POROUS ASPHALT AND TURF: EXPLORING NEW APPLICATIONS THROUGH HYDROLOGICAL CHARACTERIZATION OF CU STRUCTURAL SOIL® AND CAROLINA STALITE STRUCTURAL SOIL

A Thesis

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by

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ABSTRACT

CU Structural Soil® was invented in the mid 1990's to address health and longevity issues of urban street trees. This 80 percent gravel and 20 percent soil mixture creates a gap graded, rigid stone matrix which conforms to standards for compaction underneath pavement, yet still allows a healthier rooting media than standard urban environments. Ecologically sensitive development and environmental legislation create unique needs for this soil mixture that requires additional research.

Porous asphalt allows water to filter through the pavement profile and into a reservoir of NYSDOT Type 2 gravel (Appendix 1.4) underneath the pavement where it is held and available for groundwater recharge. While this approach addresses water quality and runoff mitigation issues as specified by National Pollution Discharge Elimination System (NPDES) legislation, replacement of the gravel reservoir with CU Structural Soil® allows for the incorporation of trees into the system to further remove water and add an inherently green aspect this technology. The target audience for this technology is urban and suburban big box parking lots.

Additionally, this work examines replacing the asphalt surfaces with turfgrass sod. The use of turfgrass as a surface treatment for periphery parking spaces that receive infrequent traffic has potential benefits as well. These include runoff mitigation, lower surface temperatures and the appearance of green space, allowing large parking lots to appear smaller than they are.

Laboratory studies undertaken to gain insight into the hydrological characteristics of both CU Structural Soil®, Carolina Stalite Structural Soil and their constituent components of gravel, expanded slate, and clay loam soil included porosity and macroporosity studies as well as infiltration and available water holding capacity trials. Our research found that total soil porosity at 95 percent Proctor Density was 31 percent for CU Structural Soil®, of which macropores comprised 57.4 percent of the

total pores. Total soil porosity for the Carolina Stalite Structural Soil at 95 percent Proctor Density was 32.5 percent, of which macropores comprised 60.3 percent of the total pores. Comparably, total soil porosity for a clay loam soil compacted to 95 percent Proctor Density was 32.9 percent with only 2.3 percent of the pores being macropores. Infiltration for both structural soils at 95 percent Proctor Density was greater than 60 cm per hour, (24"/hour) while the clay loam soil resulted in 1.24 cm (0.5") per hour. Plant available water for the CU Structural Soil® was 8.5 percent while the Carolina Stalite Structural Soil was 11 percent, classifying them as similar to a loamy sand. These results indicate that structural soil would be a strong viable alternative to the un-compacted NYSDOT Type 2 stone traditionally used in porous asphalt reservoirs.

Field tests based on this research were carried out at test plots located on the Cornell University campus. Combinations of structural soils and both porous and traditional asphalt surfaces were tested as well as different turf surfaces. These experiments not only examined stormwater and runoff mitigation, but also the feasibility and durability of the different turfgrass surfaces on the different reservoir base course materials. Results indicated that tall fescue turf on both CU and Carolina Stalite Structural Soils consistently outperformed zoysiagrass in all traffic and wear tests, as well as in turf quality ratings. Neither grass performed well on a control base of straight gravel, going completely dormant during the summer months. In surface temperature studies, the fescue on both structural soils ranged from 15° to 20° C cooler than either of the asphalt surfaces. These results conclude that a properly specified turf on structural soil will not only lower surface temperatures and mitigate stormwater runoff, but also provide a wear tolerant surface. Though the zoysiagrass performed poorly in Ithaca's cool-season climate, observation indicates it may be a suitable choice for warm-season locations in the southeast U.S.

BIOGRAPHICAL SKETCH

Edward (Ted) Haffner was born in Chicago, I.L. on June 6, 1971. He received a B.A. in both English and government from Cornell University in May 1994. After nine years he returned to Cornell for Masters degrees in Landscape Architecture and Horticulture where he focused on ecological issues in landscape design.

To all my supporters:

Mirja Spooner

My Parents

My Brother

My Teachers

My Friends

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Words cannot express the gratitude I have for all those who have been accompanied me, both professionally and personally, through my extended academic journey. This work would not be possible without the patience, guidance and support of my advisor and friend, Dr. Nina Bassuk. Thanks also go to committee members Frank Rossi and Peter Trowbridge for their advice and willingness to share their boundless depth of knowledge in the fields of turfgrass and landscape design and construction. Additionally, B.Z. Maranca, Ron White, J.C. Mosher, Mary Thurn, Bob Schindelbeck, Kim Goodwin, Missy Bidwell, Michael Dosmann and Jacob Barney for their time and invaluable mental and physical contributions to this work.

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CHAPTER ONE –

Laboratory Tests: Hydrological Characterization of CU Structural Soil® and Carolina Stalite Structural Soils

Introduction

This study was performed to further understand the physical properties relating to water retention, compaction, and drainage of both CU Structural Soil® and Carolina Stalite Structural Soil. CU Structural Soil® has been extensively studied since it's inception in 1994. Yet, at the time of this study, macroporosity, infiltration and water holding capacity data for the soil had yet to be determined (Grabosky and Bassuk 1995, Grabosky and Bassuk 1996). Additionally, although porosity data exists for Carolina Stalite Structural Soil through the Carolina Stalite Company, water holding capacity data does not exist (Appendix 1.1).

Research indicates that increased soil compaction in non-structural soils not only reduces both total pore space and soil macropores, but it also inhibits drainage and infiltration (Craul 1992). Gap-graded structural soils, however, are engineered and designed to work at compaction levels of 95 percent-100 percent Proctor Density (Grabosky and Bassuk 1995, Proctor 1933, ASTM D 698) without minimizing drainage or infiltration. This information aids urban foresters, landscape architects, field engineers, and DPW officials in specifying the proper amount of soil rooting volume based on a plant's water needs (Lindsey & Bassuk 1991). As Lindsey and Bassuk's research indicates, available water holding capacity (AWHC) is defined as the point between field capacity and the permanent wilting point, and is one of the necessary criteria to properly select trees for a specific site, whether the site is a tree pit, container, or tree lawn in an urban setting. Since structural soils are becoming more commonly used in urban environments, knowing both porosity and available water holding capacity is essential to determining not only the proper sizing of soil rooting volumes, but also appropriate recommendations for tree health in urban sites using structural soils.

This study entailed four separate but related procedures to determine the water holding characteristics of CU Structural Soil® and Carolina Stalite Structural Soil. The outcome of these studies included data on percent moisture content for optimal compaction, total and macroporosity, infiltration, and available water holding capacity of each soil at 95 percent-100 percent Standard Proctor Density.

Methods and Materials

This base course was mixed as per Carolina Stalite structural soil specifications which call for

Batches of both CU Structural Soil® and Carolina Stalite Structural Soil were mixed, each approximately measuring 1.3 m^3 (10 $ft.^3$). The CU Structural Soil® was mixed to specification using the standard formula of 80 percent NYSDOT Type 2 Stone and 20 percent silty clay loam by weight. Hydrogel was used to bind the soil to the stone at a rate of 30g/100kg of NYSDOT Type 2 stone (Appendix 1.2). The Carolina Stalite Structural Soil mixture was comprised of 80 percent 1.9 cm (0.75”) Carolina Stalite and 20 percent silty clay loam. Although the specification for Carolina Stalite (Appendix 1.3) calls for 20 percent sandy clay loam, we slightly altered this specification with the permission of the Stalite Corporation by replacing the sandy clay loam with silty clay loam so that the interstitial soils for both structural soil mixtures was identical.

The first experiment determined percent water content for optimal compaction to 95 percent-100 percent Proctor Density for both the CU Structural Soil® and the Carolina Stalite Structural Soil. For this experiment, two plastic bins measuring approximately 76 cm long by 45cm wide by 23 cm tall (2.5' x 1.5' x 9") were filled, one containing CU Structural Soil®**,** and the other containing Carolina Stalite Structural Soil. Water was gradually added to each bin and then mixed thoroughly with the soil. After each addition of water, a sample was taken, weighed, dried in a microwave oven to save time, and then weighed again to determine the moisture content of the sample before drying (Miller, Smith & Bigger 1974). This process was repeated, increasing the amount of water added to the soil. Each time a suitable target for percent moisture content was reached, the soil was placed into a 15.2 cm tall x 14.8 cm diameter (6" x 5.84"dia.) PVC core and compacted in three 5.1 cm (2") lifts by delivering 55 blows from a 2.495 kg (5.5 lb.) standard Proctor hammer for each of three layers and for all of the soil cylinder samples. After compaction, each core was weighed with the weights recorded and then placed into a soil drying oven for 27 hours at 105° C (221° F) to ensure complete dehydration (Thien & Graveel 2003). Once dried, each core was weighed and bulk density was determined for each soil core to establish the percent moisture content for optimal compaction of each structural soil type.

The second stage of the experiment was to determine the porosity of each of the soils at 95 percent-100 percent Standard Proctor Density. To do this, five repetitions of both CU Structural Soil® and Carolina Stalite Structural Soil, as well as each of its constituent components, were compacted to 95 percent-100 percent Proctor Density at their optimal moisture content. The constituent components included: NYSDOT #2 gravel (Appendix 1.4), silty-clay-loam used in each of the structural soils (with at least 20 percent clay content), and Carolina Stalite expanded shale. For this portion of the study, each medium was placed into 15.2 cm tall x 14.8 cm diameter (6" x 5.84" dia.) PVC cores. Each core was capped on the bottom by wire mesh window screen and fastened with an adjustable metal band. Each core was then filled with the assigned medium, compacted with a standard Proctor hammer in three layers of 5.1 cm (2") per lift to within +/- 5 percent of 100 percent Proctor density. This compactive effort was achieved by delivering 55 blows from a 2.495 kg (5.5 lb.) standard Proctor hammer for each of three layers and for all of the soil cylinder samples. Once filled, each core was weighed and three layers of heavy duty saran wrap were placed around the bottom and sealed with rubber bands and duct tape. The core was weighed again and the weights recorded. Each core was then filled with water to achieve saturation and weighed again. Next, the saran wrap and duct tape were removed from each core and the core was allowed to drain for three hours to attain approximate container capacity conditions. Each core was once again weighed, and then placed into an oven to dry at 105° C (221° F) for 24 hours to ensure complete dehydration. After complete dehydration, the cores were weighed one last time.

Porosity calculations were performed for bulk density, total porosity, macroporosity based on a total soil volume basis, and macroporosity based on total pore volume basis (Danielson and Sutherland 1986):

Total Porosity:

Saturated weight – oven dry weight = weight of water

$$\frac{\text{Weight of Water}}{\text{Weight of Oven Dry Soil Minus Ring Weight}} \times \text{Bulk Density} = \text{Total Porosity}$$

Macroporosity on a Total Soil Volume Basis:

Saturated weight - 3 hour weight = weight of water lost after a 3 hour drain

$$\frac{\text{3 Hour Drained Weight}}{\text{Ring Volume}} = \text{Macroporosity on Total Soil Volume Basis}$$

Macroporosity on Pore Volume Basis (Percent macroporosity measured against percent total porosity):

$$\frac{\text{Macropores on a Total Soil Volume}}{\text{Total Porosity}} = \text{Macroporosity on Tot. Pore Volume Basis}$$

The third experiment incorporated both lab and field trials to determine infiltration and runoff rates of both of the CU Structural Soil® and Carolina Stalite Structural Soil, and also the constituent silty-clay loam soil which was compacted to 95 percent-100 percent Proctor Density. For this experiment, five 30.5 cm tall x 14.8 cm diameter (6” x 5.84” dia.) PVC cores were filled with the silty-clay-loam soil and compacted to 95 percent-100 percent Proctor Density based on the same procedures outlined above. Each core was capped at the bottom end with the screen and adjustable metal bands and filled to within 2.54 cm (1”) of the top in 5.02 cm (2”) lifts. Once finished, a 1 cm (0.4”) hole was drilled into the side of each core at the top of the soil and a plastic hose inserted into the holes to allow for runoff collection. At this point, a Sprinkler Infiltrometer (Appendix 1.5) was used on the soil cores to manufacture a static rain event of 15.3 cm/hour (6.02”/hour). Runoff from each core was collected and recorded every two minutes during a twenty-minute period.

For the field trials on the structural soils, the same Sprinkler Infiltrometer was used. It is important to note that while the procedure for the Sprinkler Infiltrometer was the same, the application rate of the manufactured rainfall was accelerated to its maximum application of flow of 60 cm/hour (23.6”/hour). This effectively shortened the time of the trial from 20 minutes of simulated rainfall to 15 minutes of simulated rainfall for the trials in the field.

The last experiment utilized data found in the first two experiments to help determine available water holding capacity and the permanent wilting point for the two structural soil types. Defined as the range between the field capacity and the permanent wilting point of a soil, the available water holding capacity (AWHC) is regulated by a soil's pore space (Craul 1992, Thien & Graveel 2003). Field capacity is the point at which gravity no longer drains water from the soil, while the wilting point is the point at which water is so tightly bound to the soil that it can not be taken up by the plant, and generally occurs at negative 15 bars. (Magdorf and Van Es 2005).

For this experiment, the same large bins measuring approximately 76 cm long by 45 cm wide by 23 cm tall (2.5' x 1.5' x 9") were filled with each soil type and then wetted with the appropriate amount of water to achieve maximum compaction for each soil type, 8 percent moisture content for Carolina Stalite Structural Soil and 7 percent for CU Structural Soil®. Once this was attained, fifteen 30.5 cm tall x 14.8 cm diameter (6" x 5.84" dia.) PVC cores were filled with a predetermined volume of each soil type, based on 95 percent-100 percent Proctor Density calculations from the previous trial. Each core was capped at the bottom end with screen and adjustable metal bands and filled to within 1.3 cm (0.5") of the top. At 12.7 cm (5") from the top, a 5.1 cm (2") PVC dowel was inserted as a space saver for later use. Each core was compacted in 5.1 cm (2") lifts with a Standard Proctor hammer. Once each core was prepared, the dowel was removed and replaced with one 1cm diameter (0.4" dia.) rooted cutting of *Populus deltoides* "Siouxland" with two years of growth and topsoil. Before planting, roots were trimmed to 12.7 cm (5"). After planting, each cutting was pruned to approximately 15 cm (5.9") tall.

Each rooted cutting was allowed to grow in the core for three and one-half months. During this period the plants were kept in a greenhouse with a constant temperature of 23.88° C (75° F) and watered once each day. Additionally, 2 high intensity discharge (HID) lamps were used from 5 a.m. to 8 p.m. to increase the daily photoperiod and ensure maximal growth of each plant. At the end of this growing period, plant heights ranged from .914 m (3') to 1.219 m (4') with four plants in the .762 m (2.5') to .914 m (3') height range.

Plants were watered at 6:30 p.m. for one last time before the inception of a dry-down sequence and then covered with a black cloth. Each morning at 3:30 a.m., one leaf per day was collected from each planted core and placed into a pre-moistened bag to measure water potential using a pressure chamber manufactured by the Soilmoisture Equipment Corporation in Santa Barbara, CA (pressure bomb). These readings continued daily until the plant either wilted to the point that it could not be sampled, or the negative bars of the pressure gauge had reached the maximum reading of 4 Mpa (negative 40 bars). Once the daily pressure bomb readings for each leaf were recorded, each leaf was dried in an oven at 75° C (167° F) for twenty-four hours. When the leaves were dry, their weights were recorded. Additionally, each core was also weighed daily at pre-dawn to determine the amount of water lost from the previous day.

When pressure bomb readings could no longer be taken from a plant, the plant was cut at the base, bagged, and placed into an oven to dry for 24 hours at 75° C (167° F), while the soil core was placed into an oven at 105° C (221° F). Once dry, the total weights of each of the cores were recorded. After drying, each core was dissected, separating the soil and the root mass. The weights for each PVC core and root mass were individually taken and recorded. The weight of the soil was then found by subtracting the root weight and the core weight from the total weight of the dried core. From these weights specific measurements of soil dry weight and plant dry weight for each core were obtained.

Results

Percent Moisture Content for Optimum Compaction

A moisture/density test was performed on the two types of structural soils. The percent moisture content for the CU Structural Soil® reached optimum compaction at 7 percent moisture content (Figure 1). After this point, the soil mixture became more liquid and less compactable, resulting in a lower bulk density. The percent moisture content for the Carolina Stalite Structural soil reached optimum compaction at 8 percent moisture content, at which point the mixture became too liquid and the bulk density was reduced (Figure 2).

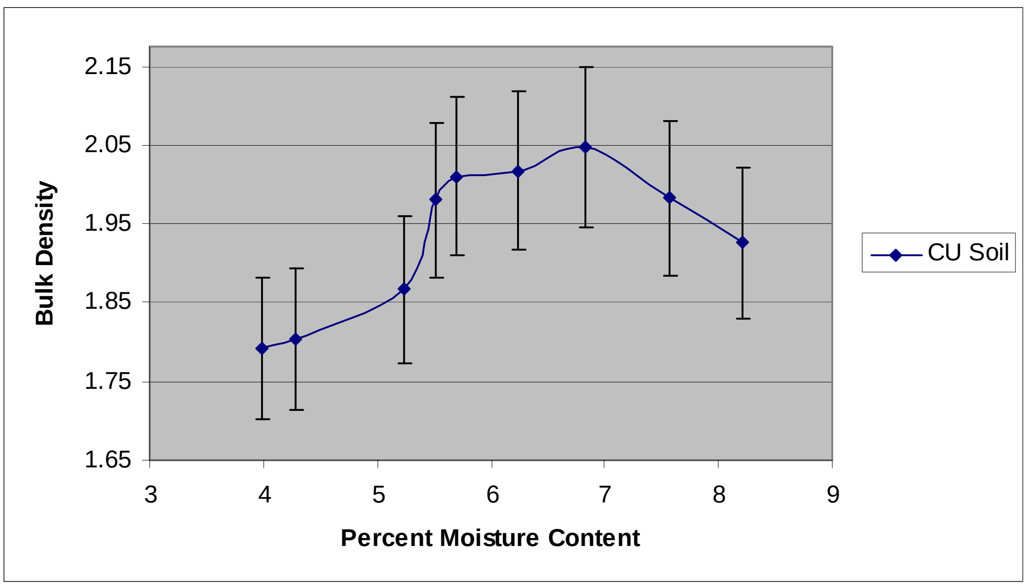

Figure 1: Moisture Content/Bulk Density relationship graph for CU Structural Soil®, where n=5. This graph illustrates that the moisture content for optimum compaction using a standard Proctor compaction effort for this soil peaked at 6.9%.

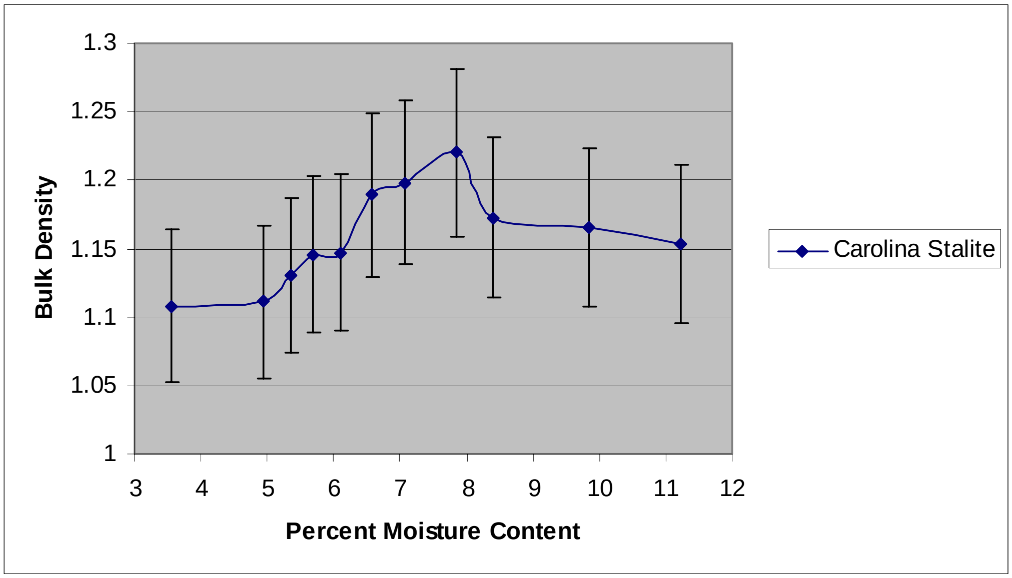

Figure 2: Moisture Content/Bulk Density relationship graph for Carolina Stalite Structural Soil, where n=5. This graph illustrates that the moisture content for optimum compaction using a standard Proctor compaction effort for this soil peaked at 7.7%.

Bulk Density

For the second set of trials the mean bulk densities and standard deviations were as follows (Table 1): CU Structural Soil® had a mean bulk density of 1.97 grams/cm³. The gravel alone had a mean bulk density of 1.75 g/cm³. The soil alone had mean bulk density of 1.75 g/cm³. While these numbers are typical of bulk density tests on this type of aggregate, the Carolina Stalite Strucural Soil and Carolina Stalite expanded shale bulk densities showed vastly different results. The Carolina Stalite Structural Soil had a bulk density of 1.16 g/cm³, while the Carolina Stalite expanded shale had a bulk density of .92 g/cm³. The low bulk densities of both the Carolina Stalite Structural Soil and Carolina Stalite expanded shale are attributable specific gravity (particle density) created by the manufacturing process of the expanded shale (appendix 1.6). This process superheats the shale to increase the volume of the aggregate particle while the weight of the aggregate particle remains constant reducing the particle density from 2.65 g/cm of a typical rock to 1.5 g/cm. Ultimately, this reduction of specific gravity (particle density) of the air entraining process affects the bulk density results of the Carolina Stalite Structural Soil.

Table 1: Mean Bulk Densities for Each of the Soil Types Tested at n=5. This graph also shows Standard Deviations and Confidence Intervals for Each Soil Tested.

	CU Structural Soil®	Carolina Stalite Structural Soil	Gravel Alone	Carolina Stalite Alone	Soil Alone
Mean Bulk Density	1.97	1.16	1.75	0.92	1.76
Standard Deviation	0.02	0.02	0.05	0.02	0.02
95% Confidence Interval of Mean (95% CI μ)	1.95 g/cm³ to 1.99 g/cm³	1.14 g/cm³ to 1.18 g/cm³	1.71 g/cm³ to 1.79 g/cm³	0.90 g/cm³ to 0.94 g/cm³	1.95 g/cm³ to 1.99 g/cm³

Porosity

Since soil porosity is closely related to soil compaction, the porosity data obtained from this experiment was intriguing, especially when combined with the bulk density data presented in the previous section. As bulk densities from compaction rise, soil porosity decreases (Craul 1992). According to Craul, a typical soil with a bulk density of 1.33 g/cm³ is 50 percent porous, while a typical soil with a bulk density of 2.06 g/cm³ is 22 percent porous. The results for the trials on percent porosity (Table 2) illustrate that both structural soils tested have higher porosities than Craul's benchmark of 22 percent. These results reveal that the CU Structural Soil® samples had a mean total porosity of 31 percent, while the Carolina Stalite Structural Soil resulted in a mean total porosity of 32.5 percent. Of the constituent components, the compacted soil had a mean total porosity similar to each of the structural soils at 32.9 percent, while with the gravel alone had a mean porosity of 43.8 percent, and the Stalite expanded shale a 46.2 percent mean porosity.

