF plots may have caused the plants to become hardier and equally able to withstand traffic as the plots maintained at the HF fertilizer level. The reason this effect did not show for the rest of the season may have been because when the final cover ratings were taken, the effects of traffic simulation were very severe. Therefore, the chances of variability between treatments had become greatly reduced.

### Surface Hardness

Statistical significance occurred between surface hardness ratings on 01 October 2001 (51.8, 49.4, and 52.7) for the LIF, LF, and HF fertilizer levels respectively (Table 22). However, because the difference between ratings was so small (less the 5 $G_{max}$), it is inconclusive whether fertilizer rate and frequency had an effect on surface hardness ratings.

### Shear Strength

Statistical significance occurred between Eijelkamp shear vane ratings on 26 October 2001 (19.2, 17.6, and 17.8) for the LIF, LF, and HF fertilizer levels respectively (Table 23). However, because the difference between ratings was very small, it is inconclusive whether or not fertilizer rate and frequency had an effect on shear strength. Previous research has shown that for treatment effects to be truly significant, the difference between ratings should be greater then five (Stier and Rogers, 2001).

### Shear/clegg

Plots fertilized at the LIF rate had higher shear/clegg ratings then plots fertilized at the HF rate on 25 August, 15 October, and 16 November 2001. Although the LIF rate of fertilizer had increased shear/clegg ratings for those three sampling dates, the increase in shear strength was minimal (Table 24). However, a possible reason for the LIF fertilizer rate having higher shear strength ratings may be because of increased rooting and shoot growth (Bredakis and Roberts, 1959; Juska, 1967).

In addition, the reason the shear/clegg ratings showed differences between fertilizer treatments and the shear vane did not could be because the shear/clegg measures lateral shear strength (plant displacement from the soil) while the shear vane measures rotational shear strength (plant and plant tillers).

**Quality**

Fertilizing at the HF rate gave a higher quality rating then fertilizing at either then LIF or the LF rate on 01 and 15 October. On 26 October and continuing through 09 November, the HF rate of fertilizer gave a higher quality rating then only the LIF rate of fertilizer (Table 25). The reason plots fertilized at the HF level gave higher quality ratings then plots fertilized at either of the other levels from 01 through 15 October 2001 may be because the plants were getting more of the nutrients they needed when they needed them. In Michigan, October is typically the end of the optimal growing season for cool season turfgrasses. Therefore, any additional nutrients will improve turfgrass growing conditions- especially considering that these plants were being grown in a sand rootzone (Baker and Jung, 1968). As a result, plants receiving more fertilizer appeared to be healthier. Plots fertilized at the LF level got the nutrients at a slightly higher frequency, but the quantity per application was lower. This could have resulted in the lower quality ratings. However, as traffic simulation continued, quality ratings for these plots were no different from quality ratings for plots fertilized at the HF level. This could be because fertilizing on a low, but frequent basis caused the plants to become hardier and better able to withstand traffic as time went continued.

**Color**

Fertilizing at the HF level gave higher color ratings then fertilizing at either the LIF or the LF level on 01 October through 26 October. This effect was seen because, at these ratings dates, plants fertilized at the HF level appeared to be getting more of the nutrients they needed when they needed them. As a result, these plants appeared to have more vibrant color. In Michigan, October is typically the end of the optimal growing season for cool season turfgrasses. Therefore, any additional nutrients will improve turfgrass growing conditions and cause the plants to appear healthier-especially considering that these plants were being grown in a sand rootzone (Baker and Jung, 1968). Plots fertilized at the LF level had lower color ratings the plots fertilized at the HF level because although they got the nutrients at a slightly higher frequency, but they got them at a lesser quantity. Plots fertilized at the LIF level had lower color ratings because although they received as much fertilizer per application as did plots at the HF level, the accumulated amount and frequency was lower. In addition, plots fertilized at the LF and HF level received fertilizer more frequently then plots fertilized at the LIF level. Hence, when color ratings were taken, these plots had usually just received a fertilizer application (Table 3 and 26).

**Cultivation**

*Plant counts*

Cultivating had no effect on plant counts. Cultivation may not have had an effect on plant counts because the study was on a three-year old, sand based root zone field. Therefore, the field was probably not compacted enough to have differences in plant counts. In addition, cultivation was done at the end of traffic simulation and again in the early spring. Thus, when plant counts were taken, almost four months had passed since the plots had been cultivated. Therefore, any long-term cultivation benefits were not attained in terms of an increase in plant counts (Table 20).

