University of Southern Queensland

Faculty of Engineering and Surveying

Soil Amendments to Improve Playability and Reduce Injury Risks on Sporting Fields

A dissertation submitted by

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Abstract

There are more than 1000 non-elite grassed sports fields in Queensland. More than 400 000 registered players and 750 000 school children use these grounds and are exposed to the risks inherent in playing on hard, uneven surfaces.

Most non-elite fields in Queensland have a very high clay content and are subjected to extreme cycles of wetting/drying and heavy traffic. Despite this they only receive inconsistent management, mostly from volunteer workers.

This project investigated the effects of two soil amendments, Hydrocells and Turf Grids, on the performance of soil under wetting and drying cycles. These tests were designed to imitate possible real case scenarios with the goal being to make recommendations regarding the viability of using these amendments to improve a soil profile.

In order to examine the effects of wetting/drying cycles on the various amendments, an experimental approach was used. A total of eight different mixes were tested for bulk density, shear and penetration over three cycles.

The results obtained were mostly as hypothesized – denser soil profiles had greater shear and less penetration; wetter soil is more susceptible to compaction than dry; soil with Turf Grids included has higher shear values than equivalent Hydrocell mixes and there is a general trend of increasing density and shear with correspondingly decreasing penetration as the number of cycles increases. Importantly there is some evidence that the Hydrocells act to reduce the effects of compaction on the soil profile. This is especially so in wetter, less dense combinations.

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Signature

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Nomenclature

Throughout this report a standard format is used to describe the samples by a three latter abbreviation. The first letter represents the product used, the second letter is the moisture content and the final letter represents the compaction rate.

First Letter: T = Turf Grids
H = Hydrocells

Second Letter: D = Dry
W = Wet

Third Letter: L = Light
H = Heavy

eg. TDH = Turf Grids / Dry / Light combination

Chapter 1 - Introduction

1.1 Background Information

There are more than 1000 non-elite grassed sports fields in Queensland. More than 400 000 registered players and 750 000 school children use these sports grounds and are exposed to the risks inherent in playing on hard uneven surfaces. There has been considerable research completed on improving elite level playing fields. However these fields are of a different construction to the grounds considered in this research project.

Most non-elite fields in Queensland have very high clay content and are subjected to extreme cycles of wetting and drying and heavy traffic but they only receive inconsistent management mostly from volunteer workers.

By comparison elite fields have a higher sand content which aids drainage and allows for a surface providing more cushion to the players. These grounds are managed by fulltime professionals who have access to the best equipment and funding. This allows them to produce a safer surface for play.

It is understandable that professionals play on the best grounds and clubs must protect their assets from avoidable injuries caused by a poor playing surface.

In an increasingly litigious society with high public liability insurance premiums it is becoming increasingly necessary for amateur clubs to consider the possibility that they face possible action from a player injured due to a poor surface on the ground that they are responsible for.

1.2 Aim

It is the aim of this project to conduct tests on various amendments to the soil profile, which will create a safer and fairer playing surface for the junior and amateur sportsmen using these fields. This will be done with consideration for the limited resources – time, money and equipment – available to these clubs. To that end, ideally a once off cost of restructuring the top layers of the field combined with a continuing maintenance program which can be performed on a part time basis will result from the research.

1.3 Objectives

The specific objectives of this research project are to:

- Evaluate the effect of various amendments on the compaction, shear and hardness of soil profiles
- Evaluate the effect of repeated wetting and drying cycles on the soil's physical properties
- Make recommendations on the appropriateness of specific soil amendments to improve the playability of sports field surfaces.

1.4 Dissertation Overview

The research work contained within this dissertation focuses on testing the effects of various amendment products on three fundamental measures of a soil profile, namely - bulk density, shear and penetration. The following five chapters provide background along with experimental procedures, results, discussion and conclusions from the work.

Chapter one discusses the basis for research into methods for improving playing field surfaces, aims and objectives for the project.

A literature review of past and current field maintenance practices and the products considered for testing is in chapter two.

Chapter three explains the methodology behind the experiments, how they were performed and the methods used to measure and calculate results.

A full analysis and discussion of all the results obtained and how they relate to and compare with each other along with their effects make up chapter 4. This also includes a discussion on any unexpected results or results that differed from the general trends.

Chapter five contains conclusions of the research and areas for possible further research.

Chapter 2 - Literature Review

2.1 Problems

2.1.1 Compaction

‘Compaction on turf occurs primarily in the upper inch or so and shows up in reduced rooting depth when the soil is moist and a reduction in total root growth when the soil is dry (Cockerham n.d.).’ The main cause of compaction is traffic. It is worst when the moisture content of the soil is highest. ‘Compaction is the most significant impact of sports traffic…’ (Cockerham n.d.) as it increases hardness that leads to a change in performance of the field and can lead to injuries. For this reason it is the most important factor to control.

2.1.2 Traction

Traction is the interface between the players’ footwear and the surface. It is a fuzzy area because of conflicting interests. It is thought that greater traction can increase the risk of injury (see Injuries) but players want better traction to help them perform better. It is necessary to find an optimum level which allows the players sufficient traction to perform as they desire whilst not being so “grippy” as to induce injury.

2.1.3 Moisture Content

This is of particular concern in soils with a high clay content. Clay is susceptible to severe swelling and shrinking cycles as it is soaked and dries out. Extreme cases of shrinkage result in the appearance of cracks in the surface which pose very real dangers of injury and significantly reduce the playability of the surface.

Ideally, the soil profile will be well drained to remove excess water but capable of maintaining moisture levels over a longer period to reduce the effects of a drought.

2.2 Injuries

According to the Medibank Private Sports Injuries Report 2004, ‘1 in 17 Australians now experience a sports related injury each year at a cost of $1.5 billion – a figure that has been growing steadily over the past five years.’ The injuries that receive the most coverage occur in high profile professional sportsmen and women but these account for only a small percentage of the total injuries. This is because the professional sports players group is significantly smaller than the amateur group. The most high risk age group is 15-29 year olds who are twice as likely to require medical treatment as any other age group (MPSIR 2004).

Research conducted by Orchard et. al. states that injuries can be divided into two basic groups – intrinsic and extrinsic. Intrinsic injuries are player related and include such factors as age, sex and past history of injury. Extrinsic factors include weather, type of play and the playing surface. It is the playing surface that is of most importance to this project.

2.2.1 The Playing Surface

Two extrinsic factors thought to be responsible for many serious injuries are surface hardness and shoe-surface traction. Dr. Orchard’s research in this area has concentrated on Anterior Cruciate Ligament (ACL) injuries as they cause the greatest amount of missed playing time in the AFL.

2.2.2 Surface Hardness

Hardness on its own is not the most important risk factor as court sports that are played on much harder surfaces than grass do not have higher rates of ACL injuries (Arendt, Agel & Dick 1999). For this reason the shoe-surface traction factor first theorised by Torg, Quendenfeld & Landau in 1974 may be the primary cause of ACL injuries on grassed sporting fields. Traction and hardness have been shown to correlate significantly (Bell & Holmes 1988). This is due to their common inverse relationship to moisture content. A soil profile with a low moisture content is harder than a soaked profile. If the surface is also dry the player can choose boots to maximise their performance. This will increase the traction between their shoe and the surface and consequently increases the risk of the player incurring an ACL injury.

2.2.3 Grass Type

A study conducted on injuries in the AFL by Orchard concluded that there was a non-significant trend towards more injuries on grounds where couch grass was the predominant species rather than rye. However the different grass types were due to varying climatic conditions and as such may not be the cause of the higher injury rate. It is believed, but not proven, that couch grass leads to greater shoe-surface traction than rye grass. Couch grass is predominantly warm climate grass whereas rye grows better in a temperate climate. For this reason couch grass often covers soil which has a lower moisture content than the soil rye covers. This is due to the higher temperatures and humidity removing the moisture from the soil.

So it is likely that it is the combination of couch grass on harder, drier soil profiles creating greater shoe-surface traction that causes a higher rate of ACL injuries rather than one single factor.

2.3 Factors of Importance

2.3.1 Factors to be measured

There are three main factors to be measured to give an overall understanding of the soil profile in terms of its likely suitability for sports use. These are:

- Hardness
- Shoe-Surface Traction (shear)
- Bulk Density

2.3.2 Factors to be controlled

A number of variables need to be controlled in any experiment to produce comparisons between the various combinations and to measure their effects on the soil profile. Research indicates that it would be useful to control and measure these variables:

- Moisture Content
    - Wet
    - Dry

- Compaction
    - High
    - Low

2.4 Possible Amendments

2.4.1 Crumbed Rubber

Crumbed rubber of diameter less than 3mm ‘creates a softer surface and provides better footing especially during wet conditions (A-GPS 2003).’ The surface is improved by ‘reducing soil compaction, retaining moisture and reducing damage during wet weather (A-GPS 2003).’ There are no known environmental problems associated with the application of crumbed rubber according to the Nebraska Department of Environmental Quality.

If crumbed rubber performs as expected the ground should be softer, retain a higher moisture content for longer without the application of water and the ground would have more traction under wet conditions.

2.4.2 Sand

Elite Sporting fields have a very high sand content. ‘Rootzone materials with a higher sand content (as opposed to soil) maintain greater grass cover, have higher traction and have less variation in hardness due to recent rainfall (Baker 1991).’ By increasing the sand content in the rootzone of high clay content fields it is hoped to achieve all of these benefits. However care must be taken not to make the sand content too high as it increases traction and higher traction has been associated with an increase in the rate of ACL injuries (Orchard 2001).

2.4.3 Turf Grids

Turf Grids are a product produced by Stabilzer Solutions Inc. of Phoenix, Arizona in the USA. They are fibres manufactured from polypropylene that are safe and non-toxic to plants, animals and humans. Stabilzer Solutions recommends they be incorporated into the soil profile at a depth of 100-150mm where they act as a mass of indestructible roots. The existing roots interlock with the fibres resulting in reinforced turf that is extremely strong and resists divoting and rutting.

Testing of Turf Grids has been conducted by the manufacturer - they claim that it works but have not made the research available. This project aims to see if it will work under the conditions prevailing in this region.

2.4.4 Aerification

'Sports turf performance is reduced proportionately with increasing compaction (Cockerham n.d.).' Dr. Minner (n.d.) recommends that a football field should be aerated at least twice per year and more often in high traffic areas. Aerating a field involves penetrating the surface to improve air, water and nutrient movement into the soil.

2.4.5 Horticultural Perlite

Another amendment of interest, which is already in used and has been proven to be beneficial to improving playability on sports fields is Horticultural Perlite. Perlite is '…a generic term for a naturally occurring volcanic glass. Formed from rhyolitic volcanic flows, it is a silicious rock, … and has enough entrapped moisture in it to "expand" when heated (Schundler n.d.).' There is two to six percent water present in crude perlite rock. When it is quickly heated to above 870 degrees Celsius, the crude rock pops like popcorn and creates countless tiny bubbles that account for the exceptionally lightweight and other physical properties of perlite. Perlite is chemically inert with a pH of about 7.

The advantages of Perlite according to Schundler:

- Keeps soil loose and friable
- Permits greater root penetration
- Improves Drainage
- Reduces Compaction
- Essentially neutral
- Sterile, weed and disease free
- Inert, odourless and non-toxic
- Resists extreme soil temperature fluctuations

- Increases water retention.

Adding perlite to heavy clay soils has shown that water ponding and surface crusting may be eliminated. This is due to the physical shape of the perlite particles. The surface of each particle is covered with tiny cavities making for an extremely large surface area. These cavities trap moisture and make it available to plant roots. The shape of the particles also causes air passages to be formed in the soil providing excellent aeration and drainage properties. This has been proven under real conditions at the Jawaharlal Nehru Stadium in Goa, India. The turf grass in the stadium has to withstand monsoon rains from June to September and virtually no rain from October to March. It also suffers from almost constant use. A test section was renovated using perlite and after two years of hard usage this section remains lush and green whilst the non-treated section is brown and devoid of grass (Schundler n.d.).

Over 40 years ago extensive research was conducted by The University of Tokyo studying the effects of adding perlite to golf courses and other turf grasses. Since that time perlite has been used extensively in Japan and is becoming more popular on golf courses in other parts of the world as its benefits are proven under playing conditions. For this reason it is unnecessary to test the perlite as it has already been proven under testing and in use. It is however necessary to highlight the potential for its use under Australian conditions, particularly those areas which suffer from extreme wetting and drying cycles.

2.4.6 Biosolids

Biosolids can take on many forms from grass compost to solid sewage. In this research biosolids are the waste sludge remaining after a typical wastewater treatment process. ‘The handling and disposal of biological waste sludge is typically the largest single cost component in the operation of a wastewater treatment plant (Sheridan & Curtis n.d.).’ Currently most treatment facilities utilise a process of thickening or dewatering before disposing of this waste as landfill or incinerating it.

It has been proposed that a more beneficial use would be to combine it with the natural soil to improve sports playing fields. For this reason it is necessary for some research and testing to be conducted on soil amended with biosolids to analyse how it will perform in this capacity. Little is known as to how it will perform and what affect it will have on the playability of a field.

There are guidelines in place for the application of biosolids on land for recreational activities. Biosolids are given both a contaminant grading (C1, C2) and a treatment grading (T1,T2, T3). Unrestricted use is only permitted for C1/T1 graded material. Other combinations up to T2 are permitted for recreational land but application management controls must be implemented. Details on these gradings and procedures are provided by the Environmental Protection Agency.

A major positive, if the use of biosolids is deemed to be beneficial, is that councils will provide it for free, which significantly reduces the cost in comparison to other amendments.

2.4.7 Hydrocells

‘Hydrocell is a stable spongy flake-like substrate that is very light, yet has enormous water absorption capacity. It is produced from a resin that is harmless to the environment and is entirely biodegradable (Fytogreen n.d.).’

Hydrocells have many purported advantages:

- increased pore volume
- increase the moisture capacity of soil
- improve aeration
- increase the re-wetability
- reduce compaction
- increase wear tolerance and recovery speed of turf

Hydrocells were provided by Fytogreen Australia.

Chapter 3 - Experimental Methodology

3.1 General Experiment Design

In order to determine the effect of different amendments on the soil profile an experimental approach involving a series of samples with varying moisture contents, compaction rates and products were chosen to accomplish the task. A laboratory experimental approach was chosen as an appropriate starting point due to the expense and difficulty involved in performing in-situ testing. It is planned that the results achieved from these laboratory tests will be used as a basis for field tests. This will only occur if the results provide encouragement of expected positive results in the field.

3.2 Products and Application Rates

Two products were chosen for final testing – Turf Grids (supplied by Stabilizer Solutions) and Hydrocells (supplied by Fytogreen Australia). In the absence of any other data or research it was decided to adopt the application rates recommended by the manufacturers. These rates are:

- Turf Grids 0.5% by weight

- Hydrocells 15% by volume

The other amendments were not included for testing for two main reasons. These were:

- Deemed unnecessary due to existing knowledge (sand, perlite, aerating and crumbed rubber) suggesting minimal benefit or known benefits well exposed.
- It was initially planned to include biosolids in the products to be tested, however delays with supplying the product resulted in this being abandoned due to time constraints.

It is expected that by testing these two products over wetting and drying cycles the knowledge base on their effectiveness will increase and if possible permit their inclusion in soil profiles to improve playability.

3.3 Moisture Contents

Two moisture contents were chosen to represent essentially dry soil (5%) and wet soil (15%). Testing showed that moisture contents above 15% were liable to saturate the soil completely leaving water pools on the top of the surface thus negating the testing protocols. Levels below 5% leave the soil too dry to be useful in conducting tests as it is unworkable.

3.4 Compaction Rates

Two compaction rates were chosen to represent the varying levels of traffic to which a sporting field is exposed. Light compaction was designed to simulate people standing on the ground and minimal foot traffic. Heavy compaction was designed to simulate the playing of sports on the ground, including running jumping and heavier usage. In practice this would also included mowing and other vehicular access to the ground.

For both compaction rates a 1.1 kg cylinder was placed on the sample prior to any compaction to level the surface and give an even starting point.

Light compaction was achieved by placing a 2 kg weight on top of the cylinder. This applied a force of 19.62 N to the surface of the core (area = 19.635 cm^2). Therefore the compaction rate was 0.999 N/cm^2.

Heavy compaction was applied by dropping a 2.47 kg rod from a height of 400 mm on to the cylinder. This resulted in an energy of 0.5 Joule per square centimeter compacting the sample.

3.5 Combinations

Combining all of the above variables produces 8 different mix / moisture / compaction combinations. They are:

- Turf Grids / Dry / Light (TDL)
- Turf Grids / Dry / Heavy (TDH)
- Turf Grids / Wet / Light (TWL)
- Turf Grids / Wet / Heavy (TWH)
- Hydrocells / Dry / Light (HDL)
- Hydrocells / Dry / Heavy (HDH)
- Hydrocells / Wet / Light (HWL)
- Hydrocells / Wet / Heavy (HWH)

3.6 Wetting / Drying Cycles

The wetting/drying cycles were fundamental to the whole experiment and represented the main point of difference from previous research. Each cycle consisted of wetting the mix to the desired moisture content and applying the appropriate compaction rate. Between cycles the samples were dried overnight in an oven at 106°C to return them to a completely dry state prior to rewetting.

The aim of this process was to simulate a cycle of the playing field being subjected to a rainfall event or controlled watering, followed by play before drying out and being exposed to the same process again.

It was decided to perform three of these cycles to establish an understanding of the effect this process was having on the various samples.

3.7 Statistical Validity

When performing experiments it is important that the data collected and calculated can be validated. One method for achieving this is to perform the tests multiple times to diminish the possibility of fluke occurrences distorting the final results. To this end it was determined that each test would be performed three times. This permitted the calculation of mean, standard deviation and spread values for the various measures taken. The statistical measures were calculated using Microsoft Excel. These measures allow for a clearer picture to be established of the overall results and their significance.

3.8 Number of Samples Required

Due to the size of the cores tested it was only possible for one measurement to be taken from each sample. So, a separate core was required to measure penetration and shear but bulk density could be calculated on all samples. This was necessary because the shear and penetration tests destroyed the samples.