Table 2: Percent Total Porosity at n=5.
This Table illustrates the means, Standard Deviations and Confidence Intervals for the porosity of each type of soil at the bulk densities listed in Table 1 As a standard, a typical sandy-loam soil has a porosity of 50% at a bulk density of 1.33 g/cm³ and 22% at a bulk density of 2.06 g/cm³

	CU Structural Soil®	Carolina Stalite Structural Soil	Gravel Alone	Carolina Stalite Alone	Soil Alone
MeanTotal Porosity	31.04%	32.52%	43.76%	46.21%	32.90%
Standard Deviation	1.76%	1.70%	1.71%	1.61%	1.55%
95% Confidence Interval of Mean (95% CI μ)	29.3% to 32.70%	30.7% to 34.20%	41.78% to 45.78%	44.7% to 47.70%	28.7% to 34.40%

Macroporosity

The bulk of water movement within the soil is conducted through soil macropores. As such, macropores are an important component to any soil (Craul 1992). Once again, as bulk densities increase, the frequencies, numbers and sizes of the macropores within the soil decrease. Tests for macroporosity in the lab yielded higher than expected macroporosity for each of the structural soils tested (Table 3) on both a total soil volume basis and a total pore volume basis (Table 4). The mean macroporosity for CU Structural Soil® based on total soil volume was 17.9 percent while the macroporosity on a pore volume basis constituted 57 percent of the total pores within the soil sample. The results for the Carolina Stalite Structural Soil were insignificantly higher than the CU Structural Soil®, resulting in a mean macroporosity based on total soil volume of 19.7 percent, and the macroporosity based on pore volume constructing 60.3 percent of the total amount of pores within the soil. Of the constituent components, gravel had a mean macroporosity based on total soil volume at 39.2 percent, of which macropores were 89.6 percent of the pores within the soil. Stalite expanded shale had a mean macroporosity based on total soil volume of 39.8

percent, of which macropores were 86.3 percent of the pores within the soil. Lastly, the compacted soil had a mean macroporosity based on total soil volume at 0.7 percent, of which macropores were only 2 percent of the pores within the soil.

Table 3: Percent Macroporosity Based on Total Soil Volume, at n=5. This table Illustrates the mean%, Standard Deviation and Confidence Interval for Macroporosity Based on Total Soil Volume for Each Type of Soil.

	CU Structural Soil®	Carolina Stalite Structural Soil	Gravel Alone	Carolina Stalite Alone	Soil Alone
Means	17.91%	19.66%	39.22%	39.89%	0.75%
Standard Deviations	3.19%	2.61%	2.10%	1.98%	0.11%
95% Confidence Interval of Mean (95% CI μ)	14.9% to 20.90%	17.1% to 19.73%	37.2% to 39.20%	37.8% to 41.80%	0.65% to 0.85%

Table 4: MeanPercent Macroporosity Based on Total Pore Volume at n=5. This Table Shows the Mean Percentage of Macropores, Their Standard Deviations and Confidence Intervals for Each Soil. This is relevant because the percentage level illustrates that macropores constitute the resulting percentage of the total porosity of each soil type.

	CU Structural Soil®	Carolina Stalite Structural Soil	Gravel Alone	Carolina Stalite Alone	Soil Alone
Means	57.41%	60.34%	89.58%	86.30%	2.26%
Standard Deviations	6.83%	5.01%	1.50%	2.17%	0.30%
95% Confidence Interval of Mean (95% CI μ)	50.4% to 63.60%	55.4% to 65.20%	88.1% to 99.10%	84.3% to 88.30%	1.98% to 2.02%

Of these findings, the compacted soil results substantiate Craul's findings that compaction greatly reduces macropore space in soil. Yet even more revealing were the total porosity levels of both of the structural soils at around 30 percent with macropores composing over half of the total pores within each of the structural soils.

These results illustrate that despite compaction to optimal Proctor Density, structural soils nevertheless retain a significant amount of macropore space, allowing water and air circulation as well as spaces through which roots can navigate that is superior to traditional urban soils under pavement.

Infiltration

The core samples for the silty clay loam soil used in these trials resulted in the following data (Table 5): a mean bulk density of 1.78g/cm^3, a mean total porosity of 35.7 percent, a macroporsity based on soil volume of 1.8 percent, and macroporosity based on total volume of 5 percent. Although this is somewhat higher than previous trials, the resultant mean infiltration rate was 1.24 cm/hour (0.5"/hour) from 15.3 cm/hour (6.02"/hour) or simulated rainfall. This amount is not unusual for urban soils (Craul 1992).

Table 5: Bulk Density, Porosity, and Macroporosity Results for Clay Loam Soil used in this Infiltration Study at n=5.

	Bulk Density	Total Porosity	Macroporsity Vs.Soil	Macroporosity Vs. Pore
Means	1.78 g/cm^3	35.7%	1.8%	5.1%
St. Devs.	0.04 g/cm^3	02.5%	0.72%	2%
95% CI	1.74 g/cm^3 to 1.82 g/cm^3	35.68% to 35.72%	1.794% to 1.806%	5.08% to 5.12%

While the infiltration trials for the clay loam soil were carried out in the lab, the infiltration trials for both the Cu Structural Soil® and the Carolina Stalite Soil were performed in the field on the Cornell test plots and assumed to have the same properties as presented in Tables 1, 2, 3 and 4.

The results for the infiltration trial were as follows (Table 6):

Table 6: Infiltration Rates for Clay Loam Soil, CU Structural Soil®, Carolina Stalite Structural Soil and Porous Asphalt Surface.

	Infiltration Rate (cm/hour)	Infiltration Rate (in/hour)
Clay Loam Soil	1.24	0.49
CU Structural Soil®	>60	>23.62
Carolina Stalite Structural Soil	>60	>23.62

The data here reinforces Craul's findings regarding infiltration on heavily compacted soils, yet shows surprising infiltration rates for each of the structural soils, which were compacted to 95 percent to 100 percent Proctor Density. Despite these high levels of compaction, these results show very high levels of infiltration, lending further credence to the fact that structural soils nevertheless retain a significant amount of macropore space, allowing better water and air circulation as well as spaces through which roots can navigate.

Available Water Holding Capacity (AWHC)

According to Craul, the water holding capacity of a soil ranges between 4 percent for sandy soils and around 24 percent for a silty loam depending on both the texture and structure of a soil and is characterized by a soil moisture retention curve (Craul 1992). Our data indicates that the mean available water holding capacity for CU Structural Soil® is 8.5 percent (Figure 3), while the Carolina Stalite Structural Soil has a mean available water holding capacity of 11 percent (Figure 4).

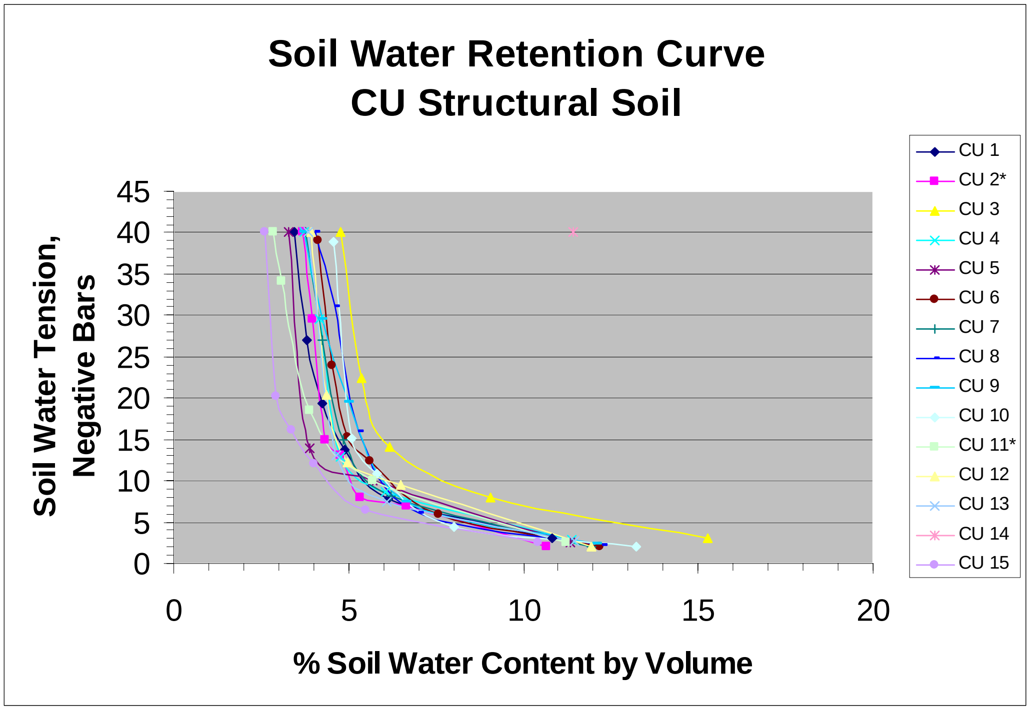

Figure 3: Soil Retention Curve for CU Structural Soil® at n=15. The available water holding capacity is the range between 12.5 Theta CU and 4.0 Theta CU.

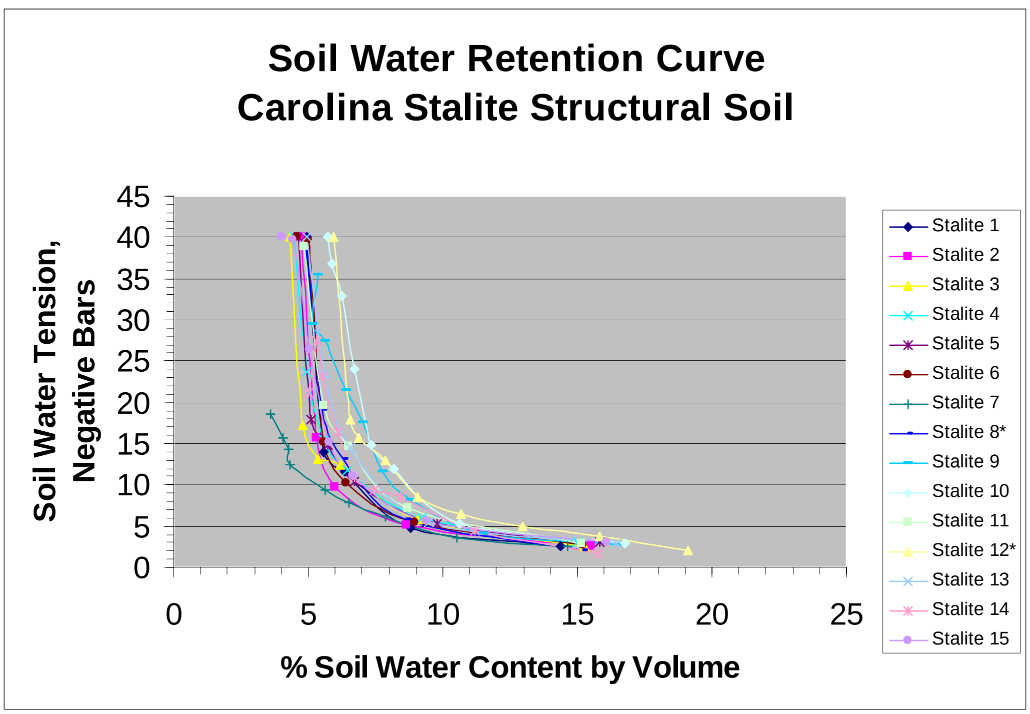

Figure 4: Soil Retention Curve for Carolina Stalite Structural Soil at n=15. The available water holding capacity is the range between 16 Theta for Stalite and 5 Theta Stalite.

These soil moisture retention curves indicate that the results for this trial illustrate a water holding capacity most closely resembling sandy loam soil. This data has ramifications for those interested in using structural soils since AWHC levels are a necessary component for determining the proper rooting volume for proper tree planting (Lindsey and Bassuk 1991). Though these numbers are at the lower to middle portion of the AWHC spectrum, the work by Lindsey and Bassuk indicates that a simple solution is to provide a greater volume of soil if a structural soil is used (Tables 7, 8, and 9).

Table 7: Soil Volume Calculations for AWHC's of 8.5% for CU Structural Soil®, and 11% for Carolina Stalite Structural Soil. These Figures were derived for a tree with a crown diameter of 20' and a height of 35'.

City	Crown Projection (Ft²)	x	Leaf Area Index (LAI)	x	Evaporation Rate*	x	Evap Ratio	=	Ft³of Water Loss/Day	/	Soil AHWC	x	Rainfall Freq. (Days)	=	Total Ft³ of Soil
Ithaca, NY	3.14	x	4	x	0.0167	x	0.2	=	4.19504	/	0.085	x	10	=	493.5341
	3.14	x	4	x	0.0167	x	0.2	=	4.19504	/	0.11	x	10	=	381.3673
Seattle, WA	3.14	x	4	x	0.0188	x	0.2	=	4.72256	/	0.085	x	20	=	1111.191
	3.14	x	4	x	0.0188	x	0.2	=	4.72256	/	0.11	x	20	=	858.6473
Mobile, AL	3.14	x	4	x	0.0193	x	0.2	=	4.84816	/	0.085	x	10	=	570.3718
	3.14	x	4	x	0.0193	x	0.2	=	4.84816	/	0.11	x	10	=	440.7418
Indianapolis, IN	3.14	x	4	x	0.0198	x	0.2	=	4.97376	/	0.085	x	15	=	877.7224
	3.14	x	4	x	0.0198	x	0.2	=	4.97376	/	0.11	x	15	=	678.24
Minneapolis, MN	3.14	x	4	x	0.0212	x	0.2	=	5.32544	/	0.085	x	10	=	626.5224
	3.14	x	4	x	0.0212	x	0.2	=	5.32544	/	0.11	x	10	=	484.1309
Miami, FL	3.14	x	4	x	0.0216	x	0.2	=	5.42592	/	0.085	x	10	=	638.3435
	3.14	x	4	x	0.0216	x	0.2	=	5.42592	/	0.11	x	10	=	493.2655
Denver, CO	3.14	x	4	x	0.0263	x	0.2	=	6.60656	/	0.085	x	15	=	1165.864
	3.14	x	4	x	0.0263	x	0.2	=	6.60656	/	0.11	x	15	=	900.8945
Phoenix, AZ	3.14	x	4	x	0.0412	x	0.2	=	10.34944	/	0.085	x	80	=	9740.649
	3.14	x	4	x	0.0412	x	0.2	=	10.34944	/	0.11	x	80	=	7526.865

Table 8: Soil Volumes and Volume Arrangements Needed for AWHC's of 8.5% for CU Structural Soil®, and 11% for Carolina Stalite Structural Soil. These Figures were derived for a tree with a crown diameter of 20' and a height of 35'.

City	Total Ft³ of Soil	Approx. Possible Soil Volume Arrangements Needed for Each Tree, With a 2' Resrvoir Depth			Approx. Possible Soil Volume Arrangements Needed for Each Tree, With a 3' Resrvoir Depth		
Ithaca, NY	493.53	(10'x24.5'x2')	(20'x12.5'x2')		(10'x16.5'x3')	(20'x8'x3')	(15'x11'x3')
	381.37	(10'x19'x2')	(15'x13'x2')		(10'x13'x3')	(20'x6.5'x3')	(15'x8.5'x3')
Seattle, WA	1111.19	(10'x56'x2')	(20'x28'x2')	(25'x22.5'x2')	(10'x37'x3')	(20'x18.5'x3')	(15'x24.5'x3')
	858.65	(10'x43'x2')	(20'x21.5'x2')	(25'x17'x2')	(10'x28.5'x3')	(20'x14.5'x3')	(15'x19'x3')
Mobile, AL	570.37	(10'x28.5'x2')	(20'x14.5'x2')	(15'x19'x2')	(10'x19'x3')	(15'x12.5'x3')	(5'x38'x3')
	440.74	(10'x22'x2')	(20'x11'x2')	(15'x14.5'x2')	(10'x14.5'x3')	(20'x7.5'x3')	(15'x10'x3')
Indianapolis, IN	877.72	(10'x44'x2')	(20'x22'x2')	(15'x30'x2')	(10'x29.5'x3')	(20'x14.5'x3')	
	678.24	(10'x34'x2')	(20'x17'x2')	(15'x22.5'x2')	(10'x22.5'x3')	(20'x11.5'x3')	(15'x15'x3')
Minneapolis, MN	626.52	(10'x32'x2')	(20'x16'x2')	(25'x12.5'x2')	(10'x21'x3')	(15'x14'x3')	(5'x42'x3')
	484.13	(10'x24.5'x2')	(20'x12'x2')	(15'x16'x2')	(10'x16.5'x3')	(20'x8.5'x3')	(15'x11'x3')
Miami, FL	638.34	(10'x32'x2')	20'x16'x2')		(10'x21.5'x3')	(15'x14'x3')	(5'x42.5'x3')
	493.27	(10'x25'x2')	(20'x12.5'x2')	(15'x16.5'x2')	(10'x16.5'x3')	(20'x8.5'x3')	(5'x33'x3')
Denver, CO	1165.86	(10'x58'x2')	(20'x30'x2')	(25'x23.5'x2')	(10'x29'x3')	(20'x19.5'x3')	(15'x26'x3')
	900.89	(10'x45'x2')	(20'x22.5'x2')	(25'x18'x2')	(10'x30'x3')	(20'x15'x3')	
Phoenix, AZ	9740.65	(100'x49'x2')	(75'x65'x2')		(100'x33'x3')	(75'x43'x3')	(50'x65'x3')
	7526.87	(100'x37.5'x2'	(75'x50'x2')	(50'x75'x2')	(100'x25'x3')	(75'x33.5'x3')	(50'x50'x3')

Table 9: Evaporation Rate Calculations Needed for Soil Volume Calculations in Table 7. These Figures were derived for a tree with a crown diameter of 20' and a height of 35'.

City	Evap. Pan Rate	/	Days/Month	=	Evap. Rate	x	Constant	=	Daily Water Evap. Rate
Ithaca, NY	6.21	/	31	=	0.20032258	x	0.0833	=	0.0167
Seattle, WA	7	/	31	=	0.22580645	x	0.0833	=	0.0188
Mobile, AL	7.19	/	31	=	0.23193548	x	0.0833	=	0.0193
Indianapolis, IN	7.13	/	30	=	0.23766667	x	0.0833	=	0.0198
Minneapolis, MN	7.88	/	31	=	0.25419355	x	0.0833	=	0.0212
Miami, FL	8.03	/	31	=	0.25903226	x	0.0833	=	0.0216
Denver, CO	9.8	/	31	=	0.31612903	x	0.0833	=	0.0263
Phoenix, AZ	14.83	/	30	=	0.49433333	x	0.0833	=	0.0412

For the AWHC trial, CU Structural Soil® resulted in a mean plant weight of 23.53 grams (Figure 5), while Carolina Stalite Structural Soil resulted in a mean plant weight of 26.06 grams.

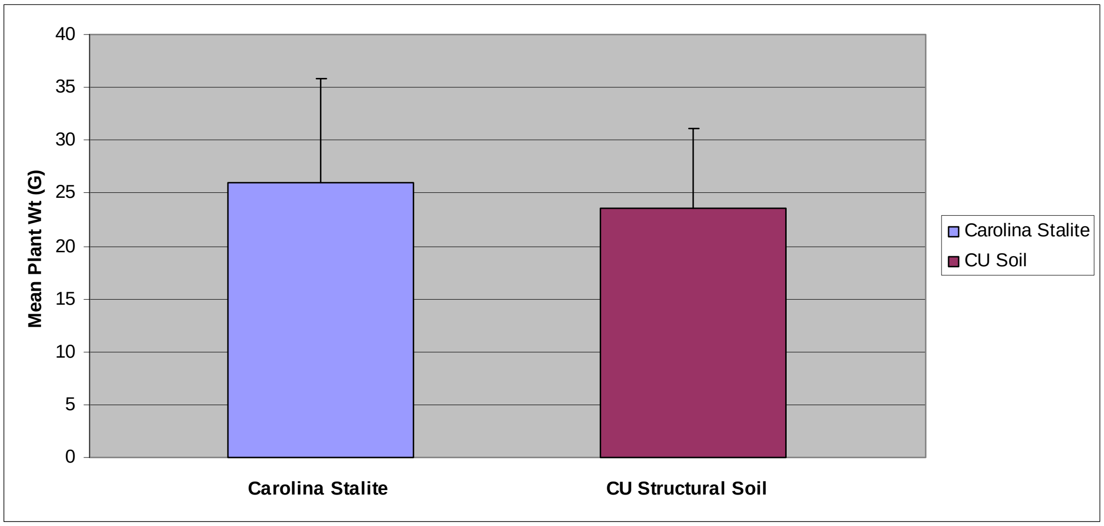

Figure 5: Mean Plant weights for 2 year old rooted cuttings of Populus deltoides 'Siouxland' in Carolina Stalite Structural Soil vs. CU Structural Soil® at n=15.

Conclusion

As previously mentioned, when soil is compacted, void space within the soil also decreases. Ultimately, this decrease in void space also decreases infiltration because of the collapse of the macropres within the soil due to compaction. However, our research shows that this is not the case for Structural Soils. Rather, these findings indicate that the drainage qualities due to the large percentages of macropores attributed to the gap graded skeletal framework of the stone and soil within both of the structural soils is quite high, retaining an available water holding capacity similar to a loamy sand soil at 95 percent-100 percent Proctor densities. It is this gap graded skeletal structure of the gravel and soil mixture that prevents the soil from collapsing during compaction, and allows the macropores to remain intact. The macropores that remain within both CU Structural Soil® and Carolina Stalite Structural Soil allows plant roots to grow through the well-drained soil media at high levels of compaction within the structural soils, ultimately resulting in larger, healthier trees in the urban environment when and where the structural soils are used.

APPENDIX 1.1

SHIPPING POINT—GOLD HILL, N. C.

CAROLINA STALITE COMPANY

MANUFACTURERS OF LIGHTWEIGHT AGGREGATE "STALITE"

PHONE 704-637-1515 FAX 704-642-1572

DRAWER 1037 SALISBURY, N.C. 28145-1037

Gold hill research laboratory

LABORATORY ANALYSIS
POROSITY AND VOID RATIO
3/4" STRUCTURAL AGGREGATE

On May 10, 2002 a sample of ¾" structural aggregate obtained from the stockpile was tested for void ratio and porosity.

PROCEDURE

The aggregate sample was dried to a constant mass and used to completely fill a ½ cubic foot bucket. The mass of the aggregate and the bucket was determined. The bucket was then filled with water and allowed to saturate for 72 hours. The bucket was then topped off with water to replace any water, which was absorbed by the aggregate and reweighed.

CALCUALTIONS

Porosity = Volume Voids/ Volume Total

Void Ratio = Volume Voids/ Volume Solids

RESULTS

Mass of Bucket = 19.90 lb
Mass of Bucket and Dry Aggregate = 43.95 lb
Mass of dry solids = 24.05 lb
Mass of Bucket, Saturated material and Water = 59.8 lb
Mass of water (total) = 15.85
Volume Solids = 24.05/1.44/62.4 = .264 cf
Volume Voids = 15.85/62.4 =. 254 cf
Volume Total = .518 cf
Weight of aggregate and water = 82.2 lb per cf

Porosity = .254 / .518 = .490

Void Ratio = .254 / .264 = .962

APPENDIX 1.2

MATERIALS

2.01 CLAY LOAM

A. Clay Loam / Loam shall be a " loam to clay loam" based on the "USDA classification system" as determined by mechanical analysis (ASTM D-422) and it shall be of uniform composition, without admixture of subsoil. It shall be free of stones greater than one-half inch, lumps, plants and their roots, debris and other extraneous matter over one inch in diameter or excess of smaller pieces of the same materials as determined by the Engineer. It shall not contain toxic substances harmful to plant growth. It shall be obtained from areas which have never been stripped of top soil before and have a history of satisfactory vegetative growth. Clay Loam shall contain not less than 2% nor more than 5% organic matter as determined by the loss on ignition of oven-dried samples.

