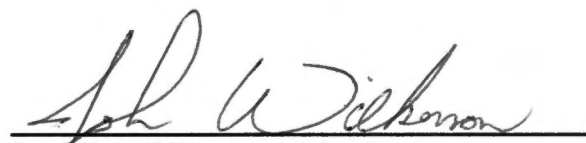


To the Graduate Council:

I am submitting herewith a thesis written by Andrew M. Arthur entitled "Evaluation of Turf Tire Sipe Density on Traction Performance and Turf Damage." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering Technology.



---

Dr. John Wilkerson, Major Professor

We have read this thesis and  
recommend its acceptance



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Dr. Luther Wilhelm



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Dr. Thomas Samples

Accepted for the Council:



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Associate Vice Chancellor and  
Dean of The Graduate School

# **Evaluation of Turf Tire Sipe Density on Traction Performance and Turf Damage**

A Thesis  
Presented for the  
Master of Science  
Degree  
The University of Tennessee, Knoxville

Andrew M. Arthur  
August 1996

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Thesis  
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.A78

**This is dedicated to:**

**To my mom Doris Arthur for her love and support throughout my life.**

**To Roger Whitlock for filling a great void in all our lives.**

**To my girlfriend Mindy Coe for her love, understanding, and patience.**

**To the memory of my father Jason Arthur. I wish he were here to see this.**

## **Acknowledgments**

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And all of my fellow graduate students who have served in the pit crew.

## Abstract

A tire's main function is to provide traction for the vehicle to which it is attached. A turf tire must be able to provide the necessary traction without causing excessive turf damage. Therefore, it is extremely important to evaluate turf tire design components, such as sipes, not only for traction considerations but for turf damage as well.

A Ford lawn and garden tractor was operated on a tall fescue, *Festuca arundinacea* Schreb, turf surface while towing a constant drawbar load. During a test, the tractor was operated in second gear and the engine speed was maintained at 3000 RPM (approximately 3 mph). A complete test run consisted of a pass down and back through a 200 ft course. Data was collected in both directions through the course and averaged to reduce the effect of slope. Turf samples were taken at the end of each test run. Six blades were removed and photographed using a camera, a specially designed camera stand, and a photo gray background. The turf pictures were then analyzed at a later date for fresh tearing and bruising. Damage was recorded as a percent of total blade area.

Included in each test were five variables: day, surface moisture, axle load, draft load, and tire sipe design. Day was defined simply as the day the test was run. The free-surface moisture level was described as either true or false, meaning that either the turf surface had moisture on it (true) or the turf surface was dry (false). The axle load was defined as the weight of the tractor, the operator and additional ballasting. The draft load, placed on the tractor by the dynamometer, had values of 0, 150, 300, and 375 lbs. Four sets of tires, each of the same general construction, were used for these tests. It was believed the only difference between the sets of tires was sipe density. The sipe density had values of 0, 50,

100, and 200 percent. During data analysis it was discovered that for tire sets B and D the left side tire was larger than the right. This proved an interesting problem.

Analysis proved that as the draft load increased the percent slip also increased. Also proven was the fact that as the axle load increased the percent slip decreased. These conclusions were as expected. An increase in sipe density appeared to decrease the amount of drive wheel slip. It was also shown, when given two drive tires under the same load and drive conditions, the small tire will have a greater amount of slip than the larger. Thus, a higher percentage of the draft load is transferred to the smaller tire. Turf damage assessment for these tests proved inconclusive. This was caused by the fact that the sample size was too small. However, it was observed that turf damage tended to occur in areas that were already stressed. Turf damage was also observed to increase in severity as the number of passes over an area increased.

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## **Chapter 1**

### **Introduction**

A tire's main function is to provide traction for the vehicle to which it is attached. Turf tires must be able to provide the necessary traction without causing excessive turf damage. The turf industry wants a tire design that maximizes traction while minimizing turf damage. Therefore, it is extremely important to evaluate turf tire designs not only for traction considerations but for turf damage as well.

The tire-tractive surface interface is the key to transferring the actions of the vehicle operator into controlled responses of the vehicle. Therefore, it is not surprising that a great deal of research has been conducted to better understand the factors affecting this interface. The tractive abilities of the tire play an important role in the performance and safety of a particular tire design. The majority of the research has been directed toward traction prediction for a wide variety of surfaces. These surfaces include snow, ice, asphalt, concrete and soil. Research has been conducted not only to validate new test procedures for snow and ice (Winter Traction Testing, 1994) but also to evaluate existing traction prediction models (Buchner et al, 1982).

Traction studies on soil have dealt primarily with comparing different tires designs (Grisso et al, 1992) and also testing to determine what type of tire best suits a particular task (Monroe et al, 1989). Research on tire operating parameters has also been conducted. Tests evaluate such factors as velocity (Burt and Lyne, 1985) and inflation pressure (Bashford et al, 1993). The tire-surface interface is unique in each of the research areas mentioned above. The performance of a tire on asphalt cannot easily be related to the performance of the same

tire on soil. Therefore it is important that the research be conducted on the same surface on which a tire will be required to perform. Research conducted involving the turfgrass-tire interface is limited. Consequently, little can be said about the effects of tire design on the traction performance of a turf tire.

Smithson and Herzegh (1971) determined that tire traction performance depends on both the tire design and the road surface on which the tire is operated. Measurement of a tire's traction capabilities indicates the performance of the tire-surface interaction. This statement holds true for all surfaces and is important not only to operator safety and vehicle efficiency but also to the turfgrass surface.

Turfgrass is a very resilient surface, barring complete removal, healthy turf often recovers from trafficking damage (Samples, 1995). However, turfgrass has its limits. Trafficking can cause sufficient stress resulting in death of the turf. Traffic is defined as "walking, playing or driving on turf" (Beard, 1990) and can lead to four distinctly different types of damage: soil compaction, soil displacement, turf removal, and turf wear (Beard, 1990). When dealing specifically with driving, soil compaction and removal can be minimized by properly dispersing the weight of the vehicle and, when possible, controlling the paths vehicles are allowed to take (Connolly, 1992; Gilhuly, 1984; Latham, 1992; Foy, 1989). Carrow and Johnson (1989) have researched the effects of various tire designs and traffic patterns on turf wear. This research involved several tire designs from different manufacturers. Only the variations between brands and models were considered, and not the varied design parameters.

Preliminary tests, conducted at The University of Tennessee-Knoxville, Agricultural

Engineering Department, indicate that turf removal and turf wear are direct results of tire tread design. These tests also indicate that the differences in turf tire designs must be separated into various design components to determine exactly which variables contribute to traction performance and turf damage.

### **Objectives**

The objectives of this research were as follows:

1. Measure the traction performance for various sipe densities within a single turf tire's tread pattern.
2. Measure the turf damage resulting from varying sipe density levels.

## **Chapter 2**

### **Literature Review**

A great deal of research has been conducted regarding traction performance and tire design. Many tire designs, surfaces, and tire operating parameters have been evaluated. However little research has been devoted to studying the turf-tire interface and the resulting turf damage caused through traction.

#### **Tractive Surfaces**

Smithson and Herzegh (1971) state that the tractive performance of a tire is related to the surface on which the tire is operated. Therefore, surfaces must be sorted in some useful manner. Several traction tests were run to validate this theory. These tests used tires that had known differences in pattern, and each tire was tested on several surfaces. It was concluded that road structure determines the effect that tread compound and tread pattern have on traction performance.

When operating vehicles on surfaces such as asphalt, concrete, and to some extent soil, there is no need to be concerned with surface damage. However, when the operating surface is as susceptible to damage as turfgrass, damage must be considered. Turfgrass can be damaged in several ways and this damage can be categorized as either direct or indirect. Direct damage may be considered as damage to the plant itself, such as tearing or bruising of turfgrass blades. Indirect damage could be described as an effect of trafficking that is detrimental to the turf. An example of this type of damage would be soil compaction. There

is a great deal of documentation regarding problems that can be caused by the trafficking of turf areas (Connolly, 1992; Latham, 1992; Foy, 1989; Gilhuly, 1984).

## **Tire Design**

The tire's function will dictate certain characteristics that are necessary for the tire to perform as needed. Advances in technology have led to safer tires and more effective tire designs. Improved tread designs and materials have also contributed to the higher level of performance from tire designs. By increasing the tire's stability, materials such as steel belts have played an important role in increased traction performance (Grogan, N.D.).

Buchner et al. (1982) conducted research to validate prediction models. Prediction models are calculations used in tire design. Buchner et al. used several tire designs, consisting of a wide variety of sizes, constructions, tread compounds, and sipe widths. The tire tests were used to validate prediction models. It was found that great care and consideration must be taken when measuring the distribution of sipe widths for use in prediction models. Further research in the areas of tread compound and tread contact pressures was also recommended.

Many tire designers have worked toward a solution to the problem of soil compaction during turf maintenance operations. Gilhuly (1984) discusses an innovation named 'Big Tires.' These tires can be fitted to almost any tractor and basically distribute the weight of the tractor such that soil compaction is minimized. These tires allow for the maintenance practices to be accomplished in less time while incurring less turf damage. Although the cost of these big tires is substantial, the tractor can replace several large and expensive pieces of equipment, such as fairway mowers.

## **Tire Operating Parameters**

Many variables must be considered once the design of a tire has been determined. These variables can be combined in a category labeled as operating parameters. Operating parameters include factors such as air pressure, loading conditions, and velocity. Bashford et al. (1993) researched the effects of tire size and inflation pressure on tractive efficiency and the dynamic traction ratio. The tractive efficiency and dynamic traction ratio were used as indicators of tractive performance. This research indicated that lower inflation pressures increase tractive performance. It also demonstrated that larger tire sizes perform better than smaller sizes on firm surfaces at the same inflation pressure. However, research conducted by Grisso et al. (1992), concluded that no advantage was gained by using a larger tire. Two tire sizes, 18.4R46 and 18.4R42, were used in Grisso et al.'s research. These tires were inflated to 29 psi. Grisso et al. speculated that the high inflation pressure and firm soil influenced the outcome of these tests.

Burt and Lyne (1985) researched the effect of velocity on traction performance. Traction performance for these tests was measured using net traction and tractive efficiency. Two tires, one bias-ply and one radial-ply, were used to conduct the traction testing. Each tire had the same size, tread pattern, inflation pressure, and dynamic load. For the conditions in these tests, forward velocity had no effect on the tractive performance of either tire construction.

## **Turf Damage**

Beard (1990) describes traffic as a general term encompassing walking, playing, or driving on turf. He also states that trafficking turf will lead to four types of stress: soil compaction, soil displacement, turf removal, and turf wear. The ability of a turfgrass to tolerate wear is dependent on several factors, for example the amount of living material above the soil surface and the cellulose content of the shoot. While wear tolerance is an important consideration, the growth rate of the turf must also be considered.

There have been few studies concerning the effect of turf tire tread design on the amount of turf damage. Carrow and Johnson (1989) conducted turf wear studies on 'Tifway' bermudagrass, *Cynodia dactylon cu.* 'Tifway', and concluded that the design of the turf tire used was of little importance. Turf damage was measured visually using color, verdure, turf quality, and leaf bruising. Several golf cart tire designs, golf carts, and traffic patterns were tested. It was found that turf damage increases as the number of passes over a site increases. The differences in tread design did cause differences in the amount of turf damage; however, these differences were minor and with these test procedures could not be explained by the tread design alone. Carrow and Johnson suggest that, in order to reduce turf damage, emphasis should be placed on controlling traffic patterns and avoiding sharp turns.

## **Traffic Control**

Many researchers have documented the need for the control of traffic to reduce the damage caused by vehicles. Connolly (1992) recognized the fact that golf carts contribute greatly to the amount of turf damage on golf courses through trafficking and soil compaction.

However, golf carts produce a great amount of revenue not only for golf courses but for other businesses. Golf carts also increase the speed of play allowing more rounds to be played per day. Connolly introduced plans that have been implemented at particular courses to restrict where the carts are driven. Latham (1992), like Connolly, recognizes the great significance of the golf cart for increased revenues and faster play. Latham also noted the damage that these vehicles cause to the soil and the turf. He cites a solution used by a golf course in Ontario. This course used a series of color coded stakes to direct traffic. These stakes could be moved to new locations easily, allowing for periodic changes in the traffic patterns. Changing the traffic patterns more uniformly distributed the amount of damage caused in an area. Foy (1989) also discussed the problem of turf damage caused by golf carts; however, he also included maintenance equipment. He specifically mentioned the areas near the cart path where golfers may pull off and park their carts before walking to their next shot. By using reflective units, generally found on highways, the traffic patterns can be controlled. The reflectors offer a great advantage compared to ropes and chains because they are permanently in place and require little or no maintenance. These reflectors do not interfere with normal mowing or trimming operations.

### **Turf Recovery**

Growth rate will greatly affect the amount of time involved in the recovery of the turfgrass species. Wear tolerance can be increased by improving the overall health of the turf area. This improvement can be accomplished with a combination of several practices, including increasing the mowing height, increasing potassium levels, using modest irrigation

practices, and using moderate nitrogen fertilization levels. Beard (1993) also described the recuperative potential of the turfgrass as its ability to recover from injury. The recuperative potential of turfgrass is affected by both morphological and physiological characteristics. It is important to remember that recuperative potential is different from recuperative rate. Beard uses an example of bermudagrass and *Zoysia* to demonstrate that two turfgrass species may have similar recuperative potentials and have greatly different recuperative rates. Several cultural practices may be manipulated to increase the recuperative potential of a turfgrass. These include mowing height, nitrogen fertilization, and the depth of the thatch layer. By manipulating the mowing height and the nitrogen fertilization levels, the amount of stored carbohydrates can be increased, allowing the turf to recover more easily from an injury. Also, maintaining the appropriate thatch layer will protect the meristematic tissues of the turfgrass.

### **Tire Performance Evaluation Equipment**

To perform research involving tires, some sort of test vehicle is used. Generally, the vehicle will be constructed in a way that allows control over such factors as velocity, and loading conditions. The vehicle will also be instrumented such that data collection is computer controlled.

Grisso et al. (1992) used two instrumented 7140 tractors for testing the differences between two tire sizes. These tractors were instrumented with strain gages on the axles and a data acquisition system to collect and record the data during a test. The loading conditions for this research were controlled by a mobile load unit, which is referred to as Dyna-truck.

A self-contained instrumented driving traction test truck was used by Buchner et al.

(1982). The vehicle allowed the driving torque to be gradually increased while a constant speed was maintained by braking on non-drive wheels. This vehicle was also adapted with instrumentation for data collection.

Sarten (1990) used an instrumented Ford LGT 14 along with a ground driven dynamometer to test the tractive performance of tires on turfgrass. The tractor had optical encoders mounted on the drive wheel axle such that forward and reverse travel of the vehicle could be monitored. Encoders were also installed to monitor the steering angle of the front tires. The dynamometer used allowed varying drawbar loads to be placed on the tractor without affecting the normal load of the tractor. All sensors were monitored by a specially designed data acquisition system which collected and displayed the data while the tractor traveled through the test course.

Advances in technology have resulted in more efficient testing methods and improved tire design and tire construction. However, more improvements still need to be made, especially in the area of turf tires.

## **Chapter 3**

### **Methods and Procedures**

#### **Test Procedures**

A Ford lawn and garden tractor was operated on a turf surface while towing a constant drawbar load. The tractor had a total weight of 638 lbs. (289.4 kg), distributed as 360 lbs. (163.3 kg) on the front axle and 278 lbs. (126.1 kg) on the rear axle. These weights do not include the weight of the driver and additional ballasting. Tests were conducted with the operator weight ballasted to two levels, 200 lbs. (90.7 kg) and 350 lbs. (158.8 kg). The constant towing load (draft load) was provided by a ground driven dynamometer. Tests were conducted with and without free surface moisture on the turf. During a test, the tractor was operated in second gear and the engine speed was maintained at 3000 RPM (approximately 3 mph). A complete test run consisted of a pass through and back across a 200 ft (61 m) course. Data were collected in both directions through the course and averaged to reduce the effect of slope. Tire operating pressures were checked immediately prior to each test to maintain a constant pressure of 15 psi (103 kPa).

#### **Test Variables**

Included in each test were five variables: day, surface moisture, axle load, draft load, and tire sipe design. Day was defined simply as the day the test was run. The free-surface moisture level was described as either true or false, meaning that either the turf surface had moisture on it (true) or the turf surface was dry (false). The axle load was defined as the weight of the tractor, the operator and additional ballasting to obtain a total axle load of 478

lbs. (216.8 kg) and 628 lbs. (284.9 kg). The draft load, placed on the tractor by the dynamometer, had values of 0, 150, 300, and 375 lbs. (0, 667, 1334, 1668 N). These were labeled as zero, low, medium, and high respectively. Four sets of tires, each of the same general construction, were used for these tests. The tires, Ultra-Trac 23x10.50-12, were manufactured by Dico Tire Inc. The only known difference between the sets of tires was sipe density. The sipe density had values of 0, 50, 100, and 200 percent. Tires were labeled as A, B, C, and D respectively. Table 1 provides a summary of all variables considered during testing. A complete listing of all tests is located in Appendix A.