Therefore the total number of cores which needed to be tested was equal to:

2 products
x 2 moisture contents
x 2 compaction rates
x 3 cycles
x 2 tests
x 3 trials
= 144 cores to be tested.

3.9 Procedures

3.9.1 Mixing

The mixing process involved five steps:

1. Pass the dry soil through a 3.35 mm sieve
2. Pass the Hydrocells through a 2.23 mm sieve
3. Add the product at the appropriate rate (see 3.2)
4. Add the appropriate amount of water (see 3.3)
5. Mix the sample thoroughly

The soil was passed through a sieve to remove larger pieces which were deemed of inappropriate size for the samples being tested. A large chunk in a small core could distort the results.

For the same reasons the Hydrocells were also passed through a sieve. It is important to note that in practice on a larger scale field this would not be necessary.

3.9.2 Compacting

Prior to the compactions being performed approximately 200mL of loose soil mix was placed in a 50 mm diameter core made of poly pipe. The pipe was 100 mm deep. A 1.1 kg cylinder was then placed on the sample before the appropriate compaction rate was applied (see 3.4).

3.9.3 Drying

Those samples that were going on to cycles two and three needed to be dried out overnight in a 106°C oven. This is hot enough to ensure all the moisture evaporated from the soil but not hot enough to cause chemical changes in the soil.

3.9.4 Re-wetting

After drying overnight in the oven the soil needed to be re-wet to the applicable moisture content. As the sample was already formed in a core this was achieved by dripping water on to the surface as if it was a rainfall event.

This was not ideal as it resulted in an uneven moisture distribution through the soil profile as the water did not penetrate the entire core. It was impossible to overcome this without destroying the existing core and as it was a reasonable approximation of reality it was deemed suitable for the purposes of the experiment.

3.9.5 Testing

3.9.5.1 Bulk Density

To measure the bulk density of the samples it is necessary to know the mass and volume of the core. To measure the mass – the empty core must be weighed and then the final core weighed with the difference equaling the mass of the sample.

To calculate the volume it is necessary to know the depth and area of the sample. Area was calculated from the diameter of the core. Depth was measured by finding the height from the top of the core to the top of the sample and finding the difference compared to the height of the core.

The first step in calculating the bulk density is to calculate the mass.
Mass of sample = (mass of sample + core) – mass of core
Area of sample = $\pi * \text{radius}^2$
Volume = area * height

$$\text{Bulk Density} = \frac{\text{mass}}{\text{volume}}$$

3.9.5.2 Shear

Shear tests were performed using a hand-held shear vane. The blades were pushed into the surface and the vane then twisted until the soil failed with the resulting measure being the shear of the soil.

The shear calculation was dependent on which size shear vane was used. One measured directly in kg/cm^2 increments, the other in $0.2kg/cm^2$. The measures taken with the $0.2kg/cm^2$ vane were multiplied by 5 to make the units kg/cm^2.

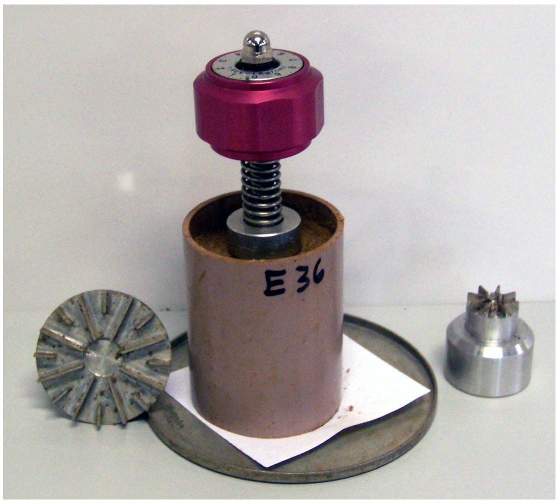

Figure 3.1 : Shear Vane

3.9.5.3 Penetration

Penetration tests were performed using a load frame. Due to the wide variety of densities in the samples it was necessary to apply different loads to achieve measurable penetrations. It was found that small loads made no impact on the hard samples, whereas large loads destroyed softer samples. To alleviate this problem penetration was measured as cubic millimetres displaced per Newton of force applied.

The actual measure taken from the load frame was in the form of the depth of penetration, so it needed to be converted to a displaced volume and divided by the load to produce a measure comparable across all the samples.

The force applied by the load frame was divided by the area of the penetrative cylinder to give a load per area (N/mm^2).

The depth of penetration was measured in millimetres. This penetration was divided by the load per area to give mm^3 displaced per N of load applied.

Penetration (mm) / load per area (N/mm^2) = Volume of soil displace per load (mm^3/N)

By performing this calculation all of the penetrations can be directly compared to each other.

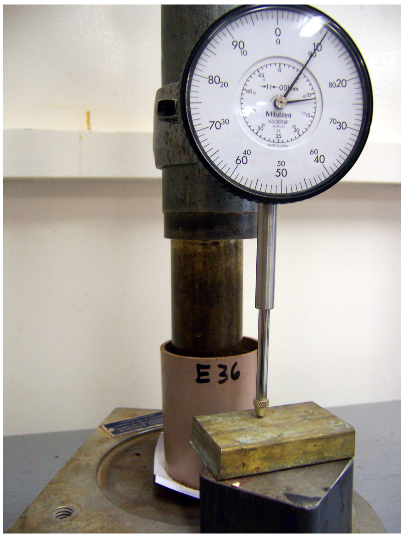

Figure 3.2 : Measuring the Penetration

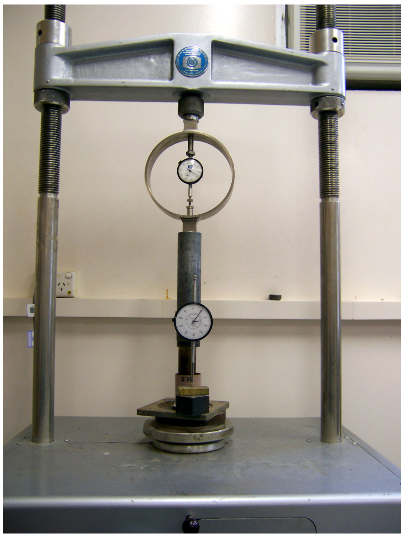

Figure 3.3 : Load Frame Penetration Test

Chapter 4 – Results, Analysis and Discussion

4.1 Bulk Density

4.1.1 General

The graph in figure 4.1 shows the average bulk densities for the various amendments at each stage of the cycle. The general trend is for the bulk density to increase with successive cycles. This indicates that the soil is becoming more compacted and harder. This result was expected.

The following sections will examine the bulk density trends on a case by case basis.

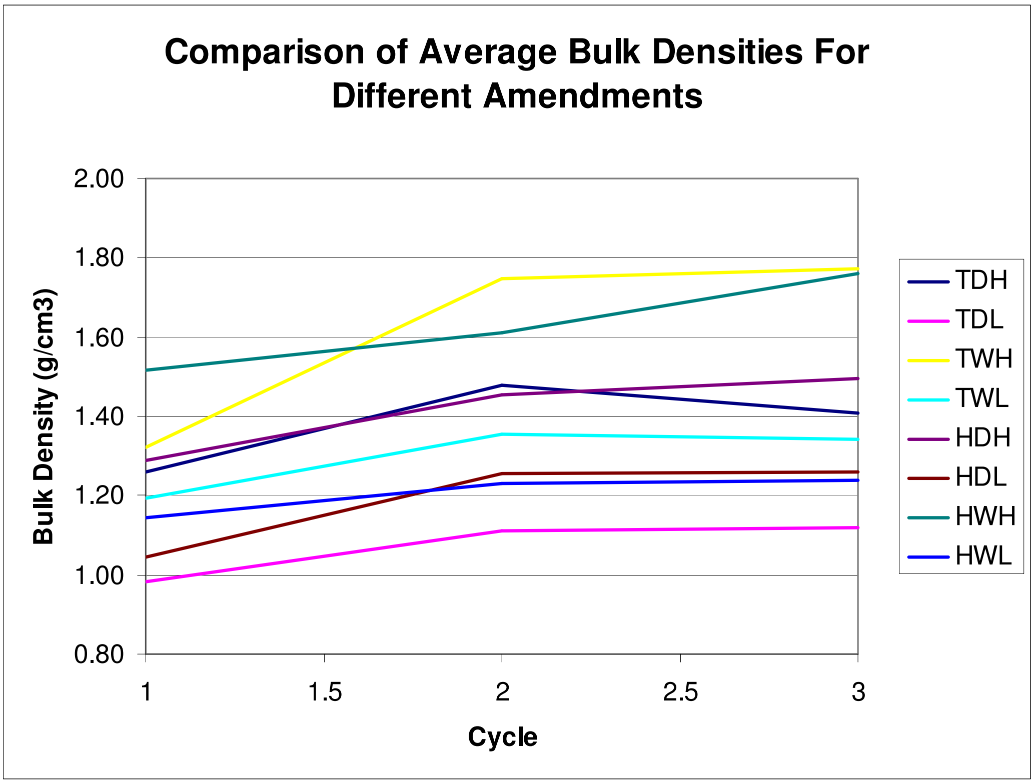

Figure 4.1 : Average Bulk Density Comparisons

4.1.2 Turf Grids / Dry / Light (TDL)

Table 4.1 : TDL Bulk Density(g/cm^3)

Code: TDL			
	Cycles		
Sample	1	2	3
Average	0.983	1.109	1.118
95%Min	0.916	1.029	1.052
95%Max	1.050	1.189	1.183

The bulk densities of the Turf Grids/Dry/Light samples show generally increasing bulk density over successive cycles, as indicated by figure 4.2. Figure 4.1 shows that the TDL samples have the lowest bulk densities of all the samples tested. The 95th percentile limits calculated for the TDL samples show there is a significant increase from the 1st to the 2nd cycle. However, whilst the trend for 2 to 3 is for increasing bulk density it is not as statistically significant as the increase from 1 to 2. The testing shows that the majority of the compaction as indicated by increasing bulk density, occurs in the earliest phases and whilst increases do appear to continue on latter cycles they are not as pronounced.

The density increase from cycle 1 to 3 for the TDL sample is 0.2%. This small change can be attributed to the higher variation of measures used in the calculations producing a wider confidence interval.

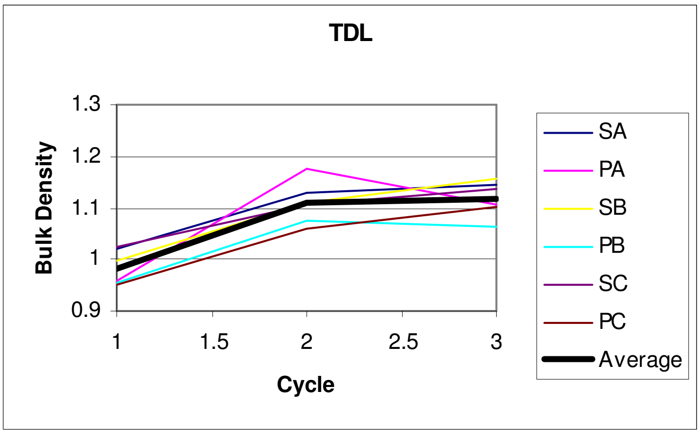

Figure 4.2 : TDL Bulk Density Trends

(The legend codes represent the shear or penetration samples and which sample they were. eg SA was the Shear A sample)

4.1.3 Turf Grids / Dry / Heavy (TDH)

Table 4.2 : TDH Bulk Density (g/cm^3)

Code: TDH			
	Cycles		
Sample	1	2	3
Average	1.258	1.478	1.410
95%Min	1.193	1.423	1.343
95%Max	1.322	1.532	1.476

The Turf Grids / Dry / Heavy samples show significant increases in bulk density over the first two cycles and the trend is for a slight decrease from cycle 2 to 3. Examination of the 95th percentile limits shows that the results attained for cycles 2 and 3 are very similar and therefore there is no significant trend apparent. However, because the 95% maximum from cycle 1 is clearly lower then the 95% minimum for cycle 2 it provides proof of increasing bulk density.

The lack of evidence for continuing increase of bulk density in the latter cycles is more evident for this heavily compacted sample than for the same lightly compacted sample. This would suggest that once a sample reaches a certain level of density it cannot become anymore dense. It is important to note that even after one cycle of heavy compaction the sample was more dense than for 3 cycles of light compaction at a 95% confidence level.

The density increase from cycle 1 to 3 for the TDH sample is 1.6%.

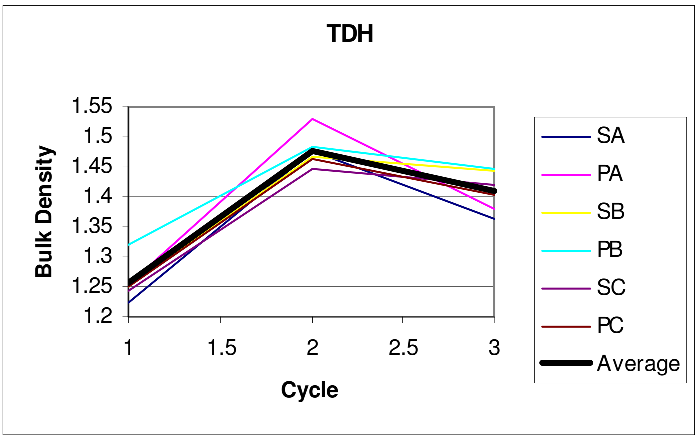

Figure 4.3 : TDH Bulk Density Trend

4.1.4 Turf Grids / Wet / Light (TWL)

Table 4.3 : TWL Bulk Density (g/cm^3)

Code: TWL			
	Cycles		
Sample	1	2	3
Average	1.195	1.355	1.344
95%Min	1.153	1.308	1.283
95%Max	1.236	1.401	1.405

As shown by figure 4.4 the trend for the Turf Grids / Wet / Light samples is for significant density increase from cycle 1 to cycle 2 before remaining similar from 2 to 3. The densities returned by this wet sample are significantly higher than the dry sample with the same level of compaction. This proves that the addition of moisture promotes higher compaction of the soil resulting in denser samples.

A comparison of the 95% confidence levels indicates that the wetter samples are 0.1 to 0.15 g/cm3 more dense than the dry samples exposed to the same compaction rates. This would suggest that use of a sporting field in a wet state is likely to accelerate the compaction process, even if it is only light use.

The density increase from cycle 1 to 3 for the TWL sample is 0.047g/cm^3 or 3.8%.

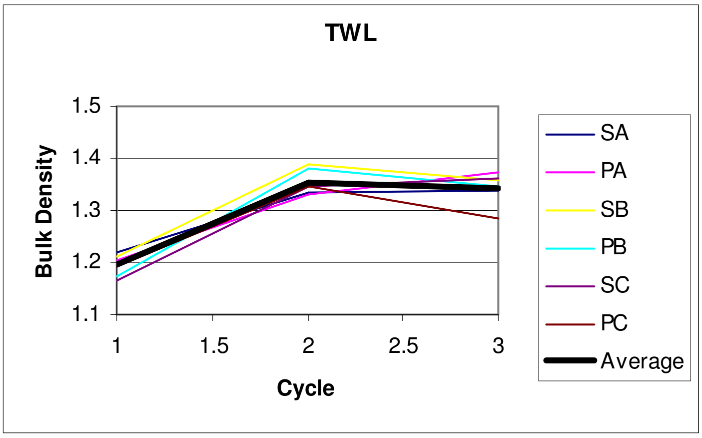

Figure 4.4 : TWL Bulk Density Trends

4.1.5 Turf Grids / Wet / Heavy (TWH)

Table 4.4 : TWH Bulk Density (g/cm^3)

Code: TWH			
	Cycles		
Sample	1	2	3
Average	1.321	1.747	1.774
95%Min	1.268	1.687	1.712
95%Max	1.374	1.808	1.835

The Turf Grids / Wet / Heavy samples show the same pattern as the other Turf Grid samples – significant increase from cycle 1 to cycle 2 before plateauing to cycle 3. Comparison with the dry sample shows that at the initial phase there is not a significant difference in the densities, although the average for the wet samples is higher. However, on the latter phases the wetter samples are significantly more dense. This indicates that the continual rewetting and compacting is having more effect on the wetter samples. The density increase from cycle 1 to 3 for the TWH sample is 24.6%.

As with the dry samples it is again clear that higher levels of compaction lead to greater bulk density. This is worsened by the soil being used when it is wet. From this it is obvious that heavy traffic, such as playing sport, on a wet field is a recipe to greatly increase the density of the soil profile.

The addition of Turf Grids to the profile has had no significant effect on the density of the soil samples.

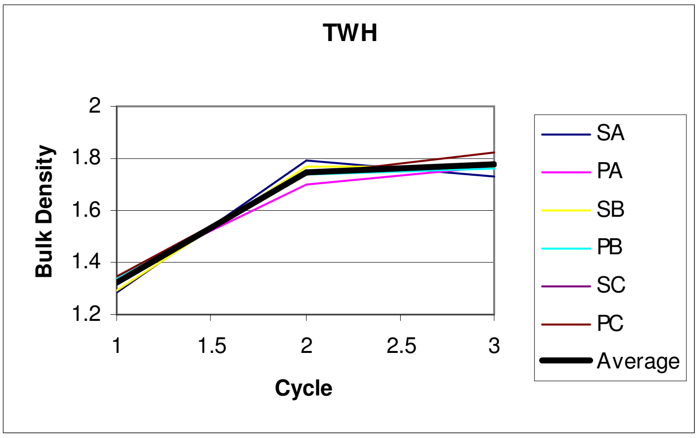

Figure 4.5 : TWH Bulk Density Trends

4.1.6 Hydrocells / Dry / Light (HDL)

Table 4.5 : HDL Bulk Density (g/cm^3)

Code: HDL			
	Cycles		
Sample	1	2	3
Average	1.043	1.257	1.259
95%Min	0.991	1.235	1.234
95%Max	1.095	1.279	1.284

As with many of the Turf Grid samples, the Hydrocells / Dry / Light samples show that the majority of the compaction of the soil occurs in the step from the 1st cycle to the 2nd. There is not a significant increase in the bulk density from 2 to 3.