B. Mechanical analysis for a Loam / Clay Loam shall be as follows:

Textural Class	% of total weight
Gravel	less than 5%
Sand	20 - 45%
Silt	20 - 50%
Clay	20- 40%

C. Chemical analysis: Meet or be amended to meet the following criteria.

1. pH between 6.0 to 7.6
2. Percent organic matter 2 -5% by dry weight.
3. Nutrient levels as required by the testing laboratory recommendations for the type of plants to be grown in the soil.
4. Toxic elements and compounds below the United States Environmental Protection Agency Standards for Exceptional Quality sludge or local standard; whichever is more stringent.
5. Soluble salt less than 1.0 Millimho per cm.
6. Cation Exchange Capacity (CEC) greater than 10
7. Carbon/Nitrogen Ratio less than 33:1.

2.02 CRUSHED STONE

A. Crushed Stone shall be a DOT certified crushed stone. Granite and limestone have been successfully used in this application. Ninety-100 percent of the stone should pass the 1.5 inch sieve, 20-55 percent should pass the 1.0 inch sieve and 10 percent should pass the 0.75 inch sieve. A ratio of nominal maximum to nominal minimum particle size of 2 is required

B. Acceptable aggregate dimensions will not exceed 2.5:1.0 for any two dimensions chosen.

C. Minimum 90 percent with one fractured face, minimum 75 percent with two or more fractured faces.

D. Results of Aggregate Soundness Loss test shall not exceed 18 percent. Losses from LA Abrasion tests shall not exceed 40%.

2.03 HYDROGEL

A Hydrogel shall be a potassium propenoate-propenamide copolymer Hydrogel or equivalent such as that which is manufactured under the name Gelscape by Amereq Corporation. (800) 832-8788

2.04 WATER

A. The Contractor shall be responsible to furnish his own supply of water to the site at no extra cost. All work injured or damaged due to the lack of water, or the use of too much water, shall be the Contractor's responsibility to correct. Water shall be free from impurities injurious to vegetation.

2.05 STRUCTURAL SOIL

A. A uniformly blended mixture of Crushed Stone, Clay Loam and Hydrogel, mixed to the following proportion:

MATERIAL	UNIT OF WEIGHT
Crushed Stone	80 units dry weight
Loam (screened)	as determined by the test of the mix. (Approx. 20 units dry weight)
Hydrogel	0.03 units dry weight/100units stone
Total moisture	(AASHTO T-99 optimum moisture)

B. The initial mix design for testing shall be determined by adjusting the ratio between the Crushed Stone and the Clay loam. Adjust final mix dry weight mixing proportion to decrease soil in mixture if CBR test results fail to meet acceptance (CBR > 50).

APPENDIX 1.3

2.1 CAROLINA STALITE STRUCTURAL SOIL SPECIFICATION

A. Provide a Structural Soil mix using the two components listed below that will meet the ASTM standards as follows:

¾" Expanded Slate	80%
Sandy Clay Loam *	20%

*Percentages of sand and clay may vary to meet testing requirements

2.2 Structural Soil Components

A. 3/4" Stalite Rotary Kiln Expanded Slate

1. ASTM C29 Unit Dry Weight loose (48 lbs/cf to 55 lbs/cf) Saturated Surface Loose (55 lbs/cf to 60 lbs/cf)

2. ASTM C127 Specific Gravity to meet 1.45 to 1.60 Dry Bulk

3. ASTM C330 to meet the ASTM Gradation 3/4" - #4 size

3/4" to #4

Sieve Size	% Passing
1"	100
3/4"	90 - 100
3/8"	20-50
#4	0 - 10

4. Absorption (ASTM C127) 5% to 12%.

5. The expanded slate must contain **no** clay lumps or any organic impurities.

B. Sandy Clay Loam

1. Texture

40%-65% sand

15%-25% silt

20%-30% clay

2%-5% 0rganic matter

2.2 MIXING OFFSITE

A. Structural Soil

1. Mechanically mix the sand and loam thoroughly if mixing is necessary to meet the specifications.

2. Saturate 4 parts 3/4" **STALITE** Expanded Slate with water and mechanically mix with 1 part of the "DRY" sandy clay loam until the slate particles are completely coated.

3. If stockpiling the finished mix for more than 5 days or if there is a threat of heavy rain, cover the pile with a plastic tarp to prevent drying out or soil separation from rain.

APPENDIX 1.4

TABLE 703-4[1] SIZES OF STONE, GRAVEL AND SLAG

Size Designation	Screen Sizes 100	75	63	50	37.5	25	12.5	6.3	3.2	180	75
Screenings[2]	-	-	-	-	-	-	100	90-100	-	-	0-1.0
1B	-	-	-	-	-	-	-	100	90-100	0-15	0-1.0
1A	-	-	-	-	-	-	100	90-100	0-15	-	0-1.0
1ST	-	-	-	-	-	-	100	0-15	-	-	0-1.0
1	-	-	-	-	-	100	90-100	0-15	-	-	0-1.0
2	-	-	-	-	100	90-100	0-15	-	-	-	0-1.0
3A	-	-	-	100	90-100	0-15	-	-	-	-	0-0.7
3	-	-	100	90-100	35-70	0-15	-	-	-	-	0-0.7
4A	-	100	90-100	-	0-20	-	-	-	-	-	0-0.7
4	100	90-100	-	0.15	-	-	-	-	-	-	0-0.7
5	90-100	0-15	-	-	-	-	-	-	-	-	0-0.7

(1)Percentage by weight passing the following square openings.
(2)Screenings shall include all of the fine material passing a 6.3 mm screen.
(3)The minus 75 :m material requirements apply only to aggregate for use in portland cement concrete, surface treatment, cold mix bituminous pavements and underdrain filter material.. The test (NYSDOT 201) will be performed on the entire sample of the designated size aggregate. Primary size does not apply in the determination of the minus 75 :m material.

TABLE 703-6 PRIMARY SIZES

Size Designation	Primary Passing	Screen Sizes Retained	Size Designation	Primary Passing	Screen Sizes Retained
1B	3.2 mm	180 mm	3A	37.5 mm	25.0 mm
1A	6.3 mm	3.2 mm	3	50 mm	25.0 mm
1ST	12.5 mm	6.3 mm	4A	63 mm	37.5 mm
1	12.5 mm	6.3 mm	4	75 mm	50 mm
2	25.0 mm	12.5 mm	5	100 mm	75 mm

APPENDIX 1.5

Field Procedures and Data Analysis for the
Cornell Sprinkle Infiltrometer

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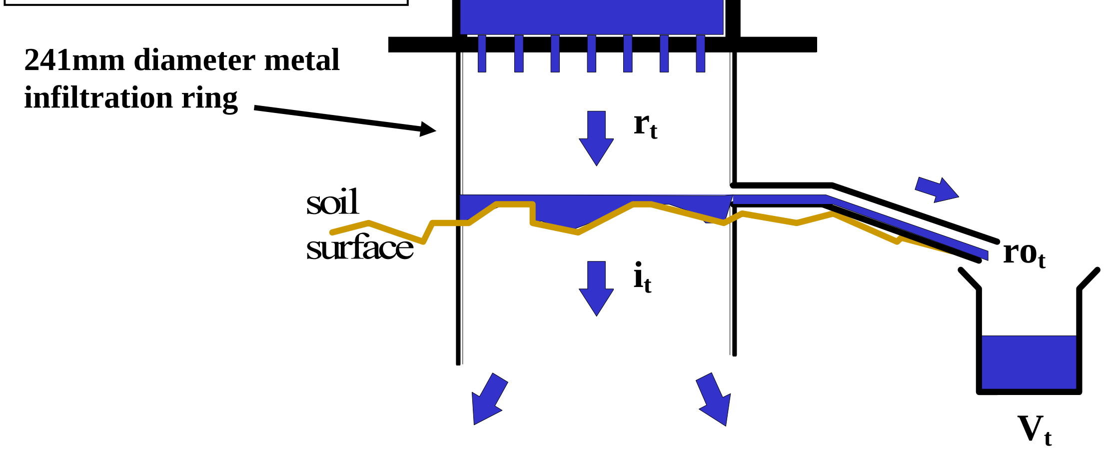
The Cornell Sprinkle Infiltrometer

Soil infiltrability is an important soil quality indicator, as it has important agricultural and environmental implications and is strongly affected by land management practices. Measurement of soil infiltrability is generally done through ponded ring infiltration or simulated rainfall, each having specific advantages and disadvantages. The Cornell Sprinkle Infiltrometer (Ogden et al., 1997) was designed to combine the advantages of both. It also allows for easy and rapid measurement of soil infiltration, as this is essential to adequately estimate spatially and temporally-variable infiltration behavior (van Es, 1993).

The Cornell Sprinkle Infiltrometer system consists of a portable rainfall simulator that is placed onto a single 241-mm (9 1/2") inner diameter infiltration ring **(Fig. 1)** and allows for application of simulated rainfall at a wide range of predetermined rates. The apparatus permits the determination of several important soil hydrological properties: Time-to-runoff, sorptivity, and field-saturated infiltrability.

Fig. 1

Infiltrometer Setup



In contrast to most other ponded infiltration measurements, this approach:

- Wets the soil in a more natural manner and eliminates soil slaking as a result of instantaneous ponding
- Reduces unnaturally high contributions of macropore flow under ponded conditions
- Provides a realistic surface boundary condition, including the effects of soil surface roughness which can greatly influence infiltration behavior
- Is conservative with water

Compared to most other rainfall simulators, the Cornell Sprinkle Infiltrometer measures infiltrability for a relatively small soil surface area. However, its main advantages are:

- Low cost
- High portability
- Allows for rapid measurements by a single person
- Easy calibration for a wide range of simulated rainfall rates
- Conservative water use

The Cornell Sprinkle Infiltrometer employs a single, rather than a double infiltration ring, and makes adjustments for three-dimensional flow at the bottom of the ring based on research by Reynolds and Elrick (1990).

<u>Field Procedures</u>

Sprinkler Preparation

Although the sprinklers are robustly built for use under field conditions, the user should be aware that the capillary tubes at the bottom of the unit are the most sensitive part of the equipment. Efforts should be made to minimize contact of the tubes with soil or debris. Use of water with high sediment content should be avoided as it may increase the potential for clogging of the capillaries. Since natural rainfall is low in soluble salts, it is recommended (but not always logistically feasible) to use water of low ionic strength. This may be especially critical for sodic and other soils that are subject to slaking.

Fill the sprinkler when positioned on a stable flat surface. Remove the large rubber stopper and air-entry tube, and pour water into the vessel. Then re-insert the stopper/tube, and place it firmly to insure that the stopper is air-tight. (This is important as air should only enter the vessel through the air-entry tube.) The interface between the large stopper and the air-entry tube should also be air-tight. Some vacuum grease may be used to insure this, while still allowing for easy adjustment of the tube.

Once the sprinkler vessel has been filled and the stopper/tube firmly reinstalled, blow gently into the air-entry tube for a few seconds to apply some additional air pressure to remove possible bubbles from the capillaries. This only needs to be done at the beginning of a set of measurements, and does not need to be repeated with refills on the same day. Then, put the small stopper on the top of the air-entry tube. This will air seal the vessel and the capillaries will cease dripping after a few seconds. The sprinkler is now on stand-by and ready for use without losing any water in the meantime.

Sprinkler calibration

The sprinklers are designed to apply water at a wide range of simulated rainfall rates. The rate can be changed by moving the air-entry tube up (for higher rates) or down (for lower rates). It is recommended to calibrate the sprinkler for a rainfall rate of 25 to 30 cm/hr. This generally insures that ponding will occur for every measurement, and still allows for a measurement period of one hour without requiring refills.

Note: Alternatively, the sprinklers may be calibrated for an event of known recurrence period for the region of the study (e.g., a 50-year, 1 hour event). This will generally not insure ponding for all measurements, in which case one might interpret the measurement location as having "sufficiently high" infiltrability. This may create challenges when trying to analyze the data statistically, as it will not provide quantitative data for those sites.

The actual sprinkling rate in the field may vary slightly from the calibrated rate as a result of temperature variations in the water. This is not a problem, as the actual application rate is directly measured in the procedure.

To calibrate the sprinkler, perform the following:

1. Set the air-entry tube to the desired level. The 30 cm/hr or 0.5 cm/min sprinkle rate is generally achieved when the bottom of the air-entry tube is located at 10 cm above the bottom of the container. This is therefore a good starting point for the calibration effort.
2. Measure the height of water level in the sprinkler vessel **(H1).** It is easiest to measure and record it in cm with one decimal value (e.g. 41.2 cm).
3. Remove the small stopper from the air-entry tube, while simultaneously starting a stopwatch
4. Allow for 3 minutes of sprinkling and read the water level exactly at this time **(H2).**
5. Calculate the rainfall rate (cm/min) as:

   [H1-H2]/3

6. If the actual rainfall rate is below the desired rate, move the air-entry tube upwards. Move it down if it is above the desired rate.
7. Repeat the procedure until the desired rate is achieved. Note that the calibrated rainfall rate does not need to be very exact, as the actual rate is determined for each field measurement, and variations are accounted for in the data analysis.

Once the sprinkler has been calibrated for the desired rate, refill the vessel and reinstall all stoppers. It is now ready for actual field measurements. Note that calibration generally does not have to be repeated. It can also easily be checked with each subsequent field measurement.

Ring Insertion

The infiltration ring should be inserted without causing significant disturbance to the soil. This is best performed with the use of a hydraulic device that pushes the ring into the soil with a steady and constant force. Pounding rings into the soil using a hammer tends to cause some soil disturbance, especially in dense soils, and is therefore less preferred. In all cases, it is recommended to lay a piece of 4" by 4" wood of about 30 cm length horizontally on top of the ring and apply the driving force to it. Before inserting the ring, carefully remove pieces of debris, crop residue and small rocks that are immediately below the edge of the ring, as they would cause soil disturbance when the ring is pushed in. In rocky soils, multiple attempts may be required to insure that ring insertion occurred without excessive disturbance.

The ring should be inserted to a depth where the lower edge of the round overflow hole is flush with the soil surface. Depending on which end is used, the rings can be inserted to a depth of 7 cm or 15 cm. The deeper insertion is preferable, but may not be feasible in many field situations, especially with dense or rocky soils, and when the rings are hammered into the soil. In soils with a rough surface, the rings should be inserted with the hole located at the level where overflow of microrelief would occur under natural rainfall conditions. This allows the infiltration measurement to account for the effect of surface storage capacity, which greatly affects infiltrability under those conditions.

Once the ring has been installed, insert the overflow tube assembly (stopper and tubing) into the ring **(Fig. 1).** At the end of the tube, dig a small hole to place the beaker. The hole for the beaker should be sufficiently distant (30 cm or more) from the infiltration ring to not interfere with water flow patterns. The tubing should slope away from the ring to insure that overflowing water does not back up and readily empties into the beaker. The beaker itself should therefore also be positioned sufficiently low.

The sprinkler may now be placed on top of the ring in preparation for the measurements (as in **Fig. 1**). Alternatively, the sprinklers may be suspended above the ring (e.g., off a tripod). This will allow the simulated raindrops to gain velocity and more closely reproduce the energy of natural rains.

Measurements

The following steps outline the measurement procedure:

1. Measure the height of the water level in the sprinkler vessel **(H1)**
2. Remove the small stopper from the air-entry tube, while simultaneously starting a stopwatch.

Monitor the outflow tube to determine whether water is being discharged into the beaker. During this period, it is advised to slightly rotate the sprinkler every minute or so (more often when the sprinkler is suspended) to prevent raindrops impacting the soil surface in the same location.

4. When water starts flowing out of the tube, record the time ($\mathbf{T_{RO}}$, time to runoff in minutes). The runoff water should now be flowing into the beaker.
5. After three (or so) minutes, pour the water from the beaker into the graduated cylinder. This should be done while not spilling water that continues to come from the outflow tube (e.g., by quickly replacing the full beaker with another empty one, or temporarily blocking the outflow tube).
6. Measure the runoff volume **($\mathbf{V_t}$)** in the graduated cylinder (in ml). Record both $\mathbf{V_t}$ and the time at which water was collected.
7. Repeat steps 5 and 6 for as long as desired (generally up to one hour), or until the water level in the vessel has reached the bottom of the air-entry tube. Do not continue beyond this point as the sprinkle rate will gradually decrease. In most cases, steady-state conditions will have occurred within an hour. It may take longer with extremely dry soils and those that have shrinkage cracks that close very gradually during extended wetting.
8. At the end of the measurement period, determine the water level in the vessel **(H2)** and the time at which it is taken **($\mathbf{T_f}$).**

Data Analysis

The simulated rainfall rate (**r**, constant throughout the experiment) is determined by

$$\mathbf{r = [H1 - H2] / T_f}$$

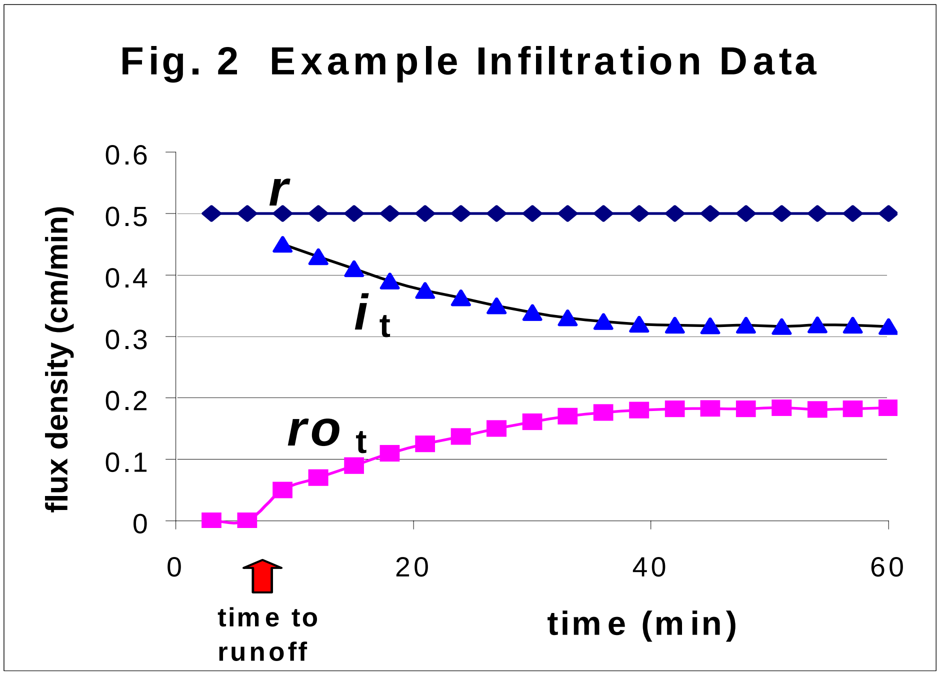
The runoff rates ($\mathbf{ro_t}$, cm/min) are determined by

$$\mathbf{ro_t = V_t / (457.30*t)}$$

where 457.30 is the area of the ring, and **t** is the time interval for which runoff water was collected (3 minutes in our case). Infiltration rates **($\mathbf{i_t}$)** are determined by the difference between the rainfall rate and runoff rate:

$$\mathbf{i_t = r - ro_t}$$

Figure 2 shows rainfall, runoff and infiltration rates for a typical measurement.



Estimation of Sorptivity

Time-to-runoff **(T_{RO})** is an important soil hydrological parameter that is dependent on the rainfall rate **(r)** as well as the initial soil water conditions. Runoff will occur earlier if **r** is higher and the soil is wetter. Sorptivity **(S)** is a more universal soil hydraulic property that describes early infiltration independent of rainfall rate. It is estimated by (Kutilek, 1980): $\mathbf{S = (2T_{RO})^{0.5} * r}$

Sorptivity also accounts for variable sprinkle rates which are difficult to avoid under field conditions, and provides an integrated assessment of early infiltration, including the effect of surface water storage with rough soil surfaces.

Estimation of Field-Saturated Infiltrability

Field-saturated infiltrability **(i_{fs})** reflects the steady-state infiltration capacity of the soil, after wet-up. It should be based on the data collected at the end of the measurement period, or whenever steady-state conditions occur. Since the apparatus has a single ring, the measured infiltration rate needs to be adjusted for three-dimensional flow at the bottom of the ring. The required adjustment is generally greater when the ring insertion depth is shallower and the soil type is finer-textured. The adjustment factors suggested below are based on Reynolds and Elrick (1990) who used numerical modeling to estimate the effects of three-dimensional flow at the bottom of the ring.

For the 7 cm and 15 cm ring insertion depth, multiply the measured infiltration rate by the constants listed in **Table 1** to obtain the field-saturated infiltrability:

For example, for a ring insertion depth of 7 cm on a loam soil, the field-saturated infiltration rate is estimated as: $\mathbf{i_{fs} = i_t * 0.80}$

Table 1. Conversion factors for field-saturated infiltrability to account for three-dimensional flow at the bottom of the ring (based on Reynolds and Elrick, 1990)

Soil Type	Ring Insertion Depth **7 cm**	**15 cm**
sands and gravels	0.95	0.99
loams	0.80	0.94
clays and heavy clay loams	0.60	0.88

Other Uses

The Cornell Sprinkle Infiltrometer can be employed for other measurements of soil physical behavior. In a manner similar to the infiltration measurements, the sprinkler system may be employed to measure soil hydraulic conductivity in the field with rings inserted in different soil horizons in-situ. This can also be done in the laboratory using soil cores, in which case no correction for three-dimensional flow would be required.

The uniform droplet size allows the rainfall simulator to be used for measurement of soil aggregate stability under predetermined rainfall energy levels. This can provide relevant information on slaking potential, which strongly relates to runoff and erosion.

The sprinkle system may also be employed when natural soil wetting is required in the laboratory or field.

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APPENDIX 1.6

STALITE

Rotary Kiln Expanded Slate Lightweight Aggregate

Rev. 10/2006

3/4" - #4 (19mm-4.75mm) Structural Aggregate

ASTM C 330 3/4" - #4

Typical Physical Characteristics

1. Dry loose unit weight ASTM C 29	46 lbs/ft^3
2. Bulk specific gravity (SSD) ASTM C 127	1.50
3. Absorption *(24 hour submerged, from oven dry)* ASTM C 127	6.0%
4. Resistance to abrasion *(% of wear-weight loss)* ASTM C 131	23.0%
5. Soundness of aggregate *(magnesium sulfate)* ASTM C 88	0.01%
6. Soundness of aggregate *(freeze and thaw)* AASHTO T 103	0.22%
7. Loss of ignition (%) ASTM C 114	None
8. Organic materials content ASTM C 40	None
9. Popouts ASTM C 151	None
10. Clay lumps ASTM C 142	None
11. Maximum dry density ASTM D 698	65 lbs/ft^3
12. Angle of internal friction	Not less than 40°

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CHAPTER TWO

Turf Plot Field Trials

Introduction

Porous asphalt and turf covered parking facilities are not new ideas. Throughout the United States, porous asphalt as a parking lot surface has become more common in the last fifteen years (Ferguson 1996, Ferguson, 2005, Cahill 1994), while turf as a formal parking surface is used often, especially in combination with a geoblock, grasspave or other open-celled paving grid system. (Ferguson 2005). Examples of porous asphalt lots include university and arboreta installations, while turfgrass surfaced lots include stadiums, flea markets, churches, car dealerships and emergency vehicle access lanes. While both porous asphalt and turf covered lots minimize runoff by allowing water to infiltrate slowly and naturally into the subgrade (Ferguson 1996, Ferguson, 2005, Cahill 1994), the benefits to parking on grass are numerous and range from lowering surface temperatures through transpiration of the turf (Asaeda and Ca 2000), absorbing CO2 and emitting 02, and reducing glare by absorbing light (Ferguson 2005). Additionally, a grass surfaced parking area gives the appearance of greenspace as opposed to paved areas which might otherwise be devoid of any landscape elements (Ferguson 2005).