Table 1 Summary of the Test Variables

| Variable     | Abr.  | Levels | Description                                                                                                                            |
|--------------|-------|--------|----------------------------------------------------------------------------------------------------------------------------------------|
| Day          | Day   | 4      | 1, 2, 3, and 4                                                                                                                         |
| Moisture     | Moist | 2      | Uniform application of surface moisture or free of surface moisture                                                                    |
| Axle Load    | NLoad | 2      | 200 and 350 pounds (ballasted weight)                                                                                                  |
| Draft Load   | DLoad | 4      | 0, 150, 300, and 375 pounds                                                                                                            |
| Sipe Density | Tire  | 4      | 4 tires of the same general construction with varying sipe densities (0, 50, 100, and 200 percent labeled A, B, C, and D respectively) |

## Tractor Instrumentation

An instrumented Ford LGT 14 lawn tractor was used in all tests. Optical encoders were installed on both rear axles of the tractor to measure the number of tire revolutions through the test course (Figure 1). A 1000 lb. (453.6 kg) load cell, with specially designed hitch clevises, was placed between the tractor and dynamometer (Figure 2). The load cell was used to insure the dynamometer provided the proper load during each test. More information

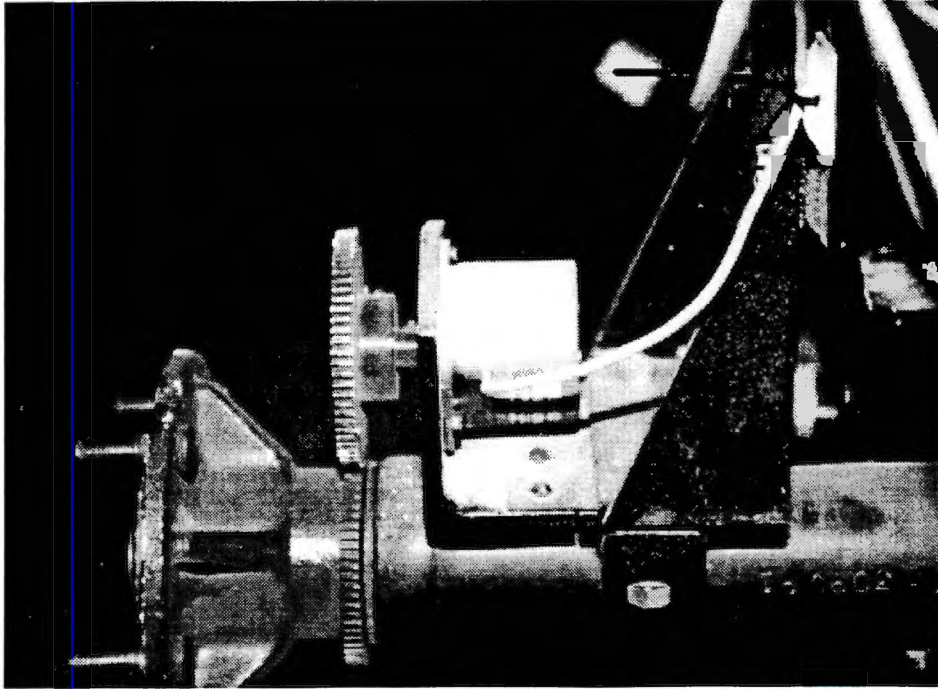


Figure 1: Photograph of an optical encoder mounted on the rear axle of the tractor.

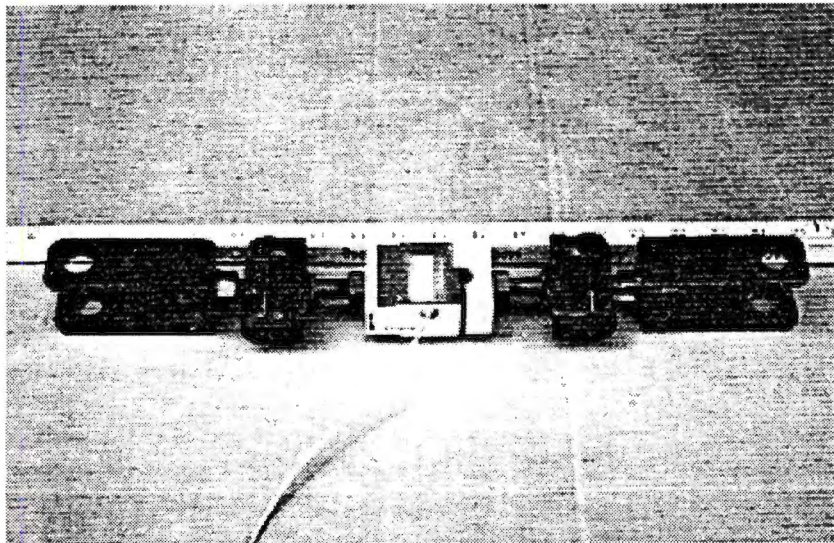


Figure 2: Photograph of drawbar load measurement system using a load cell.

on the installation of sensors and the operation of the tractor are reported by Sarten (1990). All sensors were interfaced to a Campbell Scientific 21x datalogger. A switch was connected to one of the datalogger inputs to serve as a trigger for starting and stopping data storage. Data storage began as the vehicle entered the 200 ft (61 m) test course and then was stopped as the vehicle left the test course. A flow chart of the program execution is shown in figure 3 and the code is located in Appendix B.

### **Free-Surface Moisture**

Mounted on the hood of the tractor was a Solo backpack sprayer with a 3-nozzle boom. The sprayer was used to provide near uniform free surface moisture on the turfgrass surface (Figure 4). The boom was 40 ½ inches (102.9 cm) long with nozzles on each end and the middle. The boom height was adjusted such that the coverage was a 48 in (121.9 cm) wide area. The nozzles used for spray application were Teejet XR 8002. Water was applied in front of the tractor at an application rate of approximately 33 gpa (304 L/ha).

### **Dynamometer**

The dynamometer has been designed to provide varying loads to the instrumented test vehicle (Figure 5). The dynamometer is basically a two-wheel trailer with a caster wheel mounted in front (Sarten, 1990). The design allowed the dynamometer to apply varying draft loads. Loading is accomplished using a hydraulic system which is powered by the rotation of the tires. Before each test the hydraulic pressure was adjusted to insure the proper

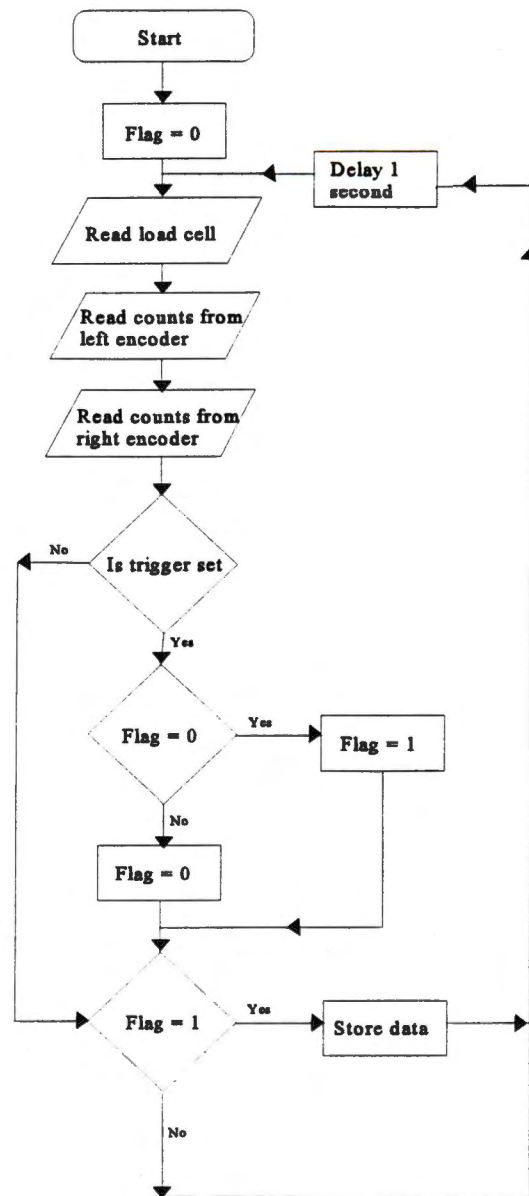


Figure 3: Flow chart of datalogger program execution.



Figure 4: Ford LGT 14 with backpack sprayer mounted on the hood for applying free surface moisture to the turf just ahead of the front wheels.

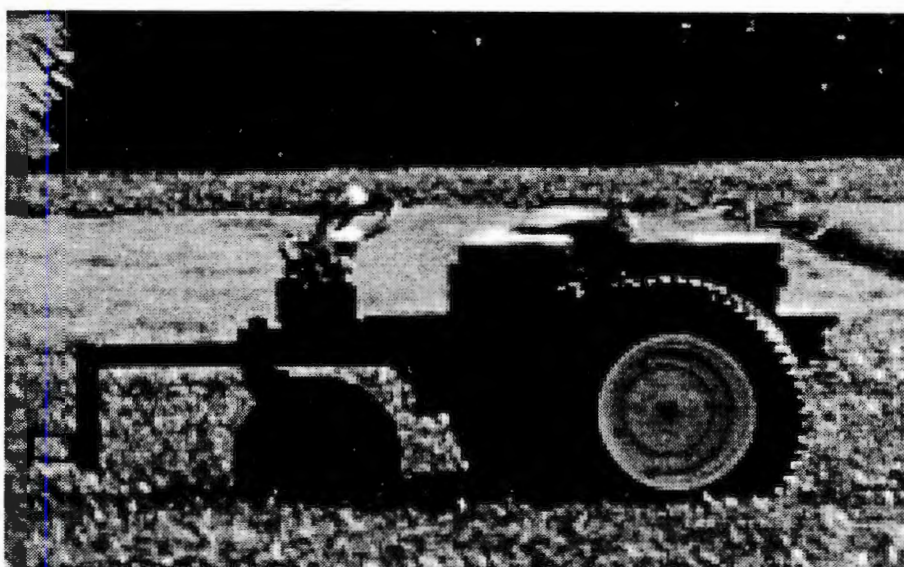


Figure 5: Ground driven dynamometer used to provide varying draft load

drawbar load was applied to the tractor. Figure 6 is a schematic of the dynamometer hydraulic system (Sarten, 1990).

### **Turf Tires**

One basic tire design was used, the Ultra-Trac size 23x10.50-12, a four-ply turf tire manufactured by Dico Tire Inc. To minimize the variability among individual tires, the same tire design and construction was used for all tires. Four levels of sipe density were hand carved into the tires: 0, 50, 100, and 200 percent (Figure 7). A sipe is being defined as a slit carved into a tire cleat. Sipe density is referred to as the percentage of cleats with a sipe. Table 2 summarizes the tire information.

Table 2 Summary of tire information

| Name | Sipe Density (%) | Number of Sipes per Cleat          |
|------|------------------|------------------------------------|
| A    | 0                | 0 Sipes per cleat                  |
| B    | 50               | Sipes on every other row of cleats |
| C    | 100              | 1 Sipe per cleat                   |
| D    | 200              | 2 Sipes per cleat                  |

### **Turf Evaluation Area**

The test area was located on The University of Tennessee Jackson Experiment Station. The area was 200 ft (61 m) by 96 ft (29.3 m). The longitudinal slope of the test area

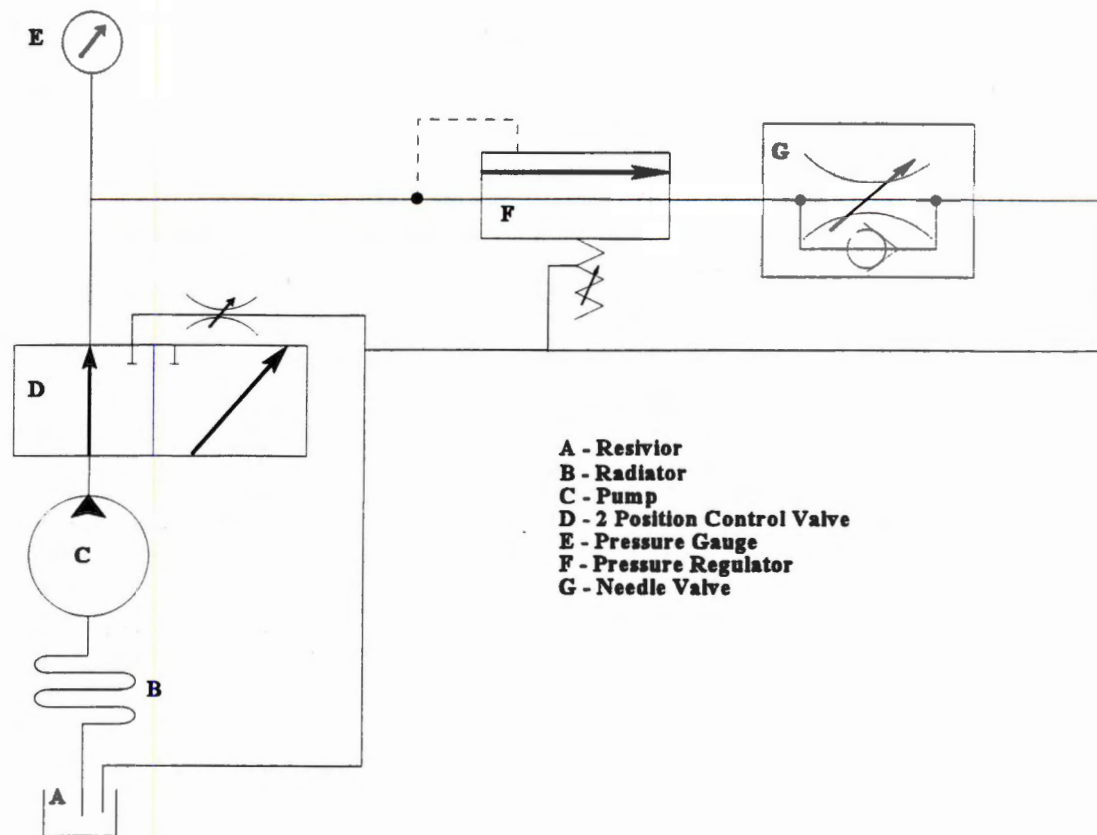
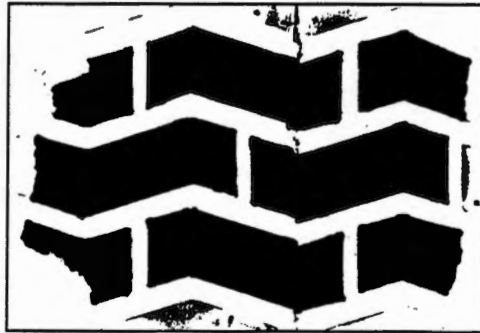
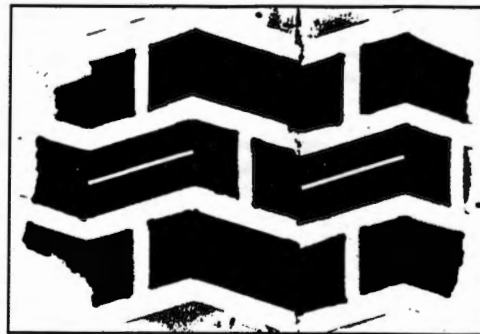


Figure 6: Schematic diagram of the hydraulic system for the dynamometer.

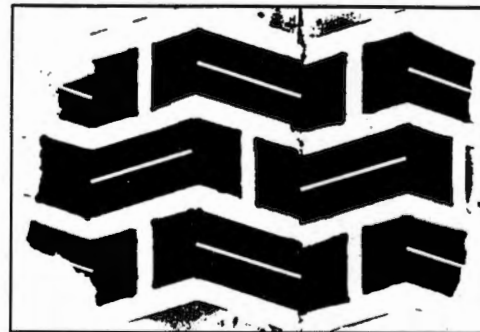
0%  
Sipe  
Density



50%  
Sipe  
Density



100%  
Sipe  
Density



200%  
Sipe  
Density

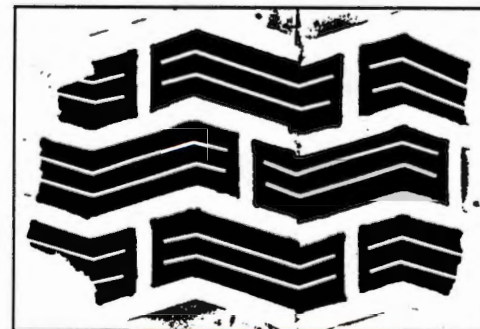


Figure 7: Footprints for all tires labeled from top to bottom as A, B, C, and D.

ranged from 0.54 to 1.07 percent with an average of 0.83 percent. The latitudinal slope of the test area ranged from 0.01 to 0.74 percent with an average of 0.36 percent. Figure 8 is a contour map of the area. The topography of the test area was measured using a laser level. Measurements were taken on a 10 ft (3 m) grid throughout the course. The grid spacing was reduced to 6 ft (1.8 m) on the left side of the test course. The test area consisted mainly of tall fescue mowed to a height of three to four inches. However, there were two small areas (less than 20 ft<sup>2</sup>) of *Zoysia* and a few broadleaf weeds (less than 1%).

### **Turf Damage Assessment**

After a test was run, turf samples were taken from between the rear tires of the tractor and the driven tires on the dynamometer. The turf sample consisted of 6 randomly selected blades of grass. During preliminary testing, turfgrass damage was assessed immediately after sample collection. Because this method was extremely time consuming a new method was developed. Each blade was then photographed using a specially designed camera stand (Figure 9) and a photo gray background. Photographs were checked for fresh tearing and bruising (Figure 10). Damage was recorded as a percentage of blade area damaged. Since the removal of blades is nearly impossible to measure, this factor was not considered.