**Turfgrass cover**

Although statistical significance occurred between turfgrass cover ratings on 01 October 2001 (52 and 56%), for the low and high cultivation frequencies respectively, the ratings did not differ enough to warrant discussion of cultivation effects on turfgrass cover. Because the ratings were qualitative, the effect only occurred once, and the variance did not show in plant counts (Table 20), the difference was probably incidental. However, more investigation is warranted because this data, although weak, does show the potential for cultivation frequency to extend turfgrass cover for at least an additional 4 traffic applications (Table 21).

**Surface Hardness**

Plots not cultivated had higher surface hardness ratings then plots cultivated twice per year from August through 26 October 2001 (Table 22). This effect may have occurred because cultivation directly affects soil conditions; therefore it has the potential to greatly influence surface characteristics as it did August through 26 October 2001. This result was also seen on *Poa pratensis* and *Festuca arundinacea* in a study done by Rogers in 1990. These results show that surface hardness can be lowered by cultivating twice per year for an additional 36 passes. The reason this effect did not show for the rest of the traffic simulation may have been because when the final surface hardness ratings were taken, the effects of traffic simulation were very severe. Therefore, the chances of variability between treatments had become greatly reduced.

**Shear strength**

Statistical significance occurred between Eijelkamp shear vane ratings on 09 November 2001 (14.8 and 13.1) and 16 November 2001 (13.9 and 12.2), for the low and high cultivation frequencies, respectively. However, because the difference between the ratings was so small, it is inconclusive as to whether cultivation frequency had an effect on shear strength. Previous research has shown that for treatment effects to be truly significant, the difference between ratings should be greater then five (Stier and Rogers, 2001). Furthermore, when these ratings were taken turfgrass cover and plant count ratings were very low (Table 20 and Table 21), therefore the differences for these dates is most likely due to chance by sampling location (Table 23).

### Shear/clegg

Plots cultivated twice per year had higher shear/clegg ratings then plots not cultivated on 26 October 2001 and 09 November 2001 (Table 24). The reason for this effect may be because the higher cultivation frequency may have caused an increase in rooting due to increased macro pore space during this period of time (Lee and Rieke, 1993). Because the shear/clegg measures lateral shear strength, an increase in rooting would have given an increase in lateral shear strength. The reason this effect was reversed on 09 November 2001 for Eijelkamp shear vane ratings may be because the shear vane measures rotational shear strength as opposed to the lateral shear strength.

### Quality

Although statistical significance between quality ratings occurred on, 15 October (3.7 and 4.2) and the 26 October 2001 (3.3 and 3.8), for the low and high cultivation frequencies respectively, the ratings did not differ enough to warrant discussion of cultivation effects on turfgrass quality. Because the ratings were qualitative, the difference was probably incidental. However, more investigation is warranted because this data, although weak, does show the potential for cultivation frequency to extend turfgrass quality for an additional 4 traffic applications (Table 25).

### Color

Cultivation did not have a visible effect on color ratings. Cultivation may not have a visible effect on color ratings because the study was on a three-year old, sand based root zone field. Therefore, the field was probably not compacted enough to warrant cultivation frequency having a significant affect on nutrient availability or nutrient holding capacity, either of which could have caused a difference in color ratings (Table 26).

### Mowing x Cultivation Interaction

Plots mown twice per week had higher color, quality and plant count ratings if they were cultivated twice per week then if they were not cultivated. However, the difference between ratings was minimal and this was the only date that this effect occurred (Table 27).

### Mowing x Fertilization x Cultivation Interaction

A three-way interaction occurred for turfgrass cover ratings on 01 October 2001. This interaction shows that cultivation by itself does not lead to increased turfgrass cover late in the season. However, cultivation does act as a catalyst for mowing and/or fertilizing applications to increase turfgrass cover. Thus, cultivation, in combination with either the low mow/HF fertilizer treatment or the

**Table 27. Significance of the interaction of mowing, cultivating and Cady traffic on turfgrass color[†], quality[‡], and plant counts[§] on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | Color | | Quality | Plant Counts (plants 100cm$^{-2}$) |
|---|---|---|---|---|
| | 10/01 | 10/15 | 11/12 | 10/15 |
| Mowing x Cultivating | | | | |
| Low mow Low cultivating | 5.1 | 4.7 | 2.0 | 118.1 |
| Low mow High cultivating | 4.8 | 4.7 | 2.2 | 120.4 |
| High mow Low cultivating | 4.8 | 4.5 | 1.9 | 112.0 |
| High mow High cultivating | 5.6 | 5.2 | 2.7 | 138.4 |
| $LSD_{(0.05)}$ | 0.7 | 0.5 | 0.4 | 17.0[¶] |
| # of Passes | 20 | 30 | 44 | 30 |

[†] Color was rated using the Spectrum™ FieldScout chlorophyll meter (Spectrum Technologies Inc., Plainfield, IL).