When designed and maintained properly, both porous asphalt and turf covered lots can be a viable surface alternative to parking lots. Unlike porous asphalt, however, turf lots necessitate other considerations before, during, and after installation (Furgeson 2005). Ferguson, along with notable turfgrass researchers James Beard and A.J. Turgeon, illustrate that through proper design and maintenance, it is possible to create a turfgrass parking system that is a viable alternative to traditional concrete or asphalt paved parking lots. Regardless of these claims however, the designer must be knowledgeable, not just in creating the proper design for a turf covered parking facility, but in the proper selection of turfgrass species and rigid paving infrastructure such as Grasspave, or Geoblock that can tolerate the wear and traffic from the vehicles using the lot. Additionally, once installed, the maintenance regimes for such systems are often rigorous and costly, requiring routine irrigation, limited traffic, frequent mowing, fertilization, pest control treatments, aeration, top dressing, over-seeding, and care with off season snow removal (Ferguson 2005, Turgeon 1999, Beard 2000).

Despite these complicated issues, we have investigated both porous asphalt and turf covered parking systems that work in combination with different structural soil media to not only test the use of structural soil with porous asphalt systems, but also examine the viability of installation and maintenance issues surrounding porous asphalt and turf covered parking lots. Both surface treatments can allow for medium duty traffic while still retaining the amount of rainfall found in a 100 year storm in central New York (Appendix 2.1), ultimately reducing the detrimental environmental and economic impacts of runoff and associated water quality issues as regulated by the National Pollution Discharge Elimination System (NPDES) (Albanese and Matlack, 1998, Brattebo and Booth 2003, Chester and Gibbons 1993, Kollin 2005, McPherson 2001, Rushton 2001).

Methods and Materials

This experiment was located in a ½ acre lot adjacent to Bluegrass Lane within the Cornell University Landscape Research facility. Square 2.44 m x 2.44 m (8’ x 8’) plots were constructed to hold four types of surface conditions on top of three types of base conditions. The surface conditions were: traditional asphalt, porous asphalt, zoysiagrass and tall fescue. The base conditions were:

1) typical medium duty pavement base course as a control,

2) CU Structural soil®, and

3) Carolina Stalite Structural soil (Figure 6).

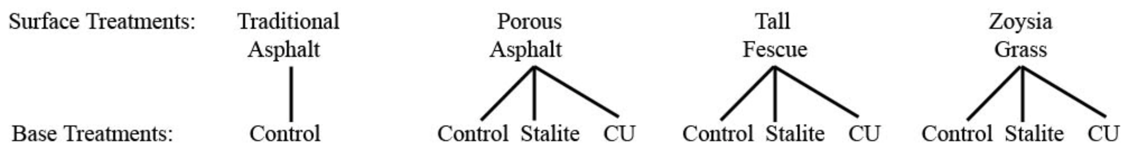
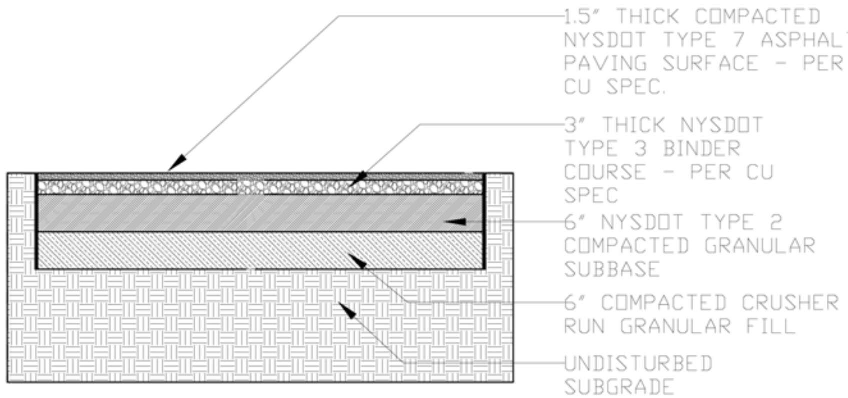


Figure 6: Base and Surface Treatments for Test Plots.

Before installation, soil boring samples were taken by a geotechnical firm, Atlantic Testing of Canton, NY, to determine parking lot base course requirements for the soil at this site. Their results showed a soil with a high clay content, little drainage and low permeability. Based on this information, thirty 2.44 m x 2.44 m (8' x 8') pits were dug into the field. Depths of each pit were determined by the geotechnical report recommendation from Atlantic Testing (Appendix 2.2) for base course depth and material and local 100 year rainfall data (Appendix 2.1). Each pit had one of three base course materials: a control base typical of Cornell University standards for medium duty pavement installations (Figure 7), CU Structural Soil® and Carolina Stalite structural soil. Because we wanted our experimental base courses to be able to hold a 100 year rain event, both structural soils were laid at a depth of 61 cm (24"), using the 32% void space data obtained from lab trials for water retention. After the pits were dug, a frame was built to the depth of each pit and a waterproof plastic barrier was installed to prevent lateral water flow between profile sections.

The control base course (Figure 2) consisted of a 15.2 cm (6") subbase of crusher run, and 15.2 cm (6") of NYSDOT Type 2 stone (Comparable to USDOT # 57 Stone). Before installation the subgrade was compacted and a Mirafi 170N Geotextile Fabric was laid over the subgrade. During installation, each course was compacted as detailed.



Note: Figure Not To Scale

Figure 7: Typical CU Medium Duty Asphalt Paving Profile.

The CU Structural Soil® base course consisted of 61 cm (24”) of CU Structural Soil® (Figure 8.) compacted in 20.3 cm (8”) lifts during installation. Prior to installation, the CU Structural Soil® was mixed using the standard formula of 80 percent NYSDOT Type 2 Stone and 20 percent silty clay loam by weight. Hydrogel was used to bind the soil to the stone at a rate of 30g/100 kg of NYSDOT Type 2 stone. Additionally, there was no compaction to the subgrade and the Mirafi 170N Geotextile Fabric was laid over the subgrade before installation. The Carolina Stalite structural soil base course installation also consisted of a profile depth of 61 cm (24”) compacted in 20.3 cm (8”) lifts (Figure 8). Prior to installation, Mirafi 170N Geotextile Fabric was laid on an uncompacted subgrade. This base course was mixed as per Carolina Stalite structural soil specifications which call for 80 percent 1.9 cm (0.75”) Carolina Stalite and 20 percent silty clay loam. The interstitial soils were identical for both the Carolina Stalite and CU Structural Soils®.

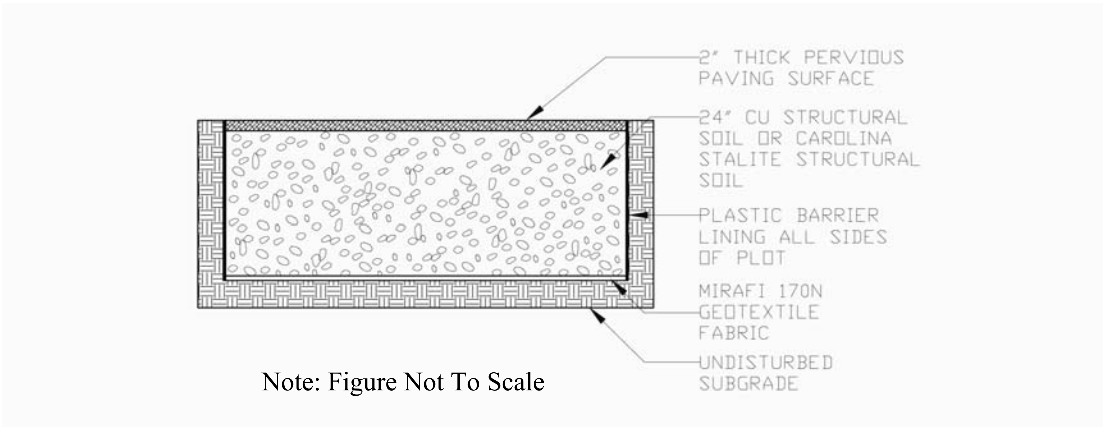


Figure 8: CU Structural Soil®/Carolina Stalite Structural Soil Detail

Each pit was then filled with the specified type of base condition: control, CU Structural Soil®, and Carolina Stalite structural soil, all assigned in a random manner across the ½ acre site. Each base condition was filled as specified. Additionally, a 5.1 cm (2") PVC pipe with removable cap and holes running the length of pipe every 3.8 cm (1.5") on center and offset 1.9 cm (0.75") was installed in the center of each pit for measurement and data collection purposes. Once the pits were filled, surface conditions were assigned in a random manner once each base location was determined with 3 repetitions for each base course/surface treatment for a total combination of 30 pits. Once the base courses were installed both the traditional asphalt and porous asphalt were installed directly onto each base course and then tamped with a hand tamper, while each sod type was laid directly onto each base course with no soil layer in between. The sod used in these experiments were *Festuca arundinacea*, hereafter called tall fescue, and *Zoysia japonica*, hereafter called Zoysia. Both sod types were irrigated for a six week period to establish healthy rooting into each base course. Once the roots were properly established, all irrigation activity was ceased.

After installation and establishment of the turf roots into the various subbase materials, a number of experiments were conducted at these plots during the summer of 2006. These included wear and traffic studies, infiltration studies, temperature readings, clip collection, and visual Turf Quality Assessment (TQA) studies.

The traffic and wear studies comprised of two different components, both performed with a 2903 kg (6400 lbs.) 2002 Chevy Silverado 1500 truck. In order to run these trials, three separate areas were delineated in each 2.44 m x 2.44 m (8’x8’) plot. The first are consisted of a 0.91 m x 0.46 m (3’x 1.5’) boxed area where the turning study would take place. The second consisted of a 2.44 m x .46 m (8’ x 1.5’) lined area where the line study took place. In the remainder of the plot, no traffic or wear studies were allowed. The turning study consisted of pulling the front tire of the truck onto the plot and then cranking the wheels all the way left followed by cranking the wheels all the way right and then backing the truck off the plot to mimic extreme traffic conditions of wheels turning on turf. The line study consisted of running the left front tire within the designated portion of each plot in a straight line to mimic vehicle traffic. After each study was performed, readings were taken with a 2.25 kg (4.96 lbs.) Clegg Impact Hammer manufactured by Lafayette Instrument Company to assess the amount of compaction from the truck to each area of the plot – turning traffic, straight line traffic and un-trafficked areas. Each Clegg Hammer Impact value was recorded. Additionally, Clegg Impact Hammer values were taken for both trafficked and un-trafficked turf in the areas adjacent to the test plots to see if these reflected similar or different values as the turf in each test plot.

Infiltration studies were measured on each of the plots following periods of both natural rainfall and simulated rainfall events where complete saturation was achieved and each plot was flooded by hand. The data from both events was recorded by placing a tape measure into the peizometer measuring device in the center of each plot and measuring the water level in each of the plot reservoirs. Water levels for each plot were recorded as often as possible to gain a sense of the infiltration and/or evaporation rates of the water from the reservoirs underneath each of the plots.

Surface temperature readings were taken three times a week during the summer with an Omega Engineering non-contact infrared thermometer. Additionally three readings were taken in two hour intervals throughout the day beginning at 6 a.m. and ending at 8 p.m. All values were recorded for each plot.

Clip collection and analysis consisted of clipping each designated section of the plot when the grass reached 11.4 cm (4.5") high (just before mowing) in order to gain a sense of the health and vigor of the turf in each specific section of a plot. A 30.5 cm x 30.5 cm (1' x 1') template was made that measured 7.6 cm (3") high (the height to which the grass was cut). Clippings from the turning study areas, the line study areas and the un-trafficked areas of each plot were collected, placed into bags and then dried for 24 hours in an oven at 70°C (158° F). Once dried the clippings from each section were weighed and the weights recorded.

Weekly visual Turf Quality Assessments were also carried out on the test plots, rating each section of each plot. Ratings were assigned to each of the three sections within every plot for the turning study, line traffic study or no-traffic study section, and were based on the NTEP (National Turf Evaluation Program) TQA rating system which assigns a number 1-9. In this system a rating of 1 is dead turf, 6 is acceptable turf, and 9 is perfectly healthy turf (Morris and Shearman, Ebdon). These ratings not only allowed insight into the health of each plot, but also the impact of each of the traffic studies on the turf as well.

Once the experimentation was finished and all of the data collected, data analysis and analysis of variance was performed the data using SAS version 9.2 General Linear Model and the Tukey multiple comparison was performed at alpha (α) $= p < .05$.

Results

Turf Quality Assessments (TQA)

To gain a clear picture of the TQA ratings over the entire summer, the following charts illustrating the chronological TQA ratings for the tall fescue over the entire summer best illustrate the results for these assessments (Figures 9-11). When examining these figures, it should be noted that a TQA rating of 6 and above is acceptable.

The mean TQA ratings for the tall fescue (*Festuca arundinacea*) on both of the structural soils hovered close to this acceptable range throughout the entire summer with a slight rebound as temperatures cooled in late summer. Although tall fescue usually goes dormant in the mid-summer due to the summer heat, there was no indication of this, as illustrated in Figures 9-11. As pertains to the Turning Study TQA assessments, the large dip in mean TQA ratings were a result of the impact of the traffic from the Turning Study early in the trials. After the first week, the Turning Study was ceased and the turf allowed to recover for the remainder of the summer, as illustrated by the rise in mean TQA readings for this Study. This recovery demonstrates that although turning wheels have quite an impact on turf, the effects of this impact may not be so disastrous as long as it can be controlled.

The TQA ratings for the tall fescue on the control base were vastly different. The lower TQA ratings towards the end of the summer for the tall fescue on the control base were primarily a result of the lack of soil in the control base. Since no irrigation was used during these trials, the tall fescue on the control base could not survive on this gravel media. Conversely, despite the minimal amount of soil in both of the structural soil base courses, there was nevertheless enough soil within these growing media to sustain healthy turf as shown through the more or less acceptable TQA ratings for the tall fescue on both of these bases.

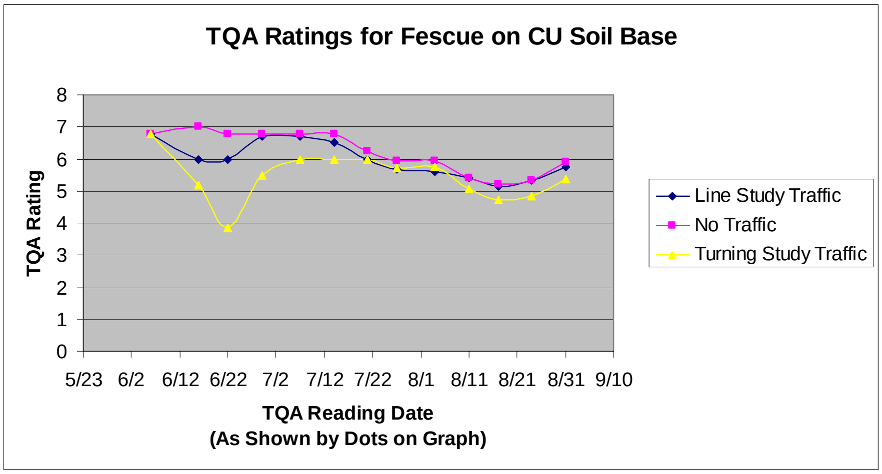


Figure 9: Mean TQA results for tall fescue on CU Structural Soil®

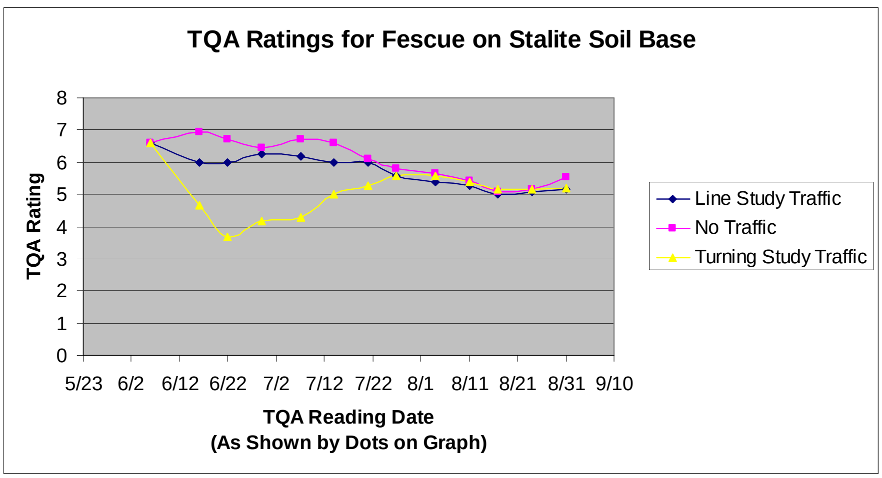


Figure 10: Mean TQA results for tall fescue on Carolina Stalite Structural Soil

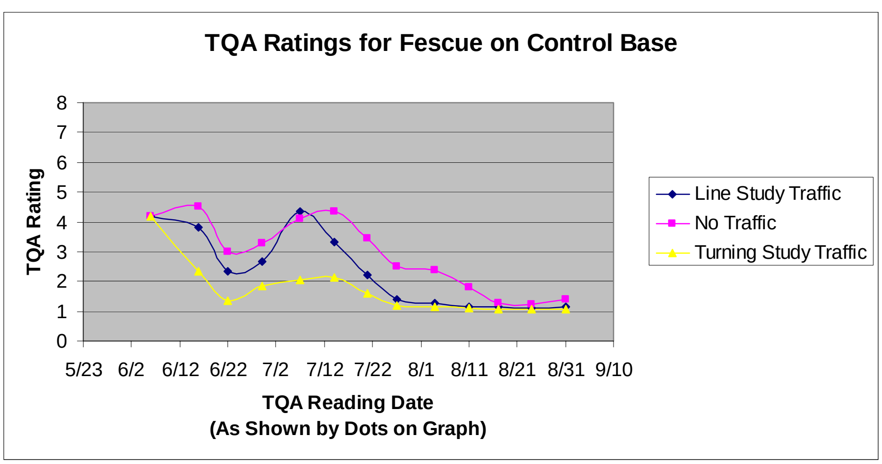


Figure 11: Mean TQA results for tall fescue on Control base Course

The following charts illustrate the chronological TQA ratings for the zoysiagrass (*Zoysia japonica*) over the entire summer, best illustrating the results for these assessments (Figures 12-14). Again, when examining these figures, it should be noted that a TQA rating of 6 and above is acceptable.

These TQA ratings for the zoysia illustrate a vastly different picture than the TQA ratings for the tall fescue. Although these TQA ratings started out in the acceptable range, they dove quickly as the summer progressed. Most likely this was due to the fact that zoysiagrass is a warm-season grass and adapted poorly to Ithaca's cool-season climate, never performing as well as expected. Another possible reason for the poor performance of the zoysiagrass might have to do with the pH requirements of the growing media. Zoysiagrass prefers a more neutral to acidic pH, while the pH of both of the structural soils is rather basic. This higher pH of both of the structural soils may have something to do with the low TQA results found in the zoysiagrass readings.

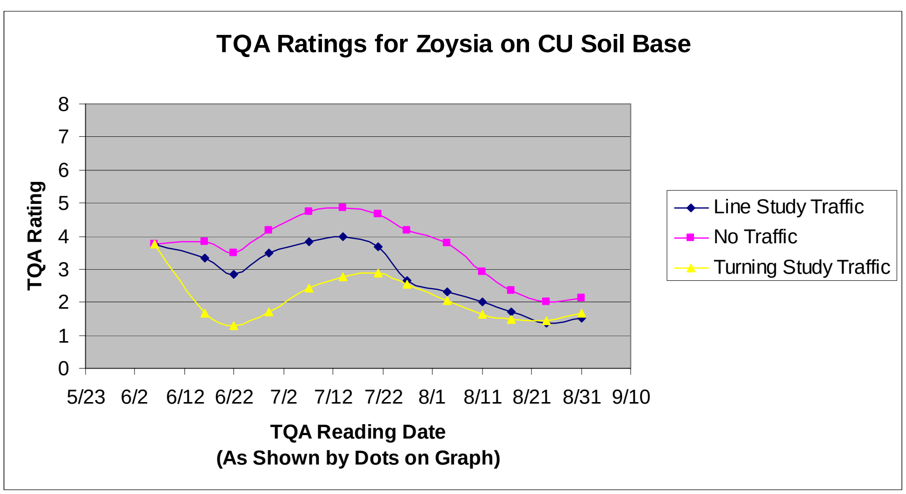


Figure 12: Mean TQA results for zoysiagrass on CU Structural Soil®

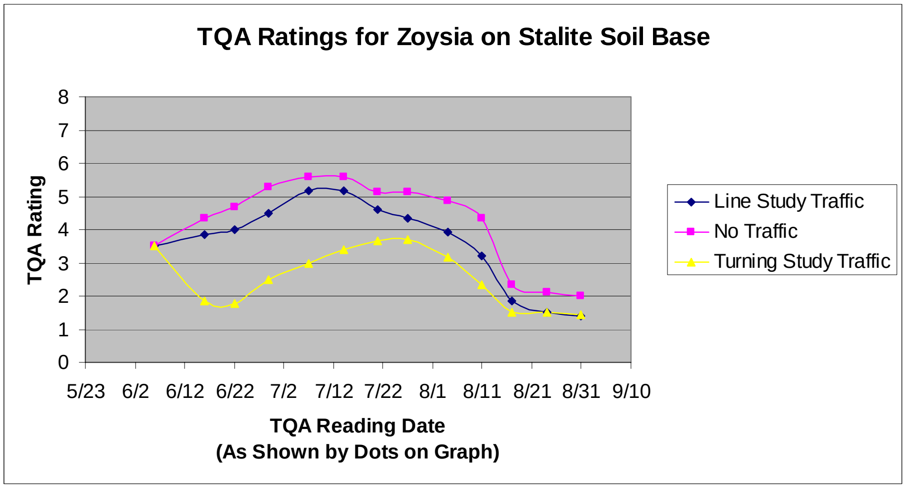


Figure 13: Mean TQA results for zoysiagrass on Carolina Stalite Structural Soil

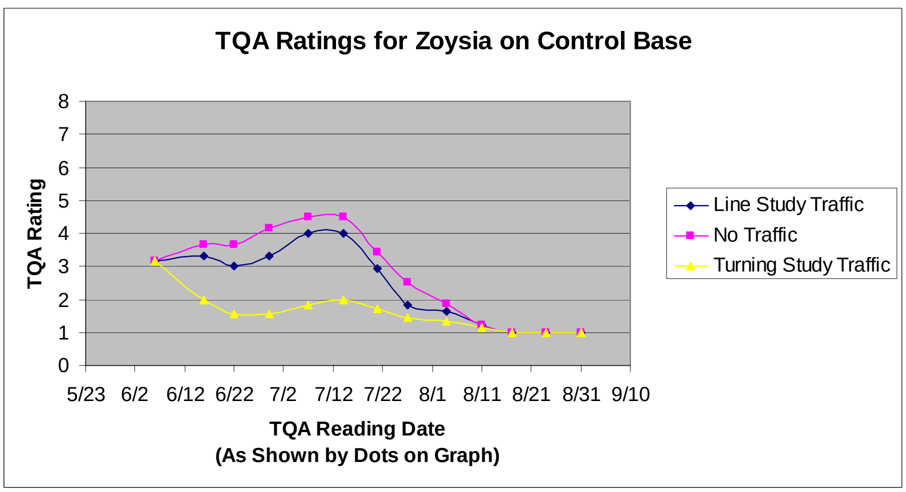


Figure 14: Mean TQA results for zoysiagrass on Control Base Course

TQA Main Effects of Individual Elements on TQA Readings

Though Figures 9-14 illustrate a clear picture of the TQA readings for each of the plots, they do not help explain the effects of traffic and base course. To better understand the results for the TQA readings, statistical analysis was run isolating and comparing not only individual main effects of the results, but also two way and three way interactions. The individual effects include turf type, base course type, and traffic type. The combined interactions include an examination of turf type and base course type, turf type and traffic type, and traffic type and base course type. Lastly the three way interaction was performed to examine the results of all three individual elements on the TQA results.