### **Traction Calculations**

Calibration tests for all tires were run on a 200 ft asphalt course. The asphalt was dry, level, and free of debris. For each tire the calibration consisted of 3 complete runs through the course. Data were averaged over the three tests and used in the percent slip calculations.

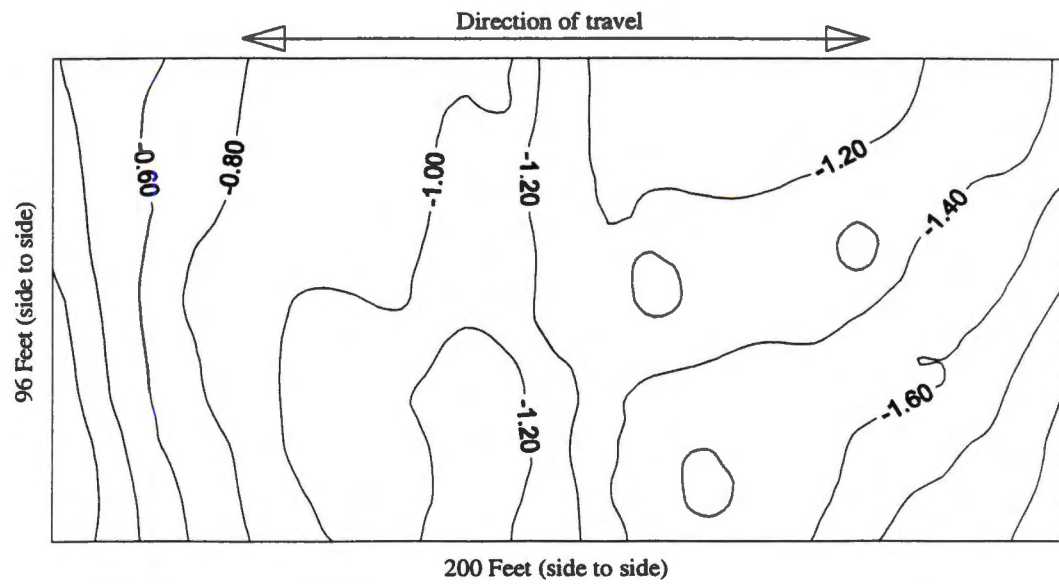


Figure 8: Contour map of the test area with elevation points taken on a 10 foot grid.

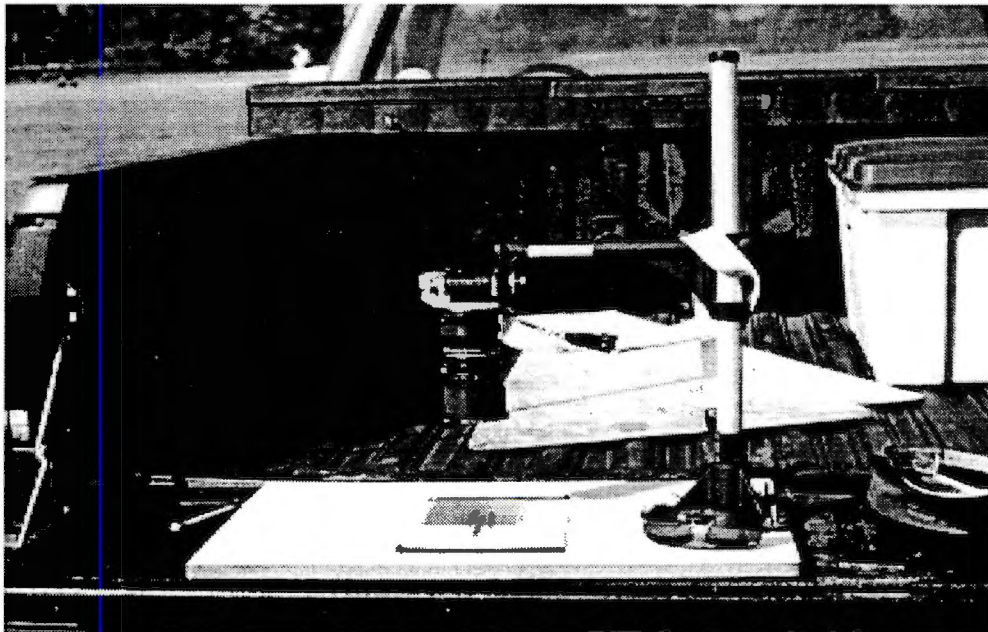


Figure 9: Photograph of the camera and mount used to document turf damage.

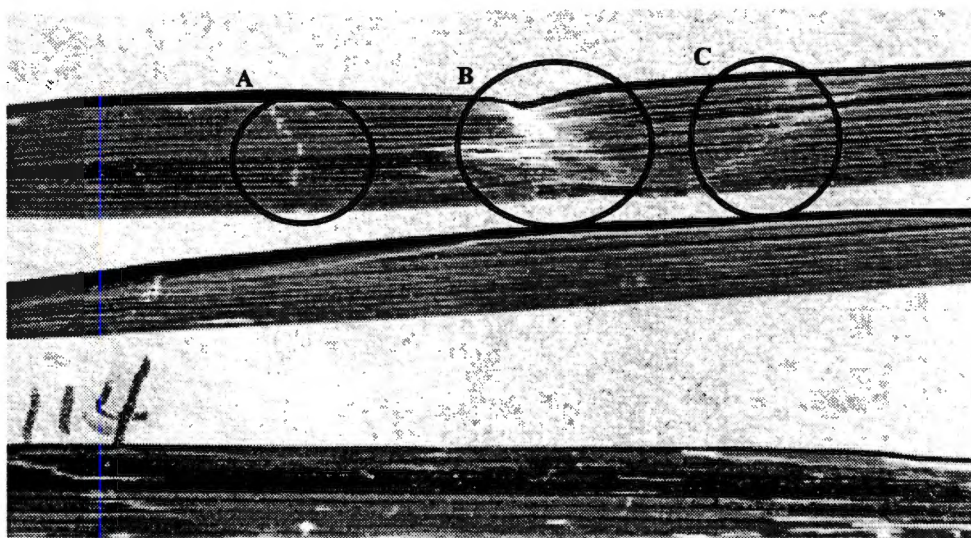


Figure 10: Example of picture used to assess turf damage. Notice the prominent creases in the top blade. The letter A indicates an area that has a minor crease which was created during the traction tests. The letter B indicates an area that was previously damaged, the damage was augmented by the traction testing. The letter C indicates a more serious crease created during traction testing. The number 114 indicates the test from which these blades were taken.

The formula below was used for slip calculations. In the formula below *test run* equals the number of counts from the optical encoders collected during a test run on turf, *calibration* equals the number of counts from the optical encoders collected during a calibration run on a dry and level asphalt surface.

$$\text{Percent Slip} = \frac{(\text{test run} - \text{calibration})}{\text{calibration}} * 100$$

## **Chapter 4**

### **Analysis and Results**

The main purpose of this experiment was to determine the effect of sipe density on traction performance and turf damage. However, several other variables and interactions with sipe density were considered in the evaluation. Comprehensive statistical analysis of the data was conducted using SAS version 6.11. Appendix C contains a listing of SAS programs and select pages of the output from each program.

#### **Traction Performance Results**

Traction data was analyzed in SAS using three different models. The first model treated the slip values for the left and right drive tires independently. For the second model, the left and right slip values were averaged. The third model, which included additional statistical techniques, will be discussed later in this chapter. All three models produced the same results for all variables except sipe density. The following conclusions and figures are based upon the second method of analysis (left and right slip values averaged) and significant difference determined by values of alpha less than 0.05. Sipe density will be discussed later in this chapter.

Excluding sipe density (tire) there were four variables in the statistical model. These variables were as follows: Day, Moist, Nload, and Dload. Day refers to the day that a test was run. The moist variable had two levels, the turf surface either had free surface moisture or was free of surface moisture. Nload refers to the ballasting load on the rear axle. This variable also had two levels, 200 and 350 pounds. The variable Dload refers to the towed

drawbar load which had four levels. The levels of draft load were classified as follows: Zero, Low, Medium, and High. Table 3 below shows these variables as well as any other significant interactions of variables using Type III Sums of Squares unless listed in this table the combination was not significant ( $\alpha < 0.05$ ).

Table 3: SAS Type III Sums of Squares for all single variables in the model and significant combinations of variables.

| Source      | DF | F Value | Pr>F   |
|-------------|----|---------|--------|
| Day         | 4  | 1.07    | 0.3818 |
| Moist       | 1  | 1.02    | 0.3170 |
| Nload       | 1  | 173.72  | 0.0001 |
| Dload       | 3  | 646.25  | 0.0001 |
| Nload*Dload | 3  | 80.34   | 0.0001 |

The table shows the day and moist variables as non-significant. Tests, conducted at The University of Tennessee, Knoxville, concluded that free surface moisture on the blades of turfgrass had a significant effect on the traction performance of a tire (Sarten, 1990). However, this conclusion can not be made for these tests due to a lack of power in the statistical model. The variables labeled above as Nload, Dload (Axle and Draft loads respectively) and the combination of the two was clearly significant ( $\alpha < 0.0001$ ). As the weight on the rear axle increased the tire slip decreased and as the towed drawbar load (draft load) increased tire slip increased. Figures 11 and 12 are graphs of the least square means for these variables. Bars are labeled with letters, the same letter above two bars indicates no significant difference ( $\alpha > 0.05$ ), bars that are not labeled are significantly different differences ( $\alpha < 0.05$ ). The variable combination Nload by Dload showed the same pattern as above,

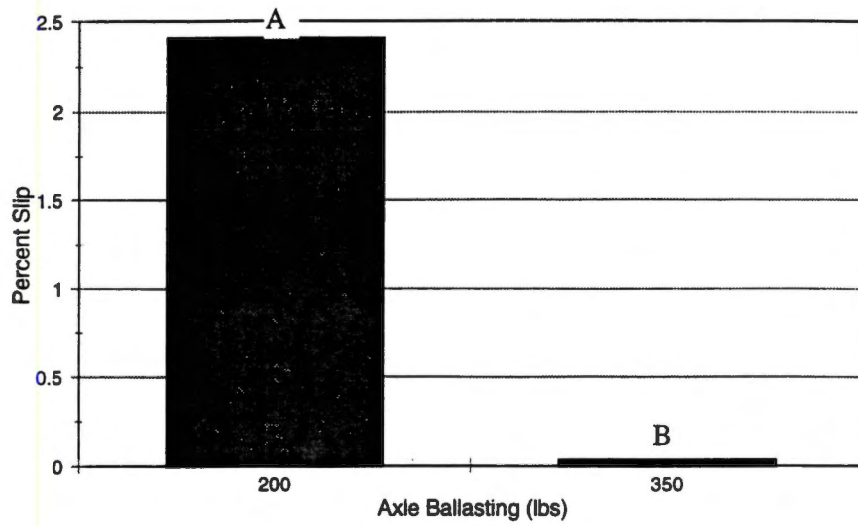


Figure 11: Graph illustrating each axle loading condition. As axle load increased the percent slip shows a considerable decrease

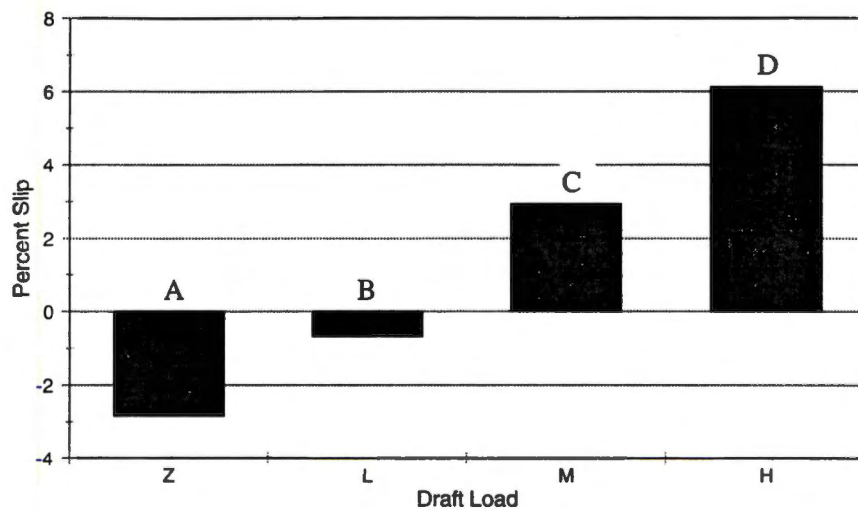


Figure 12: Graph illustrating percent slip for each draft load.

within the same draft load the increase in axle load caused the tire slip to decrease and within the same axle load the increase in draft load caused tire slip to increase (Figure 13). This variable combination also showed that axle loading produced a greater reduction in slip at the higher draft loads (Figure 14).

Analysis of sipe density (variable = tire) proved to be more difficult than previously discussed variables. Data was first analyzed using the left and right slip values separately. This provided some confusing results. The left side tires performed as expected, as sipe density increased the percent slip decreased. However, the right side tires did not perform as expected. Tires B and D had much higher values for percent slip than expected. Because of the extreme difference between the left and right side tires, the two were averaged and reanalyzed. The high values for tires B and D were still a problem. Figure 15 shows the least square mean percent slip values for the left side, right side, and average (statistical comparisons are not made on this graph). To explain the differences between the left and right side tires, a rolling radius for all tires was calculated. Readings from the optical encoders, taken during calibration runs on asphalt, were used for the calculations (Table 4 ).

Table 4: Rolling radius calculations for all tires. All units are in inches.

| Tire | Left | Right | Difference | Percent |
|------|------|-------|------------|---------|
| A    | 5.66 | 5.66  | 0.00       | 0.00    |
| B    | 5.65 | 5.68  | 0.03       | 0.67    |
| C    | 5.65 | 5.65  | 0.00       | 0.00    |
| D    | 5.57 | 5.64  | 0.07       | 1.20    |

These calculations show a difference between the right and left sides for tires B and D.

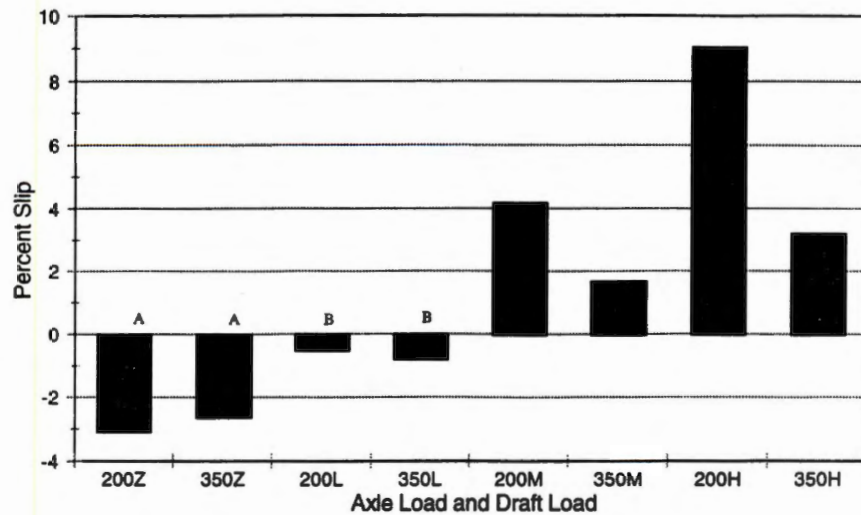


Figure 13: Graph illustrating percent slip as affected by axle and draft load. Z, L, M, and H indicate draft load and stand for zero, low, medium, and high.

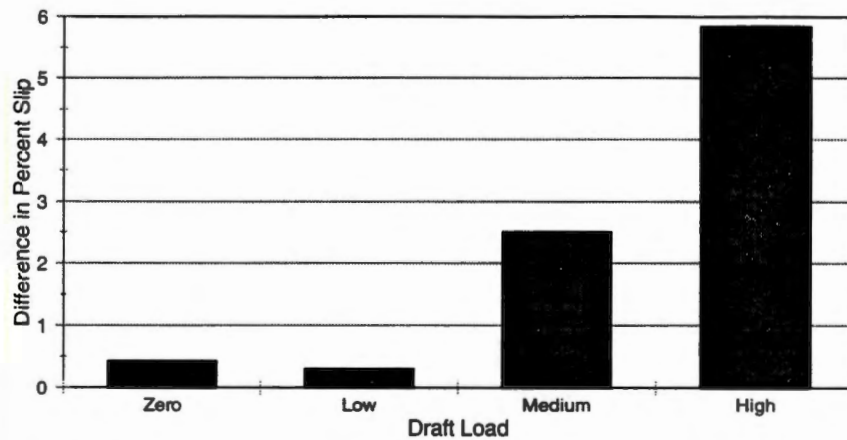


Figure 14: Graph illustrating the difference in the 200 and 350 lb axle loading conditions. As draft load increased the affect of axle loading increased.