The lightly compacted dry soil with Hydrocell amendment is more dense than the same Turf Grid combination but is still much less dense than most of the other samples.

The density increase from cycle 1 to 3 for the HDL sample is 12.7%.

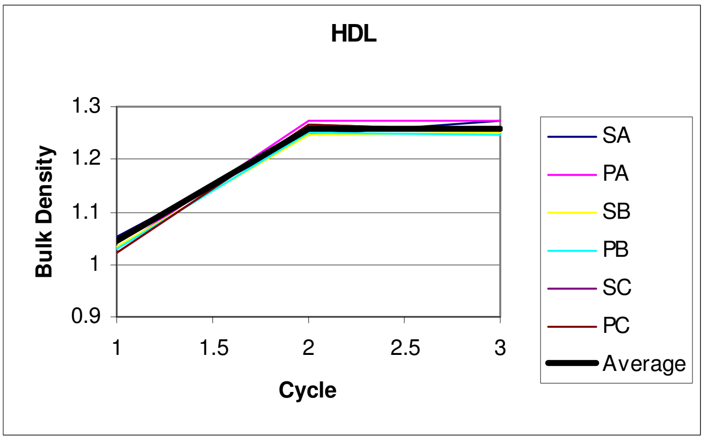

Figure 4.6 : HDL Bulk Density Trends

4.1.7 Hydrocells / Dry / Heavy (HDH)

Table 4.6 : HDH Bulk Density (g/cm^3)

Code: HDH			
	Cycles		
Sample	1	2	3
Average	1.290	1.455	1.494
95%Min	1.239	1.424	1.464
95%Max	1.341	1.486	1.525

The Hydrocells / Dry / Heavy sample shows a general upwards trend of increasing bulk density over the three cycles. The majority of this increase occurs from cycle 1 to 2 with some still evident in the 2 to 3 step.

The heavy compaction of the Hydrocell dry combination results in a denser soil profile than the more lightly compacted samples.

The density increase, as calculated by a comparison of the minimum at 3 to the maximum at 1, is 9.2%.

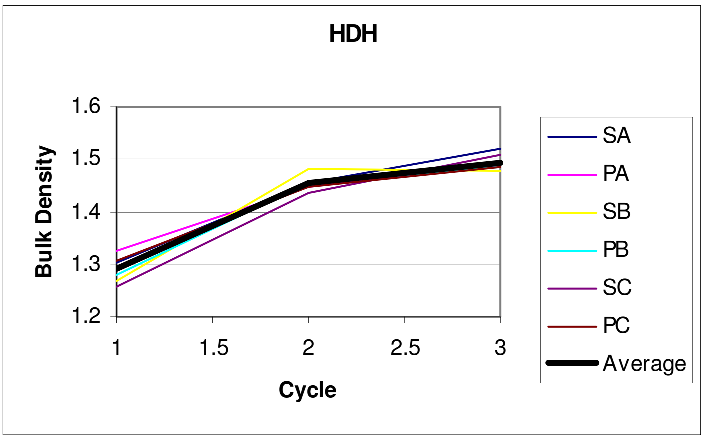

Figure 4.7 : HDH Bulk Density Trends

4.1.8 Hydrocells / Wet / Light (HWL)

Table 4.7 : HWL Bulk Density (g/cm^3)

Code: HWL			
	Cycles		
Sample	1	2	3
Average	1.142	1.229	1.239
95%Min	1.129	1.185	1.200
95%Max	1.156	1.272	1.277

The Hydrocell / Wet / Light samples show only a small increase in bulk density over the 3 cycle periods. The change from cycle 1 to 2 is again more significant than 2 to 3.

A comparison of the 95% minimum for cycle 3 and the 95% maximum for cycle 1 shows an increase of just 0.044g/cm^3 or 3.8%.

It is theorized that this is due to the nature of the Hydrocells and how they work to absorb moisture. This would cause the Hydrocells to expand in the less compacted soil, thus reducing the bulk density.

The Hydrocells samples are less dense than their Turf Grid counterparts for the wet samples – the opposite to the dry results.

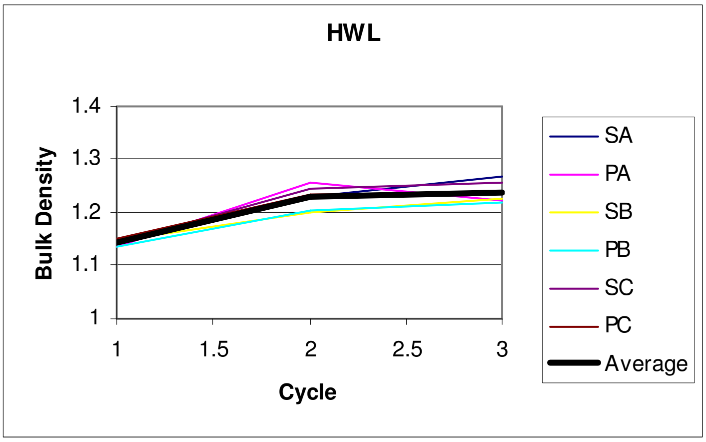

Figure 4.8 : HWL Bulk Density Trends

4.1.9 Hydrocells / Wet / Heavy (HWH)

Table 4.8 : HWH Bulk Density (g/cm^3)

Code: HWH			
	Cycles		
Sample	1	2	3
Average	1.514	1.612	1.759
95%Min	1.446	1.577	1.662
95%Max	1.582	1.647	1.856

The Hydrocells / Wet / Heavy samples show an almost linear increase in the bulk density of the samples over the 3 cycles. There is a significant increase both from cycle 1 to 2 and from 2 to 3. However in contrast to the other samples it is greater from 2 to 3.

The density increase from cycle 1 to 3 is 0.08g/cm^3 or 5.1%.

As for the Turf Grid samples it is again true that for the Hydrocell samples the wetter and more heavily compacted soils are more dense than the drier more lightly compacted samples.

The most important issue to show up is the fact that the Hydrocells were able to show smaller increases in density than the Turf Grid samples when the soil was wetter and more heavily compacted.

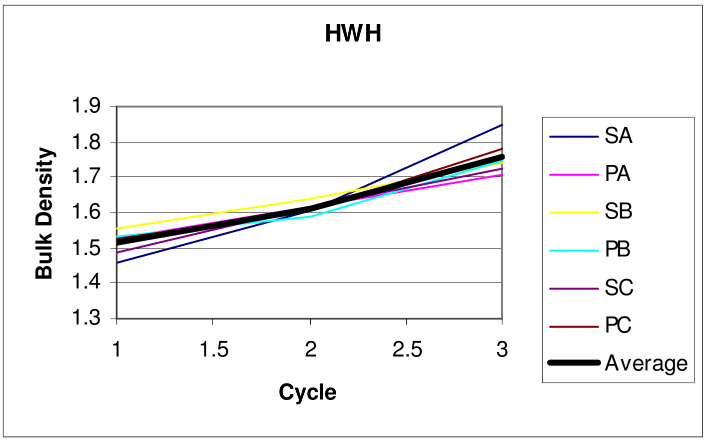

Figure 4.9 : HWH Bulk Density Trends

4.2 Shear

4.2.1 General

Figure 4.10 shows that the general trend across all the samples was for increasing shear. Some of these increases were more dramatic than others and one sample even trended slightly downwards. These issues will be dealt with on an individual basis in the sections to follow.

It was shown in section 4.1 that the bulk density of the samples increased over successive cycles. That is, the soil became harder. By the same token the general increase in shear occurring in the samples is due to the harder surface.

The graph in figure 4.10 can be broken into 2 distinct sections – upper and lower. Examination of the codes with their corresponding lines shows that the upper four lines coincide with the heavily compacted samples and the lower four lines are for the lightly compacted samples. By the stage of the 3rd cycle this split is very pronounced and clearly indicates that heavier compaction, regardless of amendments or moisture contents results in higher shear.

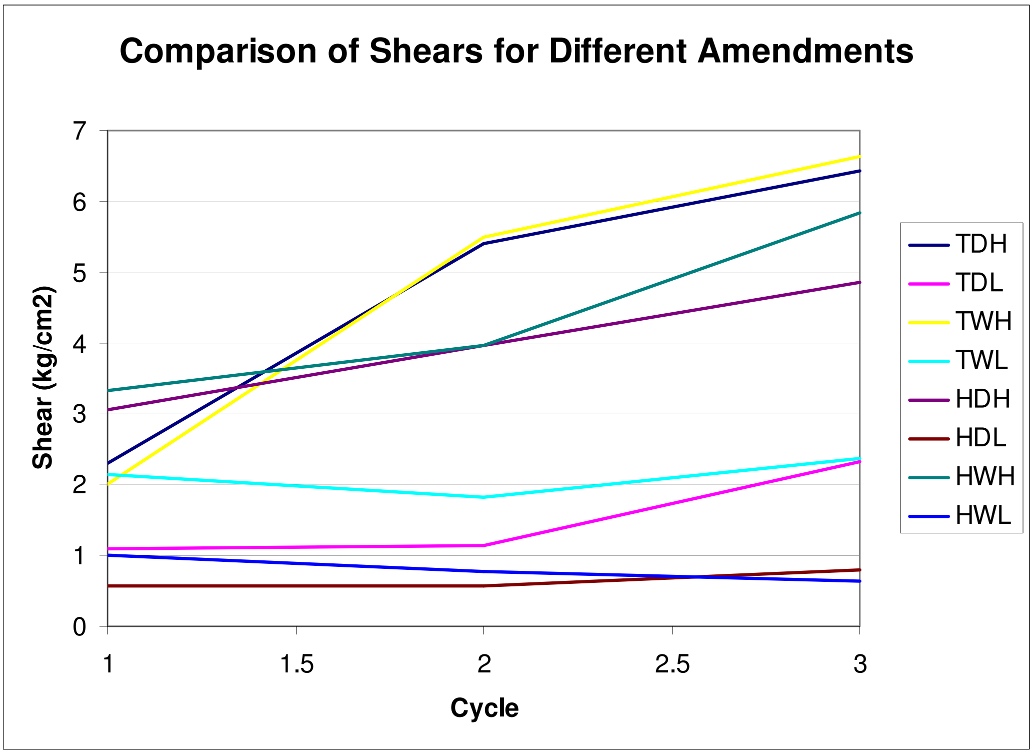

Figure 4.10 : Average Shear Comparisons

4.2.2 Turf Grids / Dry / Light (TDL)

Table 4.9 : TDL Shear (kg/cm^2)

Code: TDL			
	Cycles		
Sample	1	2	3
Average	1.100	1.133	2.333
95%Min	0.761	0.681	2.220
95%Max	1.439	1.586	2.446

As the graph of figure 4.11 shows there is no significant increase in the shear from the 1st cycle to the 2nd. The main increase occurs from cycle 2 to 3. This is in contrast to the bulk density samples, many of which showed significant increase early before lessening on the latter cycles.

There is no evidence as to why this has occurred with this sample and as figure 4.10 shows there is only one other sample which shows a similar pattern – TWL. For this reason it is hypothesized that this variation from the trend displayed by the other samples is attributable to the combination of Turf Grids and light compaction.

As will be discussed later the Turf Grids appear to have a significant impact on shear and the light compaction lends itself to a greater change in surface hardness on later cycles as the soil will not have approached its maximum compactive state due to the fact that only relatively light loads were used.

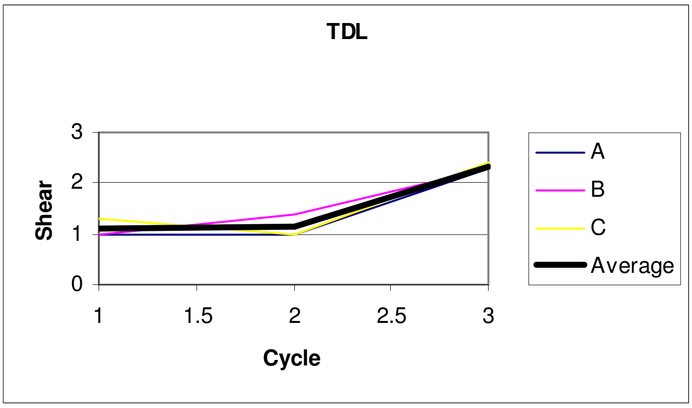

Figure 4.11 : TDL Shear Trends

4.2.3 Turf Grids / Dry / Heavy (TDH)

Table 4.10 : TDH Shear (kg/cm^2)

Code: TDH			
	Cycles		
Sample	1	2	3
Average	2.300	5.400	6.433
95%Min	1.961	3.832	1.284
95%Max	2.639	6.968	11.583

The Turf Grids / Dry / Heavy samples are representative of general trends across all of the shear samples in that there is a trend for increasing shear on successive cycles. The cycle three samples produced a wide range of results which has caused a large spread in the 95% confidence intervals. This does make it difficult to prove conclusively that this trend exists, however when viewed in an overall sense with the other samples it is expected that it would follow the similar trend that the evidence is suggesting.

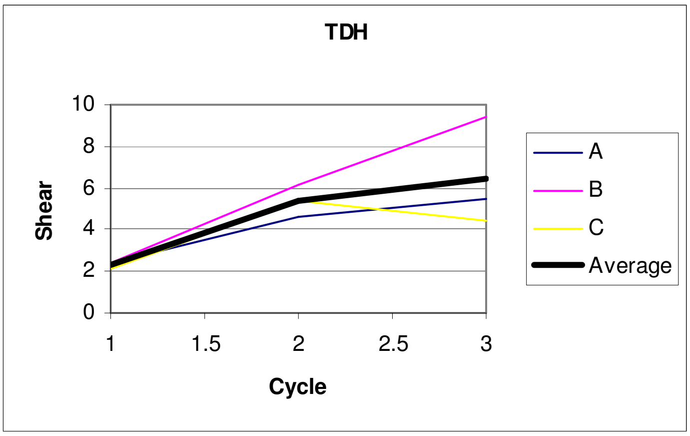

Figure 4.12 : TDH Shear Trends

4.2.4 Turf Grids / Wet / Light (TWL)

Table 4.11 : TWL Shear (kg/cm^2)

Code: TWL			
	Cycles		
Sample	1	2	3
Average	2.133	1.833	2.367
95%Min	1.640	1.720	2.067
95%Max	2.627	1.946	2.666

This is a most interesting sample, similar to the dry combination in 4.2.2, but different in that there is no significant evidence of increasing shear over successive cycles.

The shear for cycle two is a bit lower than cycle one, but it is not conclusive and it does increase from cycle 2 to 3.

The cause for this difference is probably attributable to the wetter soil preventing the surface from becoming harder as quickly as if it were dry. From Dr. Orchard's findings he suggests that drier fields result in higher levels of shear. The findings of these experiments would support that.

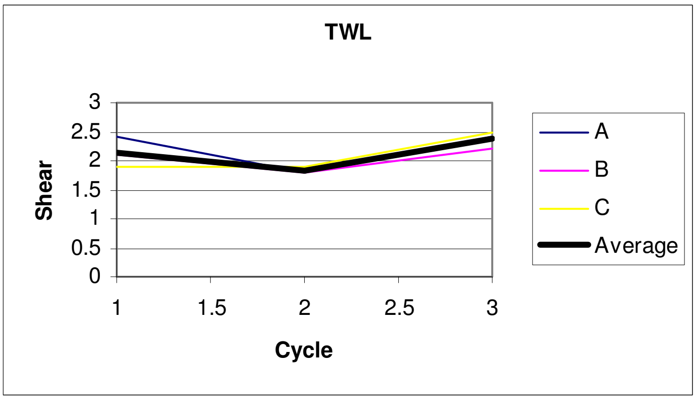

Figure 4.13 : TWL Shear Trends

4.2.5 Turf Grids / Wet / Heavy (TWH)

Table 4.12 : TWH Shear (kg/cm^2)

Code: TWH			
	Cycles		
Sample	1	2	3
Average	2.000	5.500	6.633
95%Min	2.000	3.610	6.407
95%Max	2.000	7.390	6.860

The Turf Grids / Wet / Heavy samples show the expected trend of increasing shear over successive cycles. The difference in comparison to the lightly compacted wet samples is important to note, in that under heavy compaction the increase of shear is not retarded by the wetter soil. This would tend to suggest that it is indeed the combination of less compacted soil and more moisture which slows the increase of shear.

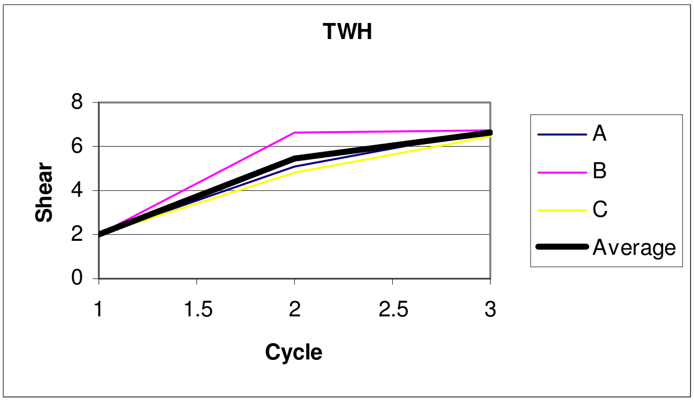

Figure 4.14 : TWH Shear Trends

4.2.6 Hydrocells / Dry / Light (HDL)

Table 4.13 : HDL Shear (kg/cm^2)

Code: HDL			
	Cycles		
Sample	1	2	3
Average	0.567	0.567	0.807
95%Min	0.454	0.340	0.614
95%Max	0.680	0.793	0.999

The HDL samples show no significant increase of shear from cycle 1 to cycle 3. The average does show signs of an increase, but at the 95% confidence level required for significance, there is no evidence of this fact.

Along with the corresponding wet samples the HDL samples have the lowest shears of all the samples. This proves that the soils were very loose, not very compacted and easily broken in the shear tests.

For lightly compacted soils the Hyrdocells either have no effect on the shear or may reduce it.