A comparison of the TQA ratings between the tall fescue and zoysiagrass revealed that regardless of base type or traffic impact, zoysiagrass has a TQA mean of 2.85 while Tall Fescue had a TQA mean of 4.6.

Table 10: Mean TQA Readings and P-Values for Turf Main Effect

Sod Type	Least Square Mean TQA Reading	P-Value
Tall Fescue (TF)	4.6	<0.0001
Zoysia (Z)	2.85	

These results indicate that the tall fescue TQA readings were significantly higher than the zoysiagrass TQA readings. Most likely, these results can be attributed to the fact that fescue is a cool-season grass, whereas zoysia is a warm-season grass. As a warm-season grass, zoysia does not grow as well in the summers of the northeastern United States. Cool-season grasses are most active and successful in the northern parts of the U.S., showing greater levels of health and vigor in the spring and fall when the weather is coolest, and often going dormant in the middle of the summer when the weather is hottest (Beard 1992, Turgeon 1999). Conversely, warm-season grasses are found primarily in the southern portions of the U.S. and flourish when the mean temperature is above 12.78° C (55° F) (Beard 1992, Turgeon 1992). Though the zoysiagrass was expected to show poor results during the cooler weather of the spring and late summer, the lower TQA results indicate that the zoysia used for this trial never flourished as expected in the middle summer months when the summer heat set in.

Looking at the TQA results for the main effects of the different base courses regardless of turf type or traffic wear study created the following results:

Table 11: Mean TQA Readings for Base Course Main Effects

Base Course	Least Square Mean TQA Reading
Carolina Stalite Structural Soil (CS)	4.54
CU Structural Soil® (CU)	4.36
Control (C)	2.28

With the following P-values for each of the comparisons:

Table 12: P-Values for Mean TQA Readings for Base Course Main Effects

Base Course	CU	CS	C
CU Structural Soil®		0.4252	<.0001
Carolina Stalite Structural Soil	0.4252		<.0001
Control	<.0001	<.0001	

The P-values of < 0.0001 illustrate that there is a significant difference between the mean TQA results for both of the structural soil base courses and for those of the control base course. This difference is most likely attributable to the lack of soil within the control base course, proving that as little as 20 percent soil by weight or volume when mixed with gravel to create each of the structural soils is sufficient to provide a healthier growing medium than a gravel base course alone. The P-values of 0.452 for each of the structural soil mean TQA results illustrates that there is no significant difference between the means of either the CU Structural Soil® or the Carolina Stalite Structural Soil base courses. This illustrates a pattern which will become common throughout the presentation of these results, illustrating that the two types of structural soils yielded similar outcomes.

The last remaining individual main effect to examine is the effect of traffic on the mean TQA rating regardless of base type or sod type. The results for this were:

Table 13: Mean TQA Ratings for Traffic Study Main Effects

Traffic Type	Least Square Mean TQA Reading
No Traffic (NT)	4.29
Line Study (LS)	3.81
Turning Study (TS)	3.08

With the following P-values for each of the comparisons:

Table 14: P-Values for Mean TQA Ratings for Traffic Study Main Effects

Traffic Type	LS	TS	NT
Line Study		<.0001	<.0001
Turning Study	<.0001		<.0001
No Traffic	<.0001	<.0001	

These P-values indicate that the mean TQA results for the non-trafficked portions of each plot were significantly higher than the portions of each plot designated for either of the traffic studies. Similarly, the means for the TQA results for the portions of the plots designated for the Line Study traffic were significantly higher than the mean TQA results for the portions of the plot designated for the Turning Study. These results indicate that damage from a turning wheel on turf is not only significant, but also more damaging than traffic from a vehicle traveling in a straight line.

Turf Quality Assessments (TQA): Effects of Combined Elements on TQA Readings

The first two-way interaction of turf type vs. base course produced the following TQA means:

Table 15: Mean TQA Ratings for Two Way Interactions of Turf and Base Course

Turf Type	Base Type	Least Square Mean TQA Reading
Tall Fescue (TF)	CU Structural Soil® (CU)	5.88
Tall Fescue (TF)	Carolina Stalite Structural Soil (CS)	5.61
Zoysia (Z)	Carolina Stalite Structural Soil (CS)	3.47
Zoysia (Z)	CU Structural Soil® (CU)	2.84
Tall Fescue (TF)	Control (C)	2.3
Zoysia (Z)	Control (C)	2.26

For each of these results, the P-values were:

Table 16: P-Values for Mean TQA readings for Two Way Interactions of Turf and Base Course

Interaction:	TFxCU	TFxCS	TFxC	ZxCU	ZxCS	ZxC
TFxCU		0.0041	<.0001	<.0001	<.0001	<.0001
TFxCS	0.0041		<.0001	<.0001	<.0001	<.0001
TFxC	<.0001	<.0001		<.0001	<.0001	0.9924
ZxCU	<.0001	<.0001	<.0001		<.0001	<.0001
ZxCS	<.0001	<.0001	<.0001	<.0001		<.0001
ZxC	<.0001	<.0001	0.9924	<.0001	<.0001	

This table illustrates that all of the means presented above were significantly different from one another with two exceptions. First, the tall fescue on both the structural soils was significantly different as the other comparisons, though still statistically different. Second, the TQA means for both the zoysia and tall fescue on the control base were virtually identical.

Otherwise, the examination of this two way interaction supported the findings: The tall fescue had higher TQA readings than the zoysia on either of the structural soils, while the control base course comprised of gravel without soil produced the least healthy turf surface. Perhaps what is most interesting with this result is that the means for the fescue on both the Structural Soils were just below 6, the TQA rating level for acceptable turf.

The next two way interaction, turf type vs. traffic, produced the following results:

Table 17: Mean TQA Readings for Two Way Interactions of Turf and Traffic Type

Turf Type	Traffic Type	Least Square Mean TQA Rating
Tall Fescue (TF)	No Traffic (NT)	5.05
Tall Fescue (TF)	Line Study (LS)	4.67
Tall Fescue (TF)	Turning Study (TS)	4.06
Zoysia (Z)	No Traffic (NT)	3.53
Zoysia (Z)	Line Study (LS)	2.95
Zoysia (Z)	Turning Study (TS)	2.09

For each of these results, the p-values were:

Table 18: P-Values for Mean TQA Readings for Two Way Interactions of Turf and Traffic Type

Interaction:	TFxLS	TFxTS	TFxNT	ZxLS	ZxTS	ZxNT
TFxLS		<.0001	<.0001	<.0001	<.0001	<.0001
TFxTS	<.0001		<.0001	<.0001	<.0001	<.0001
TFxNT	<.0001	<.0001		<.0001	<.0001	<.0001
ZxLS	<.0001	<.0001	<.0001		<.0001	<.0001
ZxTS	<.0001	<.0001	<.0001	<.0001		<.0001
ZxNT	<.0001	<.0001	<.0001	<.0001	<.0001	

These p-values indicate that the differences between each of the means presented in these two way interactions were highly significant, while patterns previously seen are once again repeated. First, tall fescue had significantly higher mean TQA readings than zoysiagrass, regardless of traffic type. In truth, there was such a difference in the readings between grass types, that even the lowest mean TQA reading for tall fescue plots allocated to the turning study were significantly higher than the mean TQA readings for zoysia surfaced plots without traffic. Of the traffic types, portions of the plots receiving no traffic had the highest mean TQA readings regardless of grass type. The next highest means, regardless of turf type, were those mean TQA readings for the portions of the plots allocated to the Line Study, followed by the mean TQA readings for those portions of the plot allocated to the Turning Study.

The last two-way interaction examined is base course vs. traffic type. This interaction produced the following results:

Table 19: Mean TQA Readings for Two Way Interactions of Base and Traffic Type

Base Type	Traffic Type	Least Square Mean TQA Rating
Carolina Stalite Structural Soil (CS)	No Traffic (NT)	5.14
CU Structural Soil® (CU)	No Traffic (NT)	4.92
Carolina Stalite Structural Soil (CS)	Line Study (LS)	4.67
CU Structural Soil® (CU)	Line Study (LS)	4.39
Carolina Stalite Structural Soil (CS)	Turning Study (TS)	3.81
CU Structural Soil® (CU)	Turning Study (TS)	3.77
Control (C)	No Traffic (NT)	2.81
Control (C)	Line Study (LS)	2.37
Control (C)	Turning Study (TS)	1.65

For each of these results, the P-values were:

Table 20: P-Values and Mean TQA Readings for Two Way Interactions of Base and Traffic Type

Interaction	CUxLS	CUxTS	CUxNT	CSxLS	CSxTS	CSxNT	CxLS	CxTS	CxNT
CUxLS		<.0001	<.0001	0.0374	<.0001	<.0001	<.0001	<.0001	<.0001
CUxTS	<.0001		<.0001	<.0001	1	<.0001	<.0001	<.0001	<.0001
CUxNT	<.0001	<.0001		0.1244	<.0001	0.2397	<.0001	<.0001	<.0001
CSxLS	0.0374	<.0001	0.1244		<.0001	<.0001	<.0001	<.0001	<.0001
CSxTS	<.0001	1	<.0001	<.0001		<.0001	<.0001	<.0001	<.0001
CSxNT	<.0001	<.0001	0.2379	<.0001	<.0001		<.0001	<.0001	<.0001
CxLS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		<.0001	<.0001
CxTS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		<.0001
CxNT	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	

Again, the majority of the mean TQA readings for these comparisons was significantly different, and reinforces patterns previously seen. As an example, the P-values for mean TQA results for non-traffic portions of either the structural soils are statistically similar. Additionally, the P-values indicate only slight statistical difference between the mean TQA readings for the line study portions of the plots containing both structural soils. Despite this, the P-values for the turning study portions of all plots for both structural soils indicate no difference between either structural soil. All three of these further illustrate and reinforce the similarity between the CU Structural Soil® and the Carolina Stalite Structural Soil.

The only P-value that showed no significance whatsoever was the comparison between the mean TQA results for the portions of plots allocated to the Line Study on the Carolina Stalite Structural Soil base course when compared to the TQA results for the non-trafficked portions of plots containing the CU Structural Soil® base courses. Further examination of three way interactions will help explain this overlap.

TQA Three Way Interactions

An examination of the three way interactions reveals the following mean TQA readings (Table 21). Of these three way interactions, two groups of mean TQA results become readily apparent and distinctly different from one another. These groupings are:

1) Structural soil plots covered with fescue, regardless of traffic type.
2) zoysia covered plots on both types of structural soil base courses regardless of traffic; and zoysia and fescue covered plots on the control base course regardless of traffic type.

Table 21: Mean TQA Readings for Three Way Interactions of Turf, Base, and Traffic Type

Sod	Base	Traffic	Mean TQA Reading
TF	CU	NT	6.23
TF	CS	NT	6.06
TF	CU	LS	5.97
TF	CS	LS	5.73
TF	CU	TS	5.44
TF	CS	TS	5.05
Z	CS	NT	4.22
Z	CU	NT	3.61
Z	CS	LS	3.61
TF	C	NT	2.88
Z	CU	LS	2.81
Z	C	NT	2.75
Z	CS	TS	2.56
Z	C	LS	2.42
TF	C	LS	2.31
Z	CU	TS	2.1
TF	C	TS	1.7
Z	C	TS	1.6

Of the top tier of three way interactions, the highest mean TQA readings are those of the un-trafficked tall fescue on both the structural soils, with the CU Structural Soil® having a mean TQA reading of 6.23 and the Carolina Stalite Structural Soil mean TQA readings of 6.06. The P-values for three way interactions show that there is no statistical difference between these mean TQA readings. Statistical overlap also exists between the TQA readings for these two un-trafficked tall fescue covered structural soil base courses and the Line Traffic portion of the CU Structural Soil® plot also surfaced with tall fescue. Additionally, statistical insignificance also exists for the mean TQA ratings for un-trafficked portions of the tall fescue covered plots with the Carolina Stalite base courses (mean TQA ratings of 6.06) and the areas of the same plots designated to the Line Study traffic (mean TQA ratings of 5.73), as well as portions of Line Study designated plots with tall fescue surfaces on CU Structural Soil® bases (mean TQA ratings of 5.97). A last grouping of statistical insignificance exists within the mean TQA ratings for this top tier of fescue covered structural soil plots. These plots include the Line Study portions of tall fescue covered Carolina Stalite bases (mean TQA ratings of 5.73), the Turning Study portions of the fescue covered CU Structural Soil® plots (mean TQA of 5.44), and the Turning Study portions of fescue covered Carolina Stalite Structural Soil bases (mean TQA rating of 5.05).

The P-values presented in Table 13 illustrate and prove that the fescue was by far and away the most successful turf covering, while base course had little effect other than to illustrate and reinforce the success of both types of structural soil as a growing media for turfgrass. Interestingly, the portions of the plots trafficked with the Line Study covered with tall fescue and with CU Structural Soil® bases had statistically the same TQA ratings as the non-trafficked portions of the same plots, ultimately showing that traffic had little effect on TQA ratings for tall fescue covered plots on CU Structural Soil® base courses.

Clegg Impact Hammer Results

Clegg impact hammers are used to understand the hardness and compaction levels of a specific surface. In some applications they are used to measure the potential for injury in playing fields, while in other instances Clegg impact values are used for determining potential failure in constructed surfaces. In this case, we used the Clegg hammer to understand the nature of the compaction resulting from the three traffic studies performed on the test plots.

Table 21: P-Values for Mean TQA Three Way Interactions for Turf, Base and Traffic Type

	TF CU LS	TF CU TS	TF CU NT	TF CS LS	TF CS TS	TF CS NT	TF C LS	TF C TS	TF C NT	Z CU LS	Z CU TS	Z CU NT	Z CS LS	Z CS TS	Z CS NT	Z C LS	Z C TS	Z C NT
TF CU LS	.	0.0036	0.8221	0.9168	<.0001	1.0000	<.0001	<.0001	<.0001	<.0001	<.000	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TF CU TS	0.0036	.	<.0001	0.6431	0.1814	0.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TF CU NT	0.8221	<.0001	.	0.0101	<.0001	0.9965	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TF CS LS	0.9168	0.6431	0.0101	.	<.0001	0.4560	<.0001	<.000	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TF CS TS	<.0001	0.1814	<.0001	<.0001	.	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TF CS NT	1.0000	0.0001	0.9965	0.4560	<.0001	.	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TF C LS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	.	0.0002	0.0011	0.0109	0.9661	<.0001	<.0001	0.8749	<.0001	1.0000	<.0001	0.0583
TF C TS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002	.	<.0001	<.0001	0.1256	<.0001	<.0001	<.0001	<.0001	<.0001	1.0000	<.0001
TF C NT	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0011	<.0001	.	1.0000	<.0001	<.0001	<.0001	0.5023	<.0001	0.0301	<.0001	0.9999
Z CU LS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0109	<.0001	1.0000	.	<.0001	<.0001	<.0001	0.8842	<.0001	0.1638	<.0001	1.0000
Z CU TS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.9661	0.1256	<.0001	<.0001	.	<.0001	<.0001	0.0281	<.0001	0.4868	0.0093	<.0001
Z CU NT	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	.	1.0000	<.0001	0.0002	<.0001	<.0001	<.0001
Z CS LS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	1.0000	.	<.0001	0.0002	<.0001	<.0001	<.0001
Z CS TS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.8749	<.0001	0.5023	0.8842	0.0281	<.0001	<.0001	.	<.0001	0.9997	<.0001	0.9920
Z CS NT	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002	0.0002	<.0001	.	<.0001	<.0001	<.0001
Z C LS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	1.0000	<.0001	0.0301	0.1638	0.4868	<.0001	<.0001	0.9997	<.0001	.	<.0001	0.4560
Z C TS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	1.0000	<.0001	<.0001	0.0093	<.0001	<.0001	<.0001	<.0001	<.0001	.	<.0001
Z C NT	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0583	<.0001	0.9999	1.0000	<.0001	<.0001	<.0001	0.9920	<.0001	0.4560	<.0001	.

To better understand the results for the Clegg Impact Hammer Tests, statistical analysis was run isolating and comparing not only individual main effects of the results, but also two way and three way interactions. The individual effects include turf type, base course type, and traffic type. The combined interactions include an examination of turf type and base course type, turf type and traffic type, and traffic type and base course type. Lastly the three way interaction was performed to examine the results of all three individual elements on the Clegg Hammer results. For this section of the results, portions of the plots allotted to the Turning Study are presented separately than the other portions of the plots since there was far fewer Clegg impact readings performed on these portions of the plots.

Main Effects of Individual Elements on Clegg Readings

A comparison of the Clegg ratings between the tall fescue and zoysiagrass revealed that regardless of base type or traffic impact, zoysiagrass had a mean Clegg impact value reading of 8.87 while tall fescue had a mean Clegg impact value reading of 8.58.

Table 22: Mean Clegg Impact Value Readings and P-Values for Turf Surface Main Effects

Sod Type	Least Square Mean Clegg Reading	P Value
Tall Fescue (TF)	8.87	<0.0001
Zoysia (Z)	8.58	

Although there mean readings seem similar, the P-value indicates that there was a significant statistical difference between the two. Without further examination of other main effects and combinations on the Clegg values, it is difficult to explain these differences by just an examination of the surface type.

A close examination of the base courses reveals a more interesting set of results. Looking at the mean Clegg impact value readings for the main effects of the different base courses regardless of turf type or traffic wear study resulted in the following means:

Table 23: Mean Clegg Impact Value Readings for Base Course Main Effects

Base Course	Least Square Mean Clegg Reading
CU Structural Soil® (CU)	9.06
Carolina Stalite Structural Soil (CS)	9.00
Control (C)	8.12

With the following P-values associated with each of the comparisons:

Table 24: P-Values for Mean Clegg Impact Value Readings for Base Course Main Effects

Base Course	CU	CS	C
CU Structural Soil®		0.7705	<.0001
Carolina Stalite Structural Soil	0.7705		<.0001
Control	<.0001	<.0001	

The P-values of < 0.0001 illustrate that there was a significant difference between the mean Clegg impact values for both of the structural soil base courses and the Clegg results for the control base courses. These result also indicated that there was no difference in the mean Clegg impact values for either of the structural soils when compared to one another. Close observation during testing indicated that the difference between the two structural soils and the control bases comprised of gravel alone most likely related to the lack of soil between the stone particles in the control base courses. This lack of soil allowed movement of the gravel when struck by the hammer, thereby softening the impact of the hammer and lowering the Clegg reading.

The soil particles within each of the structural soil particles, however, helped lock the soil in place, creating a more rigid base course, resulting in higher Clegg Impact values than those found in the control base courses.

The final one way interaction examined was the impact of traffic on the mean Clegg impact value readings. Not surprisingly, the portions of the plots that received traffic resulted in higher mean impact values due to the compactive nature found in the application of traffic over the plots:

Table 25: Mean Clegg Impact Value Readings and P-Values for Traffic Type Main Effects

Traffic Type	Least Square Mean Clegg Readings	P-Value
Line Study (LS)	10.65	<0.0001
No Turning (NT)	6.80	

With the application of the traffic, the portions of the plot receiving traffic became compacted, resulting in the higher Clegg Impact Values.

Clegg Impact Value: Effects of Combined Elements on mean Clegg Impact Value Readings

The first two-way interaction examined is turf type vs. base course. This interaction produced the following mean Clegg impact value readings:

Table 26: Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Base Course Effects

Turf Type	Base Type	Least Square Mean Clegg Readings
Tall Fescue (TF)	Carolina Stalite Structural Soil (CS)	9.55
Tall Fescue (TF)	CU Structural Soil® (CU)	9.26
Zoysia (Z)	CU Structural Soil® (CU)	8.86
Zoysia (Z)	Control (C)	8.46
Zoysia (Z)	Carolina Stalite Structural Soil (CS)	8.44
Tall Fescue (TF)	Control (C)	7.79

For each of these results, the P-values were:

Table 27: P-Values for Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Base Course Effects

Interaction:	TFxCU	TFxCS	TFxC	ZxCU	ZxCS	ZxC
TFxCU		0.1851	<.0001	0.018	<.0001	<.0001
TFxCS	0.1851		<.0001	<.0001	<.0001	<.0001
TFxC	<.0001	<.0001		<.0001	<.0001	0.9924
ZxCU	0.018	<.0001	<.0001		0.0131	0.02
ZxCS	<.0001	<.0001	<.0001	0.0131		1
ZxC	<.0001	<.0001	0.9924	0.02	1	

This table illustrates that all of the means presented above were significantly different from one another, again with three exceptions: the tall fescue surfaces on both the structural soil bases were statistically indifferent from one another. Additionally, both the mean Clegg impact values for the zoysia and tall fescue surfaces on the control base courses were virtually identical. So too were the zoysia covered control based plots statistically identical to the zoysia covered Carolina Stalite Structural Soil based plots.

The second two way interaction examined the turf type vs. traffic, producing the following results:

Table 28: Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Traffic Type Effects

Turf Type	Traffic Type	Least Square Mean Clegg Readings
Zoysia (Z)	Line Study (LS)	10.88
Tall Fescue (TF)	Line Study (LS)	10.42
Tall Fescue (TF)	No Traffic (NT)	7.31
Zoysia (Z)	No Traffic (NT)	6.29

For each of these results, the P-values were:

Table 29: P-Values for Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Traffic Type Effects

Interaction:	TFxLS	ZxLS	TFxNT	TFxNT
TFxLS		<.0001	<.0001	<.0001
ZxLS	<.0001		<.0001	<.0001
TFxNT	<.0001	<.0001		<.0001
TFxNT	<.0001	<.0001	<.0001	

These P-values indicate that the differences between each of the means presented in these two way interactions were very highly significant, while patterns previously seen in other results are once again repeated: The Line Study portions of the plots for both types of grass had higher Clegg impact value readings than the areas for the same plots receiving no traffic. These results indicate that there was significant compaction to the base course of the plots due to the traffic received.

The last of the two way interactions examined base course vs. traffic type. This interaction produced the following results:

Table 30: Mean Clegg Impact Value Readings for Two Way Interactions of Traffic Type and Base Type Effects

Base Type	Traffic Type	Least Square Mean Clegg Values
CU Structural Soil® (CU)	Line Study (LS)	11.30
Carolina Stalite Structural Soil (CS)	Line Study (LS)	11.03
Control (C)	Line Study (LS)	9.63
Carolina Stalite Structural Soil (CS)	No Traffic (NT)	6.96
CU Structural Soil® (CU)	No Traffic (NT)	6.82
Control (C)	No Traffic (NT)	6.62

For each of these results, the p-values were:

Table 31: P-Values for Mean Clegg Impact Value Readings for Two Way Interactions of Traffic Type and Base Type Effects

Interaction	CUxLS	CSxLS	CxLS	CUxNT	CSxNT	CxNT
CUxLS		0.2871	<.0001	<.0001	<.0001	<.0001
CSxLS	0.2871		<.0001	<.0001	<.0001	<.0001
CxLS	<.0001	<.0001		<.0001	<.0001	<.0001
CUxNT	<.0001	<.0001	<.0001		0.8688	0.6
CSxNT	<.0001	<.0001	<.0001	0.8688		0.0714
CxNT	<.0001	<.0001	<.0001	0.6	0.0714	

Again, the majority of the mean Clegg Hammer impact readings for these comparisons were significantly different from one another, once again reinforcing patterns previously seen. As an example, the P-values for mean Clegg readings for Line Study portions of either the structural soil base courses illustrated that there was no statistical differences between the either of the structural soils. This similarity is repeated for the Clegg readings for the non-trafficked areas of the plots based with both structural soil types as well.