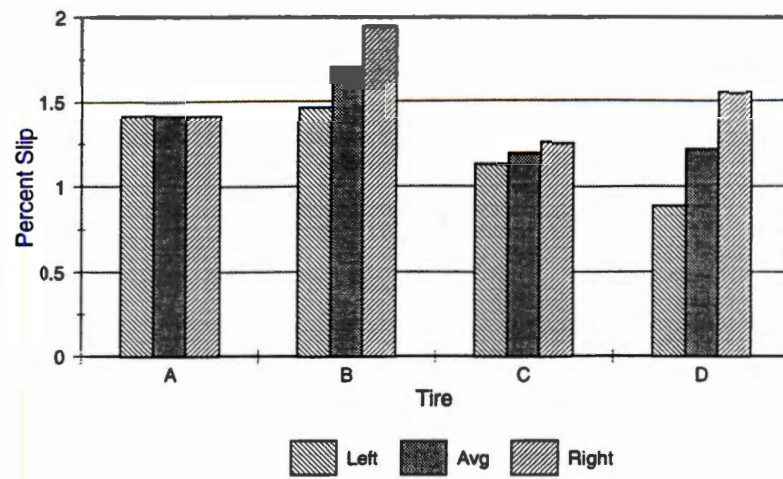


Figure 15: Graph illustrating left, average, and right percent slip for all tires. Notice the high values on the right side tires for tires B and D. Statistical comparisons are not made on this graph.

A third SAS program was written and two variables were added to the model: Tire equal and Side. Tire equal had two levels, equal and not equal. Tires A and C were equal while tires B and D were not equal. The variable side simply referred to left or right. Table 5 summarizes the variables in the model that were significant at an alpha level of less than 0.05.

Table 5: Listing of SAS Type III Sums of Squares for significant variables and combinations.

| Source         | DF | F Value | Pr>F   |
|----------------|----|---------|--------|
| Day            | 4  | 3.25    | 0.0135 |
| Moist          | 1  | 3.08    | 0.0809 |
| Nload          | 1  | 527.66  | 0.0001 |
| Dload          | 3  | 1963.45 | 0.0001 |
| Nload*Dload    | 3  | 244.00  | 0.0001 |
| Tirequal       | 1  | 3.25    | 0.0732 |
| Tire(Tirequal) | 1  | 9.52    | 0.0001 |
| Side           | 1  | 13.67   | 0.0003 |
| Tirequal*Side  | 1  | 9.20    | 0.0028 |

The variable tirequal is not significant. However, it is averaged over all tests and was not expected to be significant. The variable tire within tirequal is highly significant. This is comparing tire A to tire C and tire B to tire D. Comparisons are not made between the tires with different levels of the tirequal variable. Tires A and C are not significantly different from each other. However, tires B and D are significantly different from each other (Figure 16). When comparing the left and right sides there is a significant difference (Figure 17). The interaction of tirequal by side is also significant. For the tires where both the left and right side are of equal size there is no significant difference between the sides. However if the left and right sides are not equal there is a significant difference between the sides (Figure 18).

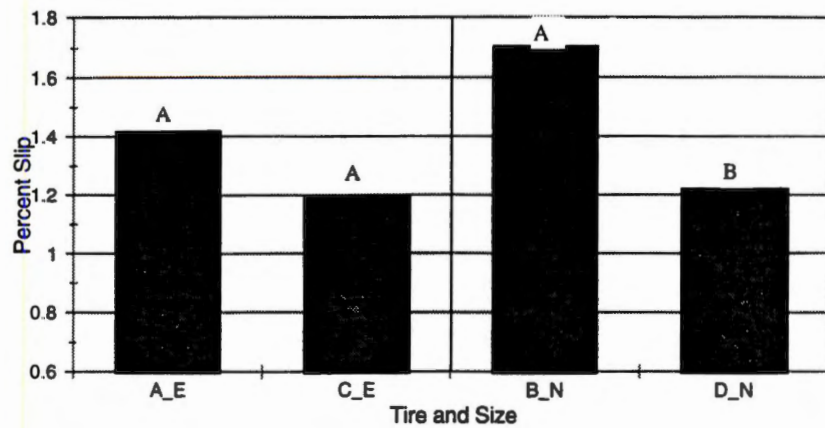


Figure 16: Graph illustrating tire comparisons based on tire size. X axis labels indicate the tire and whether both sides were equal. Comparisons are only made between tires A and C or tires B and D.

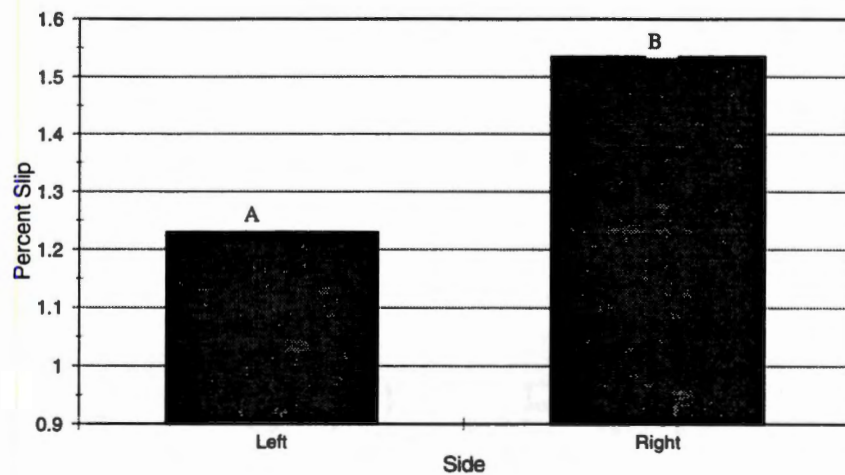


Figure 17: Graph illustrating side comparisons. All tires used on the left side of the tractor were the same size. The tires used on the right side of the tractor varied.

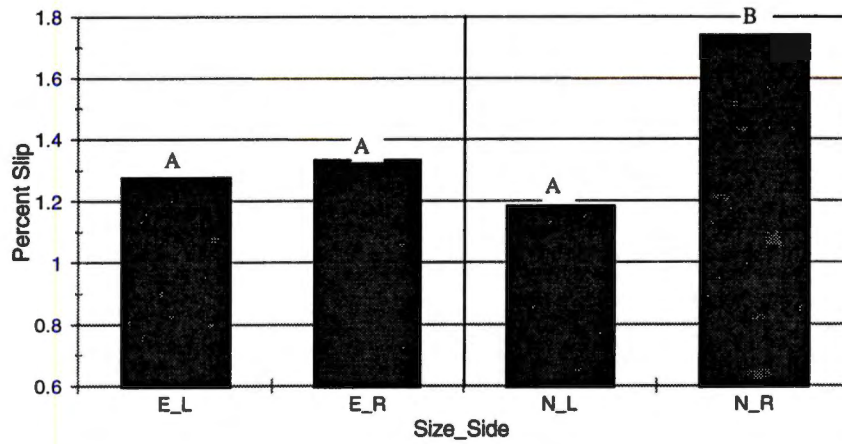


Figure 18: Graph illustrating tire size comparisons for each side. Where both sides were equal there is no significant difference between sides. Where the sides were not equal there is a significant difference between. Comparisons are not made between levels of equal and not equal.

## **Turf Damage Results**

Six turf samples were taken for each test. Samples were analyzed for fresh tearing and bruising. Damage was recorded as a percentage of the actual blade area. Also recorded was the pass number. The pass number ranged from one to five and was needed because the test area was not wide enough to conduct all runs without some overlap.

Again SAS was used to analyze the data using two slightly different methods. The first method averaged the six samples from each test. This method produced an  $R^2$  of 0.75 and had no significant variables or combinations of variables ( $\alpha < 0.05$ ). The second method used the maximum percent damage from each test. This method produced an  $R^2$  of 0.54. However, there were no significant variables or combinations of variables ( $\alpha < 0.05$ ). The percent slip values from the traction testing and the percent damage values were also tested for correlation. The correlation tests proved that there was no significant correlation between the slip and the amount of turf damage ( $\alpha > 0.30$ ). The programs used for statistical analysis are located in Appendix C along with summary output.

While no statistical conclusion can be made regarding turf damage from these tests, some common observations and suggestions for further testing are made in the conclusion section of this document.

## **Chapter 5**

### **Observations and Conclusions**

The following conclusions were made from the analysis of the data and results.

- As the downward loading on the rear axle increases drive wheel slip decreases. As the drawbar load increases drive wheel slip increases.
- As sipe density increases, the drive wheel slip appears to decrease.
- When using tires of different sizes under same load and drive conditions the smaller tire will have a greater percent slip than the larger. This results in a higher percent of the draft load being transferred to the smaller tire. Therefore, average tire slip values do not always represent the true performance of a single tire design.
- An increase in sipe density did not statistically affect turf damage for the test conditions.
- Turf damage appears to occur more readily in places where the turf has already been damaged or stressed. Therefore the severity of turf damage increases as the number of passes over an area is increased. This is a visual observation and not a statistical conclusion.

### **Suggestions for Further Research**

Throughout the course of this research the most time consuming part of data collection was the analysis of the turf damage. The photographic technique used was a considerable improvement over other in-field techniques previously evaluated. By taking pictures of the blades of grass we were able to increase the speed in which a series of tests could be conducted. However, there were still problems with this method. The pictures had to be taken at such close range that light became extremely important. So much so that cloud

cover could create a problem in picture quality. If some method of holding the grass blades flat without the use of a piece of glass could be developed then a flash could be used. This would eliminate light as the limiting factor in this method.

The second problem encountered during these tests was a lack of turf damage data. The sample size for this series of tests was six blades of turf for each combination of variables. This proved to be too few samples. A larger sample size is needed to get a more complete picture of the damage caused to the turf.

The third problem encountered was the difference between the left and right side tires. The tires used in this tests were constructed to be as close to exactly the same as possible, however there was still a small difference in size. This problem could be eliminated with the use of a single tire test unit. The use of a single tire test unit would also decrease the amount of time between tests for changing tires.

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## **Appendices**

# **Appendix A**

## **Listing of Tests and Results**

The following is a complete listing of all tests and resulting data.

| Test | Day | Tire | Moist | Nload | DLoad | L%Slip | R%Slip | Avg Slip |
|------|-----|------|-------|-------|-------|--------|--------|----------|
| 1    | 1   | A    | Moist | 200   | H     | 8.21   | 8.12   | 8.16     |
| 2    | 1   | B    | Moist | 200   | Z     | -2.89  | -2.66  | -2.77    |
| 3    | 1   | B    | Moist | 200   | L     | -0.84  | -0.46  | -0.65    |
| 4    | 1   | D    | Moist | 200   | M     | 4.49   | 5.65   | 5.07     |
| 5    | 1   | A    | Moist | 200   | Z     | -3.29  | -3.48  | -3.39    |
| 6    | 1   | C    | Moist | 200   | H     | 8.55   | 8.48   | 8.51     |
| 7    | 1   | C    | Moist | 200   | M     | 4.51   | 4.48   | 4.49     |
| 8    | 1   | D    | Moist | 200   | L     | -0.32  | 0.05   | -0.13    |
| 9    | 1   | D    | Moist | 350   | H     | 2.66   | 3.5    | 3.08     |
| 10   | 1   | B    | Moist | 350   | H     | 2.9    | 3.32   | 3.11     |
| 11   | 1   | B    | Moist | 350   | M     | 1.57   | 2.07   | 1.82     |
| 12   | 1   | C    | Moist | 350   | Z     | -1.6   | -1.77  | -1.68    |
| 13   | 1   | A    | Moist | 350   | M     | 3.45   | 3.28   | 3.37     |
| 14   | 1   | A    | Moist | 350   | L     | 0.13   | -0.03  | 0.05     |
| 15   | 1   | C    | Moist | 350   | L     | -0.78  | -0.76  | -0.77    |
| 16   | 1   | D    | Moist | 350   | Z     | -2.62  | -2.45  | -2.54    |
| 17   | 1   | B    | Dry   | 350   | Z     | -1.88  | .      | .        |
| 18   | 1   | C    | Dry   | 350   | H     | 5.66   | .      | .        |
| 19   | 1   | A    | Dry   | 350   | Z     | -1.9   | .      | .        |
| 20   | 1   | A    | Dry   | 350   | H     | 4.95   | .      | .        |
| 21   | 1   | D    | Dry   | 350   | L     | -0.89  | .      | .        |
| 22   | 1   | C    | Dry   | 350   | M     | 3.84   | .      | .        |
| 23   | 1   | D    | Dry   | 350   | M     | 2.71   | .      | .        |
| 24   | 1   | B    | Dry   | 350   | L     | -0.58  | -0.23  | -0.41    |
| 25   | 1   | B    | Dry   | 200   | M     | 4.46   | 5.1    | 4.78     |
| 26   | 1   | B    | Dry   | 200   | H     | 10.12  | 10.7   | 10.41    |
| 27   | 1   | D    | Dry   | 200   | Z     | -3.88  | -3.76  | -3.82    |
| 28   | 1   | C    | Dry   | 200   | M     | -0.09  | .      | .        |
| 29   | 1   | D    | Dry   | 200   | H     | 8.81   | 9.83   | 9.32     |
| 30   | 1   | A    | Dry   | 200   | M     | 4.79   | 4.64   | 4.71     |
| 31   | 1   | C    | Dry   | 200   | Z     | -3.19  | -3.46  | -3.33    |
| 32   | 1   | A    | Dry   | 200   | L     | 0.7    | 0.72   | 0.71     |
| 33   | 2   | D    | Dry   | 200   | M     | 4.13   | 5.21   | 4.67     |
| 34   | 2   | A    | Dry   | 200   | Z     | -2.97  | -3.09  | -3.03    |
| 35   | 2   | A    | Dry   | 200   | L     | -1.11  | -1.14  | -1.13    |
| 36   | 2   | D    | Dry   | 200   | H     | 8.75   | 9.77   | 9.26     |
| 37   | 2   | B    | Dry   | 200   | Z     | -2.67  | -2.7   | -2.68    |
| 38   | 2   | C    | Dry   | 200   | M     | 4.43   | 4.59   | 4.51     |

| Test | Day | Tire | Moist | Nload | DLoad | L%Slip | R%Slip | Avg Slip |
|------|-----|------|-------|-------|-------|--------|--------|----------|
| 39   | 2   | B    | Dry   | 200   | L     | -0.37  | 0.13   | -0.12    |
| 40   | 2   | C    | Dry   | 200   | H     | 8.51   | 8.81   | 8.66     |
| 41   | 2   | A    | Dry   | 350   | M     | 0.97   | 0.98   | 0.97     |
| 42   | 2   | A    | Dry   | 350   | H     | 3.31   | 3.43   | 3.37     |
| 43   | 2   | B    | Dry   | 350   | M     | 1.24   | 1.95   | 1.6      |
| 44   | 2   | D    | Dry   | 350   | L     | -0.74  | -0.47  | -0.61    |
| 45   | 2   | B    | Dry   | 350   | H     | 3.95   | 4.7    | 4.32     |
| 46   | 2   | C    | Dry   | 350   | L     | -1.07  | -1.02  | -1.05    |
| 47   | 2   | D    | Dry   | 350   | Z     | -3.48  | -3.5   | -3.49    |
| 48   | 2   | C    | Dry   | 350   | Z     | -2.78  | -2.84  | -2.81    |
| 49   | 2   | B    | Moist | 350   | L     | -0.04  | 0.36   | 0.16     |
| 50   | 2   | C    | Moist | 350   | H     | 2.74   | 2.85   | 2.8      |
| 51   | 2   | D    | Moist | 350   | H     | 3.31   | 4.23   | 3.77     |
| 52   | 2   | A    | Moist | 350   | Z     | -2.7   | -2.96  | -2.83    |
| 53   | 2   | C    | Moist | 350   | M     | 1.73   | 1.75   | 1.74     |
| 54   | 2   | D    | Moist | 350   | M     | 1.22   | 1.96   | 1.59     |
| 55   | 2   | A    | Moist | 350   | L     | -0.54  | -0.59  | -0.57    |
| 56   | 2   | B    | Moist | 350   | Z     | -2.79  | -2.66  | -2.72    |
| 57   | 2   | B    | Moist | 200   | H     | 11.23  | 12.51  | 11.87    |
| 58   | 2   | D    | Moist | 200   | L     | -0.74  | -0.18  | -0.46    |
| 59   | 2   | C    | Moist | 200   | L     | 0.32   | 0.49   | 0.41     |
| 60   | 2   | C    | Moist | 200   | Z     | -3.39  | -3.33  | -3.36    |
| 61   | 2   | B    | Moist | 200   | M     | 4.57   | 5.31   | 4.94     |
| 62   | 2   | D    | Moist | 200   | Z     | -2.46  | -2.42  | -2.44    |
| 63   | 2   | A    | Moist | 200   | M     | 4.74   | 4.94   | 4.84     |
| 64   | 2   | A    | Moist | 200   | H     | 8.62   | 8.55   | 8.59     |
| 65   | 3   | D    | Dry   | 350   | M     | 1.29   | 2.05   | 1.67     |
| 66   | 3   | D    | Dry   | 350   | L     | -1.62  | -1.23  | -1.43    |
| 67   | 3   | C    | Dry   | 200   | Z     | -3.47  | -3.55  | -3.51    |
| 68   | 3   | A    | Dry   | 200   | H     | 7.65   | 7.87   | 7.76     |
| 69   | 3   | C    | Dry   | 200   | M     | 3.98   | 4.18   | 4.08     |
| 70   | 3   | A    | Dry   | 200   | Z     | -3.33  | -3.43  | -3.38    |
| 71   | 3   | B    | Dry   | 200   | H     | 8.63   | 9.35   | 8.99     |
| 72   | 3   | B    | Dry   | 200   | L     | -1.03  | -0.59  | -0.81    |
| 73   | 3   | A    | Dry   | 350   | L     | -1.68  | -1.68  | -1.68    |
| 74   | 3   | D    | Dry   | 350   | Z     | -3.38  | -3.3   | -3.34    |
| 75   | 3   | B    | Dry   | 350   | Z     | -2.75  | -2.66  | -2.7     |
| 76   | 3   | D    | Dry   | 350   | H     | 2.39   | 3.52   | 2.95     |
| 77   | 3   | C    | Dry   | 350   | H     | 3.04   | 3.17   | 3.1      |
| 78   | 3   | B    | Dry   | 350   | M     | 0.87   | 1.37   | 1.12     |