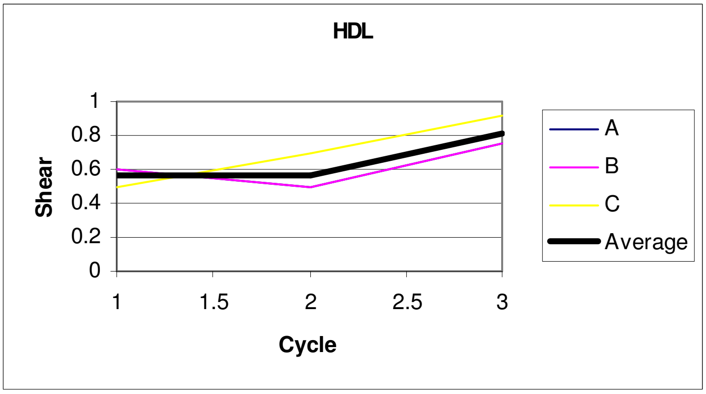

Figure 4.15 : HDL Shear Trends

4.2.7 Hydrocells / Dry / Heavy (HDH)

Table 4.14 - HDH Shear (kg/cm^2)

Code: HDH			
	Cycles		
Sample	1	2	3
Average	3.067	3.967	4.850
95%Min	2.378	3.040	4.591
95%Max	3.755	4.893	5.109

The HDH samples show a linearly increasing shear trend over the three cycles. There is a significant increase from start to end but the internal differences whilst apparent, are not significant enough to be conclusive.

The lack of a significant increase provides the suggestion that the Hydrocells may be acting to retard the compactive effect in some way, although there is no quantitative evidence of this.

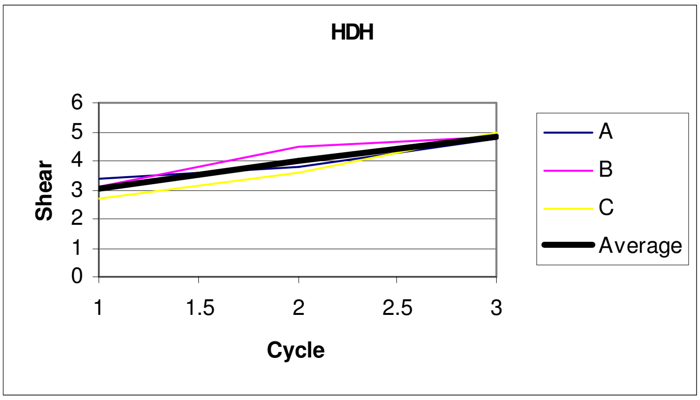

Figure 4.16 : HDH Shear Trends

4.2.8 Hydrocells / Wet / Light (HWL)

Table 4.15 – HWL Shear (kg/cm^2)

Code: HWL			
	Cycles		
Sample	1	2	3
Average	1.000	0.783	0.633
95%Min	0.804	0.537	0.577
95%Max	1.196	1.030	0.690

The HWL samples are unique in that the shear values measured on these samples trend in the opposite direction – that is downwards. This trend is significant from cycle one to three. This is very important as the samples are not merely maintaining a level – the shear is actually reducing and importantly, by a significant amount.

This provides the strongest evidence yet that the Hydrocells do in fact work to reduce the amount of shear in the soil profile. The combination of wet soil and light compaction has amplified this to the point that the shear is actually reducing over time.

This supports the theory expressed in 4.2.6 that the Hydrocells may actually act to reduce shear and at least help to prevent it increasing.

It does defy logic that with each successive round of compaction the shear could reduce, however under the ideal circumstances present in these samples it is possible at least in the short term.

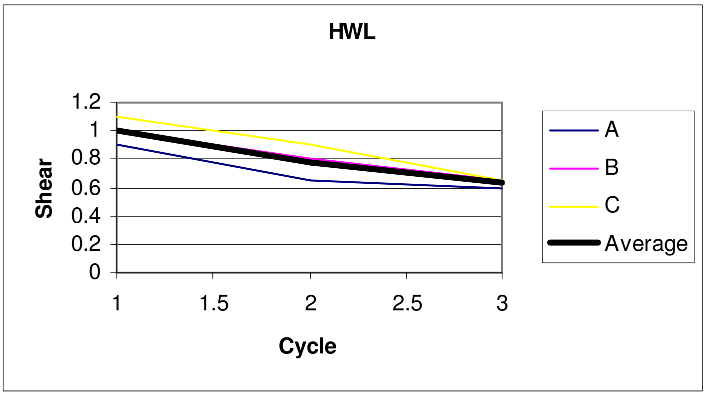

Figure 4.17 : HWL Shear Trends

4.2.9 Hydrocells / Wet / Heavy (HWH)

Table 4.16 - HWH Shear (kg/cm^2)

Code: HWH			
	Cycles		
Sample	1	2	3
Average	3.333	3.967	5.833
95%Min	3.220	3.083	3.223
95%Max	3.446	4.850	8.443

The Hydrocells / Wet / Heavy samples again show no significant increase from cycle one to three. There is a slight increasing trend based on the averages. This further supports the supposition that the Hydrocells act to reduce the amount of shear in the soil samples and that this effect is magnified by wetter soil.

This is a significant finding as in many cases hard grounds are the primary problem on Queensland’s amateur sporting fields. Hard grounds have typically higher values of shear than softer grounds which in turns leads to an increased likelihood of incurring a knee injury according to Dr. Orchard’s findings.

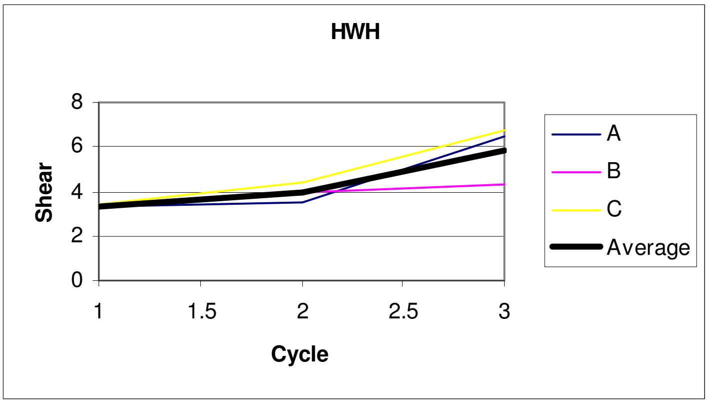

Figure 4.18 : HWH Shear Trends

4.3 Penetration

4.3.1 General

Figure 4.19 shows that with the one obvious exception (HWL) the general trend is for the penetration to reduce over successive cycles. This is in line with the hardening of the soil samples and matches with the other two measurements taken.

A log scale has been used to make the graph more readable as there is a wide range of values present on the penetration y-axis. Using a standard scale makes it impossible to detect any trends in the harder samples.

The main exception to the general trend found here is with the HWL samples however, the HDL samples also show signs of disagreement with the norm. This agrees with differences highlighted in the shear analysis section and will be discussed further in the relevant sections to follow.

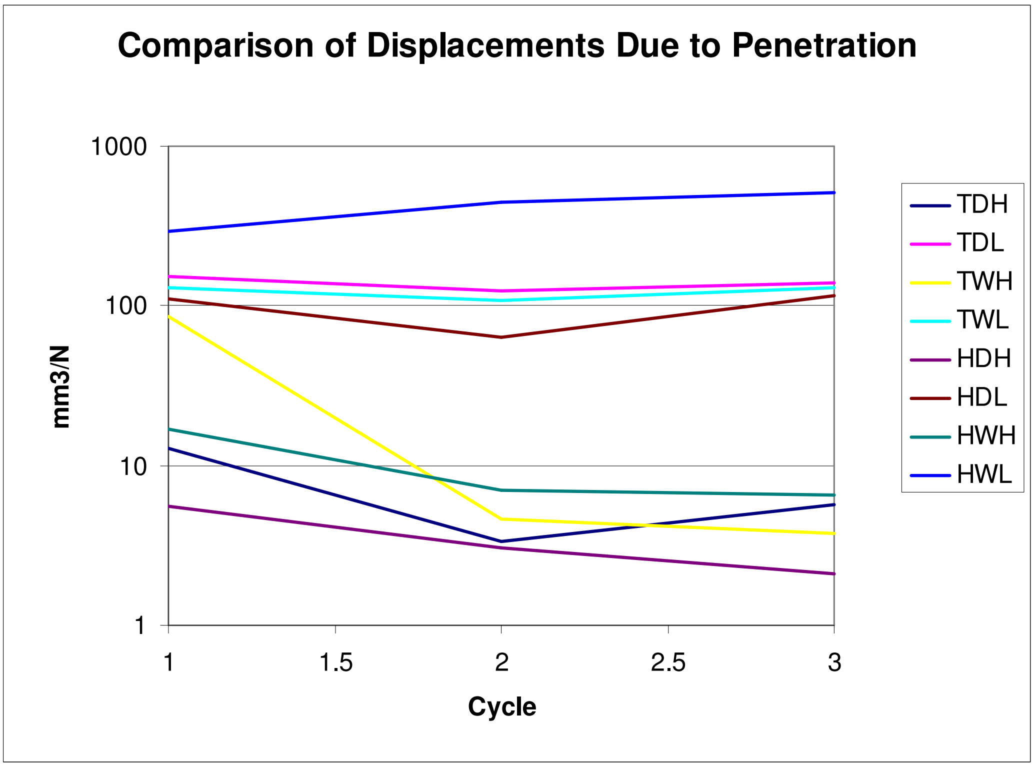

Figure 4.19 : Average Penetration Comparisons (log scale on y-axis)

4.3.2 Turf Grids / Dry / Light (TDL)

Table 4.17 – TDL Penetration (mm^3/N)

Code: TDL			
	Cycles		
Sample	1	2	3
Average	152.07	123.09	139.94
95%Min	109.82	83.70	132.62
95%Max	194.31	162.48	147.25

The Turf Grids / Dry / Light samples show a significant trend of decreasing penetration as would be expected if the soil profile was becoming gradually harder with successive cycles of compaction.

The likely cause of this is that the dry, loosely compacted soil is only harder right on the surface and once that barrier is penetrated the soil below is just the same as it was prior to the compactive load being applied.

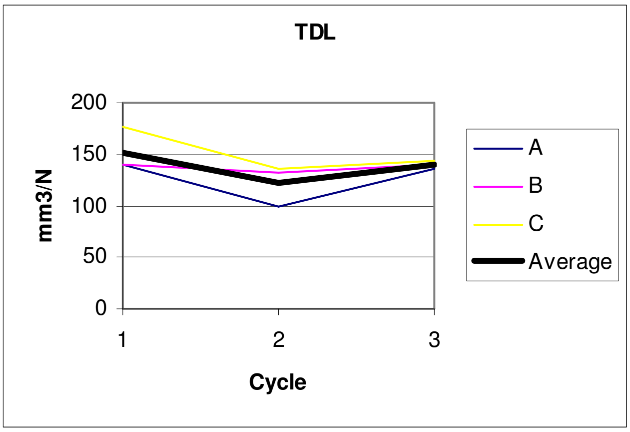

Figure 4.20 : TDL Penetration Trend

4.3.3 Turf Grids / Dry / Heavy (TDH)

Table 4.18 – TDH Penetration (mm^3/N)

Code: TDH			
	Cycles		
Sample	1	2	3
Average	12.66	3.31	5.66
95%Min	10.70	2.85	4.32
95%Max	14.62	3.78	7.00

The TDH sample shows a significant drop in the amount of soil displaced in the penetration test from cycle one to two. This is in line with the major increase in bulk density occurring between these two cycles also.

Interestingly the amount of penetration actually appears to increase from cycle 2 to 3. There can be no logical explanation for this except to say that it may be due to the sample reaching a minimum level of penetration (maximum hardness) on the second cycle and it was not repeated after rewetting and further compaction.

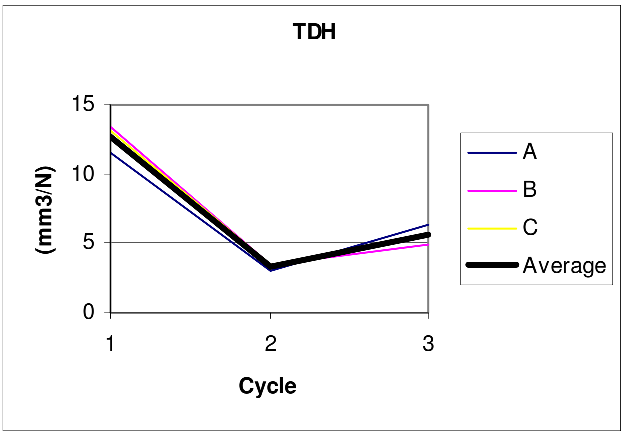

Figure 4.21 : TDH Penetration Trend

4.3.4 Turf Grids / Wet / Light (TWL)

Table 4.19 – TWL Penetration (mm^3/N)

Code: TWL			
	Cycles		
Sample	1	2	3
Average	131.45	107.10	131.54
95%Min	112.92	77.32	47.28
95%Max	149.98	136.87	215.79

The results achieved from the TWL samples are similar to their dry counterparts in that there is no proof of decreasing penetration associated with increasing hardness. The huge variation in the results for the third cycle is of some concern, however the fact that the averages match up reasonably well with the trends found in similar samples suggests that the results are credible, if not precise.

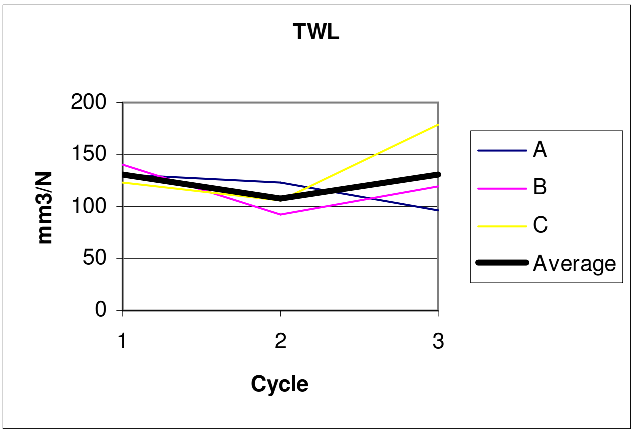

Figure 4.22 : TWL Penetration Trend

4.3.5 Turf Grids / Wet / Heavy (TWH)

Table 4.20 – TWH Penetration (mm^3/N)

Code: TWH			
	Cycles		
Sample	1	2	3
Average	86.37	4.62	3.74
95%Min	74.24	2.97	1.81
95%Max	98.50	6.27	5.66

The Turf Grids / Wet / Heavy samples provide the most conclusive evidence supporting the theory expressed in the bulk density discussion that the majority of compaction occurs early and whilst successive loading does have an effect the increases are only small.

The graph in figure 4.24 displays this clearly. It is likely that the presence of more moisture and heaver compaction accelerates this above what occurs with the drier soils exposed to less loading.

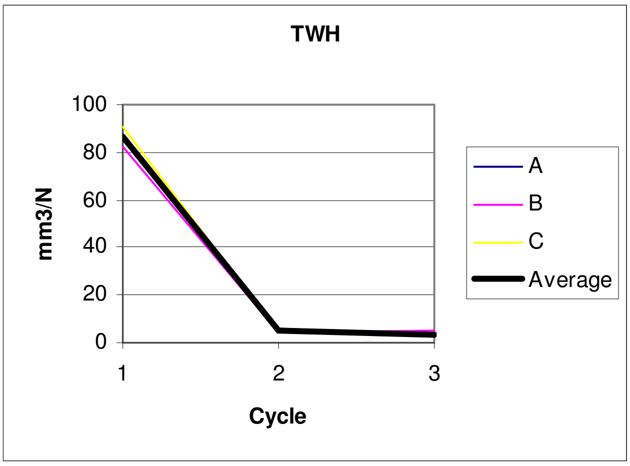

Figure 4.23 : TWH Penetration Trend

4.3.6 Hydrocells / Dry / Light (HDL)

Table 4.21 – HDL Penetration (mm^3/N)

Code: HDL			
	Cycles		
Sample	1	2	3
Average	111.59	63.16	117.16
95%Min	104.87	59.20	87.83
95%Max	118.31	67.13	146.49

As with the Turf Grid sample similar to this there is no significant evidence of decreasing penetration from cycle one to three. Whilst it is clear that some occurs between one and two the expected is reversed from two to three. In both cases the numbers are deemed to be significant at a 95 % confidence level.

There can be no logical explanation for this except to say that the variation would suggest that no definitive trend has occurred at this stage and therefore the compacting has not had a uniform impact on the samples.

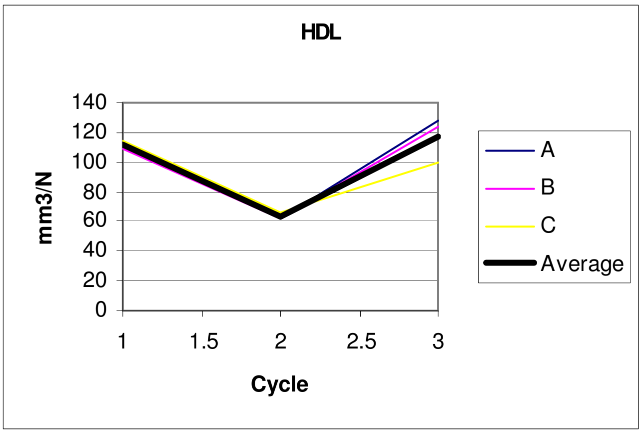

Figure 4.24 : HDL Penetration Trend

4.3.7 Hydrocells / Dry / Heavy (HDH)

Table 4.22 – HDH Penetration (mm^3/N)

Code: HDH			
	Cycles		
Sample	1	2	3
Average	5.62	3.04	2.10
95%Min	3.19	2.91	1.88
95%Max	8.04	3.18	2.32

The HDH samples returned the lowest levels of penetration. This on the surface means that they were the hardest samples from all of those tested. The only contention to this is that they were dry samples and it is likely that the wetter samples were prone to more penetration.

They did show significant decreases from both one to two and two to three. The change from two to three was smaller than one to two and this is in line with the trends present in other samples.