Additionally, the P-values indicate that there was no statistical difference between any of the non-trafficked mean Clegg readings, regardless of base course soil type. While this shows that traffic certainly had an impact on Clegg readings, it also shows that the traffic had differing effects on the Clegg readings, depending on the base course type.

Clegg Hammer Three Way Interaction

An examination of the three way interactions reveals the following mean Clegg Impact Value readings:

Table 32: Mean Clegg Impact Value Readings for Three Way Interactions of Traffic Type, Surface Type and Base Type Effects

Traffic Type	Surface Type	Base Type	Mean Clegg Reading
Line Study (LS)	Zoysia (Z)	Cornell Structural Soil® (CU)	11.53
Line Study (LS)	Tall Fescue (TF)	Carolina Stalite Structural Soil (CS)	11.22
Line Study (LS)	Tall Fescue (TF)	Cornell Structural Soil® (CU)	11.06
Line Study (LS)	Zoysia (Z)	Carolina Stalite Structural Soil (CS)	10.85
Line Study (LS)	Zoysia (Z)	Control (C)	10.26
Line Study (LS)	Tall Fescue (TF)	Control (C)	9
No Traffic (NT)	Tall Fescue (TF)	Carolina Stalite Structural Soil (CS)	7.89
No Traffic (NT)	Tall Fescue (TF)	Cornell Structural Soil® (CU)	7.46
No Traffic (NT)	Zoysia (Z)	Control (C)	6.65
No Traffic (NT)	Tall Fescue (TF)	Control (C)	6.58
No Traffic (NT)	Zoysia (Z)	Cornell Structural Soil® (CU)	6.18
No Traffic (NT)	Zoysia (Z)	Carolina Stalite Structural Soil (CS)	6.03

Of these three way interactions, two groups of mean Clegg results become readily apparent and distinctly different from one another. These groupings are:

1) Portions of the plots which received traffic from the Line Study.
2) Portions of the plots which received no traffic.

Although these two groupings produced mean Clegg readings that were hierarchically easy to differentiate, there was quite a bit of statistical overlap among the Clegg means within these distinct groups. For instance, there was statistical similarity among on the P-values for those portions of the plots with both types of structural soil base courses which received traffic from the Line Study. The next statistically similar group occurred within the middle values of mean Clegg readings consisting of the trafficked control bases and the untrafficked structural soil bases covered in Fescue. The next statistical delineation occurred with the un-trafficked control base courses and the remainder of the structural soil bases covered in zoysia (Table 25).

While it is clear that traffic impacted the compaction of the base courses and resulted in higher Clegg hammer readings, it also seems apparent that this increased compaction had little effect on the quality and health of the turf as illustrated through the results of the TQA readings. Referring back to the TQA section, the plot types with the highest Clegg impact value readings also corresponded with the some of the highest TQA readings. While it seems plausible that the traffic and compaction contributed to the poor TQA readings of the zoysiagrass, it should be noted that the zoysiagrass plots without traffic had both some of the lowest Clegg impact value readings, as well as some of the lowest TQA results. This leads to the conclusion that environmental factors such as Ithaca's cool-season climate, rather than traffic and compaction, lead to the poor TQA results of the zoysiagrass covered plots.

Clegg Impact Results for Turning Study

The Turning Study was performed for the first week of the trials in early June, and abandoned shortly after the emergence of bald spots in the portions of plots designated to this type of traffic. After the week of trials, the plots were untouched, but monitored by the TQA and occasional Clegg Studies to determine recovery.

Main Effects of Individual Elements on Clegg Readings

A comparison of the Clegg ratings between the tall fescue and zoysiagrass revealed that regardless of base type or traffic impact, zoysiagrass had a mean Clegg impact value reading of 6.62 while tall fescue had a mean Clegg impact value reading of 6.48.

Table 33: P-Values for Mean Clegg Impact Values for Three Way Interactions for Turf, Base and Traffic Type for the Line Study

i/j	LSxTFxCU	LSxTFxCS	LSxTFxC	LSxZxCU	LSxZxCS	LSxZxC	NTxTFxCU	NTxTFxCS	NTxTFxC	NTxZxCU	NTxZxCS	NTxZxC
LSxTFxCU	.	0.9993	<.0001	0.2520	0.9896	0.0005	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LSxTFxCS	0.9993	.	<.0001	0.8260	0.6514	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LSxTFxC	<.0001	<.0001	.	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LSxZxCU	0.2520	0.8260	<.0001	.	0.0074	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LSxZxCS	0.9896	0.6514	<.0001	0.0074	.	0.0468	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
LSxZxC	0.0005	<.0001	<.0001	<.0001	0.0468	.	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
NTxTFxCU	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	.	0.3943	<.0001	<.0001	<.0001	0.0005
NTxTFxCS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.3943	.	<.0001	<.0001	<.0001	<.0001
NTxTFxC	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	.	0.5103	0.0905	1.0000
NTxZxCU	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.5103	.	0.9996	0.2449
NTxZxCS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0905	0.9996	.	0.0258
MTxZxC	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0005	<.0001	1.0000	0.2449	0.0258	.

Table 34: Mean Clegg Impact Value Readings and P-Values for Sod Type Main Effects of Turning Study

Sod Type	Least Square Mean Clegg Reading	P Value
Zoysia (Z)	6.62	<0.2251
Tall Fescue (TF)	6.48	

The P-value for these means indicates that there was not a significant statistical difference between the two. The reason for this similarity most likely has to do with the fact that fewer Clegg trials were run, increasing the width of the statistical variability of this analysis. Additionally, it should be noted that these means are far lower than the mean Clegg impact readings presented in the previous section. This most likely is a result of the fewer number of Clegg readings performed on these portions of the plots.

Close examination of the base courses reveals a more interesting set of results. Looking at the mean Clegg impact value readings for the main effects of the different base courses regardless of turf type or traffic wear study resulted in the following means:

Table 35: Mean Clegg Impact Value Readings for Base Course Type Main Effects of Turning Study

Base Course	Least Square Mean Clegg Reding
CU Structural Soil® (CU)	6.99
Carolina Stalite Structural Soil (CS)	6.46
Control (C)	6.2

With the following P-values associated with each of the comparisons:

Table 36: P-Values for Mean Clegg Impact Value Readings for Base Course Type Main Effects of Turning Study

Base Course	CU	CS	C
CU Structural Soil® (CU)		0.0007	<.0001
Carolina Stalite Structural Soil (CS)	0.0007		<.1677
Control (C)	<.0001	<.1677	

The P-values of < 0.0001 and .0007 illustrate that there was a significant difference between the mean Clegg impact values for both of the structural soil base courses and the mean Clegg results for the comparison between the control base courses and the CU Structural Soil® base courses. These result also indicated that there was no difference between the mean Clegg impact values for the Carolina Stalite Structural Soil bases courses and the control base courses. Once again, it should be noted that reason for this similarity most likely has to do with the fact that fewer Clegg trials were run, increasing the width of the statistical variability of this analysis. Additionally, these means are far lower than the mean Clegg impact readings presented in the section documenting the Clegg values for the portions of the plots designated to no traffic and the Line Study. This most likely is a result of the fewer number of Clegg readings performed on these portions of the plots.

The final one way interaction examined was the impact of traffic on the mean Clegg impact value readings. Not surprisingly, the portions of the plots that received traffic resulted in higher mean impact values due to the compactive nature found in the application of traffic over the plots:

Table 37: Mean Clegg Impact Value Readings for Traffic Type Main Effects of Turning Study

Traffic Type	Least Square Mean Clegg Reading	P Value
Turning Study (TS)	7.33	<0.0001
No Traffic (NT)	5.78	

With the application of the traffic, the portions of the plot receiving traffic became compacted, resulting in the higher Clegg Impact Values. The P-value of <.0001, shows that this difference is significant, despite the low number of Clegg readings. Although lower than the means for the Clegg impact value readings for the portions of plots designated to no traffic and the Turning Study, these results nevertheless show the same patterns.

Clegg Impact Value: Effects of Combined Elements on mean Clegg Impact Value Readings

The first two-way interaction examined is turf type vs. base course. This interaction produced the following mean Clegg impact value readings:

Table 38: Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Base Type Effects of Turning Study

Turf Type	Base Type	Least Square Mean Clegg Reading
Tall Fescue (TF)	CU Structural Soil® (CU)	6.74
Tall Fescue (TF)	Carolina Stalite Structural Soil (CS)	6.82
Tall Fescue (TF)	Control (C)	5.9
Zoysia (Z)	CU Structural Soil® (CU)	7.26
Zoysia (Z)	Carolina Stalite Structural Soil (CS)	6.11
Zoysia (Z)	Control (C)	6.51

For each of these results, the P-values were:

Table 39: P-Values for Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Base Type Effects of Turning Study

i/j	TFxCU	TFxCS	TFxC	ZxCU	ZxCS	ZxC
TFxCU		0.9986	0.0007	0.1052	0.0247	0.8718
TFxCS	0.9986		0.0001	0.2489	0.0069	0.649
TFxC	0.0007	0.0001		<.0001	0.9028	0.0311
ZxCU	0.1052	0.2489	<.0001		<.0001	0.0037
ZxCS	0.0247	0.0069	0.9028	<.0001		0.3409
ZxC	0.8718	0.649	0.0311	0.0037	0.3409	

This table reinforces the results from the previous examination of the one way interactions for the mean Clegg impact results presented in the one way main effects. Although it is possible to analyze these results, it seems sufficient to say that not enough readings were taken to gain a clear understanding of these results.

The second two way interaction examined the turf type vs. traffic, producing the following results:

Table 40: Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Traffic Type Effects of Turning Study

Turf Type	Traffic Type	Least Square Mean Clegg Reading
Tall Fescue (TF)	Turning Study (TS)	6.98
Zoysia (Z)	Turning Study (TS)	7.67
Tall Fescue (TF)	No Traffic (NT)	5.98
Zoysia (Z)	No Traffic (NT)	5.58

For each of these results, the P-values were:

Table 41: P-Values for Mean Clegg Impact Value Readings for Two Way Interactions of Turf Type and Traffic Type Effects of Turning Study

Interaction	TSxTF	TSxZ	NTxTF	NTxZ
TSxTF		0.003	<0.0001	<0.0001
TSxZ	0.003		<0.0001	<0.0001
NTxTF	<0.0001	<0.0001		0.0711
NTxZ	<0.0001	<0.0001	0.0711	

Although the same issues apply in terms of the lower amounts of Clegg measurements taken, these p-values nevertheless illustrate that significant differences appear between all of these mean Clegg impact Values. Again, caution should be taken in interpretation of these meanings since so few measurements were taken. Nevertheless, there seems to be a clear delineation between the means and resulting P-values for the portions of the plots allotted to the Turning Study and those allotted to no traffic.

The last of the two way interactions examined base course vs. traffic type. This interaction produced the following results:

Table 33: Mean Clegg Impact Value Readings for Two Way Interactions of Traffic Type and Base Type Effects of Turning Study

Traffic Type	Base Type	Least Square Mean
Turning Study (TS)	CU Structural Soil® (CU)	8.2
Turning Study (TS)	Carolina Stalite Structural Soil (CS)	7.15
Turning Study (TS)	Control (C)	6.63
No Traffic (NT)	CU Structural Soil® (CU)	5.79
No Traffic (NT)	Carolina Stalite Structural Soil (CS)	5.77
No Traffic (NT)	Control (C)	5.78

For each of these results, the P-values were:

Table 34: P-Values for Mean Clegg Impact Value Readings for Two Way Interactions of Traffic Type and Base Type Effects of Turning Study

Interaction	TSxCU	TSxCS	TSxC	NTxCU	NTxCS	NTxC
TSxCU		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
TSxCS	<0.0001		0.1082	<0.0001	<0.0001	<0.0001
TSxC	<0.0001	0.1082		0.0006	0.0005	0.0005
NTxCU	<0.0001	<0.0001	0.0006		1	1
NTxCS	<0.0001	<0.0001	0.0005	1		1
NTxC	<0.0001	<0.0001	0.0005	1	1	

These P-values indicate a significant similarity between the all the Clegg impact value readings for the portions of the plots designated to no traffic, and a high degree of difference for those portions of the plots designated to the Turning Study. Interestingly, the mean Clegg readings for all of the portions of the plots assigned to the Turning Study were also significantly different. Although these mean Clegg impact value readings and their associated P-values were interpreted as shown in Table 36 and 37 (Table 36, and 37), caution must be used in interpreting their meanings since so few readings were taken.

Clegg Hammer Three Way Interaction

An examination of the three way interactions reveals the following mean Clegg Impact Value readings:

Table 35: Mean Clegg Impact Value Readings for Three Way Interactions of Traffic Type, Surface Type, and Base Type Effects of Turning Study

Traffic	Surface	Base	Reading Mean Clegg
Line Study (LS)	Zoysia (Z)	CU	8.96
Line Study (LS)	Tall Fescue (TF)	CU	7.44
Line Study (LS)	Tall Fescue (TF)	CS	7.34
Line Study (LS)	Zoysia (Z)	C	7.09
Line Study (LS)	Zoysia (Z)	CS	6.96
No Traffic (NT)	Tall Fescue (TF)	CS	6.29
Line Study (LS)	Tall Fescue (TF)	C	6.17
No Traffic (NT)	Tall Fescue (TF)	CU	6.03
No Traffic (NT)	Zoysia (Z)	C	5.93
No Traffic (NT)	Tall Fescue (TF)	C	5.62
No Traffic (NT)	Zoysia (Z)	CU	5.55
No Traffic (NT)	Zoysia (Z)	CS	5.25

Of these three way interactions, two groups of mean Clegg results become readily apparent and distinctly different from one another. These groupings are:

1) Portions of the plots which received traffic from the Turning Study.

2) Portions of the plots which received no traffic.

Although these two groupings produced mean Clegg readings that were hierarchically easy to differentiate, there was quite a bit of statistical overlap among the Clegg means within these distinct groups. For instance, there was statistical similarity among on the P-values for those portions of the plots with tall fescue on the control base courses which received traffic from the Turning Study, and those portions of the plots with tall fescue surfaces and both structural soil base courses which received no traffic. Although these mean Clegg impact value readings and their associated P-values were interpreted as shown in Table 37 (Table 37), caution must be used in interpreting their meanings since so few readings were taken.

Temperature Studies

Throughout the summer season, a number of temperature studies were performed on the test plots. The mean surface temperature studies for these trials are illustrated in figure 15. As expected, surface temperatures for the Asphalt covered surfaces were significantly higher than the surface temperatures recorded for the plots covered in turf (Figures 15).

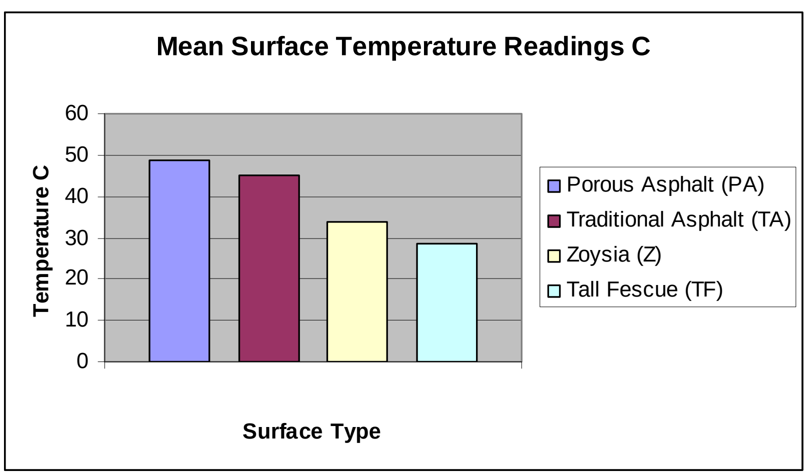


Figure 15: Mean Temperature Readings in °C for Plot Surfaces.

Table 44: P-Values for Mean Clegg Impact Values for Three Way Interactions for Turf, Base and Traffic Type for the Turning Study

i/j	TSxTFxCU	TSxTFxCS	TSxTFxC	TSxZxCU	TSxZxCS	TSxZxC	NTxTFxCU	NTxTFxCS	NTxTFxC	NTxZxCU	NTxZxCS	NTxZxC
TSxTFxCU		1.0000	0.0009	<.0001	0.8668	0.9849	<.0001	0.0045	<.0001	<.0001	<.0001	<.0001
TSxTFxCS	1.0000		0.0035	<.0001	0.9733	0.9993	0.0005	0.0159	<.0001	<.0001	<.0001	0.0001
TSxTFxC	0.0009	0.0035		<.0001	0.2026	0.0641	1.0000	1.0000	0.7300	0.5636	0.0621	0.9994
TSxZxCU	<.0001	<.0001	<.0001		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TSxZxCS	0.8668	0.9733	0.2026	<.0001		1.0000	0.0555	0.4489	0.0003	0.0001	<.0001	0.0191
TSxZxC	0.9849	0.9993	0.0641	<.0001	1.0000		0.0132	0.1881	<.0001	<.0001	<.0001	0.0039
NTxTFxCU	<.0001	0.0005	1.0000	<.0001	0.0555	0.0132		0.9987	0.9548	0.8768	0.2205	1.0000
NTxTFxCS	0.0045	0.0159	1.0000	<.0001	0.4489	0.1881	0.9987		0.4335	0.2836	0.0168	0.9807
NTxTFxC	<.0001	<.0001	0.7300	<.0001	0.0003	<.0001	0.9548	0.4335		1.0000	0.9787	0.9948
NTxZxCU	<.0001	<.0001	0.5636	<.0001	0.0001	<.0001	0.8768	0.2836	1.0000		0.9960	0.9741
NTxZxCS	<.0001	<.0001	0.0621	<.0001	<.0001	<.0001	0.2205	0.0168	0.9787	0.9960		0.4221
NTxZxC	<.0001	0.0001	0.9994	<.0001	0.0191	0.0039	1.0000	0.9807	0.9948	0.9741	0.4221	

To better understand the results of the temperature trials, however, the same statistical analysis and interpretation methods as the previous sections were run. As before, not only individual main effects were compared, but also two way and three way interactions. It should be noted, however, that temperature studies were performed late in the season – well after the environmental effects to each plot was readily apparent. For this particular study, no temperature readings were taken on the portions of the plots which received traffic from the Turning Study.

Main Effects of Individual Elements on Temperature Readings

A comparison of the temperature readings between the different surface types (tall fescue, zoysiagrass, traditional asphalt and porous asphalt) revealed that regardless of base type or traffic impact the tall fescue had a mean temperature reading of 28.76° C, the zoysiagrass had a mean temperature of 33.96° C, the traditional asphalt surface had a mean temperature of 45.21° C, and the porous asphalt surface had a mean temperature of 48.55° C.

Table 36: Mean Temperature Readings in °C for Plot Surface Main Effects

Surface Type	Least Square Mean Temperature (°C)
Porous Asphalt (PA)	48.55
Traditional Asphalt (TA)	45.21
Zoysia (Z)	33.96
Tall Fescue (TF)	28.76

With the following P-Values for each surface:

Table 37: P-Values for Mean Temperature Readings in °C for Plot Surface Main Effects

Interaction	TF	Z	PA	TA
TF		<.0001	<.0001	<.0001
Z	<.0001		<.0001	<.0001
PA	<.0001	<.0001		0.4388
TA	<.0001	<.0001	0.4388	

These P-values indicate that the differences in mean temperature were highly significant for every value except for the two types of asphalt. This makes sense since both of the asphalt surfaces were similar in both construction and material composition, save for the lack of fine-grade particles in the porous asphalt. What is surprising, however, was the difference in temperature between the two types of grass. It was previously noted that this particular temperature study occurred late in the season, well after the zoysiagrass began to die off or go dormant. This dormancy resulted in higher surface temperatures since the zoysia was not actively transpiring. Conversely, the tall fescue surfaces were healthy, and actively transpiring, resulting in the lower mean surface temperature readings.

Examining the results of the effects of the base courses on mean temperature reveals the following:

Table 38: Mean Temperature Readings in °C for Base Course Main Effects

Base Course	Temperature (°C) Least Square Mean
Control (C)	41.9
Carolina Stalite Structural Soil (CS)	38.37
CU Structural Soil® (CU)	37.1

With the following P-values:

Table 39: P-Values for Mean Temperature Readings in °C for Base Course Main Effects

Interaction	CU	CS	C
CU		0.5198	0.0002
CS	0.5198		0.0077
C	0.0002	0.0077	

These P-values illustrate that the differences in mean temperatures for both types of structural soil bases were statistically insignificant, once again showing a similarity between these two types of base courses. This was primarily due to the fact that on average, the grass on these structural soil base courses was healthier and as such actively transpiring. Ultimately this transpiration lowered the surface temperature of the grasses on these two base courses. Conversely, the control base course had a much higher mean temperature. This also was due to the fact that at the time of this test, the grass on the gravel only control base courses had either died or gone dormant and was not actively respiring.

The final main effect examination looks at the results of the traffic type on the mean surface temperature of the plots. The mean surface temperature and P-value of this main effect was:

Table 40: P-Values for Mean Temperature Readings in °C for Traffic Type Main Effects

Traffic Type	Least Square Mean (°C)	P Value
Line Study	39.33	0.69
No Traffic	38.91	

This examination illustrates that there was statistically no difference between the surface temperatures recorded on the portions of the plots allocated to the different traffic types. This correlates the findings of the TQA sections, showing that traffic had little effect on the mean temperature results of this test.

Effects of Combined Elements on Temperature Readings

The first two-way interaction examined was turf type vs. base course. This interaction produced the following mean surface temperature Readings:

Table 41: Mean Temperature Readings in °C for Two Way Interactions of Turf Type and Base Type Effects

Turf Type	Base Type	Least Square Mean Temp.
Porous Asphalt (PA)	Control (C)	48.78
Porous Asphalt (PA)	Carolina Stalite Structural Soil (CS)	48.33
Porous Asphalt (PA)	CU Structural Soil® (CU)	47.89
Traditional Asphalt (TA)	Control (C)	47.78
Zoysia (Z)	Control (C)	36.33
Tall Fescue (TF)	Control (C)	33.11
Zoysia (Z)	Carolina Stalite Structural Soil(CS)	33
Zoysia (Z)	CU Structural Soil® (CU)	32.56
Tall Fescue (TF)	Carolina Stalite Structural Soil(CS)	27.83
Tall Fescue (TF)	CU Structural Soil® (CU)	25.33

For each of these results, the p-values were:

Table 42: P-Values for Mean Temperature Readings in °C for Two Way Interactions of Turf Type and Base Type Effects

i/j	TFxCU	TFxCS	TFxC	ZxCU	ZxCS	ZxC	PAxCU	PAxCS	PAxC	TAxC
TFxCU		0.9322	0.0014	0.0043	0.0018	<.0001	<.0001	<.0001	<.0001	<.0001
TFxCS	0.9322		0.1138	0.2275	0.1320	0.0003	<.0001	<.0001	<.0001	<.0001
TFxC	0.0014	0.1138		1.0000	1.0000	0.7496	<.0001	<.0001	<.0001	<.0001
ZxCU	0.0043	0.2275	1.0000		1.0000	0.5441	<.0001	<.0001	<.0001	<.0001
ZxCS	0.0018	0.1320	1.0000	1.0000		0.7111	<.0001	<.0001	<.0001	<.0001
ZxC	<.0001	0.0003	0.7496	0.5441	0.7111		<.0001	<.0001	<.0001	<.0001
PAxCU	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		1.0000	1.0000	1.0000
PAxCS	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	1.0000		1.0000	1.0000
PAxC	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	1.0000	1.0000		1.0000
TAxC	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	1.0000	1.0000	1.0000	

This table illustrates that all of the means presented above were highly significantly except for a few correlations in three distinctive groups. The most obvious of these distinct groups was the mean surface temperatures and matching P-values of the porous asphalt and traditional asphalt surfaces. All of the asphalt surfaces have P-values showing that the means were statistically identical. They also have P-values distinctively different than the other distinctive group: those whose surfaces are covered with sod. An examination of the mean temperatures of sod coved plots shows that the turf covered plots have two groupings of means. Those whose median temperature were in the 33-36° C range and those whose surface temperatures were in the 25-28°C range, each with their own distinctive set of P-values which illustrates that the surfaces and base combinations within each of these groups were statistically similar to each other, but different than the other group.