| Test | Day | Tire | Moist | Nload | DLoad | L%Slip | R%Slip | Avg Slip |
|------|-----|------|-------|-------|-------|--------|--------|----------|
| 79   | 3   | A    | Dry   | 350   | M     | 1.88   | 1.81   | 1.85     |
| 80   | 3   | C    | Dry   | 350   | L     | -0.31  | -0.33  | -0.32    |
| 81   | 3   | C    | Moist | 350   | L     | -1.35  | -1.25  | -1.3     |
| 82   | 3   | C    | Moist | 350   | H     | 3.49   | 3.55   | 3.52     |
| 83   | 3   | B    | Moist | 200   | Z     | -2.67  | -2.8   | -2.74    |
| 84   | 3   | D    | Moist | 200   | Z     | -2.78  | -2.7   | -2.74    |
| 85   | 3   | A    | Moist | 200   | L     | -0.99  | -0.84  | -0.92    |
| 86   | 3   | B    | Moist | 200   | M     | 3.41   | 4.27   | 3.84     |
| 87   | 3   | A    | Moist | 200   | M     | 4.05   | 4.48   | 4.26     |
| 88   | 3   | D    | Moist | 200   | H     | 6.27   | 7.9    | 7.08     |
| 89   | 3   | A    | Moist | 350   | H     | 3.16   | 3.35   | 3.26     |
| 90   | 3   | D    | Moist | 350   | M     | 1.62   | 2.47   | 2.04     |
| 91   | 3   | D    | Moist | 350   | L     | -1.46  | -1.02  | -1.24    |
| 92   | 3   | C    | Moist | 350   | Z     | -3.18  | -3.3   | -3.24    |
| 93   | 3   | C    | Moist | 350   | M     | 0.84   | 1.06   | 0.95     |
| 94   | 3   | B    | Moist | 350   | L     | -1.05  | -0.63  | -0.84    |
| 95   | 3   | B    | Moist | 350   | M     | 1.52   | 2.14   | 1.83     |
| 96   | 3   | A    | Moist | 350   | Z     | -2     | -2.22  | -2.11    |
| 97   | 5   | C    | Moist | 200   | Z     | -3.68  | -3.68  | -3.68    |
| 98   | 5   | C    | Moist | 200   | M     | 3.04   | 3.48   | 3.26     |
| 99   | 5   | B    | Moist | 200   | H     | 9.99   | .      | .        |
| 100  | 5   | D    | Moist | 200   | H     | 5.96   | 7.55   | 6.76     |
| 101  | 5   | B    | Moist | 200   | L     | -0.3   | 0.39   | 0.04     |
| 102  | 5   | A    | Moist | 200   | Z     | -2.62  | -2.84  | -2.73    |
| 103  | 5   | A    | Moist | 200   | L     | -1.23  | -1.18  | -1.2     |
| 104  | 5   | D    | Moist | 200   | M     | 2.51   | 3.75   | 3.13     |
| 105  | 5   | D    | Moist | 350   | L     | -1.17  | -0.74  | -0.95    |
| 106  | 5   | B    | Moist | 350   | Z     | -2.58  | -2.56  | -2.57    |
| 107  | 5   | C    | Moist | 350   | L     | -0.55  | -0.48  | -0.51    |
| 108  | 5   | A    | Moist | 350   | M     | 0.83   | 0.89   | 0.86     |
| 109  | 5   | D    | Moist | 350   | Z     | -3.97  | -3.89  | -3.93    |
| 110  | 5   | B    | Moist | 350   | M     | 1.61   | 2.2    | 1.9      |
| 111  | 5   | A    | Moist | 350   | H     | 2.91   | 2.87   | 2.89     |
| 112  | 5   | C    | Moist | 350   | H     | 2.23   | 2.51   | 2.37     |
| 113  | 4   | C    | Dry   | 350   | M     | 1.78   | 2.04   | 1.91     |
| 114  | 4   | B    | Dry   | 350   | L     | -1.46  | -1.19  | -1.32    |
| 115  | 4   | C    | Dry   | 350   | Z     | -2.46  | -2.43  | -2.45    |
| 116  | 4   | D    | Dry   | 350   | M     | 1.59   | 2.4    | 1.99     |
| 117  | 4   | A    | Dry   | 350   | L     | -1.17  | -1.2   | -1.19    |
| 118  | 4   | B    | Dry   | 350   | H     | 2.52   | 3.15   | 2.83     |

| Test | Day | Tire | Moist | Nload | DLoad | L%Slip | R%Slip | Avg Slip |
|------|-----|------|-------|-------|-------|--------|--------|----------|
| 119  | 4   | A    | Dry   | 350   | Z     | -1.32  | -1.54  | -1.43    |
| 120  | 4   | D    | Dry   | 350   | M     | 1.11   | 1.77   | 1.44     |
| 121  | 4   | D    | Dry   | 200   | Z     | -2.39  | -2.31  | -2.35    |
| 122  | 4   | B    | Dry   | 200   | Z     | -2.74  | -2.73  | -2.73    |
| 123  | 4   | C    | Dry   | 200   | L     | -1.32  | -1.08  | -1.2     |
| 124  | 4   | A    | Dry   | 200   | M     | 4.37   | 4.45   | 4.41     |
| 125  | 4   | D    | Dry   | 200   | L     | -0.77  | -0.23  | -0.5     |
| 126  | 4   | A    | Dry   | 200   | H     | 9.25   | 9.7    | 9.47     |
| 127  | 4   | B    | Dry   | 200   | M     | 4.23   | 4.9    | 4.56     |
| 128  | 4   | C    | Dry   | 200   | H     | 9.7    | 10.99  | 10.35    |

The following is a listing of all turf data. Damage reported as a percent of total leaf area.

| Test | Sample | Damage |
|------|--------|--------|
| 1    | 1      | 0.00   |
| 1    | 2      | 0.00   |
| 1    | 3      | 0.00   |
| 1    | 4      | 0.00   |
| 1    | 5      | 0.00   |
| 1    | 6      | 6.67   |
| 2    | 1      | 0.00   |
| 2    | 2      | 0.00   |
| 2    | 3      | 0.00   |
| 2    | 4      | 0.00   |
| 2    | 5      | 0.17   |
| 2    | 6      | 1.39   |
| 3    | 1      | 0.00   |
| 3    | 2      | 0.00   |
| 3    | 3      | 0.66   |
| 3    | 4      | 1.67   |
| 3    | 5      | 0.76   |
| 3    | 6      | 2.60   |
| 4    | 1      | 0.00   |
| 4    | 2      | 0.00   |
| 4    | 3      | 0.00   |
| 4    | 4      | 0.75   |
| 4    | 5      | 5.15   |
| 4    | 6      | 0.47   |
| 5    | 1      | 0.00   |
| 5    | 2      | 0.00   |
| 5    | 3      | 0.00   |
| 5    | 4      | 0.60   |
| 5    | 5      | 0.00   |
| 5    | 6      | 0.00   |
| 6    | 1      | 0.00   |
| 6    | 2      | 0.00   |
| 6    | 3      | 0.91   |
| 6    | 4      | 0.00   |
| 6    | 5      | 0.00   |
| 6    | 6      | 1.44   |
| 7    | 1      | 0.00   |
| 7    | 2      | 0.00   |

| Test | Sample | Damage |
|------|--------|--------|
| 43   | 5      | 2.86   |
| 43   | 6      | 4.00   |
| 44   | 1      | .      |
| 44   | 2      | 0.00   |
| 44   | 3      | 0.00   |
| 44   | 4      | 1.60   |
| 44   | 5      | 1.60   |
| 44   | 6      | 0.77   |
| 45   | 1      | 0.00   |
| 45   | 2      | 0.00   |
| 45   | 3      | 1.46   |
| 45   | 4      | 3.46   |
| 45   | 5      | 2.05   |
| 45   | 6      | 1.91   |
| 46   | 1      | 6.67   |
| 46   | 2      | 8.89   |
| 46   | 3      | 10.94  |
| 46   | 4      | 1.90   |
| 46   | 5      | 0.23   |
| 46   | 6      | 1.46   |
| 47   | 1      | 0.00   |
| 47   | 2      | 2.50   |
| 47   | 3      | 7.50   |
| 47   | 4      | 4.24   |
| 47   | 5      | 1.54   |
| 47   | 6      | 1.02   |
| 48   | 1      | 0.00   |
| 48   | 2      | 11.28  |
| 48   | 3      | 9.66   |
| 48   | 4      | 0.89   |
| 48   | 5      | 0.48   |
| 48   | 6      | 0.49   |
| 49   | 1      | 0.00   |
| 49   | 2      | 0.00   |
| 49   | 3      | 8.15   |
| 49   | 4      | 1.67   |
| 49   | 5      | 2.49   |
| 49   | 6      | 0.42   |

| Test | Sample | Damage |
|------|--------|--------|
| 86   | 3      | 1.70   |
| 86   | 4      | 3.27   |
| 86   | 5      | 1.03   |
| 86   | 6      | 1.54   |
| 87   | 1      | 0.00   |
| 87   | 2      | 1.41   |
| 87   | 3      | 4.17   |
| 87   | 4      | 4.05   |
| 87   | 5      | 0.97   |
| 87   | 6      | 1.50   |
| 88   | 1      | .      |
| 88   | 2      | 0.00   |
| 88   | 3      | 0.64   |
| 88   | 4      | 0.97   |
| 88   | 5      | 0.71   |
| 88   | 6      | 0.92   |
| 89   | 1      | 0.00   |
| 89   | 2      | 0.00   |
| 89   | 3      | 0.79   |
| 89   | 4      | 2.22   |
| 89   | 5      | 0.95   |
| 89   | 6      | 1.41   |
| 90   | 1      | 2.02   |
| 90   | 2      | 2.84   |
| 90   | 3      | 0.65   |
| 90   | 4      | 2.08   |
| 90   | 5      | 7.57   |
| 90   | 6      | 0.71   |
| 91   | 1      | 0.00   |
| 91   | 2      | 0.00   |
| 91   | 3      | 1.52   |
| 91   | 4      | 1.17   |
| 91   | 5      | 0.44   |
| 91   | 6      | 1.90   |
| 92   | 1      | 0.00   |
| 92   | 2      | 1.88   |
| 92   | 3      | 0.91   |
| 92   | 4      | 1.67   |

| Test | Sample | Damage |
|------|--------|--------|
| 7    | 3      | 0.00   |
| 7    | 4      | 0.00   |
| 7    | 5      | 0.61   |
| 7    | 6      | 3.33   |
| 8    | 1      | 0.00   |
| 8    | 2      | 0.00   |
| 8    | 3      | 0.00   |
| 8    | 4      | 4.44   |
| 8    | 5      | 0.15   |
| 8    | 6      | 1.90   |
| 9    | 1      | 0.00   |
| 9    | 2      | 0.00   |
| 9    | 3      | 0.00   |
| 9    | 4      | 5.65   |
| 9    | 5      | 1.18   |
| 9    | 6      | 1.00   |
| 10   | 1      | .      |
| 10   | 2      | .      |
| 10   | 3      | .      |
| 10   | 4      | .      |
| 10   | 5      | .      |
| 10   | 6      | .      |
| 11   | 1      | .      |
| 11   | 2      | .      |
| 11   | 3      | .      |
| 11   | 4      | .      |
| 11   | 5      | .      |
| 11   | 6      | .      |
| 12   | 1      | .      |
| 12   | 2      | .      |
| 12   | 3      | .      |
| 12   | 4      | .      |
| 12   | 5      | .      |
| 12   | 6      | .      |
| 13   | 1      | .      |
| 13   | 2      | .      |
| 13   | 3      | .      |
| 13   | 4      | .      |
| 13   | 5      | .      |
| 13   | 6      | .      |

| Test | Sample | Damage |
|------|--------|--------|
| 50   | 1      | .      |
| 50   | 2      | 0.91   |
| 50   | 3      | 0.83   |
| 50   | 4      | 4.81   |
| 50   | 5      | 6.09   |
| 50   | 6      | 1.48   |
| 51   | 1      | .      |
| 51   | 2      | 0.00   |
| 51   | 3      | 0.83   |
| 51   | 4      | 1.84   |
| 51   | 5      | 1.67   |
| 51   | 6      | 0.83   |
| 52   | 1      | 0.00   |
| 52   | 2      | 4.00   |
| 52   | 3      | 1.67   |
| 52   | 4      | 3.81   |
| 52   | 5      | 6.00   |
| 52   | 6      | 1.67   |
| 53   | 1      | 0.00   |
| 53   | 2      | 0.00   |
| 53   | 3      | 3.54   |
| 53   | 4      | 0.30   |
| 53   | 5      | 1.77   |
| 53   | 6      | 0.83   |
| 54   | 1      | .      |
| 54   | 2      | .      |
| 54   | 3      | 0.00   |
| 54   | 4      | 0.00   |
| 54   | 5      | 1.67   |
| 54   | 6      | 2.38   |
| 55   | 1      | ERR    |
| 55   | 2      | 2.12   |
| 55   | 3      | 5.71   |
| 55   | 4      | 2.86   |
| 55   | 5      | 1.91   |
| 55   | 6      | 1.79   |
| 56   | 1      | .      |
| 56   | 2      | .      |
| 56   | 3      | 1.14   |
| 56   | 4      | 1.09   |

| Test | Sample | Damage |
|------|--------|--------|
| 92   | 5      | 0.96   |
| 92   | 6      | 2.67   |
| 93   | 1      | 3.70   |
| 93   | 2      | 6.15   |
| 93   | 3      | 0.67   |
| 93   | 4      | 3.12   |
| 93   | 5      | 5.21   |
| 93   | 6      | 1.52   |
| 94   | 1      | 0.00   |
| 94   | 2      | 0.00   |
| 94   | 3      | 0.69   |
| 94   | 4      | 4.03   |
| 94   | 5      | 3.21   |
| 94   | 6      | 1.28   |
| 95   | 1      | 0.00   |
| 95   | 2      | 1.88   |
| 95   | 3      | 2.67   |
| 95   | 4      | 2.74   |
| 95   | 5      | 0.47   |
| 95   | 6      | 0.51   |
| 96   | 1      | 0.44   |
| 96   | 2      | 2.14   |
| 96   | 3      | 2.14   |
| 96   | 4      | 0.00   |
| 96   | 5      | 0.00   |
| 96   | 6      | 0.00   |
| 97   | 1      | .      |
| 97   | 2      | .      |
| 97   | 3      | .      |
| 97   | 4      | 0.00   |
| 97   | 5      | 0.58   |
| 97   | 6      | 5.56   |
| 98   | 1      | 5.51   |
| 98   | 2      | 1.88   |
| 98   | 3      | 0.78   |
| 98   | 4      | 2.95   |
| 98   | 5      | 1.24   |
| 98   | 6      | 1.76   |
| 99   | 1      | 2.98   |
| 99   | 2      | 1.05   |

| Test | Sample | Damage |
|------|--------|--------|
| 14   | 1      | .      |
| 14   | 2      | .      |
| 14   | 3      | .      |
| 14   | 4      | .      |
| 14   | 5      | .      |
| 14   | 6      | .      |
| 15   | 1      | .      |
| 15   | 2      | .      |
| 15   | 3      | .      |
| 15   | 4      | .      |
| 15   | 5      | .      |
| 15   | 6      | .      |
| 16   | 1      | .      |
| 16   | 2      | .      |
| 16   | 3      | .      |
| 16   | 4      | .      |
| 16   | 5      | .      |
| 16   | 6      | .      |
| 17   | 1      | 0.00   |
| 17   | 2      | 0.00   |
| 17   | 3      | 0.00   |
| 17   | 4      | 0.00   |
| 17   | 5      | 0.10   |
| 17   | 6      | 1.11   |
| 18   | 1      | 0.00   |
| 18   | 2      | 0.00   |
| 18   | 3      | 0.00   |
| 18   | 4      | 0.00   |
| 18   | 5      | 0.00   |
| 18   | 6      | 2.78   |
| 19   | 1      | 0.00   |
| 19   | 2      | 0.00   |
| 19   | 3      | 1.82   |
| 19   | 4      | 1.25   |
| 19   | 5      | 0.56   |
| 19   | 6      | 0.59   |
| 20   | 1      | 0.00   |
| 20   | 2      | 0.00   |
| 20   | 3      | 0.00   |
| 20   | 4      | 0.00   |