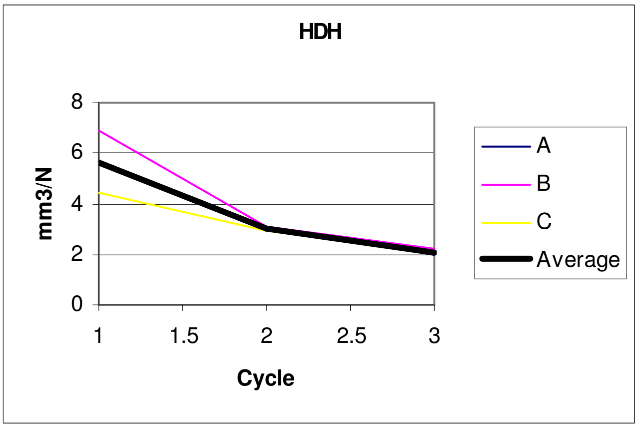

Figure 4.25 : HDH Penetration Trend

4.3.8 Hydrocells / Wet / Light (HWL)

Table 4.23 – HWL Penetration (mm^3/N)

Code: HWL			
	Cycles		
Sample	1	2	3
Average	294.43	440.06	512.86
95%Min	267.93	363.43	506.20
95%Max	320.93	516.69	519.51

As with the Hydrocells / Wet / Light samples tested for shear, the penetration results produced a trend completely opposite to that occurring in all the other samples.

Not only was the expected trend reversed but the measurements were massively higher than those returned from the other samples. The values were mostly above 300mm^3/N compared with no measurements above 200mm^3/N returned by the other samples. This provides further evidence that the Hydrocells have an effect on the compaction of the soil and when combined with more water and less compaction this effect is exaggerated.

The decreasing values of measured compaction are significant at the 95% confidence level, a fact that lends more weight to the argument that the Hydrocells affect the compaction of the soil profile.

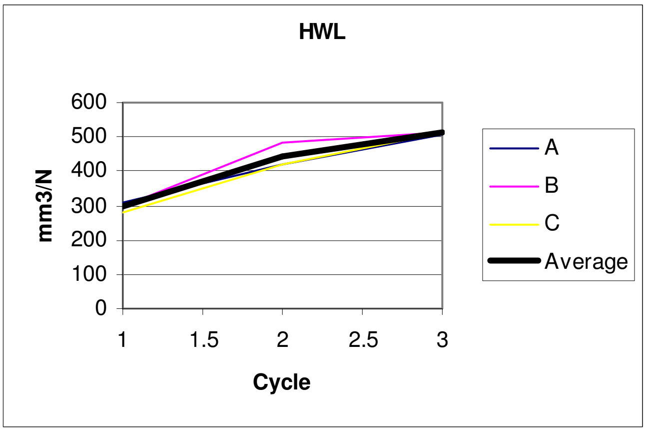

Figure 4.26 : HWL Penetration Trend

4.3.9 Hydrocells / Wet / Heavy (HWH)

Table 4.24 – HWH Penetration (mm^3/N)

Code: HWH			
	Cycles		
Sample	1	2	3
Average	16.94	6.95	6.50
95%Min	15.69	5.75	5.65
95%Max	18.18	8.15	7.36

The wet and heavy combination with Hydrocells returns a more expected result of decreasing penetration over successive cycles with the majority of this occurring between cycle one and cycle two.

From this evidence and that found in the other measurements it is clear that the Hydrocells do have some effect on the profiles, but heavy compaction and the presence of less moisture negates this effect to the degree that it is not immediately obvious.

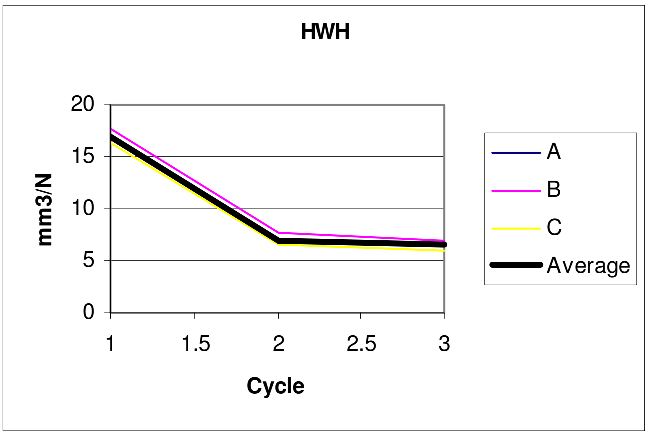

Figure 4.27 : HWH Penetration Trend

4.4 Hydrocell Correlations

4.4.1 Bulk Density vs Shear

For the Hydrocells samples the graph in figure 4.28 shows that there exists a strong relationship between bulk density and shear. This relationship is positive – as bulk density increases so does the shear.

The r2 value of 0.78 suggests that the correlation between the two measures is quite strong and 78% of the variation in the shear values can be explained by the bulk density of the samples.

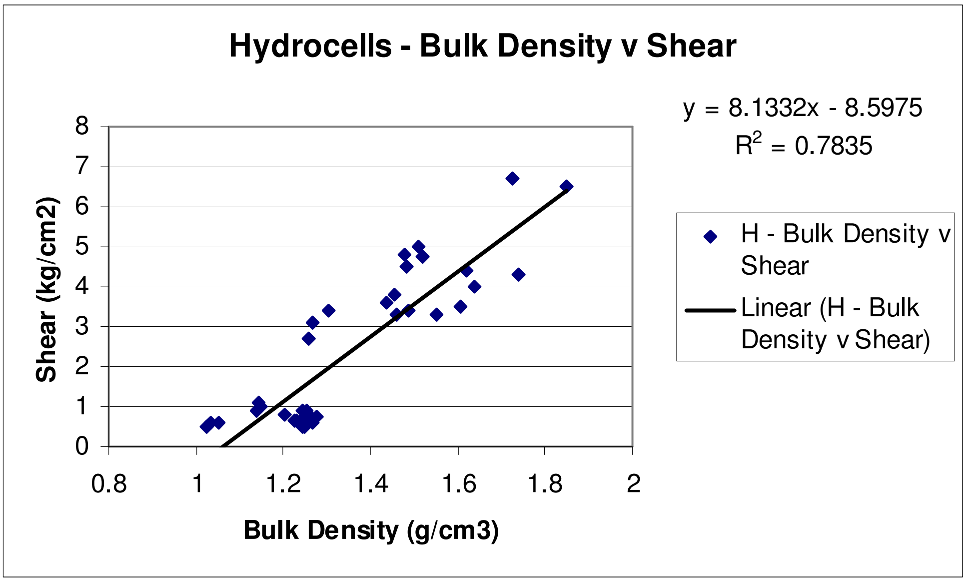

Figure 4.28 : Hydrocells – Bulk Density/Shear Correlation

4.4.2 Bulk Density vs Penetration

The relationship between bulk density and penetration is negative and quite weak from a predictive sense. Only 35% of the variation in penetration can be attributed to the bulk density of the sample.

It is very clear though that the two measures are inversely proportional – as the bulk density increase the penetration decreases.

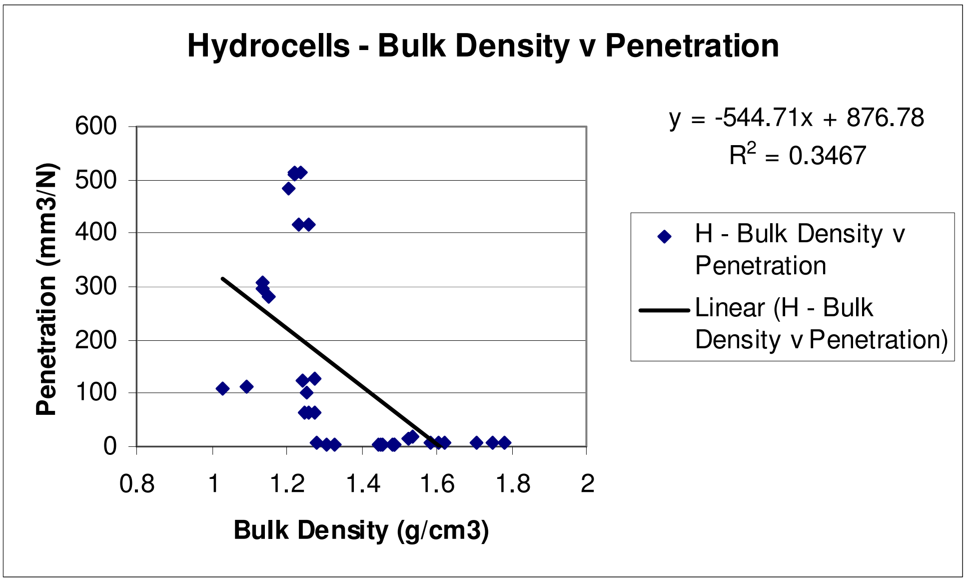

Figure 4.29 : Hydrocells – Bulk Density/Penetration Correlation

4.4.3 Shear vs Penetration

An inverse relationship exists between the measures of shear and penetration – as the shear increases the amount of penetration decreases. This is expected given the relationships already established in comparing these two measures to bulk density.

The relationship is not as strong as the bulk density shear relationship but stronger than that which exists between bulk density and penetration. About 43% of the variation in the penetration measures is attributable to the shear values. This makes it unreliable from a predictive nature for the purposes of determining penetration from measures of shear.

The correlations between the all of the various measures do not present strong predictive values but the generalizations are clear cut. Increasing bulk density relates to increasing shear which relates to decreasing penetration. This finding was to be expected.

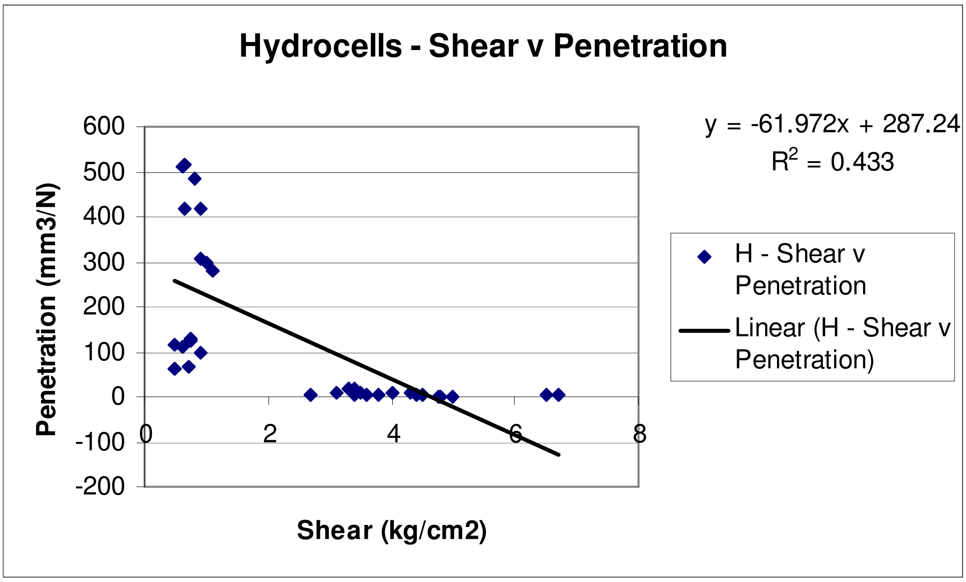

Figure 4.30 : Hydrocells – Shear/Penetration Correlation

4.5 Turf Grid Correlations

4.5.1 Bulk Density vs Shear

As for the Hydrocells samples the Turf Grid samples show a positive relationship between bulk density and shear. 63% of the variation in the shear can be accounted for by the variation in the bulk density of the samples. This is a weaker relationship than that which existed for the Hydrocells samples between these two measures.

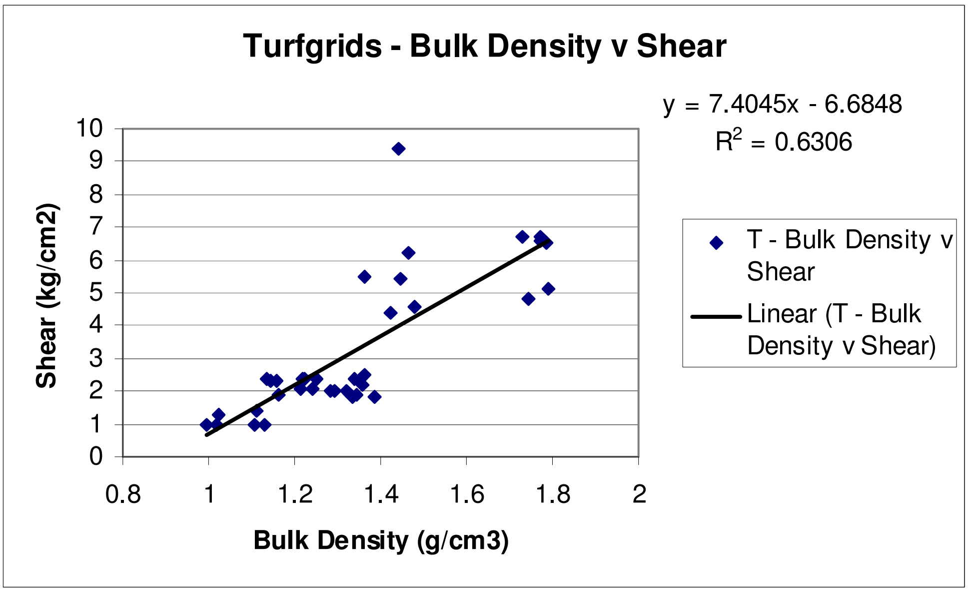

Figure 4.31 : Turf Grids – Bulk Density/Shear Correlation

4.5.2 Bulk Density vs Penetration

There is an inverse relationship present between the measures of bulk density and penetration. This is the same as for the Hydrocells samples. However, for the Turf Grids this relationship is much stronger with 62% of the variation in the penetration being attributable to the bulk densities.

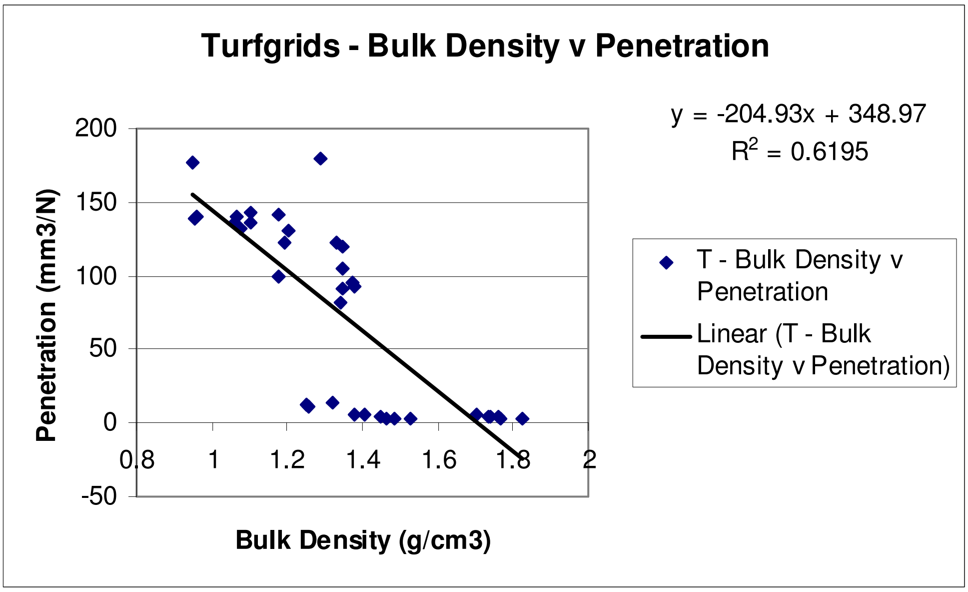

Figure 4.32 : Turf Grids – Bulk Density/Penetration Correlation

4.5.3 Shear vs Penetration

For the Turf Grids samples an inverse relationship exists between the measures of shear and penetration. Approximately 60% of the variation in penetration is attributable to the variation in shear. This is a stronger relationship than that which exists between these measures for the Hydrocells samples.

Over the three correlations the Turf Grid samples display all the same relationships as those present in the Hydrocells samples. Generally the Turf Grid samples have stronger predictive relationships, all being about the 60% mark. By comparison the Hydrocells samples were closer to 40% with the exception of the bulk density-shear relationship which was 78%.

From this a few factors can be assessed. The Turf Grids samples are more uniform in their nature and therefore more predictable. This fits with the previously expressed theory of the Hydrocells having more of an influence on the soil profile. It has been shown that this effect was not uniform and therefore the greater variation and less predictable measures are to be expected.

The Hydrocells would be expected to have less of an influence on the shear of the soil than the Turf Grids. If less effect is imparted it could be expected that the measures returned would be more predictable. Again, this was the case.

In summary, the individual measures have little predictive values as far as actual values for the other measures but can be used for comparative purposes.

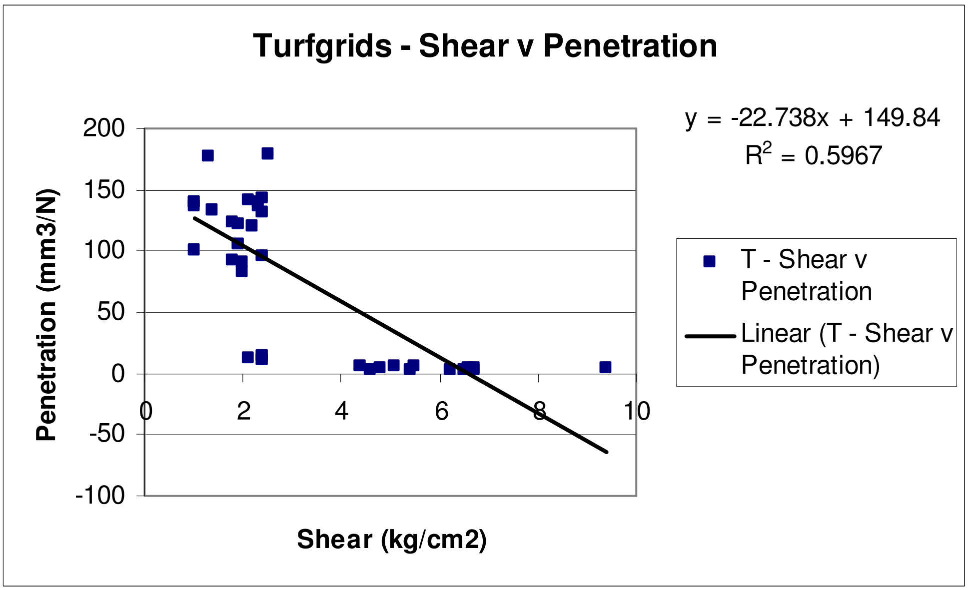

Figure 4.33 : Turf Grids : Shear/Penetration Correlation

4.6 Product Comparisons

The graphs for this section can be found in Appendix C.