The reason behind this was due to the fact that, as previously mentioned, the soil component of both of the structural soil mixtures grows healthier turf. Since this turf was actively respiring, it had lower mean surface temperatures than any of the other plots. Once again, the plots surfaced with zoysia had higher temperatures because it was not as healthy and therefore not actively respiring.

The second two-way interaction examined was turf type vs. base course. This interaction produced the following mean surface temperature readings:

Table 43: Mean Temperature Readings in °C for Two Way Interactions of Traffic Type and Surface Type Effects

Traffic Type	Surface Type	Mean Surface Temp. ° C
No Traffic (NT)	Porous Asphalt (PA)	48.83
No Traffic (NT)	Traditional Asphalt (TA)	47.78
Line Study (LS)	Zoysia (Z)	34.41
No Traffic (NT)	Zoysia (Z)	33.52
No Traffic (NT)	Tall Fescue (TF)	28.78
Line Study (LS)	Tall Fescue (TF)	28.74

For each of these results, the p-values were:

Table 44: P-Values and Mean Temperature Readings in °C for Two Way Interactions of Traffic Type and Surface Type Effects

Interaction	LSxTF	LSxZ	NTxTF	NTxZ	NTxPA	NTxTA
LSxTF		0.0064	1	0.0358	<.0001	<.0001
LSxZ	0.0064		0.0069	0.9934	<.0001	<.0001
NTxTF	1	0.0069		0.0382	<.0001	<.0001
NTxZ	0.0358	0.9934	0.0382		<.0001	<.0001
NTxPA	<.0001	<.0001	<.0001	<.0001		0.9999
NTxTA	<.0001	<.0001	<.0001	<.0001	0.999	

Perhaps much more elegantly than the previous two way examination, these tables and means also illustrate three distinct groups: Asphalt covered surfaces, zoysia covered surfaces, and fescue covered surfaces. Again, these p-values and surface temperature means indicate that the healthy tall fescue turf covered surfaces had lower surface temperatures than the zoysiagrass turf covered surfaces, most likely due to the respiration of the turf. Interestingly, however, there was virtually no temperature differential between the portions of the plots which received traffic and those that did not.

The last two-way interaction examined the mean surface temperature readings for traffic type vs. base course. This interaction produced the following mean surface temperature readings:

Table 45: Mean Temperature Readings in °C for Two Way Interactions of Traffic Type and Base Type Effects

Traffic Type	Base Type	Temp. ° C Mean Surface
No Traffic (NT)	Control	41.72
No Traffic (NT)	Carolina Stalite Structural Soil	36.15
No Traffic (NT)	CU Structural Soil®	34.78
Line Study (LS)	Control	34.28
Line Study (LS)	Carolina Stalite Structural Soil	30.78
Line Study (LS)	CU Structural Soil®	29.67

For each of these results, the p-values were:

Table 46: P-Values and Mean Temperature Readings in °C for Two Way Interactions of Traffic Type and Base Type Effects

Interaction	LSxCU	LSxCS	LSxC	NTxCU	NTxCS	NTxC
LSxCU		0.999	0.06153	0.3979	0.154	<.0001
LSxCS	0.999		0.8378	0.666	0.3412	0.0004
LSxC	0.06153	0.8378		1	0.9816	0.0438
NTxCU	0.3979	0.666	1		0.9926	0.0271
NTxCS	0.154	0.3412	0.9816	0.9926		0.1326
NTxC	<.0001	0.0004	0.0438	0.0271	0.1326	

Up to this point, all of the statistical comparisons have straightforwardly illustrated the findings of these experiments, as well as reinforcing common patterns. These findings, however, do not. As such, interpretation of them is somewhat difficult with the only explanation being tied to the fact that the surface variable was left out. Leaving the surface temperature out of the analysis, the higher temperatures for the asphalt surfaces unfairly influenced the base course and traffic type variables within this analysis. With this as the likely explanation, it seems wasteful to closely examine this combination of effects, and instead, more time should be spent on examining the three way combinations presented in the next section.

Temperature Study Three Way Interaction

An examination of the three way interactions reveals the following mean surface temperature readings:

Table 47: Mean Temperature Readings in °C for Three Way Interactions of Traffic Type, Surface Type and Base Type Effects

Traffic	Surface	Base	Mean Surface Temp. ° C
No Traffic (NT)	Porous Asphalt (PA)	C	48.78
No Traffic (NT)	Porous Asphalt (PA)	CS	48.33
No Traffic (NT)	Porous Asphalt (PA)	CU	47.89
No Traffic (NT)	Traditional Asphalt (TA)	C	47.78
No Traffic (NT)	Zoysia (Z)	C	36.67
Line Study (LS)	Zoysia (Z)	C	36
Line Study (LS)	Zoysia (Z)	CU	33.78
No Traffic (NT)	Tall Fescue (TF)	C	33.67
Line Study (LS)	Zoysia (Z)	CS	33.44
No Traffic (NT)	Zoysia (Z)	CS	32.56
Line Study (LS)	Tall Fescue (TF)	C	32.55
No Traffic (NT)	Zoysia (Z)	CU	31.33
Line Study (LS)	Tall Fescue (TF)	CS	28.11
No Traffic (NT)	Tall Fescue (TF)	CS	27.56
Line Study (LS)	Tall Fescue (TF)	CU	25.56
No Traffic (NT)	Tall Fescue (TF)	CU	25.11

Of these three way interactions, three distinct groups of mean surface temperature readings become readily apparent and distinctly different from one another. These groupings are:

1) Mean temperatures ranging from 49-47°C
   (Plots covered in porous asphalt and traditional asphalt.)
2) Mean temperatures ranging from 31-37°C
   (Plots either covered in Zoysia and/or plots containing the control base course.)
3) Mean temperatures ranging from 25-28°C
   (Tall Fescue covered plots on both of the structural soils.)

Analysis of the means results in the following P-values in Table 56. Close examination of these P-values indicate that there is no statistical difference between the mean temperatures of any of the asphalt surfaces. Additionally, These P-values indicate that there is statistically no difference in the means of any of the turf covered surfaces either, regardless of traffic, surface, or base type.

Summary

As pertains to these groups of experiments, it seems clear that turfgrass can grow successfully on structural soil growing media with little to no maintenance regimes. As witnessed by both the TQA results and analysis and the Clegg impact value readings results and analysis the results from these series of trials clearly indicates that the compaction of the soil from traffic application has little effect on healthy grass growth on a structural soil media.

Additionally, it appears that with this structural soil technology, there is no need for the installation of a Grasspave or Geoblock product when using grass in a parking lot situation. As illustrated through minimal differences in TQA ratings for trafficked and non-trafficked portions of the plots, turf can stand up to traffic application and wear without a rigid system, and still remain healthy throughout the

Table 56: P-Values for Mean Temperature Readings in ° C for Three Way Interactions for Turf, Base and Traffic Type

i/j	LSxTFxCU	LSxTFxC	LSxTFx	LSxZxCU	LSxZxCS	LSxZxC	NTxTFxCU	NTxTFxCS	NTxTFxC	NTxZxCU	NTxZxCS	NTxZxC	NTxPAxCU	NTxPAxCS	NTxPAxC	NTxTAxC
LSxTFxCU	.	0.9998	0.3562	0.1297	0.1764	0.0100	1.0000	1.0000	0.1440	0.6880	0.3562	0.0040	<.0001	<.0001	<.0001	<.0001
LSxTFxCS	0.9998	.	0.9430	0.7171	0.7976	0.1764	0.9988	1.0000	0.7452	0.9973	0.9430	0.0932	<.0001	<.0001	<.0001	<.0001
LSxTFxC	0.3562	0.9430	.	1.0000	1.0000	0.9946	0.2563	0.8650	1.0000	1.0000	1.0000	0.9703	<.0001	<.0001	<.0001	<.0001
LSxZxCU	0.1297	0.7171	1.0000	.	1.0000	1.0000	0.0831	0.5653	1.0000	0.9999	1.0000	0.9992	<.0001	<.0001	<.0001	<.0001
LSxZxCS	0.1764	0.7976	1.0000	1.0000	.	0.9998	0.1164	0.6581	1.0000	1.0000	1.0000	0.9973	<.0001	<.0001	<.0001	<.0001
LSxZxC	0.0100	0.1764	0.9946	1.0000	0.9998	.	0.0055	0.1043	0.9999	0.9170	0.9946	1.0000	0.0013	0.0007	0.0003	0.0015
NTxTFxCU	1.0000	0.9988	0.2563	0.0831	0.1164	0.0055	.	0.9999	0.0932	0.5653	0.2563	0.0021	<.0001	<.0001	<.0001	<.0001
NTxTFxCS	1.0000	1.0000	0.8650	0.5653	0.6581	0.1043	0.9999	.	0.5965	0.9863	0.8650	0.0514	<.0001	<.0001	<.0001	<.0001
NTxTFxC	0.1440	0.7452	1.0000	1.0000	1.0000	0.9999	0.0932	0.5965	.	0.9999	1.0000	0.9988	<.0001	<.0001	<.0001	<.0001
NTxZxCU	0.6880	0.9973	1.0000	0.9999	1.0000	0.9170	0.5653	0.9863	0.9999	.	1.0000	0.7976	<.0001	<.0001	<.0001	<.0001
NTxZXCS	0.3562	0.9430	1.0000	1.0000	1.0000	0.9946	0.2563	0.8650	1.0000	1.0000	.	0.9703	<.0001	<.0001	<.0001	<.0001
NTxZxC	0.0040	0.0932	0.9703	0.9992	0.9973	1.0000	0.0021	0.0514	0.9988	0.7976	0.9703	.	0.0034	0.0018	0.0009	0.0040
NTxPAxCU	<.0001	<.0001	<.0001	<.0001	<.0001	0.0013	<.0001	<.0001	<.0001	<.0001	<.0001	0.0034	.	1.0000	1.0000	1.0000
NTxPAxCS	<.0001	<.0001	<.0001	<.0001	<.0001	0.0007	<.0001	<.0001	<.0001	<.0001	<.0001	0.0018	1.0000	.	1.0000	1.0000
NTxPAxC	<.0001	<.0001	<.0001	<.0001	<.0001	0.0003	<.0001	<.0001	<.0001	<.0001	<.0001	0.0009	1.0000	1.0000	.	1.0000
NTxTAxC	<.0001	<.0001	<.0001	<.0001	<.0001	0.0015	<.0001	<.0001	<.0001	<.0001	<.0001	0.0040	1.0000	1.0000	1.0000	.

growing season. Once again, it is important to note here, that during these trials no irrigation, fertilization or other maintenance regimes were used other than regular mowing.

While the temperature studies indicate that turf surfaces can lower temperatures, it may not be the most suitable surface for a parking lot situation. Ongoing studies will examine other aspects which relate to this issue. While porous asphalt is certainly a beneficial technology which allows for water filtration and groundwater recharge, the Cornell turf covered system greatly reduces the costs of installation and maintenance over traditional turf surfaced lots parking surfaces, yet still provides many of the benefits of a rigid surfaced parking facility.

APPENDIX 2.1

Precipitation Extremes
Station: ITHACA CORNELL UNIV **State:** NY **ID:** 304174
Latitude: 42.45 degrees **Longitude:** -76.45 degrees **Elevation:** 960 feet
Station period of record: 01/01/1893 - 06/14/2005

CLIMOD Product: Precipitation Extremes **Creation Time:** 06/15/2005 07:27 EDT
Complete: 96.1% **Non-Missing Years:** 108.5 **Computational Years:** 1893 -2005

Return Period

Duration	**2 year**	**5 year**	**10 year**	**25 year**	**50 year**	**100 year**
10 days	3.99	4.86	5.65	6.89	8.01	9.31
5 days	3.10	3.91	4.66	5.88	7.01	8.36
2 days	2.53	3.21	3.85	4.90	5.87	7.04
1 day	2.14	2.69	3.19	4.01	4.77	5.67
Empirical estimates from 1-day values:						
24 hours	2.42	3.04	3.61	4.53	5.39	6.40
12 hours	2.07	2.61	3.10	3.89	4.62	5.50
6 hours	1.69	2.12	2.52	3.17	3.77	4.48
3 hours	1.42	1.74	2.03	2.46	2.83	3.23
2 hours	1.18	1.44	1.68	2.03	2.32	2.64
1 hour	0.99	1.22	1.41	1.71	1.96	2.23
30 mins	0.73	0.91	1.09	1.36	1.62	1.93
15 mins	0.53	0.67	0.80	1.00	1.19	1.42
10 mins	0.41	0.51	0.61	0.76	0.91	1.08
5 mins	0.24	0.30	0.35	0.44	0.52	0.62

APPENDIX 2.2

ATLANTIC TESTING LABORATORIES, Limited

Canton
6431 U.S. Highway 11
P.O. Box 29
Canton, NY 13617
315/386-4578 (T)
315/386-1012 (F)

June 28, 2005

Cornell University Department of Landscape Architecture
440 Kennedy Hall
Ithaca, New York 14853

Attention: Mr. Peter J. Trowbridge

Telephone: (607) 255-9552
Facsimile: (607) 255-1405

Re: Warren Road Research Plot Project
Cornell University, New York
ATL File No. CD2455-4-05

Ladies and Gentlemen:

On May 2, 2005, ATL performed a subsurface investigation which consisted of three soil borings in the Warren Road Research Plot area. The purpose of the investigation was to determine the in-situ soil types for purposes of medium duty gravel surface pavement design and heavy duty gravel surface pavement design.

The Cornell University "medium duty bituminous concrete pavement" section and the "heavy duty bituminous concrete pavement" section were utilized as a guide.

It is our understanding the pavement will be utilized for overflow parking. The gravel surface may have turf placed on top of the gravel surface.

The in-situ soils immediately below the topsoil layer are a medium-stiff Standard Penetration Test (SPT) (N Values 4-8) to stiff (SPT, N Values 8-15) silty clay or clayey silt. The soils are classified as CL (clay with low plasticity) and MH silt with high plasticity) using the Unified Soil Classification System (USCS). These soils are rated as poor with respect to subgrade soils for roadways. An empirical CBR value for these soils would typically be in the range of 5 to 10 and subgrade modules of 50 pci.

The pavement design was performed using a CBR Value of 5 and subgrade modulus of 50 pci.

- We assumed passenger vehicle traffic for the medium duty pavement design, which resulted in the following pavement design.

Medium Duty Gravel Surface

Thickness	Course	NYSDOT Item No.
8"	*Granular Subbase	304, Type 2
8"	Granular Fill	**
1 Layer	Separation Fabric	Mirafi 170N

- We assumed 10,000 – 18 ton single axle loads and that 1.5" deep ruts were acceptable, which resulted in the following pavement design.

Heavy Duty Gravel Surface

Thickness	Course	NYSDOT Item No.
8"	*Granular Subbase	304, Type 2
12"	Granular Fill	**
1 Layer	Separation Fabric	Mirafi

* The product of crushed ledge rock. A copy of the gradation specification is enclosed. NYSDOT Number 2 crushed stone could be substituted for the granular subbase.

** Granular Fill should consist of a clean, screened, crushed, or bank-run gravel conforming to the following gradation:

Sieve Size	Percent Passing
4"	100
¼	35-65
#200	0 - 7

To reduce the thickness of granular subbase and granular fill, a geogrid design was considered. If a geogrid was utilized the following pavement sections would be adequate.

Medium Duty Gravel Surface

Thickness	Course	NYSDOT Item No.
8"	*Granular Subbase	304, Type 2
1 Layer	Geogrid	Tensar 1200

Heavy Duty Gravel Surface

Thickness	Course	NYSDOT Item No.
12"	*Granular Subbase	304, Type 2
1 Layer	Geogrid	Tensar 1200

There are other alternative designs that could be considered.

Should you have any questions or if we may be of service, please contact our office. We look forward to our continued relationship to obtain project completion.

Respectfully submitted,

Spencer F. Thew, PE/LS
Principal

SFT/jm

ATLANTIC TESTING LABORATORIES, Limited

Subsurface Investigation

Report No.: CD2455-4-05

Client: Cornell University

Boring Location: See Boring Location Plan

Project: Subsurface Investigation

Warren Road Research Plot Project

Ithaca, New York

Start Date: 5/2/2005 Finish Date: 5/2/2005

Boring No.: B-1 Sheet 1 of 1

Groundwater Observations

Date	Time	Depth	Casing at
5/2/2005	2:03 PM	DRY	

Casing Hammer Weight: ____ lbs. Fall: ____ in.

Sampler Hammer Weight: 140 lbs. Fall: 30 in.

Ground Elev.:

Boring Advance By: 4-1/4" Auger

DEPTH	METHOD OF ADVANCE	SAMPLE NO.	DEPTH OF SAMPLE From	To	SAMPLE TYPE	BLOWS ON SAMPLER PER 6" 2" O.D. SAMPLER	DEPTH OF CHANGE	CLASSIFICATION OF MATERIAL (f - fine, m - medium, c - coarse; and - 35-50%, some - 20-35%, little - 10-20%, trace - 0-10%)	Recovery (Inches)
0	AUGER	1	0.0	2.0	SS	3 6 6 7	0.3	4" TOPSOIL & ORGANIC MATERIAL	14
1								Brown CLAY; some SILT: trace f SAND; trace f GRAVEL (moist, plastic)	
2		2	2.0	4.0	SS	8 10 17 21	3.0		18
3								Brown SILT; little CLAY; trace f SAND (moist, non-plastic)	
4		3	4.0	6.0	SS	17 17 16 15		Brown SILT; some mf SAND; little CLAY; trace mf GRAVEL (moist, non-plastic)	20
6							6.0	Boring terminated at 6.0 feet.	

Notes:

1. Borehole backfilled upon completion with on-site soils and surface was patched with asphalt cold patch.

ATL-LOG1 CD2455.GPJ ATL-WELL.GDT 6/29/05

SS Split Spoon Sample
NX Rock Core
SH Undisturbed Sample (Shelby Tube)
Estimated Groundwater

Drillers: Robin Pryce; Cory Farmer

Inspector:

ATLANTIC TESTING LABORATORIES, Limited

Subsurface Investigation

Report No.: CD2455-4-05

Client: Cornell University

Boring Location: See Boring Location Plan

Project: Subsurface Investigation
Warren Road Research Plot Project
Ithaca, New York

Start Date: 5/2/2005 Finish Date: 5/2/2005

Boring No.: B-2 Sheet 1 of 1

Groundwater Observations

Date	Time	Depth	Casing at
5/2/2005	2:40 PM	3.9'	OUT
5/2/2005	2:50 PM	3.1'	OUT

Casing Hammer
Weight: ______ lbs.
Fall: ______ in.

Sampler Hammer
Weight: 140 lbs.
Fall: 30 in.

Ground Elev.: ______

Boring Advance By: 4-1/4" Auger

Borehole caved at 5.9 feet.

DEPTH	METHOD OF ADVANCE	SAMPLE NO.	DEPTH OF SAMPLE From	DEPTH OF SAMPLE To	SAMPLE TYPE	BLOWS ON SAMPLER PER 6" 2" O.D. SAMPLER	DEPTH OF CHANGE	CLASSIFICATION OF MATERIAL (f - fine, m - medium, c - coarse; and - 35-50%, some - 20-35%, little - 10-20%, trace - 0-10%)	Recovery (Inches)
	AUGER	1	0.0	2.0	SS	2 4 5 6	0.5	6" TOPSOIL & ORGANIC MATERIAL	16
1								Brown SILT; some CLAY; little f SAND (moist, slightly plastic)	
2		2	2.0	4.0	SS	5 7 8 8	2.0	Brown CLAY; some SILT; trace f SAND; trace f GRAVEL (moist, plastic)	15
3									
4		3	4.0	6.0	SS	6 6 6 6		Brown CLAY; and SILT; little mf SAND; trace f GRAVEL (wet, plastic)	14
5									
6							6.0	Boring terminated at 6.0 feet. Notes: 1. Borehole backfilled upon completion with on-site soils and surface was patched with asphalt cold patch.	
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									

ATL-LOG1 CD2455.GPJ ATL-WELL.GDT 6/29/05

SS Split Spoon Sample
NX Rock Core
SH Undisturbed Sample (Shelby Tube)
Estimated Groundwater

Drillers: Robin Pryce; Cory Farmer

Inspector: ______

ATLANTIC TESTING LABORATORIES, Limited

Subsurface Investigation

Report No.: CD2455-4-05

Client: Cornell University

Boring Location: See Boring Location Plan

Project: Subsurface Investigation
Warren Road Research Plot Project
Ithaca, New York

Start Date: 5/2/2005 Finish Date: 5/2/2005

Boring No.: B-3 Sheet 1 of 1

Casing Hammer
Weight: ____ lbs.
Fall: ____ in.

Sampler Hammer
Weight: 140 lbs.
Fall: 30 in.

Groundwater Observations

Date	Time	Depth	Casing at
5/2/2005	3:15 PM	DRY	OUT

Ground Elev.: ____

Boring Advance By: 4-1/4" Auger

Borehole caved at 5.5 feet.

DEPTH	METHOD OF ADVANCE	SAMPLE NO.	DEPTH OF SAMPLE From	DEPTH OF SAMPLE To	SAMPLE TYPE	BLOWS ON SAMPLER PER 6" 2" O.D. SAMPLER	DEPTH OF CHANGE	CLASSIFICATION OF MATERIAL (f - fine, m - medium, c - coarse; and - 35-50%, some - 20-35%, little - 10-20%, trace - 0-10%)	Recovery (Inches)
	AUGER	1	0.0	2.0	SS	1 3 4 4	0.5	6" TOPSOIL & ORGANIC MATERIAL	12
1								Brown CLAY; some SILT; trace f SAND; trace m GRAVEL (moist, plastic)	
2		2	2.0	4.0	SS	5 6 7 9		Brown CLAY; some SILT; trace f SAND (moist, plastic)	17
3									
4		3	4.0	6.0	SS	12 19 23 31	4.5		18
5								Brown SILT; little CLAY; trace f SAND (moist, very slightly plastic)	
6							6.0	Boring terminated at 6.0 feet.	
7								Notes:	
8								1. Borehole backfilled upon completion with on-site soils and surface was patched with asphalt cold patch.	
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									

SS Split Spoon Sample
NX Rock Core
SH Undisturbed Sample (Shelby Tube)
Estimated Groundwater

Drillers: Robin Pryce; Cory Farmer

Inspector: ____

ATL-LOG1 CD2455.GPJ ATL-WELL.GDT 6/29/05

APPENDIX 2.3

A. Porous Bituminous Asphalt

1. Bituminous surface course for porous paving shall be two and one-half (2.5) inches thick with a bituminous mix of 5.5% to 6% by weight dry aggregate. In accordance with ASTM D6390, draindown of the binder shall be no greater than 0.3%. If more absorptive aggregates, such as limestone, are used in the mix then the amount of bitumen is to be based on the testing procedures outlined in the National Asphalt Pavement Association's Information Series 131 – "Porous Asphalt Pavements" (2003) or NYSDOT equivalent.
2. Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22. The elastomeric polymer shall be styrene-butadiene-styrene (SBS), or approved equal, applied at a rate of 3% by total weight of the binder. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable.
3. Aggregate in the asphalt mix shall be minimum 90% crushed material and have a gradation of:

U.S. Standard Sieve Size	Percent Passing
½" (12.5mm)	100
3/8" (9.5mm)	92-98
4 (4.75mm)	32-38
8 (2.36mm)	12-18
16 (1.18mm)	7-13
30 (600 µm)	0-5
200 (75 µm)	0-3

4. Add hydrated lime at a dosage rate of 1.0% by weight of the total dry aggregate to mixes containing granite. Hydrated lime shall meet the requirements of ASTM C 977. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% on the asphalt mix.