| Test | Sample | Damage |
|------|--------|--------|
| 56   | 5      | 4.62   |
| 56   | 6      | 0.00   |
| 57   | 1      | 0.00   |
| 57   | 2      | 0.00   |
| 57   | 3      | 0.00   |
| 57   | 4      | 1.58   |
| 57   | 5      | 1.49   |
| 57   | 6      | 3.33   |
| 58   | 1      | 0.00   |
| 58   | 2      | 0.00   |
| 58   | 3      | 2.00   |
| 58   | 4      | 2.08   |
| 58   | 5      | 0.94   |
| 58   | 6      | 2.52   |
| 59   | 1      | .      |
| 59   | 2      | .      |
| 59   | 3      | .      |
| 59   | 4      | 2.86   |
| 59   | 5      | 2.12   |
| 59   | 6      | 2.01   |
| 60   | 1      | 4.00   |
| 60   | 2      | 1.33   |
| 60   | 3      | 0.00   |
| 60   | 4      | 0.00   |
| 60   | 5      | 0.00   |
| 60   | 6      | 0.00   |
| 61   | 1      | 1.00   |
| 61   | 2      | 2.20   |
| 61   | 3      | 1.79   |
| 61   | 4      | 2.08   |
| 61   | 5      | 2.50   |
| 61   | 6      | 0.33   |
| 62   | 1      | 0.00   |
| 62   | 2      | 0.00   |
| 62   | 3      | 0.00   |
| 62   | 4      | 0.00   |
| 62   | 5      | 0.00   |
| 62   | 6      | .      |
| 63   | 1      | .      |
| 63   | 2      | .      |

| Test | Sample | Damage |
|------|--------|--------|
| 99   | 3      | 2.15   |
| 99   | 4      | 1.27   |
| 99   | 5      | 5.67   |
| 99   | 6      | 1.00   |
| 100  | 1      | 0.00   |
| 100  | 2      | 0.00   |
| 100  | 3      | 0.00   |
| 100  | 4      | 1.83   |
| 100  | 5      | 1.13   |
| 100  | 6      | 4.16   |
| 101  | 1      | 0.00   |
| 101  | 2      | 0.63   |
| 101  | 3      | 1.67   |
| 101  | 4      | 1.31   |
| 101  | 5      | 1.63   |
| 101  | 6      | 3.33   |
| 102  | 1      | .      |
| 102  | 2      | 0.00   |
| 102  | 3      | 1.15   |
| 102  | 4      | 1.92   |
| 102  | 5      | 3.33   |
| 102  | 6      | 1.85   |
| 103  | 1      | 0.00   |
| 103  | 2      | 3.27   |
| 103  | 3      | 2.03   |
| 103  | 4      | 1.17   |
| 103  | 5      | 1.58   |
| 103  | 6      | 1.59   |
| 104  | 1      | 0.00   |
| 104  | 2      | 2.98   |
| 104  | 3      | 0.68   |
| 104  | 4      | 1.75   |
| 104  | 5      | 4.67   |
| 104  | 6      | 5.56   |
| 105  | 1      | 0.00   |
| 105  | 2      | 0.00   |
| 105  | 3      | 0.50   |
| 105  | 4      | 0.51   |
| 105  | 5      | 3.02   |
| 105  | 6      | 2.40   |

| Test | Sample | Damage |
|------|--------|--------|
| 20   | 5      | 3.56   |
| 20   | 6      | 1.42   |
| 21   | 1      | 0.00   |
| 21   | 2      | 0.00   |
| 21   | 3      | 1.38   |
| 21   | 4      | 0.43   |
| 21   | 5      | 0.42   |
| 21   | 6      | 1.53   |
| 22   | 1      | .      |
| 22   | 2      | .      |
| 22   | 3      | .      |
| 22   | 4      | .      |
| 22   | 5      | 0.00   |
| 22   | 6      | 1.39   |
| 23   | 1      | 0.00   |
| 23   | 2      | 1.32   |
| 23   | 3      | 1.30   |
| 23   | 4      | 1.03   |
| 23   | 5      | 2.16   |
| 23   | 6      | 2.43   |
| 24   | 1      | 0.00   |
| 24   | 2      | 0.00   |
| 24   | 3      | 1.17   |
| 24   | 4      | 2.06   |
| 24   | 5      | 1.57   |
| 24   | 6      | 2.59   |
| 25   | 1      | 0.00   |
| 25   | 2      | 0.70   |
| 25   | 3      | 2.10   |
| 25   | 4      | 0.84   |
| 25   | 5      | 0.93   |
| 25   | 6      | 1.10   |
| 26   | 1      | 0.00   |
| 26   | 2      | 0.00   |
| 26   | 3      | 0.00   |
| 26   | 4      | 0.00   |
| 26   | 5      | 1.27   |
| 26   | 6      | 2.00   |
| 27   | 1      | 0.00   |
| 27   | 2      | 0.00   |

| Test | Sample | Damage |
|------|--------|--------|
| 63   | 3      | .      |
| 63   | 4      | .      |
| 63   | 5      | .      |
| 63   | 6      | .      |
| 64   | 1      | .      |
| 64   | 2      | .      |
| 64   | 3      | .      |
| 64   | 4      | .      |
| 64   | 5      | .      |
| 64   | 6      | .      |
| 65   | 1      | .      |
| 65   | 2      | .      |
| 65   | 3      | .      |
| 65   | 4      | 3.58   |
| 65   | 5      | 1.56   |
| 65   | 6      | 2.34   |
| 66   | 1      | 0.42   |
| 66   | 2      | 2.45   |
| 66   | 3      | 2.08   |
| 66   | 4      | 2.43   |
| 66   | 5      | 1.30   |
| 66   | 6      | 0.95   |
| 67   | 1      | 0.00   |
| 67   | 2      | 0.00   |
| 67   | 3      | 0.71   |
| 67   | 4      | 4.51   |
| 67   | 5      | 0.95   |
| 67   | 6      | 1.82   |
| 68   | 1      | 1.67   |
| 68   | 2      | 0.48   |
| 68   | 3      | 2.50   |
| 68   | 4      | 1.30   |
| 68   | 5      | 2.18   |
| 68   | 6      | 4.58   |
| 69   | 1      | 0.99   |
| 69   | 2      | 1.70   |
| 69   | 3      | 3.96   |
| 69   | 4      | 0.54   |
| 69   | 5      | 0.97   |
| 69   | 6      | 0.00   |

| Test | Sample | Damage |
|------|--------|--------|
| 106  | 1      | 0.00   |
| 106  | 2      | 4.20   |
| 106  | 3      | 1.67   |
| 106  | 4      | 2.50   |
| 106  | 5      | 2.50   |
| 106  | 6      | 3.42   |
| 107  | 1      | 0.00   |
| 107  | 2      | 0.00   |
| 107  | 3      | 1.04   |
| 107  | 4      | 1.15   |
| 107  | 5      | 2.50   |
| 107  | 6      | 2.31   |
| 108  | 1      | .      |
| 108  | 2      | 1.79   |
| 108  | 3      | 3.26   |
| 108  | 4      | 4.36   |
| 108  | 5      | 1.05   |
| 108  | 6      | 0.53   |
| 109  | 1      | .      |
| 109  | 2      | 5.45   |
| 109  | 3      | 1.79   |
| 109  | 4      | 3.23   |
| 109  | 5      | 3.14   |
| 109  | 6      | 2.71   |
| 110  | 1      | 0.00   |
| 110  | 2      | 0.00   |
| 110  | 3      | 0.00   |
| 110  | 4      | 1.94   |
| 110  | 5      | 1.56   |
| 110  | 6      | 5.47   |
| 111  | 1      | 0.00   |
| 111  | 2      | 6.09   |
| 111  | 3      | 1.30   |
| 111  | 4      | 3.81   |
| 111  | 5      | 1.27   |
| 111  | 6      | 0.65   |
| 112  | 1      | .      |
| 112  | 2      | 1.35   |
| 112  | 3      | 0.50   |
| 112  | 4      | 3.40   |

| Test | Sample | Damage |
|------|--------|--------|
| 27   | 3      | 1.95   |
| 27   | 4      | 0.56   |
| 27   | 5      | 1.17   |
| 27   | 6      | 1.82   |
| 28   | 1      | 0.00   |
| 28   | 2      | 0.00   |
| 28   | 3      | 3.35   |
| 28   | 4      | 0.69   |
| 28   | 5      | 0.50   |
| 28   | 6      | 2.88   |
| 29   | 1      | 0.00   |
| 29   | 2      | 0.00   |
| 29   | 3      | 1.33   |
| 29   | 4      | 6.10   |
| 29   | 5      | 4.80   |
| 29   | 6      | 1.72   |
| 30   | 1      | 0.00   |
| 30   | 2      | 0.00   |
| 30   | 3      | 1.68   |
| 30   | 4      | 1.17   |
| 30   | 5      | 2.33   |
| 30   | 6      | 1.40   |
| 31   | 1      | .      |
| 31   | 2      | 0.00   |
| 31   | 3      | 0.92   |
| 31   | 4      | 2.22   |
| 31   | 5      | 2.85   |
| 31   | 6      | 1.21   |
| 32   | 1      | 0.00   |
| 32   | 2      | 0.00   |
| 32   | 3      | 0.00   |
| 32   | 4      | 0.00   |
| 32   | 5      | 0.00   |
| 32   | 6      | 0.00   |
| 33   | 1      | 0.00   |
| 33   | 2      | 0.00   |
| 33   | 3      | 6.28   |
| 33   | 4      | 1.98   |
| 33   | 5      | 3.89   |

| Test | Sample | Damage |
|------|--------|--------|
| 70   | 1      | 3.33   |
| 70   | 2      | 1.56   |
| 70   | 3      | 3.13   |
| 70   | 4      | 3.92   |
| 70   | 5      | 3.74   |
| 70   | 6      | 3.00   |
| 71   | 1      | 0.00   |
| 71   | 2      | 0.00   |
| 71   | 3      | 2.22   |
| 71   | 4      | 2.58   |
| 71   | 5      | 1.56   |
| 71   | 6      | 8.11   |
| 72   | 1      | .      |
| 72   | 2      | .      |
| 72   | 3      | .      |
| 72   | 4      | .      |
| 72   | 5      | .      |
| 72   | 6      | .      |
| 73   | 1      | 0.83   |
| 73   | 2      | 3.67   |
| 73   | 3      | 1.07   |
| 73   | 4      | 2.80   |
| 73   | 5      | 1.77   |
| 73   | 6      | 4.13   |
| 74   | 1      | 0.00   |
| 74   | 2      | 0.00   |
| 74   | 3      | 0.00   |
| 74   | 4      | 0.00   |
| 74   | 5      | 0.40   |
| 74   | 6      | 8.28   |
| 75   | 1      | 1.59   |
| 75   | 2      | 1.11   |
| 75   | 3      | 2.22   |
| 75   | 4      | 7.54   |
| 75   | 5      | 0.00   |
| 75   | 6      | 0.00   |
| 76   | 1      | 0.00   |
| 76   | 2      | 2.42   |
| 76   | 3      | 1.63   |

| Test | Sample | Damage |
|------|--------|--------|
| 112  | 5      | 1.51   |
| 112  | 6      | 2.01   |
| 113  | 1      | 1.17   |
| 113  | 2      | 1.74   |
| 113  | 3      | 0.61   |
| 113  | 4      | 1.81   |
| 113  | 5      | 3.26   |
| 113  | 6      | 3.93   |
| 114  | 1      | .      |
| 114  | 2      | 0.00   |
| 114  | 3      | 3.17   |
| 114  | 4      | 2.82   |
| 114  | 5      | 1.67   |
| 114  | 6      | 3.69   |
| 115  | 1      | 0.00   |
| 115  | 2      | 1.11   |
| 115  | 3      | 2.86   |
| 115  | 4      | 4.93   |
| 115  | 5      | 3.45   |
| 115  | 6      | 5.24   |
| 116  | 1      | 0.98   |
| 116  | 2      | 2.64   |
| 116  | 3      | 2.56   |
| 116  | 4      | 4.50   |
| 116  | 5      | 1.20   |
| 116  | 6      | 1.21   |
| 117  | 1      | 0.00   |
| 117  | 2      | 1.53   |
| 117  | 3      | 0.67   |
| 117  | 4      | 2.88   |
| 117  | 5      | 1.71   |
| 117  | 6      | 2.56   |
| 118  | 1      | 0.00   |
| 118  | 2      | 0.00   |
| 118  | 3      | 3.19   |
| 118  | 4      | 4.83   |
| 118  | 5      | 0.98   |
| 118  | 6      | 0.91   |
| 119  | 1      | 0.00   |

| Test | Sample | Damage |
|------|--------|--------|
| 33   | 6      | 1.67   |
| 34   | 1      | 0.00   |
| 34   | 2      | 0.00   |
| 34   | 3      | 1.67   |
| 34   | 4      | 5.76   |
| 34   | 5      | 1.67   |
| 34   | 6      | 1.67   |
| 35   | 1      | 0.00   |
| 35   | 2      | 0.00   |
| 35   | 3      | 1.25   |
| 35   | 4      | 0.86   |
| 35   | 5      | 1.80   |
| 35   | 6      | 0.67   |
| 36   | 1      | 0.00   |
| 36   | 2      | 0.48   |
| 36   | 3      | 1.28   |
| 36   | 4      | 2.67   |
| 36   | 5      | 3.27   |
| 36   | 6      | 1.18   |
| 37   | 1      | 1.55   |
| 37   | 2      | 1.39   |
| 37   | 3      | 0.77   |
| 37   | 4      | 2.22   |
| 37   | 5      | 3.75   |
| 37   | 6      | 4.44   |
| 38   | 1      | 0.00   |
| 38   | 2      | 1.11   |
| 38   | 3      | 2.64   |
| 38   | 4      | 0.93   |
| 38   | 5      | 2.46   |
| 38   | 6      | 4.83   |
| 39   | 1      | 0.00   |
| 39   | 2      | 0.67   |
| 39   | 3      | 2.14   |
| 39   | 4      | 3.36   |
| 39   | 5      | 1.33   |
| 39   | 6      | 1.27   |
| 40   | 1      | 0.00   |
| 40   | 2      | 0.00   |
| 40   | 3      | 0.00   |

| Test | Sample | Damage |
|------|--------|--------|
| 76   | 4      | 1.39   |
| 76   | 5      | 4.17   |
| 76   | 6      | 5.19   |
| 77   | 1      | 0.00   |
| 77   | 2      | 0.00   |
| 77   | 3      | 2.19   |
| 77   | 4      | 1.67   |
| 77   | 5      | 2.81   |
| 77   | 6      | 6.39   |
| 78   | 1      | 0.00   |
| 78   | 2      | 0.00   |
| 78   | 3      | 2.41   |
| 78   | 4      | 1.54   |
| 78   | 5      | 2.29   |
| 78   | 6      | 0.52   |
| 79   | 1      | 0.00   |
| 79   | 2      | 0.83   |
| 79   | 3      | 0.77   |
| 79   | 4      | 1.81   |
| 79   | 5      | 2.35   |
| 79   | 6      | 0.83   |
| 80   | 1      | .      |
| 80   | 2      | 6.59   |
| 80   | 3      | 0.76   |
| 80   | 4      | 2.19   |
| 80   | 5      | 2.00   |
| 80   | 6      | 0.74   |
| 81   | 1      | 5.76   |
| 81   | 2      | 4.42   |
| 81   | 3      | 0.83   |
| 81   | 4      | 1.06   |
| 81   | 5      | 1.92   |
| 81   | 6      | 0.17   |
| 82   | 1      | 4.38   |
| 82   | 2      | 3.58   |
| 82   | 3      | 1.39   |
| 82   | 4      | 1.67   |
| 82   | 5      | 0.83   |
| 82   | 6      | 3.65   |
| 83   | 1      | .      |

| Test | Sample | Damage |
|------|--------|--------|
| 119  | 2      | 0.00   |
| 119  | 3      | 2.22   |
| 119  | 4      | 1.09   |
| 119  | 5      | 1.55   |
| 119  | 6      | 3.75   |
| 120  | 1      | 0.00   |
| 120  | 2      | 0.00   |
| 120  | 3      | 2.20   |
| 120  | 4      | 1.52   |
| 120  | 5      | 2.67   |
| 120  | 6      | 2.32   |
| 121  | 1      | .      |
| 121  | 2      | 0.83   |
| 121  | 3      | 1.18   |
| 121  | 4      | 1.19   |
| 121  | 5      | 14.17  |
| 121  | 6      | 1.74   |
| 122  | 1      | .      |
| 122  | 2      | .      |
| 122  | 3      | 2.27   |
| 122  | 4      | 6.46   |
| 122  | 5      | 6.93   |
| 122  | 6      | 0.71   |
| 123  | 1      | .      |
| 123  | 2      | 0.00   |
| 123  | 3      | 0.00   |
| 123  | 4      | 0.00   |
| 123  | 5      | 3.21   |
| 123  | 6      | 0.71   |
| 124  | 1      | 0.00   |
| 124  | 2      | 0.00   |
| 124  | 3      | 3.70   |
| 124  | 4      | 1.01   |
| 124  | 5      | 1.53   |
| 124  | 6      | 3.70   |
| 125  | 1      | 0.00   |
| 125  | 2      | 3.32   |
| 125  | 3      | 3.08   |
| 125  | 4      | 1.59   |
| 125  | 5      | 2.86   |

| Test | Sample | Damage |
|------|--------|--------|
| 40   | 4      | 13.00  |
| 40   | 5      | 5.56   |
| 40   | 6      | 0.78   |
| 41   | 1      | 1.98   |
| 41   | 2      | 14.14  |
| 41   | 3      | 7.04   |
| 41   | 4      | 3.08   |
| 41   | 5      | 0.61   |
| 41   | 6      | 6.25   |
| 42   | 1      | 0.00   |
| 42   | 2      | 0.00   |
| 42   | 3      | 0.00   |
| 42   | 4      | 2.38   |
| 42   | 5      | 0.90   |
| 42   | 6      | 1.07   |
| 43   | 1      | 0.00   |
| 43   | 2      | 1.50   |
| 43   | 3      | 0.36   |
| 43   | 4      | 5.80   |

| Test | Sample | Damage |
|------|--------|--------|
| 83   | 2      | 0.00   |
| 83   | 3      | 0.00   |
| 83   | 4      | 0.97   |
| 83   | 5      | 0.34   |
| 83   | 6      | 3.13   |
| 84   | 1      | 0.00   |
| 84   | 2      | 0.00   |
| 84   | 3      | 0.00   |
| 84   | 4      | 2.62   |
| 84   | 5      | 0.78   |
| 84   | 6      | 1.33   |
| 85   | 1      | 0.00   |
| 85   | 2      | 0.00   |
| 85   | 3      | 0.00   |
| 85   | 4      | 5.15   |
| 85   | 5      | 1.33   |
| 85   | 6      | 0.83   |
| 86   | 1      | 0.00   |
| 86   | 2      | 0.69   |

| Test | Sample | Damage |
|------|--------|--------|
| 125  | 6      | 0.82   |
| 126  | 1      | 3.15   |
| 126  | 2      | 2.69   |
| 126  | 3      | 3.14   |
| 126  | 4      | 4.33   |
| 126  | 5      | 1.30   |
| 126  | 6      | 1.11   |
| 127  | 1      | 0.00   |
| 127  | 2      | 0.97   |
| 127  | 3      | 4.08   |
| 127  | 4      | 3.24   |
| 127  | 5      | 10.55  |
| 127  | 6      | 1.54   |
| 128  | 1      | 4.72   |
| 128  | 2      | 0.71   |
| 128  | 3      | 0.94   |
| 128  | 4      | 3.06   |
| 128  | 5      | 1.55   |
| 128  | 6      | 1.97   |