4.6.1 Bulk Density

The graphs for the bulk density comparisons highlight some important points regarding the bulk density comparisons. For soil that has been heavily compacted there is no discernable difference between the products. That suggests the amendments have little effect under heavy compaction in reducing the bulk density of the soil.

The lightly compacted samples do provide an interesting result. For the dry samples the Hydrocells have higher bulk density. However for the wet samples this situation is clearly reversed. This lends further weight to the theory that under wet conditions the Hydrocells are effective at reducing the density of the soil.

4.6.2 Shear

For the heavily compacted samples at the initial stage the Hydrocells had higher shear, however this was quickly reversed and the Turf Grids took affect resulting in an increasingly higher shear level on cycles two and three.

The difference between the two products was clear cut right from the beginning on the lightly compacted cycle. Turf Grids always had significantly greater shear. The main aim of the Turf Grids is to act as fake roots and interact with the real roots to form a stronger system for the grass. This results in higher shear. It was unclear prior to this testing whether the Turf Grids would have any effect on plain soil with no grass roots. These results clearly show that they have increased the shear in the soil.

4.6.3 Penetration

As far as penetration measurements go, the reversing effect in the wet samples that were lightly compacted is present again as it was for the bulk density measures. The Hydrocells samples were less receptive to penetration under dry conditions but the Turf Grids were harder under wet conditions.

Under heavy compaction the Turf Grids samples had initially higher penetration indicating the soil was softer, but this difference disappeared on later cycles. This suggests that the higher rates of compaction can negate any difference between the performance of the products.

4.7 Moisture Content Comparisons

The graphs for this section can be found in Appendix D.

4.7.1 Bulk Density

All the wetter samples clearly have higher bulk densities with the only exception being the Hydrocells and light compaction sample for which there is no significant difference between the wet and dry bulk densities on cycles two and three.

The addition of water to the soil then clearly indicates that it is likely to become more compacted and hence denser with the one exception. The exceptional sample is the same one which defied all other trends in previous sections.

4.7.2 Shear

For shear comparisons there is no difference between the wet and dry samples if they are heavily compacted. For the lightly compacted samples there is some evidence that the wetter samples have higher shears, however this effect is lessened on the latter cycles.

4.7.3 Penetration

The wet samples generally had higher rates of penetration than the dry samples. This was true for the heavy and lightly compacted samples. The only exception to this was for the lightly compacted Turf Grid samples where the dry samples actually had more penetration than the wet ones, but it was not a significant amount. Under heavy compaction the difference between wet and dry samples was lessened significantly on the last two cycles especially for the Turf Grid samples. This is the first piece of evidence that has suggested that the Hydrocells are better at reducing compaction than Turf Grids under heavy loading.

4.8 Compaction Rate Comparisons

The graphs for this section can be found in Appendix E.

4.8.1 Bulk Density

The results here were both conclusive and clear cut. Heavier compaction results in increased bulk density. The trend was also for this density to increase with successive cycles. This was uniform across the board.

4.8.2 Shear

As for the bulk density measures it is very clear that heavier compaction results in increased shear. The trend in all samples was for the shear to increase over successive cycles and also for the gap between heavy and light values to widen.

4.8.3 Penetration

In line with the other two measures the heavily compacted samples suffered significantly smaller amounts of compaction than the lightly compacted samples. As with the shears, the differences between the two compaction rates tended to increase over the latter cycles.

It is clear from this evidence that the rate of compaction is a major determinant in how compacted a soil profile becomes.

Chapter 5 - Conclusions

5.1 Application of Results

5.1.1 Effect of Wetting and Drying Cycles

The aim of the wetting and drying cycles was to simulate the natural cycle of rainfall followed by drying. Across all the samples with the one discussed exception, there was a clear trend of increasing hardness over successive cycles. This was the logical and anticipated result. The trend of increasing hardness was evident in all three measures as shown by the increasing bulk density, increasing shear and decreasing penetration values measured.

The early cycles had a greater effect on the soil profile causing more significant changes than the latter cycles. The latter cycles still showed some increase in hardness, however as expected the amount of change became less as the soil became gradually more compacted.

The real world application of this is that early on in a field’s lifetime it is more susceptible to significant compaction due to heavy use. This would also apply if a field received remedial work to improve the surface.

5.1.2 Effect of Compaction

The results for the compaction were very significant and also expected prior to testing. Heavier compaction has a far greater effect on the soil profile, causing far more compaction than lighter loads. The recommendation to be drawn from this is that the amount of traffic going over a field should be carefully monitored to ensure that it is not having an unnecessarily detrimental effect on the field. One method to avoid this would be to avoid using the main field for training and reserve it for games. This is common practice in elite sports already.

5.1.3 Effect of Moisture

A comparison of the results for wet and dry soils showed that wetter profiles contributed to soil profiles being more easily compacted than their dry counterparts.

As a result of this it is recommended that use of fields should be reduced to an absolute minimum at times when the field is significantly wet. This is obviously difficult to do during matches but easily avoidable for training or other activities that can be relocated.

5.1.4 Turf Grids

The Turf Grids product supplied by Stabilizer Solutions had no significant effect on the soil profile in terms of reducing the effects of compaction. However, it was successful in achieving its stated benefit of increasing the shear of a soil profile. The fact that it achieved this without being able to work within a grasses root structure bears testament to its likely effectiveness when used on a soil profile that has grass growing in it.

The Turf Grids product should be used on grounds were there are stability problems due to shifting surfaces. The product when added to the profile will increase the shear and therefore provide the players with a higher level of traction, thus allowing them to perform with more confidence in the ground on which they are playing.

5.1.5 Hydrocells

There was some evidence produced by the testing procedures to suggest that the Hydrocells supplied by Fytogreen do have an effect on the soil profile. This effect was most obvious in the wet and lightly compacted soil where it clearly negated the effects of compaction. Whilst not working as well in dry or heavily compacted soils it is still suspected that some effect was occurring with regards to reducing the density and therefore hardness of the profile.

This is extremely beneficial in a Queensland climate where hard grounds are a primary problem and any method to improve this would be worthy of closer investigation, possibly leading to instigation.

5.2 Achievement of Objectives

In the introductory section of this report three objectives were stated:

- Evaluate the effect of various amendments on the compaction, shear and hardness of soil profiles
- Evaluate the effect of repeated wetting and drying cycles on the soil's physical properties
- Make recommendations on the appropriateness of specific soil amendments to improve the playability of sports field surfaces.

All these objectives have been achieved after the experiments were conducted and the results compiled and analysed in this report.

5.3 Further Research

Some areas of possible further research have been generated by this work. Given that the Hydrocells product returned encouraging results regarding reducing the effects of compaction, it would be beneficial to conduct in-situ field tests to further evaluate their effectiveness prior to formally proposing the effectiveness of the product in improving sports fields.

Within the Hydrocells research branch, it would be useful to conduct tests to discover the effect the Hydrocells water absorption abilities have with regards to the amount of watering a field requires if the soil contains Hydrocells. If it could be determined that the addition of Hydrocells to the soil profile had a significant effect on the amount of water a field required, it would have substantial benefits in a climate which experiences dry spells and where water supply is a real issue.

The next logical step in the research involving Turf Grids is to test the product in a profile that is growing grass. The results would be expected to be positive given the results achieved without grass in these tests and that this is the recommendation of the manufacturer.

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Appendix A - Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR: Benjamin Geoffrey LUSK

TOPIC: SOIL AMENDMENTS TO IMPROVE PLAYABILITY AND REDUCE INJURY RISKS ON SPORTING FIELDS

SUPERVISOR: A/Professor Steven Raine

SPONSOR: National Centre for Engineering in Agriculture

PROJECT AIM: This project aims to investigate methods for improving defective sports field surfaces with common problems such as compaction, wear and drainage.

PROGRAMME: Issue A, 24 March 2004

1. Identify the problems that reduce the playability and increase risk of injury on sporting fields.
2. Identify current techniques used to alleviate these problems and their effectiveness.
3. Identify techniques used to measure the playability of sporting fields.
4. Prepare and evaluate alternative soil amendment treatments to improve sports surfaces.
5. Analyse results and develop recommendations on the effectiveness of different soil amendments to improve turf management and playability.

AGREED:

_________________ (Student) __/__/__ _____________ (Supervisor) __/__/__

Appendix B - Data Tables

Penetration (mm)

Code: TDH			
	Cycles		
Sample	1	2	3
A	5.72	1.51	3.15
B	6.63	1.71	2.47
C	6.52	1.72	2.82
Average	6.290	1.647	2.813
St. Dev	0.497	0.118	0.340

Code: TDL			
	Cycles		
Sample	1	2	3
A	10.37	7.42	10.09
B	10.35	9.84	10.42
C	13.13	10.14	10.64
Average	11.283	9.133	10.383
St. Dev	1.599	1.491	0.277

Load per Area (N/mm2)

Code: TDH			
	Cycles		
Sample	1	2	3
A	0.4969	0.4969	0.4969
B	0.4969	0.4969	0.4969
C	0.4969	0.4969	0.4969
Average	0.497	0.497	0.497
St. Dev	0.000	0.000	0.000

Code: TDL			
	Cycles		
Sample	1	2	3
A	0.0742	0.0742	0.0742
B	0.0742	0.0742	0.0742
C	0.0742	0.0742	0.0742
Average	0.074	0.074	0.074
St. Dev	0.000	0.000	0.000

Penetration per load per area (mm3/N)

Code: TDH			
	Cycles		
Sample	1	2	3
A	11.51	3.04	6.34
B	13.34	3.44	4.97
C	13.12	3.46	5.68
Average	12.66	3.31	5.66
St. Dev	1.00	0.24	0.68
95%Min	10.70	2.85	4.32
95%Max	14.62	3.78	7.00

Code: TDL			
	Cycles		
Sample	1	2	3
A	139.76	100.00	135.98
B	139.49	132.61	140.43
C	176.95	136.66	143.40
Average	152.07	123.09	139.94
St. Dev	21.55	20.10	3.73
95%Min	109.82	83.70	132.62
95%Max	194.31	162.48	147.25

Penetration (mm)

Code: TWH			
	Cycles		
Sample	1	2	3
A		2.77	1.55
B	8.15	2.14	2.42
C	9.02	1.98	1.6
Average	8.585	2.297	1.857
St. Dev	0.615	0.418	0.489

Code: TWL			
	Cycles		
Sample	1	2	3
A	9.7	9.14	7.11
B	10.48	6.9	8.87
C	9.08	7.8	13.3
Average	9.753	7.947	9.760
St. Dev	0.702	1.127	3.190

Load per Area (N/mm2)

Code: TWH			
	Cycles		
Sample	1	2	3
A		0.4969	0.4969
B	0.0994	0.4969	0.4969
C	0.0994	0.4969	0.4969
Average	0.099	0.497	0.497
St. Dev	0.000	0.000	0.000

Code: TWL			
	Cycles		
Sample	1	2	3
A	0.0742	0.0742	0.0742
B	0.0742	0.0742	0.0742
C	0.0742	0.0742	0.0742
Average	0.074	0.074	0.074
St. Dev	0.000	0.000	0.000

Penetration per load per area (mm3/N)

Code: TWH			
	Cycles		
Sample	1	2	3
A		5.57	3.12
B	81.99	4.31	4.87
C	90.74	3.98	3.22
Average	86.37	4.62	3.74
St. Dev	6.19	0.84	0.98
95%Min	74.24	2.97	1.81
95%Max	98.50	6.27	5.66

Code: TWL			
	Cycles		
Sample	1	2	3
A	130.73	123.18	95.82
B	141.24	92.99	119.54
C	122.37	105.12	179.25
Average	131.45	107.10	131.54
St. Dev	9.45	15.19	42.99
95%Min	112.92	77.32	47.28
95%Max	149.98	136.87	215.79

Penetration (mm)

Code: HDH			
	Cycles		
Sample	1	2	3
A	1.24	0.69	0.44
B	1.53	0.68	0.49
C	0.98	0.66	0.47
Average	1.250	0.677	0.467
St. Dev	0.275	0.015	0.025

Code: HDL			
	Cycles		
Sample	1	2	3
A		2.3	4.73
B	4.05	2.3	4.6
C	4.23	2.43	3.71
Average	4.140	2.343	4.347
St. Dev	0.127	0.075	0.555

Load per Area (N/mm2)

Code: HDH			
	Cycles		
Sample	1	2	3
A	0.2225	0.2225	0.2225
B	0.2225	0.2225	0.2225
C	0.2225	0.2225	0.2225
Average	0.223	0.223	0.223
St. Dev	0.000	0.000	0.000

Code: HDL			
	Cycles		
Sample	1	2	3
A	0.0371	0.0371	0.0371
B	0.0371	0.0371	0.0371
C	0.0371	0.0371	0.0371
Average	0.037	0.037	0.037
St. Dev	0.000	0.000	0.000

Penetration per load per area (mm3/N)

Code: HDH			
	Cycles		
Sample	1	2	3
A	5.57	3.10	1.98
B	6.88	3.06	2.20
C	4.40	2.97	2.11
Average	5.62	3.04	2.10
St. Dev	1.24	0.07	0.11
95%Min	3.19	2.91	1.88
95%Max	8.04	3.18	2.32

Code: HDL			
	Cycles		
Sample	1	2	3
A		61.99	127.49
B	109.16	61.99	123.99
C	114.02	65.50	100.00
Average	111.59	63.16	117.16
St. Dev	3.43	2.02	14.96
95%Min	104.87	59.20	87.83
95%Max	118.31	67.13	146.49

Penetration (mm)

Code: HWH			
	Cycles		
Sample	1	2	3
A	1.24	1.5	1.47
B	1.31	1.7	1.53
C	1.22	1.44	1.34
Average	1.257	1.547	1.447
St. Dev	0.047	0.136	0.097

Code: HWL			
	Cycles		
Sample	1	2	3
A	11.4	9.3	11.35
B	10.97	10.82	11.49
C	10.4	9.32	11.47
Average	10.923	9.813	11.437
St. Dev	0.502	0.872	0.076

Load per Area (N/mm2)

Code: HWH			
	Cycles		
Sample	1	2	3
A	0.0742	0.2225	0.2225
B	0.0742	0.2225	0.2225
C	0.0742	0.2225	0.2225
Average	0.074	0.223	0.223
St. Dev	0.000	0.000	0.000

Code: HWL			
	Cycles		
Sample	1	2	3
A	0.0371	0.0223	0.0223
B	0.0371	0.0223	0.0223
C	0.0371	0.0223	0.0223
Average	0.037	0.022	0.022
St. Dev	0.000	0.000	0.000

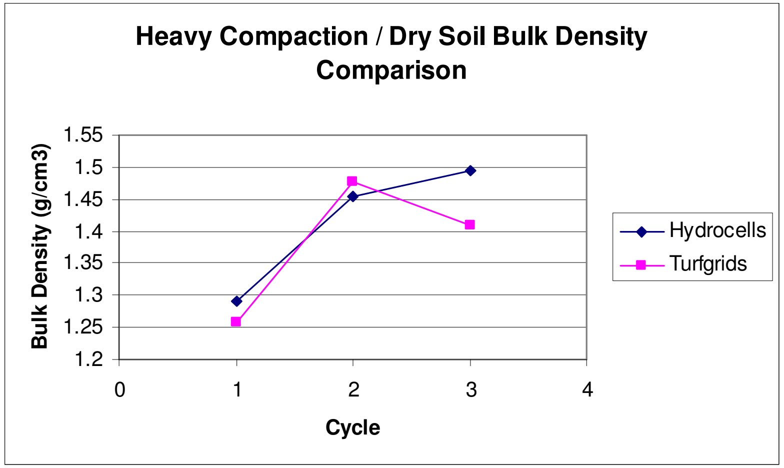
Penetration per load per area (mm3/N)

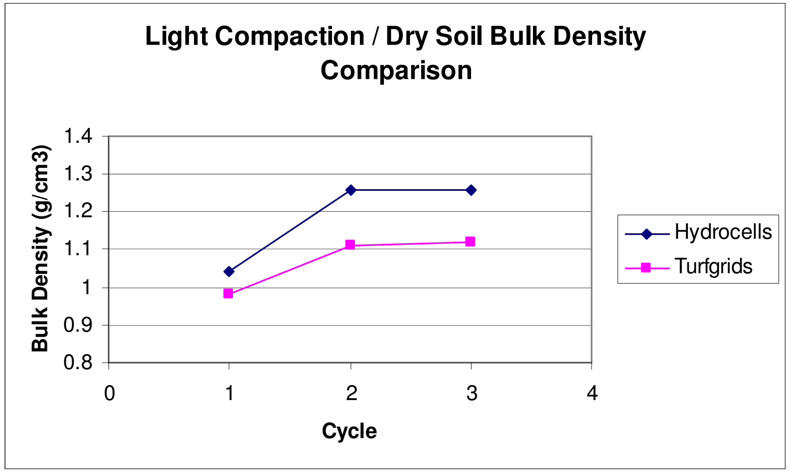
Code: HWH			
	Cycles		
Sample	1	2	3
A	16.71	6.74	6.61
B	17.65	7.64	6.88
C	16.44	6.47	6.02
Average	16.94	6.95	6.50
St. Dev	0.64	0.61	0.44
95%Min	15.69	5.75	5.65
95%Max	18.18	8.15	7.36