[‡] Quality was rated visually on a 1-9 scale: 1=necrotic turf/bare soil, 9=dense, uniform turf with acceptable color (color $\geq$ 5).

[§] Plant counts were hand counted using three subsamples per treatment.

[¶] Significant to the 0.10 value.

high mow/LF or HF fertilizer treatment, did increase turfgrass cover. Furthermore, if both mowing and fertilizing are applied at the HF rate, there is not an increase in turfgrass cover. This is likely a result of the environmental and plant limitations. A three-way interaction also occurred for turfgrass cover ratings on 16 November 2001. On this date, it was shown that cultivation would increase turfgrass cover if plots were maintained at the low mowing and LIF fertilizer levels. If plots were maintained at either the high mowing frequency, or the LF or HF fertilizer level, cultivation would not increase turfgrass cover. Furthermore, cultivation increased plant counts if it was combined with either low mowing and LIF fertilizing or if it was combined with high mowing and HF fertilizing. A three-way interaction also occurred for various other ratings throughout the study. However, each of the observations were isolated, thus, no trend can be made (Table 28).

**Treatment Comparisons**

The highest and lowest level treatment regimes were compared to quantify the number of additional games gained from increased inputs. In addition, fertilizer regimes were compared to quantify the number of additional games gained from the varying fertilizer inputs (Appendix D).

**Table 28. Significance of the interaction of mowing, fertilizing, cultivating and Cady traffic on turfgrass cover[†], plant counts[‡], surface hardness[§] and Clegg/shear strength[¶] on a *Poa pratensis/Lolium perenne* turf stand, East Lansing, MI. 2001**

| | Turf cover | | Plant counts (plants $100cm^{-2}$) | Surface hardness ($G_{max}$) | Shear/clegg (Nm) |
|---|---|---|---|---|---|
| | 10/01 | 11/16 | 11/09 | 10/26 | 10/26 |
| Mowing x Fertilizing[#] x Cultivating | | | | | |
| 1x/week, Low infrequent, Low | 45.0 | 6.7 | 51.4 | 52.3 | 24.2 |
| 1x/week, Low infrequent, High | 46.7 | 15.0 | 83.3 | 55.4 | 21.0 |
| 1x/week, Low frequent, Low | 50.0 | 13.3 | 97.2 | 57.6 | 25.2 |
| 1x/week, Low frequent, High | 46.7 | 10.0 | 73.6 | 52.2 | 29.7 |
| 1x/week, High, Low | 50.0 | 12.7 | 88.9 | 56.3 | 22.7 |
| 1x/week, High, High. | 58.3 | 11.7 | 87.5 | 54.0 | 27.8 |
| 2x/week, Low infrequent, Low | 50.0 | 15.0 | 97.2 | 57.9 | 20.7 |
| 2x/week, Low infrequent, High | 58.3 | 13.3 | 84.7 | 50.7 | 30.0 |
| 2x/week, Low frequent, Low | 50.0 | 14.3 | 76.4 | 57.8 | 27.3 |
| 2x/week, Low frequent, High | 61.7 | 14.3 | 73.6 | 52.4 | 29.2 |
| 2x/week, High, Low | 65.0 | 16.7 | 87.5 | 56.6 | 23.0 |
| 2x/week, High, High | 65.0 | 18.3 | 112.5 | 58.4 | 23.7 |
| $LSD_{(0.10)}$ | 8.1 | 5.7 | 29.6 | 5.4[††] | 6.4 |
| # of Passes | 20 | 50 | 44 | 38 | 38 |

[†] Turf cover was visually estimated on a percent (0-100%) scale.
[‡]Plants were hand counted using three subsamples per treatment.
[§] Surface hardness was measured using the Clegg Impact Soil Tester in gravity deceleration ($G_{max}$).
[¶] Shear strength was also measured using the shear/clegg in Newton meters.
[#] Low infrequent fertilizer = 25 g N $m^{-2}$ $year^{-1}$ with 5 applications; Low frequent = 25 g N $m^{-2}$ $year^{-1}$ with 8 applications; High = 35 g N $m^{-2}$ $year^{-1}$ with 7 applications.
[††] Significant to the 0.05 value.