## **Appendix B**

### **Datalogger Program**

# Datalogger Program written for Campbell Scientific 21x

## MODE 1

### SCAN RATE 1

|          |                                 |
|----------|---------------------------------|
| 1:P6     | Full Bridge                     |
| 1:1      | Repetitions                     |
| 2:12     | Range $\pm 15\text{mV}$         |
| 3:3      | In Channel                      |
| 4:1      | Excite Channel                  |
| 5:5000   | Excite +5000 mV                 |
| 6:1      | Location                        |
| 7:-333.3 | Multiply                        |
| 8:0      | Offset                          |
|          |                                 |
| 2:P3     | Pulse                           |
| 1:4      | Repetitions                     |
| 2:1      | In Channel                      |
| 3:0      | High Frequency                  |
| 4:2      | Location                        |
| 5:1      | Multiply                        |
| 6:0      | Offset                          |
|          |                                 |
| 3:P20    | Port set                        |
| 1:1      | High                            |
| 2:1      | Port Number                     |
|          |                                 |
| 4:P1     | Volt (SE)                       |
| 1:1      | Repetitions                     |
| 2:15     | $\pm 5000\text{ mV Fast Range}$ |
| 3:1      | In Channel                      |
| 4:6      | Location                        |
| 5:1      | Multiply                        |
| 6:0      | Offset                          |
|          |                                 |
| 5:P89    | If X $\leq$ F                   |
| 1:6      | X Location                      |
| 2:3      | <                               |
| 3:1000   | F Location                      |
| 4:30     | Then Do                         |
|          |                                 |
| 6:P91    | If Flag                         |
| 1:21     | 1 Low                           |
| 2:30     | Then Do                         |

|        |                 |
|--------|-----------------|
| 7:P32  | Z=Z+1           |
| 1:7    | Z Location      |
| 8:P86  | Do              |
| 1:11   | Set Flag 1 High |
| 9:P86  | Do              |
| 1:10   | Set Flag 0 High |
| 10:P94 | Else            |
| 11:P86 | Do              |
| 1:10   | Set Flag 0 High |
| 12:P95 | End             |
| 13:P94 | Else            |
| 14:P86 | Do              |
| 1:21   | Set Flag 1 Low  |
| 15:P95 | End             |
| 16:P70 | Sample          |
| 1:7    | Repetitions     |
| 2:1    | Location        |

# **Appendix C**

## **SAS Programs and Output**

The following are the SAS programs used to analyze the turf and tire test data. The output located on the following pages will refer to the programs using the number which is in italics above each.

**Program 1:** Left and Right tire values for slip treated separately

```
data tiretest;
  infile 'c:\ama\tiredata.txt' firstobs=2;
  input day tire $ moist $ nload dload $ lslip rslip;
run;

proc glm;
  class day tire moist nload dload;
  model lslip rslip = day tire|moist|nload|dload;
  lsmeans nload dload nload*dload tire moist tire*dload /s p;
  means tire*moist*nload*dload;
  output out=rrr r=rleft rright;
run;

proc univariate plot normal;
  var rleft rright;
run;
```

**Program 2:** Left and Right tire values for slip averaged

```
data tiretest;
  infile 'c:\ama\tiredat2.txt' firstobs=2;
  input day tire $ moist $ nload dload $ avgslip;
run;

proc glm;
  class day tire moist nload dload;
  model avgslip = day tire|moist|nload|dload;
  lsmeans nload dload nload*dload tire moist tire*dload /s p;
  means tire*moist*nload*dload;
  output out=rrr r=ravgslip;
run;

proc univariate plot normal;
  var ravgslip;
run;
```

**Program 3:** Tire slip values treated as left and right, however the difference in size between the left and right side tires is accounted for in this program.

```
data tiretest;
  infile 'tiredata.txt' firstobs=2;
  input day tire $ moist $ nload dload $ lslip rslip;
run;

data final; set tiretest;
  if tire in ('A','C') then tirequal=' Equal';
  else tirequal='Notequal';
  side='Left '; slip=lslip; output;
  side='Right'; slip=rslip; output;
run;

proc glm;
  class day tire tirequal side moist nload dload;
  model slip = day tirequal tire(tirequal) tirequalmoistnloaddload
    tire(tirequal)lmoistnloaddload
    side side|tirequalmoistnloaddload @2;
  lsmeans nload dload nload*dload tirequal moist tirequal*dload
    tirequal*nload moist*dload moist*nload
    tire*moist*nload*dload(tirequal)
    side tire(tirequal) side*tirequal side*dload /s p;
  means tirequal*moist*nload*dload;
  output out=rrr r=rslip;
run;

proc univariate plot normal;
  var rslip;
run;
```

#### **Program 4: Turfgrass damage analysis**

```
data one; infile 'c:\ama\turfdata.txt' firstobs=2 expandtabs;
  input test pass row sample day moist $ nload dload $ tire $ percent;
  if 97 le test le 112 then day=5;
run;
```

```
proc means noprint; by test;
  id day tire dload nload moist pass;
  var percent;
  output out=mmm mean=mpcnt;
run;
```

```
proc glm;
  class day tire dload nload moist pass;
  model mpcnt =pass*day tire|dload|nload|moist ;
  lsmeans pass*day tire dload nload moist tire*nload*moist
    dload*nload*moist/s p;
  means tire*dload*nload*moist;
  output out=rrr r=rpcnt;
run;
```

```
data tiretest;
  infile 'c:\ama\tiredata.txt' firstobs=2;
  input day tire $ moist $ nload dload $ lslip rslip;
  dload=upcase(dload);
run;
```

```
proc sort; by day tire moist nload dload;
```

```
proc sort data=mmm; by day tire moist nload dload;
  data final; merge tiretest mmm; by day tire moist nload dload;
```

```
proc print; run;
```

```
proc plot; plot mpcnt*(lslip rslip);
run;
```

```
proc corr; var mpcnt lslip rslip;
run;
```

## **Program 1**

General Linear Models Procedure  
Class Level Information

| Class | Levels | Values    |
|-------|--------|-----------|
| DAY   | 5      | 1 2 3 4 5 |
| TIRE  | 4      | A B C D   |
| MOIST | 2      | Dry Moist |
| NLOAD | 2      | 200 350   |
| DLOAD | 4      | h l m z   |

Number of observations in data set = 128

NOTE: All dependent variable are consistent with respect to the presence or absence of missing values. However only 120 observations can be used in this analysis.

Dependent Variable: LSLIP

| Source          | DF       | Sum of Squares | Mean Square | F Value | Pr > F     |
|-----------------|----------|----------------|-------------|---------|------------|
| Model           | 67       | 1576.62384681  | 23.53169921 | 38.41   | 0.0001     |
| Error           | 52       | 31.85752319    | 0.61264468  |         |            |
| Corrected Total | 119      | 1608.48137000  |             |         |            |
|                 | R-Square | C.V.           | Root MSE    |         | LSLIP Mean |
|                 | 0.980194 | 68.99217       | 0.78271622  |         | 1.13450000 |

| Source           | DF | Type III SS  | Mean Square  | F Value | Pr > F |
|------------------|----|--------------|--------------|---------|--------|
| DAY              | 4  | 2.88947681   | 0.72236920   | 1.18    | 0.3309 |
| TIRE             | 3  | 5.96631551   | 1.98877184   | 3.25    | 0.0292 |
| MOIST            | 1  | 0.51869951   | 0.51869951   | 0.85    | 0.3617 |
| TIRE*MOIST       | 3  | 0.80535106   | 0.26845035   | 0.44    | 0.7266 |
| NLOAD            | 1  | 100.36313959 | 100.36313959 | 163.82  | 0.0001 |
| TIRE*NLOAD       | 3  | 2.93757513   | 0.97919171   | 1.60    | 0.2010 |
| MOIST*NLOAD      | 1  | 0.01299350   | 0.01299350   | 0.02    | 0.8848 |
| TIRE*MOIST*NLOAD | 3  | 1.57302316   | 0.52434105   | 0.86    | 0.4699 |

|                      |   |               |              |        |        |
|----------------------|---|---------------|--------------|--------|--------|
| DLOAD                | 3 | 1125.23287080 | 375.07762360 | 612.23 | 0.0001 |
| TIRE*DLOAD           | 9 | 5.09346329    | 0.56594037   | 0.92   | 0.5125 |
| MOIST*DLOAD          | 3 | 1.25542826    | 0.41847609   | 0.68   | 0.5664 |
| TIRE*MOIST*DLOAD     | 9 | 2.69400716    | 0.29933413   | 0.49   | 0.8756 |
| NLOAD*DLOAD          | 3 | 144.97645348  | 48.32548449  | 78.88  | 0.0001 |
| TIRE*NLOAD*DLOAD     | 9 | 5.50857824    | 0.61206425   | 1.00   | 0.4526 |
| MOIST*NLOAD*DLOAD    | 3 | 0.30811577    | 0.10270526   | 0.17   | 0.9177 |
| TIRE*MOIS*NLOA*DLOAD | 9 | 6.71575021    | 0.74619447   | 1.22   | 0.3045 |

Dependent Variable: RSLIP

| Source          | DF       | Sum of Squares | Mean Square | F Value    | Pr > F |
|-----------------|----------|----------------|-------------|------------|--------|
| Model           | 67       | 1782.37592051  | 26.60262568 | 41.74      | 0.0001 |
| Error           | 52       | 33.14227199    | 0.63735138  |            |        |
| Corrected Total | 119      | 1815.51819250  |             |            |        |
|                 | R-Square | C.V.           | Root MSE    | RSLIP Mean |        |
|                 | 0.981745 | 55.54656       | 0.79834290  | 1.43725000 |        |

| Source               | DF | Type III SS   | Mean Square  | F Value | Pr > F |
|----------------------|----|---------------|--------------|---------|--------|
| DAY                  | 4  | 2.50337801    | 0.62584450   | 0.98    | 0.4255 |
| TIRE                 | 3  | 7.03128600    | 2.34376200   | 3.68    | 0.0177 |
| MOIST                | 1  | 0.75431017    | 0.75431017   | 1.18    | 0.2817 |
| TIRE*MOIST           | 3  | 0.82924237    | 0.27641412   | 0.43    | 0.7298 |
| NLOAD                | 1  | 115.87945867  | 115.87945867 | 181.81  | 0.0001 |
| TIRE*NLOAD           | 3  | 3.34586041    | 1.11528680   | 1.75    | 0.1683 |
| MOIST*NLOAD          | 1  | 0.00682051    | 0.00682051   | 0.01    | 0.9180 |
| TIRE*MOIST*NLOAD     | 3  | 1.45851155    | 0.48617052   | 0.76    | 0.5201 |
| DLOAD                | 3  | 1288.57467384 | 429.52489128 | 673.92  | 0.0001 |
| TIRE*DLOAD           | 9  | 6.28211621    | 0.69801291   | 1.10    | 0.3826 |
| MOIST*DLOAD          | 3  | 1.77938349    | 0.59312783   | 0.93    | 0.4326 |
| TIRE*MOIST*DLOAD     | 9  | 3.36320600    | 0.37368956   | 0.59    | 0.8022 |
| NLOAD*DLOAD          | 3  | 154.72594042  | 51.57531347  | 80.92   | 0.0001 |
| TIRE*NLOAD*DLOAD     | 9  | 6.39023784    | 0.71002643   | 1.11    | 0.3697 |
| MOIST*NLOAD*DLOAD    | 3  | 0.18498091    | 0.06166030   | 0.10    | 0.9615 |
| TIRE*MOIS*NLOA*DLOAD | 9  | 7.01639592    | 0.77959955   | 1.22    | 0.3015 |

| TIRE | LSLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | LSMEAN<br>Number |
|------|-----------------|-------------------|-------------------------|------------------|
| A    | 1.41830099      | 0.14984303        | 0.0001                  | 1                |

|   |            |            |        |   |
|---|------------|------------|--------|---|
| B | 1.46071442 | 0.15525471 | 0.0001 | 2 |
| C | 1.13045005 | 0.15756612 | 0.0001 | 3 |
| D | 0.88547246 | 0.15341212 | 0.0001 | 4 |

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

| i/j | 1      | 2      | 3      | 4      |
|-----|--------|--------|--------|--------|
| 1   | .      | 0.8408 | 0.1836 | 0.0140 |
| 2   | 0.8408 | .      | 0.1326 | 0.0090 |
| 3   | 0.1836 | 0.1326 | .      | 0.2617 |
| 4   | 0.0140 | 0.0090 | 0.2617 | .      |

| TIRE | RSLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | LSMEAN<br>Number |
|------|-----------------|-------------------|-------------------------|------------------|
| A    | 1.41483294      | 0.15283460        | 0.0001                  | 1                |
| B    | 1.94828111      | 0.15835432        | 0.0001                  | 2                |
| C    | 1.25451799      | 0.16071187        | 0.0001                  | 3                |
| D    | 1.55215268      | 0.15647494        | 0.0001                  | 4                |

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

| i/j | 1      | 2      | 3      | 4      |
|-----|--------|--------|--------|--------|
| 1   | .      | 0.0160 | 0.4651 | 0.5235 |
| 2   | 0.0160 | .      | 0.0027 | 0.0725 |
| 3   | 0.4651 | 0.0027 | .      | 0.1824 |
| 4   | 0.5235 | 0.0725 | 0.1824 | .      |

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

## **Program 2**

General Linear Models Procedure  
Class Level Information

| Class | Levels | Values    |
|-------|--------|-----------|
| DAY   | 5      | 1 2 3 4 5 |
| TIRE  | 4      | A B C D   |
| MOIST | 2      | Dry Moist |
| NLOAD | 2      | 200 350   |
| DLOAD | 4      | h l m z   |

Number of observations in data set = 128

NOTE: Due to missing values, only 120 observations can be used in this analysis.