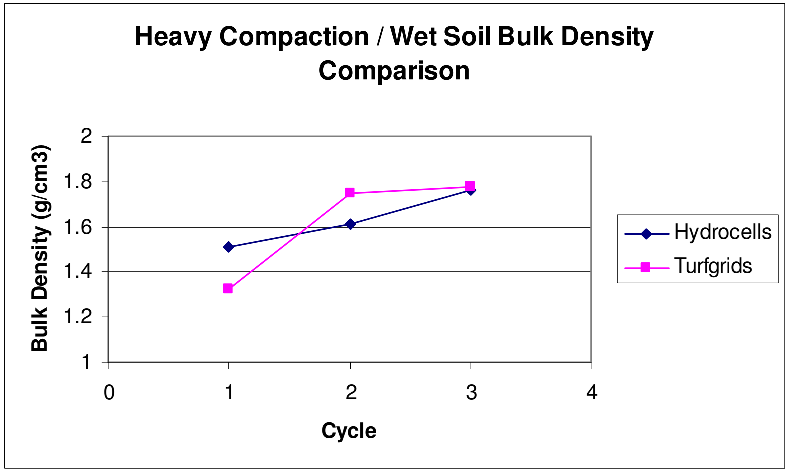
Code: HWL			
	Cycles		
Sample	1	2	3
A	307.28	417.04	508.97
B	295.69	485.20	515.25
C	280.32	417.94	514.35
Average	294.43	440.06	512.86
St. Dev	13.52	39.10	3.40
95%Min	267.93	363.43	506.20
95%Max	320.93	516.69	519.51

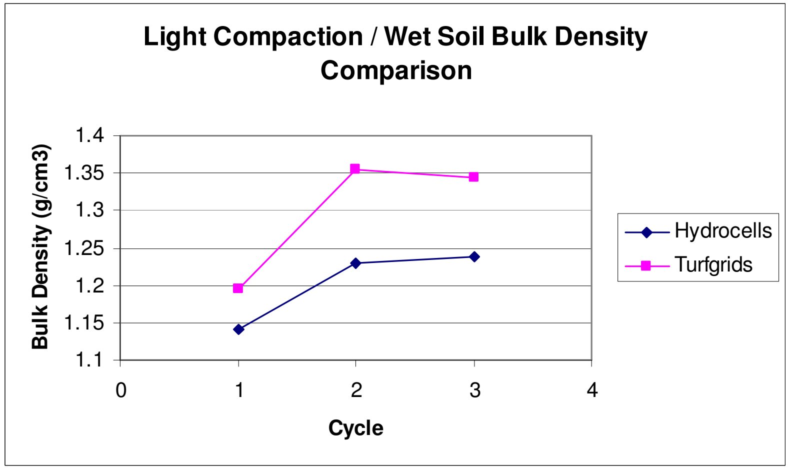
Appendix C - Product Comparison

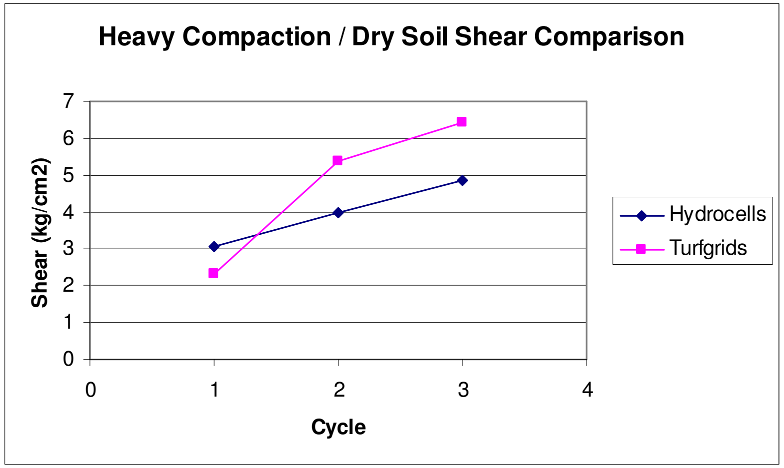
Graphs

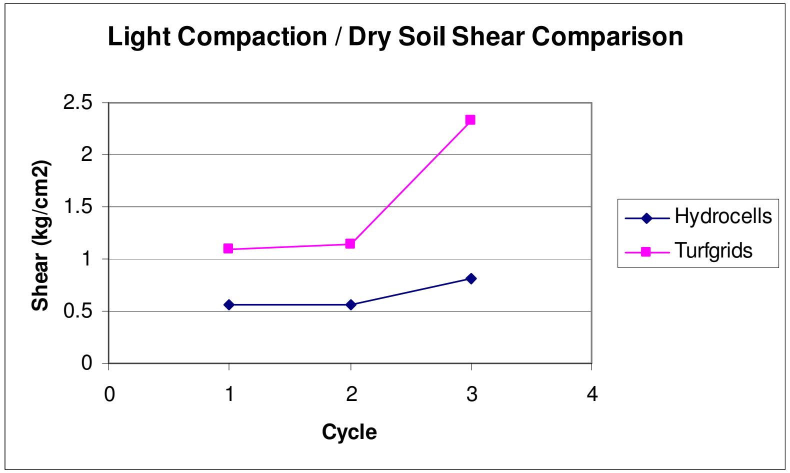

Heavy Compaction / Dry Soil Bulk Density Comparison
Bulk Density (g/cm3)
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

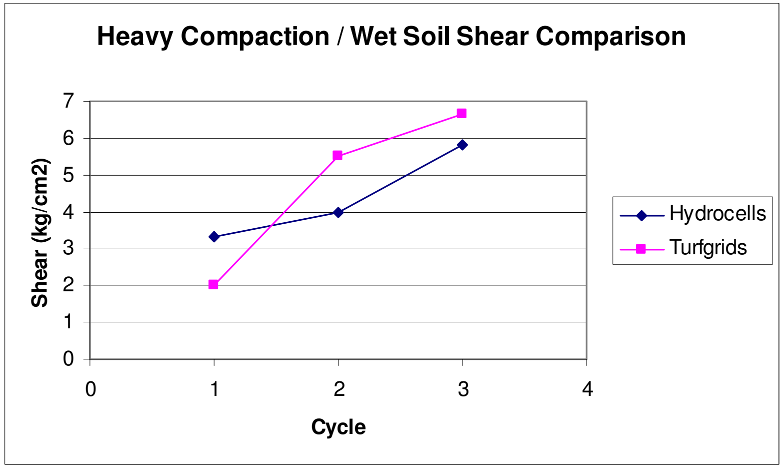

Light Compaction / Dry Soil Bulk Density Comparison
Bulk Density (g/cm3)
1.4
1.3
1.2
1.1
1
0.9
0.8
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

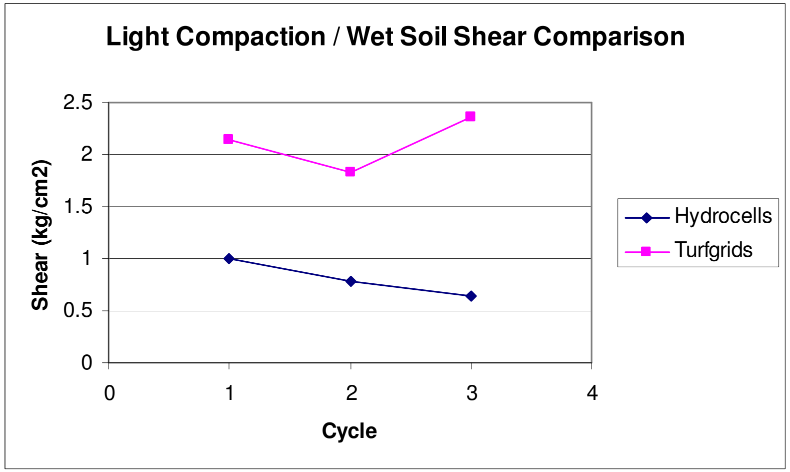

Heavy Compaction / Wet Soil Bulk Density Comparison
Bulk Density (g/cm3)
2
1.8
1.6
1.4
1.2
1
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

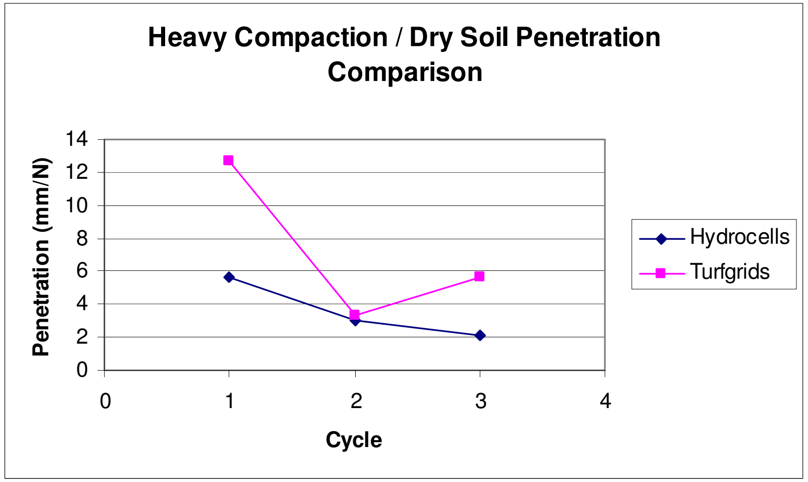

Light Compaction / Wet Soil Bulk Density Comparison
Bulk Density (g/cm3)
1.4
1.35
1.3
1.25
1.2
1.15
1.1
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

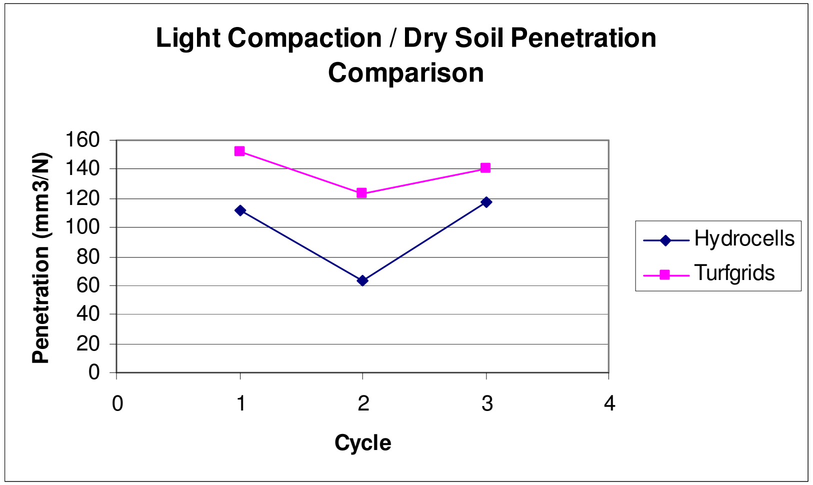

Heavy Compaction / Dry Soil Shear Comparison
Shear (kg/cm2)
7
6
5
4
3
2
1
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

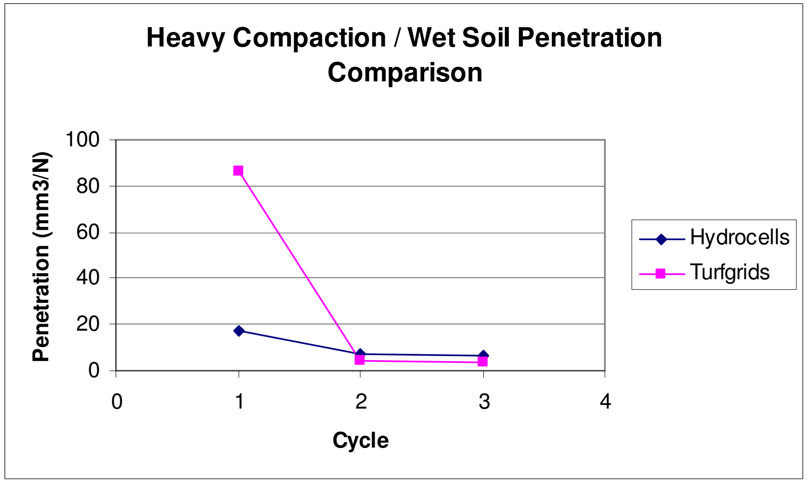

Light Compaction / Dry Soil Shear Comparison
Shear (kg/cm2)
2.5
2
1.5
1
0.5
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

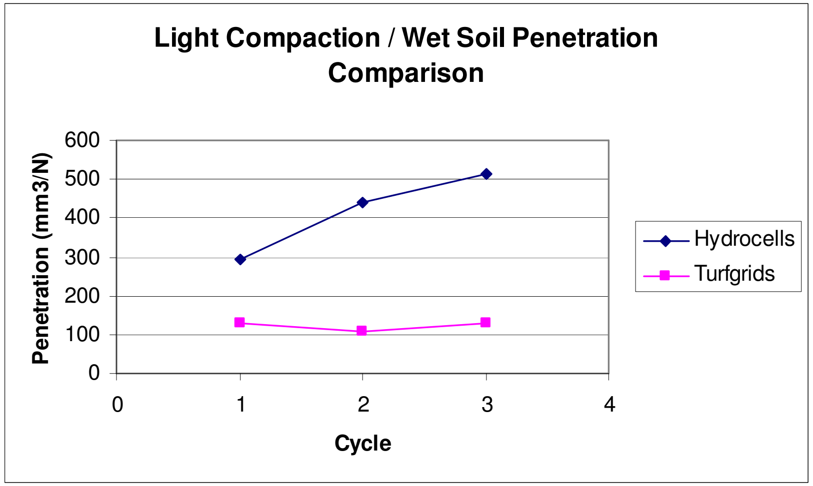

Heavy Compaction / Wet Soil Shear Comparison
Shear (kg/cm2)
7
6
5
4
3
2
1
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids


Light Compaction / Wet Soil Shear Comparison
Shear (kg/cm2)
2.5
2
1.5
1
0.5
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids


Heavy Compaction / Dry Soil Penetration Comparison
Penetration (mm/N)
14
12
10
8
6
4
2
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

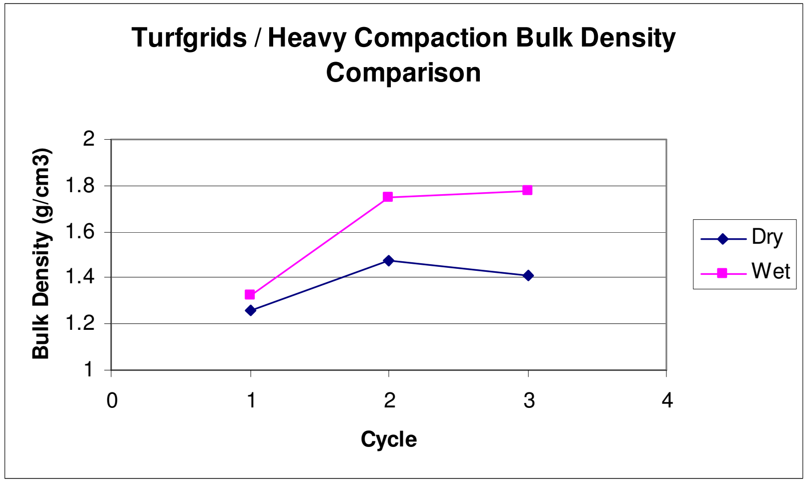

Light Compaction / Dry Soil Penetration Comparison
Penetration (mm3/N)
160
140
120
100
80
60
40
20
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

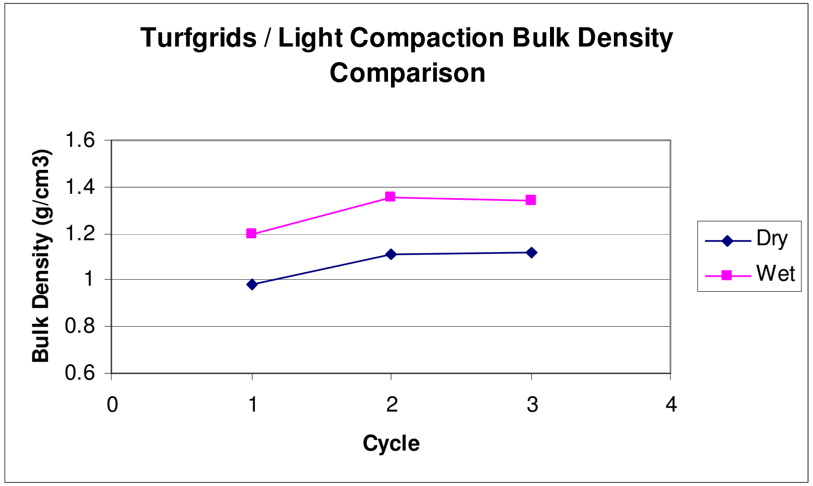

Heavy Compaction / Wet Soil Penetration Comparison
Penetration (mm3/N)
100
80
60
40
20
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

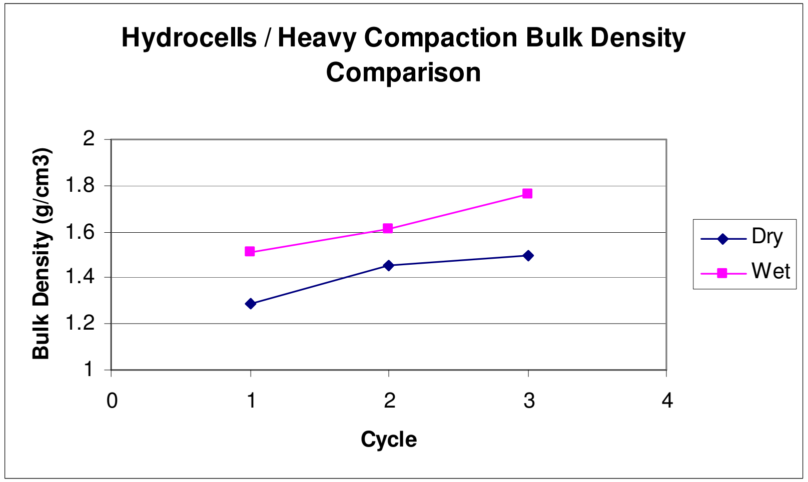

Light Compaction / Wet Soil Penetration Comparison
Penetration (mm3/N)
600
500
400
300
200
100
0
0
1
2
3
4
Cycle
Hydrocells
Turfgrids