   The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-3625. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.

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CHAPTER THREE

Porous Asphalt Parking Lot, Ithaca, N.Y.

Introduction

Parking lots in all but the most urban environments are a necessity in contemporary America. In most cases, these parking areas serve as surface lots, creating a host of ecological issues for not only the community in which and for which they are built, but also the larger region as well (Albanese and Matlack, 1998, McPherson 2001, Rushton 2001). Parking lots contribute to increased temperatures within urban settings, have been proven to increase runoff, overload municipal storm sewer systems, and decrease water quality through both point source, and non point source pollution (Albanese and Matlack 1998, Brattebo and Booth 2003, Chester and Gibbons 1993). In response to these impacts on both ecology and infrastructure, urban planners, engineers, and governmental agencies have created various solutions to help communities deal with the effects of these impervious surfaces.

To address the detrimental effects of increased temperatures caused by these surface parking lots, many municipalities have initiated shading ordinances to increase tree cover, mandating that a certain percentage of the parking surface be covered by shade produced from trees installed within and adjacent to the lot. The most aggressive of these municipalities is Sacramento, CA., mandating a minimum of 50 percent tree cover (City of Sacramento 1982, 2003). While this type of ordinance seems to be a positive solution, studies of the city's parking lots by USDA Forest Service Center for Urban Forest Research Director Gregory McPherson show otherwise (McPherson 2001). In his findings, only one of the fifteen lots sampled comes close to this 50 percent goal with a projected attainment of 48.7 percent canopy cover within 15 years after construction as outlined by the ordinances, while only two other lots are at projected levels above 30 percent canopy cover. Of the remaining lots, seven lots are projected to range from 20 percent to 30 percent canopy cover, while four lots will have below 20 percent. The McPherson study also found that of the trees planted, many were stunted and/or in poor health due to improper sizing of tree pits within the lots, poor soil used during construction and installation of the trees, or lack of irrigation. All of these factors aided in many of the parking lots' inabilities to meet the mandated standard set forth by the City of Sacramento (McPherson 2001).

Another solution at the federal level has been initiated to help control runoff, mitigate pollution, and reduce both infrastructure overload and ecological damage to streams. Referred to as "First Flush" regulations, this Phase I and Phase II National Pollution Discharge Elimination System (NPDES) legislation mandates a framework of guidelines that each federally certified NPDES state adopts into law (all states but Alaska, Idaho, Massachussettes, New Hampsire, and New Mexico). While Phase I regulations were enacted in 1990 and regulate large sites over 5 acres in size, recently enacted Phase II rules regulate sites one to five acres in size. Although regulations differ, New York State rules are typical and, among other requirements, state that (NYS Department of Conservation TOGS 5.1.10):

- The release of stormwater runoff from development should not exceed pre-development (natural) conditions.
- It is not necessary that peak flow attenuation requirements be satisfied only by means of detention basins. For example, infiltration trenches, dry wells, or stone reservoirs underneath paving, may be used for the purpose of attenuating peak flows for smaller storms with appropriate consideration for length of life of the stormwater facility, and feasibility of maintenance.
- Provide for control of the first 1/2-inch of runoff from all land areas for which the perviousness has been changed over pre- development (natural) conditions due to land clearing, land grading and construction.

  Control of thermal energy in stormwater runoff in watersheds having streams which support cold water fisheries is essential. Impervious surfaces, for example, asphalt parking areas and roofs, store large quantities of heat during hot weather in summer. The heat from such surfaces is released to stormwater through conduction during storm events.

- Hierarchy of Methods for Managing Stormwater Quality

  The following stormwater management systems, summarized in descending order of preference, should be used to control the first flush when designing stormwater facilities. The practices are: (1) infiltration, (2) retention, and (3) extended detention.

- Infiltration - Infiltration of runoff on- site by use of vegetated depressions and buffer areas, pervious surfaces, drywells, infiltration basins and trenches permits immediate recharge of groundwater and aids quality treatment through soil filtration. This practice eliminates or minimizes direct stormwater discharges to a waterbody and provides thermal benefits to cold water fisheries.

Though these regulations are progressive, they often translate into space that is sacrificed for retention/detention ponds, bioswales and other control measures which both mitigate and attenuate stormwater runoff at the expense of space allocated to parking.

One solution which has gained recent attention, and is encouraged by the NYSDEC regulations outlined above, is the creation and use of porous asphalt as a means of attempting to minimize and control runoff and increase water quality through natural infiltration of stormwater events (Ferguson 1996, Ferguson, 2005, Cahill 1994). Unlike traditional asphalt, porous asphalt leaves out fine particles in the stone used for the asphalt, creating large gaps that allow water to penetrate the asphalt profile (Appendix 3.1). Underneath the profile is a reservoir of stone that retains the water until it can percolate into the subgrade below the reservoir. (Fergeson 2005, NAPA 2004). While this is a promising technology to reduce runoff and increase water quality, certain aspects of this system make it difficult to install. Moreover, it does nothing to either reduce surface temperatures, or promote tree growth in and around the parking lot to appease those municipalities which have instituted canopy cover or other landscape regulations and requirements.

In this study, we investigated combining CU Structural Soil® (Grabosky and Bassuk 1995, Grabosky and Bassuk 1996) and porous asphalt (Ferguson 2005) to create a healthier environment for tree growth in and around parking lots, while simultaneously mitigating stormwater runoff and reducing parking lot temperatures. CU Structural Soil® is a gap graded material composed of 80 percent fractured face crushed stone of approximately 2.5cm (1”) diameter, 20 percent loam-clay soil (composed of at least 20 percent clay) mixed by weight with an addition of 30g/100kg of stone of a hydrated hydrogel (Gelscape-Amareq) to prevent separation of materials during mixing and installation (Appendix 3.2). It is important to note that CU Structural Soil® is patented by Cornell University and licensed to Amereq to insure quality control of the soil mixture.

The use of CU Structural Soil® underneath the porous asphalt, rather than un-compacted gravel, allowed for two important differences between the Cornell porous asphalt system and a traditional porous asphalt system. First, the CU Structural Soil® permitted the use of compaction during installation, easing the installation process for contractors (Grabosky and Bassuk 1995, NAPA 2004). Second, the design of CU Structural Soil® allowed for the incorporation and installation of trees and shrubs within the system (Grabosky and Bassuk 1996). The introduction of plants within the system helped not only to remove water from the reservoir through transpiration of the water byway of the tree roots, but also increases canopy cover over the parking lot, further reducing temperatures created by sunlight hitting the dark pavement surface (McPherson, 2001). This system would then satisfy both local tree cover regulations as well as the federally mandated state NDSEP regulations.

Methods and Materials

For the purpose of this investigation a 12 car handicap accessible parking lot was designed and constructed in partnership with the Department of Public Works for the City of Ithaca, NY. This lot was an improvement on an existing gravel parking lot adjacent to the Cayuga Waterfront Trail and the Flood Control Channel for the City of Ithaca, and is located on Park Road, a cul-de-sac between NYS routes 89 and 96. This improved lot was divided in half, with the southern half of the lot using the porous asphalt surface on a base course of CU Structural Soil®, while the northern half used a traditional impervious asphalt surface, also on a base course of CU Structural Soil®.

The 45.72 m by 5.49 m (150' x 18') parking lot was excavated to a depth of 0.61 m (2'). CU Structural Soil® was prepared per specification (Appendix 3.2), mixed and installed the entire length and width of the lot as a sub base to each pavement surface. On the northern half of the lot, a 22.86 m by 5.49 m (75'x18') section, a 7.6 cm (3") layer of NYSDOT type 6 medium-duty asphalt was installed using NYSDOT and City of Ithaca DPW standards (Appendix 3.3). For the remaining southern half, 7.6 cm (3") of porous asphalt was installed to complete the paving surface of the lot.

In the middle of each pavement profile type, .91 m (3') tree pits were cut, running the entire 5.49 m (18') width of the lot to the shoulder of Park Road. Within each tree pit, two bare root 3.8 cm (1.5") caliper Accolade Elms (*Ulmus japonica x Ulmus wilsoniana* 'Accolade') were installed on 8 November of 2005. Eight other Accolade Elms of the same size were planted within a two foot adjacent planting bed surrounding the parking lot with four of these adjacent to the porous asphalt profile and four of these adjacent to the traditional asphalt profile (Figure 24).

Once the trees were planted, three monitoring wells were installed in a triangle within each of the paving profiles spaced at 1.4 m (4.5') apart. The monitoring wells were constructed from 5.1 cm (2") metal pipes with 1.3 cm (0.5") holes drilled into the pipe running the length of pipe at centers of 3.8 cm (1.5"). On alternating sides, holes were offset 1.9 cm (0.75"). The pipes were tipped with steel tips on their bottom and removable caps on their top (Figure 25). Once constructed, holes were drilled within each pavement type and the pipes installed with a post hole digger. Lastly, wheel chocks and tree protection bollards were installed and lot lines were painted to complete the improved lot (Figure 24).

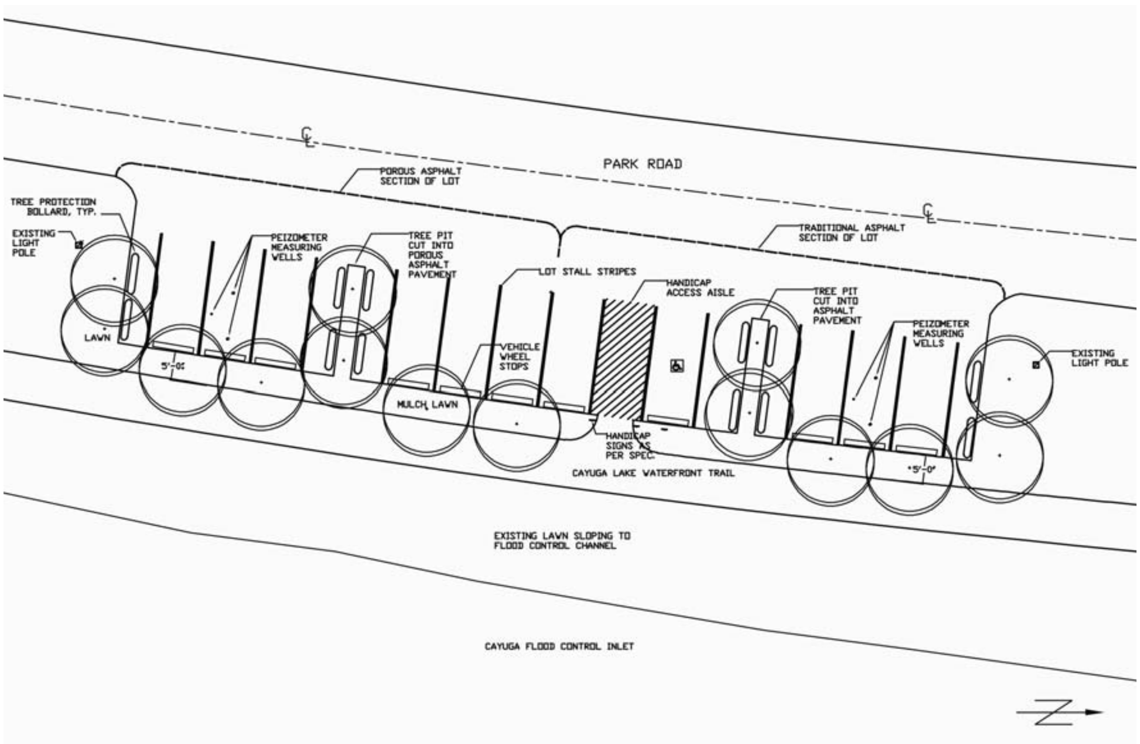

Figure 10: As Built drawing of Parking Lot. The left side of lot is constructed of porous asphalt on a structural soil base, while the right side of the lot is constructed of traditional asphalt and structural soil base.

Results

Due to establishment of the Accolade Elms there was no formal data collection at this site during the summer of 2006. Data collection for this site will start in 2007, and include monitoring of the wells inset into the pavement. Additional data collection will include evapo-transpiration measurements for the elm trees, as well as other growth measurement assays.

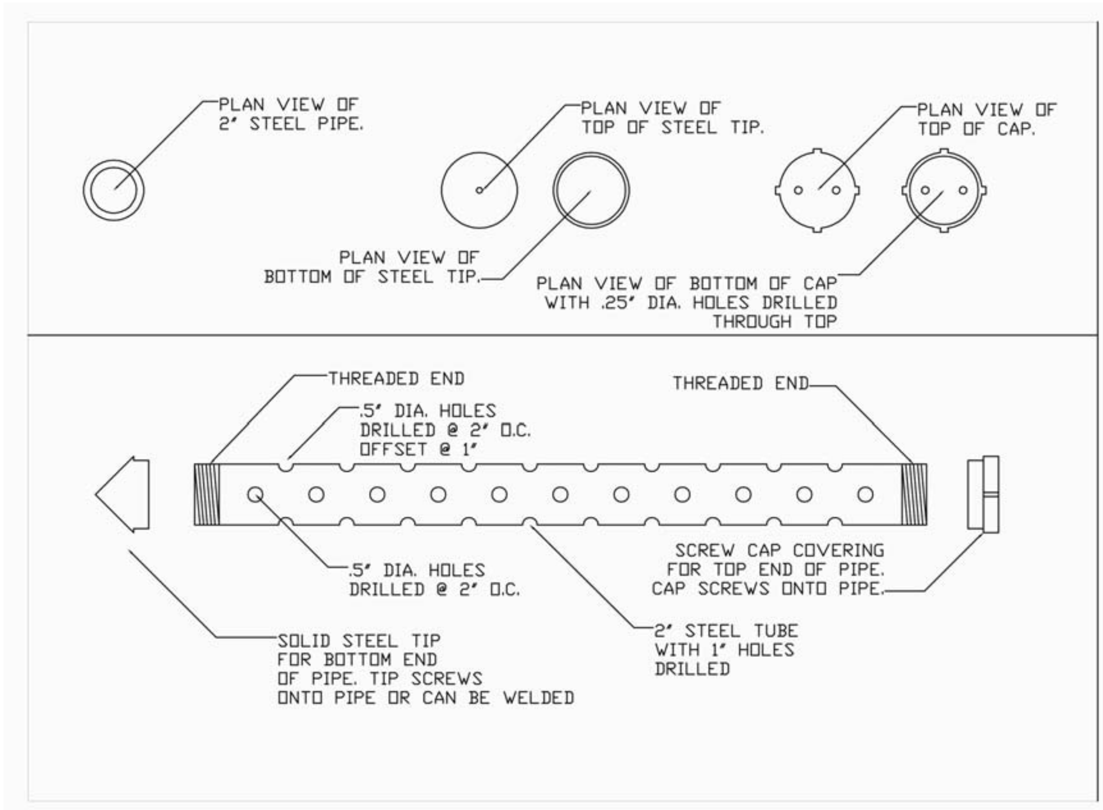

Figure 11: Water Level Monitoring Well Construction Drawing. Three of each well were placed into each type of paving profile to monitor water levels within each paving profile type.

Conclusion

Although there was no official data collected from this installation, there were nevertheless valuable insights gained through the installation process. First, the Ithaca DPW contractors found the installation of the compactable CU-Structural Soil® to be much preferable and easier to install than the NYSDOT Type 2 stone traditionally used in porous asphalt installations. The reason behind this ease of installation is due to the fact that the NYSDOT Type 2 stone is placed into the reservoir of traditional porous asphalt parking lots un-compacted. Although it is thought that this un-compacted specification makes the NYSDOT Type 2 stone more porous, research indicates that it is not. Additionally, this un-compacted specification makes the stone very difficult to install.

The other important lesson was learned through the installation of both types of asphalt, which were installed in sheets. Not until after the installation were the tree pits cut out of the pavement and the trees installed. Planting the trees in the later stages proved to be not only much more efficient and effective than working around pre-installed trees and tree pits, but also healthier for the trees as well. Trees installed early in the construction process are not only exposed to damage from equipment used in the installation process, but also all of the dust and debris that often gets placed in the tree pits.

APPENDIX 3.1

B. Porous Bituminous Asphalt

1. Bituminous surface course for porous paving shall be two and one-half (2.5) inches thick with a bituminous mix of 5.5% to 6% by weight dry aggregate. In accordance with ASTM D6390, draindown of the binder shall be no greater than 0.3%. If more absorptive aggregates, such as limestone, are used in the mix then the amount of bitumen is to be based on the testing procedures outlined in the National Asphalt Pavement Association's Information Series 131 – "Porous Asphalt Pavements" (2003) or NYSDOT equivalent.
2. Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22. The elastomeric polymer shall be styrene-butadiene-styrene (SBS), or approved equal, applied at a rate of 3% by total weight of the binder. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable.
3. Aggregate in the asphalt mix shall be minimum 90% crushed material and have a gradation of:

U.S. Standard Sieve Size	Percent Passing
½" (12.5mm)	100
3/8" (9.5mm)	92-98
4 (4.75mm)	32-38
8 (2.36mm)	12-18
16 (1.18mm)	7-13
30 (600 µm)	0-5
200 (75 µm)	0-3

4. Add hydrated lime at a dosage rate of 1.0% by weight of the total dry aggregate to mixes containing granite. Hydrated lime shall meet the requirements of ASTM C 977. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% on the asphalt mix.

   The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-3625. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.

APPENDIX 3.2

CU STRUCTURAL SOIL® MATERIALS

2.01 CLAY LOAM

C. Clay Loam / Loam shall be a " loam to clay loam" based on the "USDA classification system" as determined by mechanical analysis (ASTM D-422) and it shall be of uniform composition, without admixture of subsoil. It shall be free of stones greater than one-half inch, lumps, plants and their roots, debris and other extraneous matter over one inch in diameter or excess of smaller pieces of the same materials as determined by the Engineer. It shall not contain toxic substances harmful to plant growth. It shall be obtained from areas which have never been stripped of top soil before and have a history of satisfactory vegetative growth. Clay Loam shall contain not less than 2% nor more than 5% organic matter as determined by the loss on ignition of oven-dried samples.

D. Mechanical analysis for a Loam / Clay Loam shall be as follows:

Textural Class	% of total weight
Gravel	less than 5%
Sand	20 - 45%
Silt	20 - 50%
Clay	20- 40%

C. Chemical analysis: Meet or be amended to meet the following criteria.

1. pH between 6.0 to 7.6
2. Percent organic matter 2 -5% by dry weight.
3. Nutrient levels as required by the testing laboratory recommendations for the type of plants to be grown in the soil.
4. Toxic elements and compounds below the United States Environmental Protection Agency Standards for Exceptional Quality sludge or local standard; whichever is more stringent.
5. Soluble salt less than 1.0 Millimho per cm.
6. Cation Exchange Capacity (CEC) greater than 10
7. Carbon/Nitrogen Ratio less than 33:1.

2.02 CRUSHED STONE

A. Crushed Stone shall be a DOT certified crushed stone. Granite and limestone have been successfully used in this application. Ninety-100 percent of the stone should pass the 1.5 inch sieve, 20-55 percent should pass the 1.0 inch sieve and 10 percent should pass the 0.75 inch sieve. A ratio of nominal maximum to nominal minimum particle size of 2 is required

B. Acceptable aggregate dimensions will not exceed 2.5:1.0 for any two dimensions chosen.

C. Minimum 90 percent with one fractured face, minimum 75 percent with two or more fractured faces.

E. Results of Aggregate Soundness Loss test shall not exceed 18 percent. Losses from LA Abrasion tests shall not exceed 40%.

2.03 HYDROGEL

A. Hydrogel shall be a potassium propenoate-propenamide copolymer Hydrogel or equivalent such as that which is manufactured under the name Gelscape by Amereq Corporation. (800) 832-8788

2.04 WATER

A. The Contractor shall be responsible to furnish his own supply of water to the site at no extra cost. All work injured or damaged due to the lack of water, or the use of too much water, shall be the Contractor's responsibility to correct. Water shall be free from impurities injurious to vegetation.

2.05 STRUCTURAL SOIL

A. A uniformly blended mixture of Crushed Stone, Clay Loam and Hydrogel, mixed to the following proportion:

MATERIAL	UNIT OF WEIGHT
Crushed Stone	80 units dry weight
Loam (screened)	as determined by the test of the mix. (Approx. 20 units dry weight)
Hydrogel	0.03 units dry weight/100units stone
Total moisture	(AASHTO T-99 optimum moisture)

APPENDIX 3.3

TABLE 403-1 COMPOSITION OF HOT MIX ASPHALT MIXTURES												
Mixture	**Base**				**Binder**		**Shim**		**Top[3,4]**			
Require-ments[1]	**Type 1**		**Type 2**		**Type 3**		**Type 5**		**Type 6, 6F2, 6F3**		**Type 7, 7F2, 7F3**	
Screen Sizes	General limits % Passing	Job Mix Tol. %	General limits % Passing	Job Mix Tol. %	General limits % Passing	Job Mix Tol. %	General limits % Passing	Job Mix Tol. %	General limits % Passing	Job Mix Tol. %	General limits % Passing	Job Mix Tol. %
50.0 mm	100	-	100	-	-	-	-	-	-	-	-	-
37.5 mm	90 -100	-	75 - 100	± 7	100	-	-	-	-	-	-	-
25.0 mm	78 - 95	± 5	55 - 80	± 8	95 - 100	-	-	-	100	-	-	-
12.5 mm	57 - 84	± 6	23 - 42	± 7	70 - 90	± 6	-	-	95-100	-	100	-
6.3 mm	40 - 72	± 7	5 - 20	± 6	48 - 74	± 7	100	-	65 - 85	± 7	90 -100	--
3.2 mm	26 - 57	± 7	2 - 15	± 4	32 - 62	± 7	80 - 100	± 6	36 - 65	± 7	45 - 70	± 6
850 μm	12 - 36	± 7	-	-	15 - 39	± 7	32 - 72	± 7	15 - 39	± 7	15 - 40	± 7
425 μm	8 - 25	± 7	-	-	8 - 27	± 7	18 - 52	± 7	8 - 27	± 7	8 - 27	± 7
180 μm	4 -16	± 4	-	-	4 - 16	± 4	7- 26	± 4	4 - 16	± 4	4 - 16	± 4
75 μm	2 - 8	± 2	-	-	2 - 8	± 2	2- 12	± 2	2- 6	± 2	2 - 6	± 2
PGB Content, %[2]	4.0 - 6.0	±0.4	2.5 - 4.5	±0.4	4.5 - 6.5	±0.4	7.0-9.5	±0.4	5.4- 7.0	NA	5.7 -8.0	NA
Mixing and[5] Placing Temp. Range,°C	120-165		110-150		120-165		120-165		120-165		120-165	
Descrip-tion and Typical Uses	Dense Base: For general use		Open Base: For permeable base layer		Dense Binder: Intermediate layer for general use		Shim: Fine HMA mixture for shimming ruts and leveling		Top Course: Dense course for single course resurfacing of rural, suburban, and urban roadways			

NOTES:

1. All aggregate percentages are based on the total weight of the aggregate.
2. The asphalt content is based on the total weight of the mix. When using slag aggregates in the mix, increase the PGB content accordingly, a minimum of 25 percent for an all slag mix.
3. 6F2, 6F3, 7F2, 7F3 mix types require friction coarse aggregates., and are required for mainline driving surface courses.
4 For Type 6 and Type 7 (F9) aggregate requirements, Marshall design will not be required.. These mix types are suitable where the State's requirements for F9 aggregate apply.
5. Introduce the PG Binder into the pugmill between 110°C and 175°C, or as recommended by the PG Binder supplier.

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