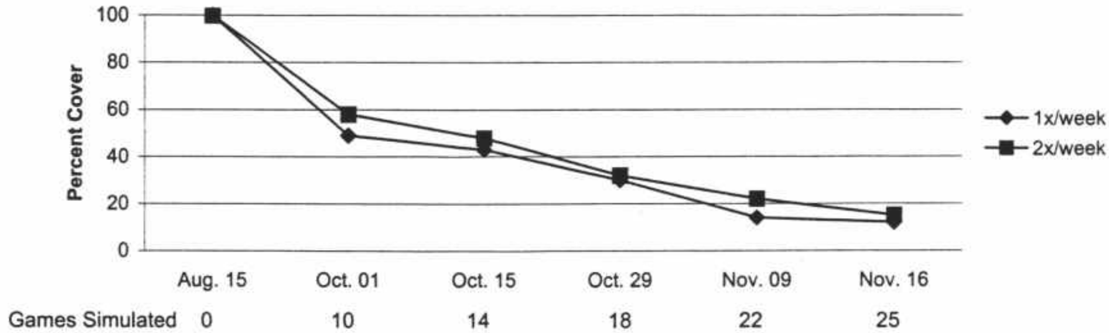


Figure 6. Effect of mowing and Cady traffic on turfgrass cover over time, East Lansing, MI, 2001

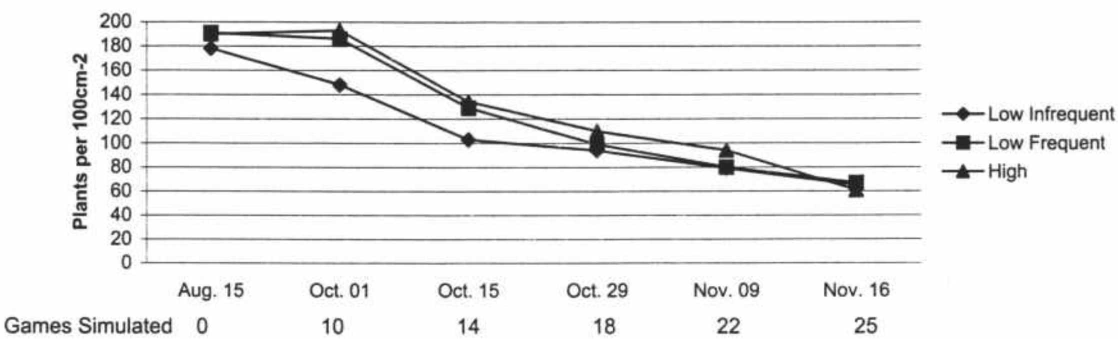


Figure 7. Effect of Fertilizer and Cady traffic on plant counts over time, East Lansing, MI, 2001

## Conclusions

*Sand soil*

The objectives of this study were ascertained, as we were able to quantitatively define differences between treatment applications. We are confident this research, coupled with continued research will set a foundation for which the future expectations of athletic fields based on cultural inputs of mowing, fertilizing, and cultivating can be determined.

## Mowing

The object of this experiment was defined and it was determined that mowing twice per week versus once per week increased plant counts and turfgrass cover. Mowing twice per week also improved quality and cover ratings and on occasion, turfgrass shear strength and surface hardness characteristics.

## Fertilizing

It was determined that when fertilizing with 25 g N $m^{-2}$ $year^{-1}$ frequent applications are best on a sand based root zone (at least 8 applications per year). In addition, less frequent fertilizer applications can be used if a greater amount of annual nitrogen is applied (35 g N $m^{-2}$ $year^{-1}$).

The higher annual nitrogen (35 g N $m^{-2}$ $year^{-1}$) or the increased frequency of nitrogen application at the lower rate of nitrogen 25 g N $m^{-2}$ $year^{-1}$ increased plant counts, percent cover, quality, and on occasion turfgrass shear strength and surface hardness. Deciding between these two rates can be determined by environmental factors as well as labor and fertilizer costs.

## Cultivating

Cultivating at the end of traffic simulation and again in the early spring provided increased turfgrass cover near the end of the experiment. Lower surface hardness values were obtained from core-cultivation throughout the study. In contrast, core cultivating showed a negative effect on turfgrass shear strength.