Dependent Variable: AVGLSLIP

| Source          | DF       | Sum of Squares | Mean Square | F Value       | Pr > F |
|-----------------|----------|----------------|-------------|---------------|--------|
| Model           | 67       | 1674.48537390  | 24.99231901 | 40.21         | 0.0001 |
| Error           | 52       | 32.32220527    | 0.62158087  |               |        |
| Corrected Total | 119      | 1706.80757917  |             |               |        |
|                 | R-Square | C.V.           | Root MSE    | AVGLSLIP Mean |        |
|                 | 0.981063 | 61.33451       | 0.78840400  | 1.28541667    |        |

| Source           | DF | Type III SS   | Mean Square  | F Value | Pr > F |
|------------------|----|---------------|--------------|---------|--------|
| DAY              | 4  | 2.65532807    | 0.66383202   | 1.07    | 0.3818 |
| TIRE             | 3  | 4.51818852    | 1.50606284   | 2.42    | 0.0762 |
| MOIST            | 1  | 0.63454796    | 0.63454796   | 1.02    | 0.3170 |
| TIRE*MOIST       | 3  | 0.77473732    | 0.25824577   | 0.42    | 0.7426 |
| NLOAD            | 1  | 107.98014642  | 107.98014642 | 173.72  | 0.0001 |
| TIRE*NLOAD       | 3  | 3.13547297    | 1.04515766   | 1.68    | 0.1823 |
| MOIST*NLOAD      | 1  | 0.00041560    | 0.00041560   | 0.00    | 0.9795 |
| TIRE*MOIST*NLOAD | 3  | 1.47705810    | 0.49235270   | 0.79    | 0.5038 |
| DLOAD            | 3  | 1205.09021549 | 401.69673850 | 646.25  | 0.0001 |

|                      |   |              |             |       |        |
|----------------------|---|--------------|-------------|-------|--------|
| TIRE*DLOAD           | 9 | 5.20159301   | 0.57795478  | 0.93  | 0.5075 |
| MOIST*DLOAD          | 3 | 1.50339490   | 0.50113163  | 0.81  | 0.4961 |
| TIRE*MOIST*DLOAD     | 9 | 2.96732202   | 0.32970245  | 0.53  | 0.8457 |
| NLOAD*DLOAD          | 3 | 149.81661662 | 49.93887221 | 80.34 | 0.0001 |
| TIRE*NLOAD*DLOAD     | 9 | 5.90855362   | 0.65650596  | 1.06  | 0.4101 |
| MOIST*NLOAD*DLOAD    | 3 | 0.23962680   | 0.07987560  | 0.13  | 0.9428 |
| TIRE*MOIS*NLOA*DLOAD | 9 | 6.72102239   | 0.74678027  | 1.20  | 0.3143 |

| NLOAD | AVGSLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | Pr >  T  H0:<br>LSMEAN1=LSMEAN2 |
|-------|-------------------|-------------------|-------------------------|---------------------------------|
| 200   | 2.40901419        | 0.11180586        | 0.0001                  | 0.0001                          |
| 350   | 0.35639659        | 0.11529283        | 0.0032                  |                                 |

| DLOAD | AVGSLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | LSMEAN<br>Number |
|-------|-------------------|-------------------|-------------------------|------------------|
| h     | 6.11917718        | 0.16954054        | 0.0001                  | 1                |
| l     | -0.66784166       | 0.15356825        | 0.0001                  | 2                |
| m     | 2.92262024        | 0.14672874        | 0.0001                  | 3                |
| z     | -2.84313420       | 0.15084489        | 0.0001                  | 4                |

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

| i/j | 1      | 2      | 3      | 4      |
|-----|--------|--------|--------|--------|
| 1   | .      | 0.0001 | 0.0001 | 0.0001 |
| 2   | 0.0001 | .      | 0.0001 | 0.0001 |
| 3   | 0.0001 | 0.0001 | .      | 0.0001 |
| 4   | 0.0001 | 0.0001 | 0.0001 | .      |

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

| NLOAD | DLOAD | AVGSLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | LSMEAN<br>Number |
|-------|-------|-------------------|-------------------|-------------------------|------------------|
| 200   | h     | 9.03678250        | 0.22580596        | 0.0001                  | 1                |
| 200   | l     | -0.51849479       | 0.23405253        | 0.0311                  | 2                |
| 200   | m     | 4.17352189        | 0.20846185        | 0.0001                  | 3                |
| 200   | z     | -3.05575284       | 0.19978071        | 0.0001                  | 4                |
| 350   | h     | 3.20157187        | 0.24532666        | 0.0001                  | 5                |

|     |   |             |            |        |   |
|-----|---|-------------|------------|--------|---|
| 350 | l | -0.81718853 | 0.19838740 | 0.0001 | 6 |
| 350 | m | 1.67171859  | 0.20602555 | 0.0001 | 7 |
| 350 | z | -2.63051557 | 0.22333648 | 0.0001 | 8 |

Dependent Variable: AVGSLLP

| i/j | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      |
|-----|--------|--------|--------|--------|--------|--------|--------|--------|
| 1   | .      | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| 2   | 0.0001 | .      | 0.0001 | 0.0001 | 0.0001 | 0.3343 | 0.0001 | 0.0001 |
| 3   | 0.0001 | 0.0001 | .      | 0.0001 | 0.0035 | 0.0001 | 0.0001 | 0.0001 |
| 4   | 0.0001 | 0.0001 | 0.0001 | .      | 0.0001 | 0.0001 | 0.0001 | 0.1590 |
| 5   | 0.0001 | 0.0001 | 0.0035 | 0.0001 | .      | 0.0001 | 0.0001 | 0.0001 |
| 6   | 0.0001 | 0.3343 | 0.0001 | 0.0001 | 0.0001 | .      | 0.0001 | 0.0001 |
| 7   | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | .      | 0.0001 |
| 8   | 0.0001 | 0.0001 | 0.0001 | 0.1590 | 0.0001 | 0.0001 | 0.0001 | .      |

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

| TIRE | AVGSLLP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | LSMEAN<br>Number |
|------|-------------------|-------------------|-------------------------|------------------|
| A    | 1.41583837        | 0.15093190        | 0.0001                  | 1                |
| B    | 1.70479698        | 0.15638291        | 0.0001                  | 2                |
| C    | 1.19205073        | 0.15871111        | 0.0001                  | 3                |
| D    | 1.21813547        | 0.15452692        | 0.0001                  | 4                |

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

| i/j | 1      | 2      | 3      | 4      |
|-----|--------|--------|--------|--------|
| 1   | .      | 0.1780 | 0.3031 | 0.3534 |
| 2   | 0.1780 | .      | 0.0223 | 0.0267 |
| 3   | 0.3031 | 0.0223 | .      | 0.9050 |
| 4   | 0.3534 | 0.0267 | 0.9050 | .      |

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

## **Program 3**

The SAS System

15:54 Monday, February 26, 1996

General Linear Models Procedure  
Class Level Information

| Class    | Levels | Values         |
|----------|--------|----------------|
| DAY      | 5      | 1 2 3 4 5      |
| TIRE     | 4      | A B C D        |
| TIREQUAL | 2      | Equal Notequal |
| SIDE     | 2      | Left Right     |
| MOIST    | 2      | Dry Moist      |
| NLOAD    | 2      | 200 350        |
| DLOAD    | 4      | h l m z        |

Number of observations in data set = 256

NOTE: Due to missing values, only 240 observations can be used in this analysis.

Dependent Variable: SLIP

| Source          | DF       | Sum of Squares | Mean Square | F Value | Pr > F     |
|-----------------|----------|----------------|-------------|---------|------------|
| Model           | 74       | 3361.96633023  | 45.43197744 | 111.00  | 0.0001     |
| Error           | 165      | 67.53268602    | 0.40928901  |         |            |
| Corrected Total | 239      | 3429.49901625  |             |         |            |
|                 | R-Square | C.V.           | Root MSE    |         | SLIP Mean  |
|                 | 0.980308 | 49.75266       | 0.63975699  |         | 1.28587500 |

Dependent Variable: SLIP

| Source         | DF | Type III SS  | Mean Square  | F Value | Pr > F |
|----------------|----|--------------|--------------|---------|--------|
| DAY            | 4  | 5.32101925   | 1.33025481   | 3.25    | 0.0135 |
| TIREQUAL       | 1  | 1.33074748   | 1.33074748   | 3.25    | 0.0732 |
| TIRE(TIREQUAL) | 2  | 7.79669833   | 3.89834916   | 9.52    | 0.0001 |
| MOIST          | 1  | 1.26201288   | 1.26201288   | 3.08    | 0.0809 |
| TIREQUAL*MOIST | 1  | 0.00287816   | 0.00287816   | 0.01    | 0.9333 |
| NLOAD          | 1  | 215.96389872 | 215.96389872 | 527.66  | 0.0001 |

|                      |   |               |              |         |        |
|----------------------|---|---------------|--------------|---------|--------|
| TIREQUAL*NLOAD       | 1 | 4.41936331    | 4.41936331   | 10.80   | 0.0012 |
| MOIST*NLOAD          | 1 | 0.00049306    | 0.00049306   | 0.00    | 0.9724 |
| TIREQUAL*MOIST*NLOAD | 1 | 0.11296597    | 0.11296597   | 0.28    | 0.6000 |
| DLOAD                | 3 | 2410.85773833 | 803.61924611 | 1963.45 | 0.0001 |
| TIREQUAL*DLOAD       | 3 | 1.82843126    | 0.60947709   | 1.49    | 0.2194 |
| MOIST*DLOAD          | 3 | 3.00361978    | 1.00120659   | 2.45    | 0.0657 |
| TIREQUAL*MOIST*DLOAD | 3 | 1.28461815    | 0.42820605   | 1.05    | 0.3737 |
| NLOAD*DLOAD          | 3 | 299.60510152  | 99.86836717  | 244.00  | 0.0001 |
| TIREQUAL*NLOAD*DLOAD | 3 | 1.30521709    | 0.43507236   | 1.06    | 0.3664 |
| MOIST*NLOAD*DLOAD    | 3 | 0.47525984    | 0.15841995   | 0.39    | 0.7625 |
| TIRE*MOIS*NLOA*DLOAD | 3 | 1.16682320    | 0.38894107   | 0.95    | 0.4178 |
| TIRE*MOIST(TIREQUAL) | 2 | 1.55897690    | 0.77948845   | 1.90    | 0.1522 |
| TIRE*NLOAD(TIREQUAL) | 2 | 1.83141838    | 0.91570919   | 2.24    | 0.1100 |
| TIRE*MOIS*NLOA(TIRE) | 2 | 2.89721996    | 1.44860998   | 3.54    | 0.0313 |
| TIRE*DLOAD(TIREQUAL) | 6 | 8.96923756    | 1.49487293   | 3.65    | 0.0020 |
| TIRE*MOIS*DLOA(TIRE) | 6 | 4.67041692    | 0.77840282   | 1.90    | 0.0834 |
| TIRE*NLOA*DLOA(TIRE) | 6 | 10.47215052   | 1.74535842   | 4.26    | 0.0005 |
| TIR*MOI*NLO*DLO(TIR) | 6 | 12.12186358   | 2.02031060   | 4.94    | 0.0001 |
| SIDE                 | 1 | 5.59522180    | 5.59522180   | 13.67   | 0.0003 |
| TIREQUAL*SIDE        | 1 | 3.76393017    | 3.76393017   | 9.20    | 0.0028 |
| SIDE*MOIST           | 1 | 0.00777660    | 0.00777660   | 0.02    | 0.8905 |
| SIDE*NLOAD           | 1 | 0.24151950    | 0.24151950   | 0.59    | 0.4435 |
| SIDE*DLOAD           | 3 | 3.14637735    | 1.04879245   | 2.56    | 0.0566 |

| TIREQUAL | SLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | Pr >  T  H0:<br>LSMEAN1=LSMEAN2 |
|----------|----------------|-------------------|-------------------------|---------------------------------|
| Equal    | 1.30452549     | 0.06392855        | 0.0001                  | 0.0732                          |
| Notequal | 1.46165517     | 0.06487971        | 0.0001                  |                                 |

| SIDE  | SLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | Pr >  T  H0:<br>LSMEAN1=LSMEAN2 |
|-------|----------------|-------------------|-------------------------|---------------------------------|
| Left  | 1.22981525     | 0.06299388        | 0.0001                  | 0.0003                          |
| Right | 1.53636541     | 0.06299388        | 0.0001                  |                                 |

| TIRE | TIREQUAL | SLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | LSMEAN<br>Number |
|------|----------|----------------|-------------------|-------------------------|------------------|
| A    | Equal    | 1.41656696     | 0.08660286        | 0.0001                  | 1                |
| C    | Equal    | 1.19248402     | 0.09106648        | 0.0001                  | 2                |
| B    | Notequal | 1.70449776     | 0.08973058        | 0.0001                  | 3                |
| D    | Notequal | 1.21881257     | 0.08866565        | 0.0001                  | 4                |

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

| i/j | 1      | 2      | 3      | 4      |
|-----|--------|--------|--------|--------|
| 1   | .      | 0.0713 | 0.0189 | 0.1045 |
| 2   | 0.0713 | .      | 0.0001 | 0.8332 |
| 3   | 0.0189 | 0.0001 | .      | 0.0001 |
| 4   | 0.1045 | 0.8332 | 0.0001 | .      |

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

| TIREQUAL | SIDE  | SLIP<br>LSMEAN | Std Err<br>LSMEAN | Pr >  T <br>H0:LSMEAN=0 | LSMEAN<br>Number |
|----------|-------|----------------|-------------------|-------------------------|------------------|
| Equal    | Left  | 1.27655360     | 0.08665511        | 0.0001                  | 1                |
| Equal    | Right | 1.33249738     | 0.08665511        | 0.0001                  | 2                |
| Notequal | Left  | 1.18307689     | 0.08740024        | 0.0001                  | 3                |
| Notequal | Right | 1.74023344     | 0.08740024        | 0.0001                  | 4                |

Pr > |T| H0: LSMEAN(i)=LSMEAN(j)

| i/j | 1      | 2      | 3      | 4      |
|-----|--------|--------|--------|--------|
| 1   | .      | 0.6332 | 0.4375 | 0.0002 |
| 2   | 0.6332 | .      | 0.2159 | 0.0009 |
| 3   | 0.4375 | 0.2159 | .      | 0.0001 |
| 4   | 0.0002 | 0.0009 | 0.0001 | .      |

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.

## **Program 4**

General Linear Models Procedure  
Class Level Information

| Class | Levels | Values    |
|-------|--------|-----------|
| DAY   | 5      | 1 2 3 4 5 |
| TIRE  | 4      | A B C D   |
| DLOAD | 4      | H L M Z   |
| NLOAD | 2      | 200 350   |
| MOIST | 2      | Dry Moist |
| PASS  | 5      | 1 2 3 4 5 |

Number of observations in data set = 128

NOTE: Due to missing values, only 118 observations can be used in this analysis.

Dependent Variable: MPCNT

| Source          | DF       | Sum of Squares | Mean Square | F Value | Pr > F     |
|-----------------|----------|----------------|-------------|---------|------------|
| Model           | 71       | 83.67969366    | 1.17858723  | 1.92    | 0.0098     |
| Error           | 46       | 28.25080131    | 0.61414785  |         |            |
| Corrected Total | 117      | 111.93049498   |             |         |            |
|                 | R-Square | C.V.           | Root MSE    |         | MPCNT Mean |
|                 | 0.747604 | 45.48080       | 0.78367586  |         | 1.72309181 |

| Source           | DF | Type III SS | Mean Square | F Value | Pr > F |
|------------------|----|-------------|-------------|---------|--------|
| DAY*PASS         | 8  | 22.56611412 | 2.82076426  | 4.59    | 0.0004 |
| TIRE             | 3  | 1.49873423  | 0.49957808  | 0.81    | 0.4930 |
| DLOAD            | 3  | 2.89038689  | 0.96346230  | 1.57    | 0.2097 |
| TIRE*DLOAD       | 9  | 4.52579156  | 0.50286573  | 0.82    | 0.6018 |
| NLOAD            | 1  | 1.11172176  | 1.11172176  | 1.81    | 0.1851 |
| TIRE*NLOAD       | 3  | 2.25896389  | 0.75298796  | 1.23    | 0.3110 |
| DLOAD*NLOAD      | 3  | 3.69375000  | 1.23125000  | 2.00    | 0.1265 |
| TIRE*DLOAD*NLOAD | 9  | 6.77482476  | 0.75275831  | 1.23    | 0.3032 |

|                        |   |            |            |      |        |
|------------------------|---|------------|------------|------|--------|
| MOIST                  | 1 | 1.74791570 | 1.74791570 | 2.85 | 0.0984 |
| TIRE*MOIST             | 3 | 0.62940932 | 0.20980311 | 0.34 | 0.7953 |
| DLOAD*MOIST            | 3 | 1.50483616 | 0.50151205 | 0.82 | 0.4912 |
| TIRE*DLOAD*MOIST       | 9 | 5.63370241 | 0.62596693 | 1.02 | 0.4392 |
| NLOAD*MOIST            | 1 | 0.00763752 | 0.00763752 | 0.01 | 0.9117 |
| TIRE*NLOAD*MOIST       | 3 | 5.46260855 | 1.82086952 | 2.96 | 0.0417 |
| DLOAD*NLOAD*MOIST      | 3 | 5.76008878 | 1.92002959 | 3.13 | 0.0347 |
| TIRE*DLOAD*NLOAD*MOIST | 9 | 9.77833529 | 1.08648170 | 1.77 | 0.1005 |

### Correlation Analysis

3 'VAR' Variables: MPCNT LSLIP RSLIP

### Simple Statistics

| Variable | N   | Mean    | Std Dev | Sum       | Minimum  | Maximum  |
|----------|-----|---------|---------|-----------|----------|----------|
| MPCNT    | 119 | 1.72695 | 0.97485 | 205.50650 | 0        | 5.51667  |
| LSLIP    | 120 | 1.13450 | 3.67650 | 136.14000 | -3.97000 | 11.23000 |
| RSLIP    | 120 | 1.43725 | 3.90595 | 172.47000 | -3.89000 | 12.51000 |

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0  
/ Number of Observations

|       | MPCNT                     | LSLIP                     | RSLIP                     |
|-------|---------------------------|---------------------------|---------------------------|
| MPCNT | 1.00000<br>0.0<br>119     | -0.05979<br>0.5466<br>104 | -0.06305<br>0.5249<br>104 |
| LSLIP | -0.05979<br>0.5466<br>104 | 1.00000<br>0.0<br>120     | 0.99594<br>0.0001<br>120  |
| RSLIP | -0.06305<br>0.5249<br>104 | 0.99594<br>0.0001<br>120  | 1.00000<br>0.0<br>120     |

## **Vita**

Andy Arthur graduated from Mauldin High School in the May of 1989. He began work on a Bachelors degree in Ornamental Horticulture and Landscape Design at The University of Tennessee in the Fall of the same year. His main concentration was in Turfgrass Management. He received his Bachelors in May of 1993. Immediately upon graduation he began work in the Department of Agricultural Engineering as a Graduate Teaching Assistant. He was responsible for the College of Agriculture and Natural Resources Microcomputer Lab. He received his Masters degree from The University of Tennessee in Agricultural Engineering Technology in May of 1996, and is currently employed by Course Crafters Inc.