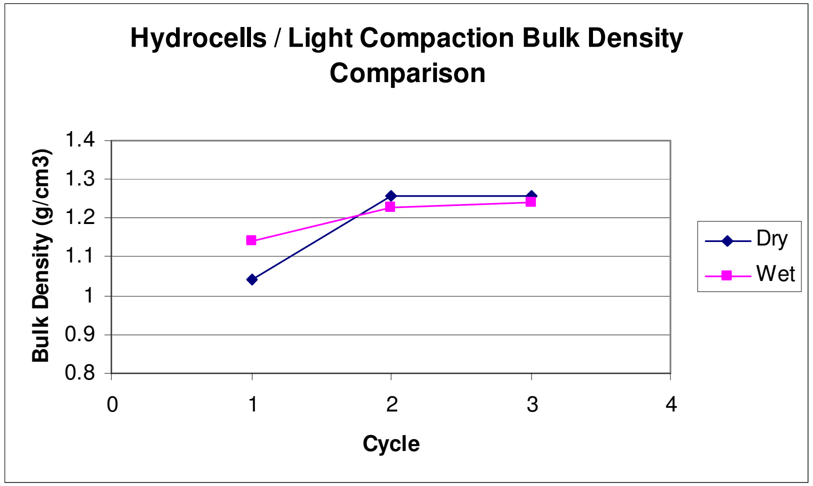
Appendix D - Moisture Content

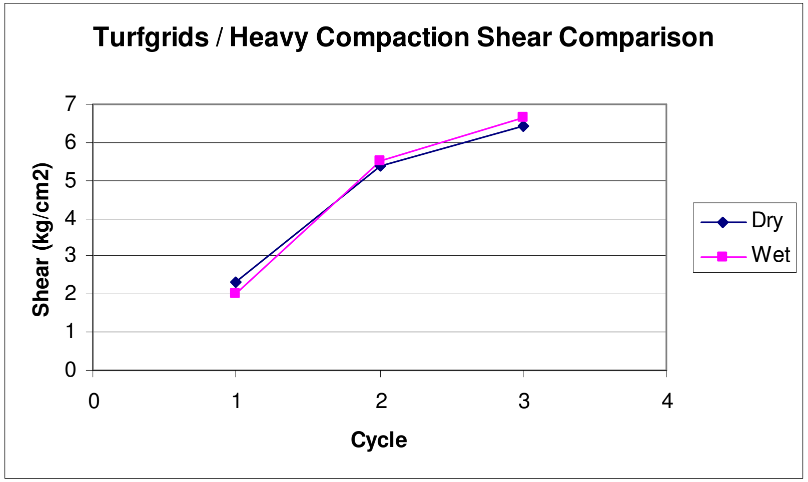
Comparison Graphs

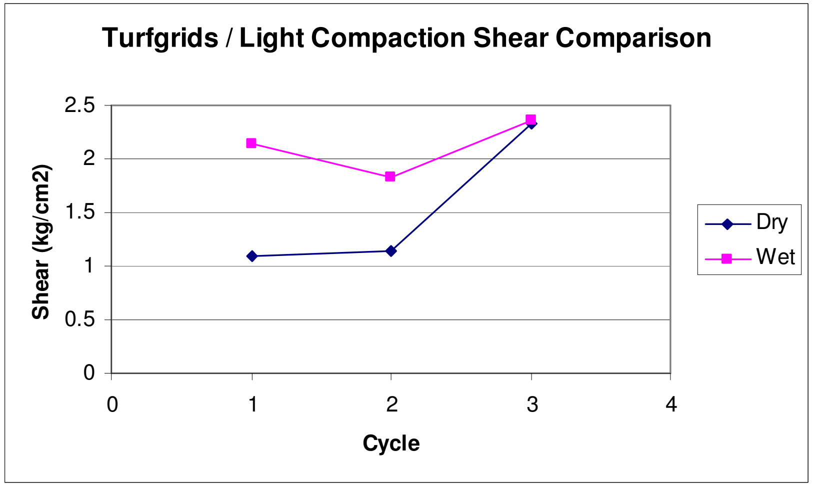

Turfgrids / Heavy Compaction Bulk Density Comparison

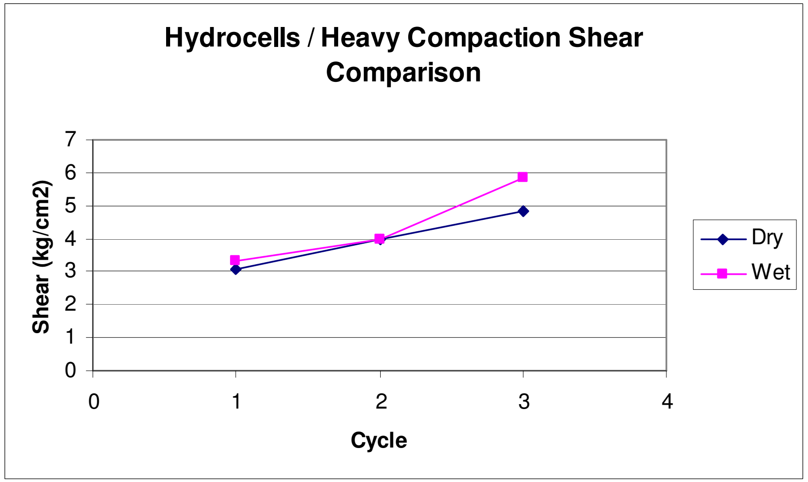

Turfgrids / Light Compaction Bulk Density Comparison

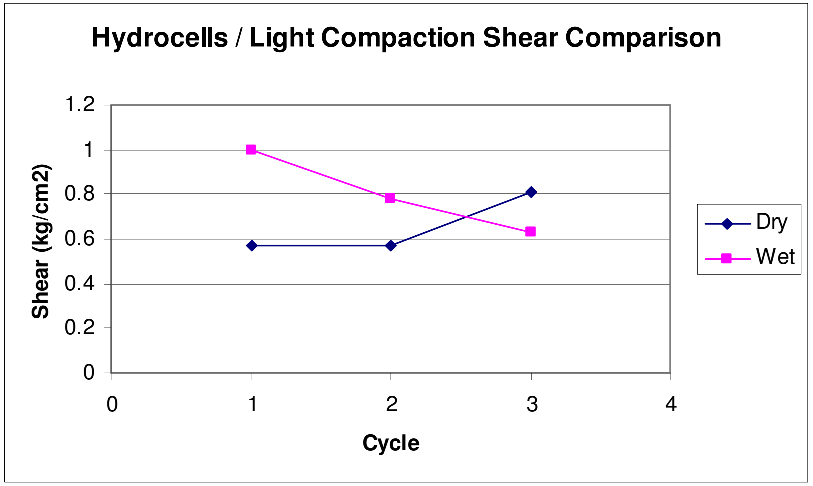

Hydrocells / Heavy Compaction Bulk Density Comparison

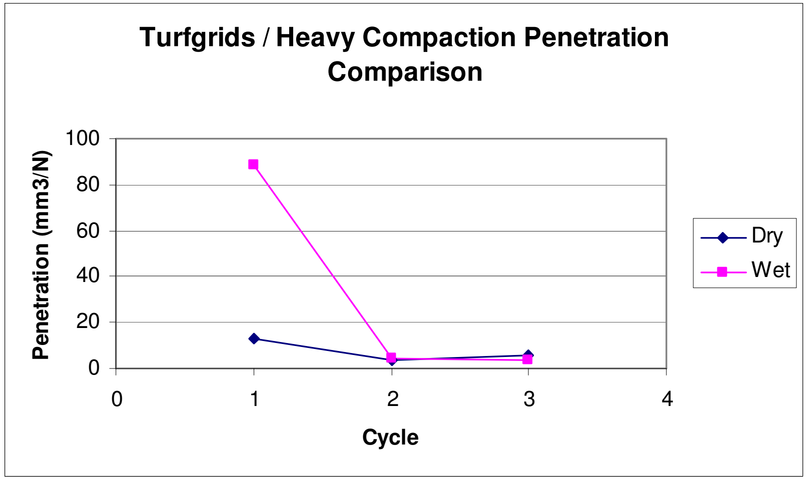

Hydrocells / Light Compaction Bulk Density Comparison


Turfgrids / Heavy Compaction Shear Comparison
Shear (kg/cm2)
0
1
2
3
4
5
6
7
Cycle
0
1
2
3
4
Dry
Wet

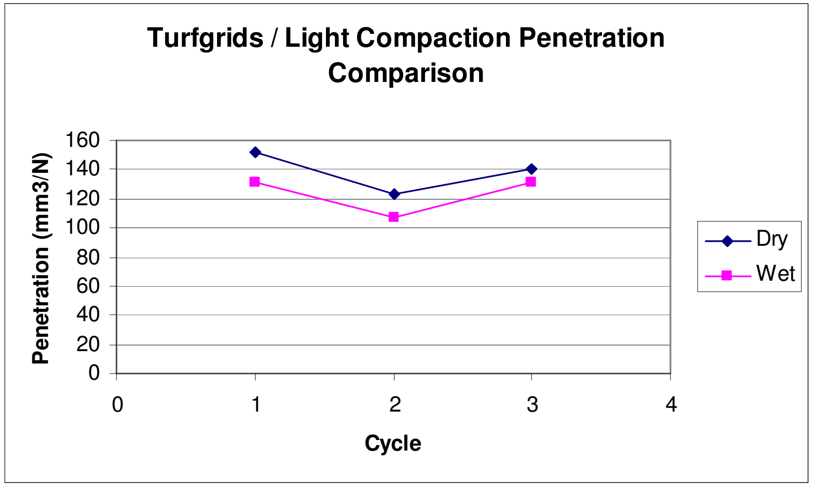

Turfgrids / Light Compaction Shear Comparison
Shear (kg/cm2)
0
0.5
1
1.5
2
2.5
Cycle
0
1
2
3
4
Dry
Wet


Hydrocells / Heavy Compaction Shear Comparison
Shear (kg/cm2)
0
1
2
3
4
5
6
7
Cycle
0
1
2
3
4
Dry
Wet

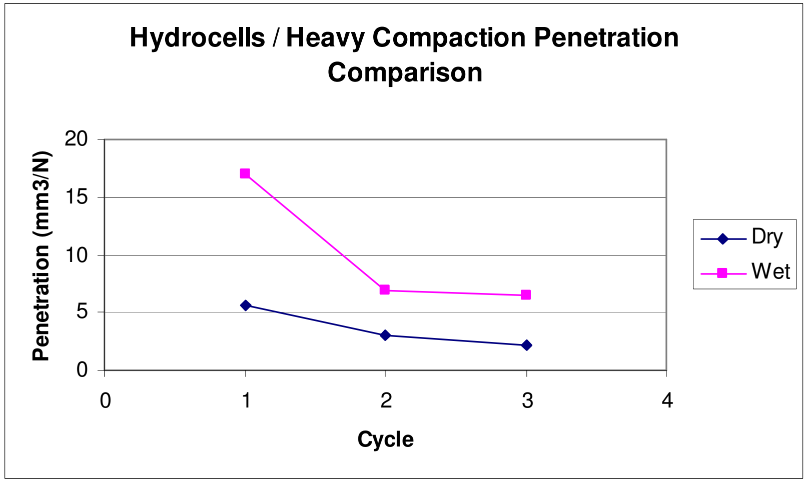

Hydrocells / Light Compaction Shear Comparison
Shear (kg/cm2)
0
0.2
0.4
0.6
0.8
1
1.2
Cycle
0
1
2
3
4
Dry
Wet



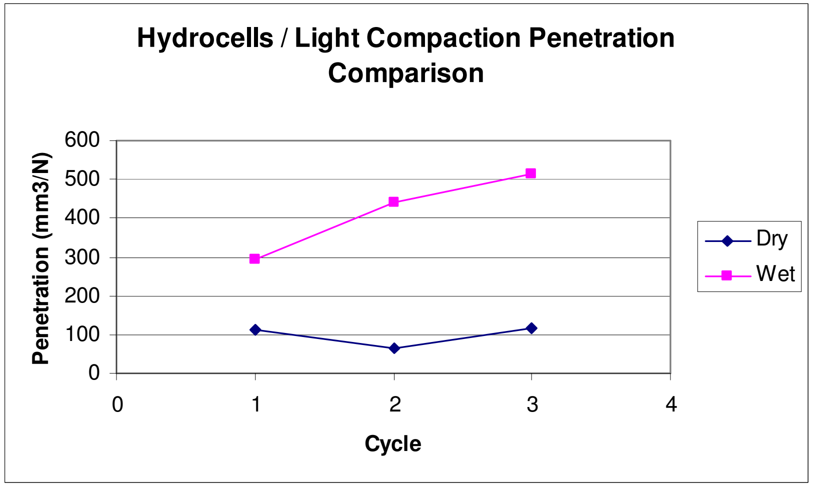
Turfgrids / Heavy Compaction Penetration Comparison



Turfgrids / Light Compaction Penetration Comparison



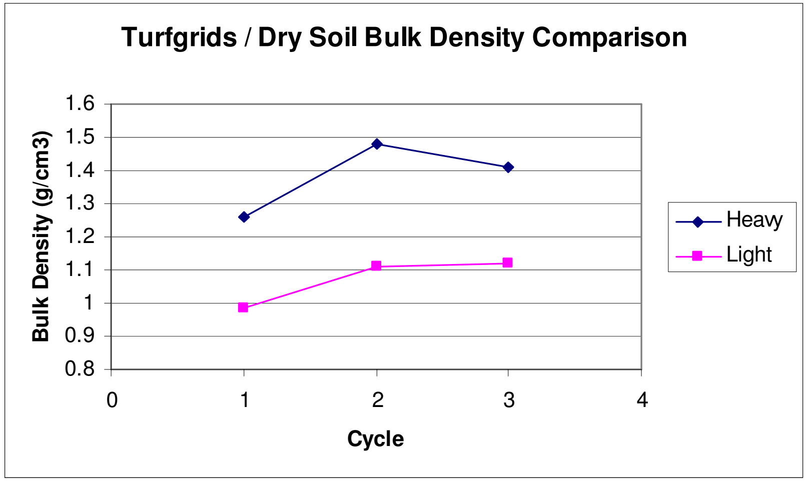
Hydrocells / Heavy Compaction Penetration Comparison

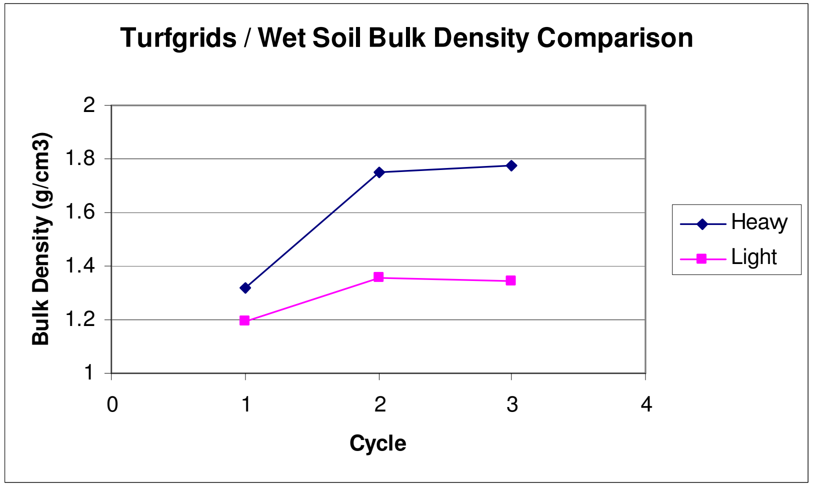


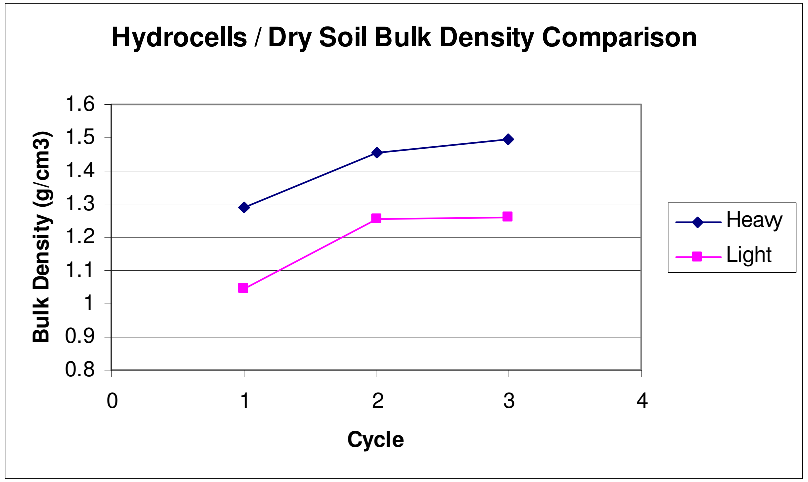
Hydrocells / Light Compaction Penetration Comparison

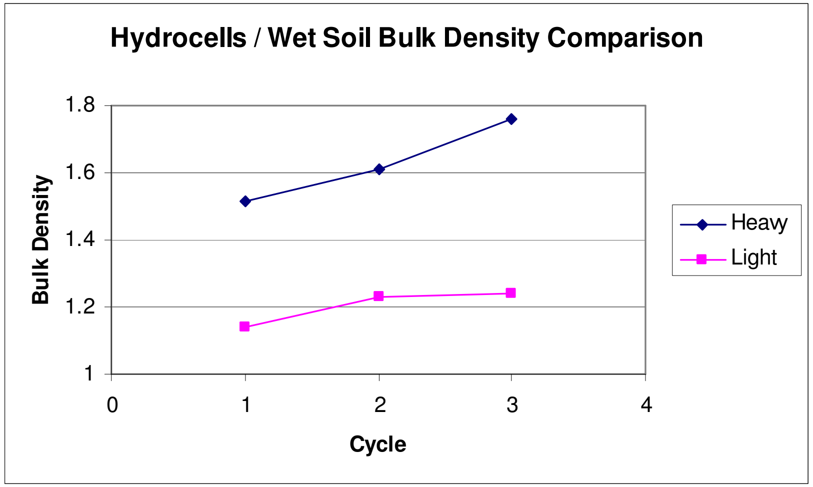
Appendix E - Compaction Rate

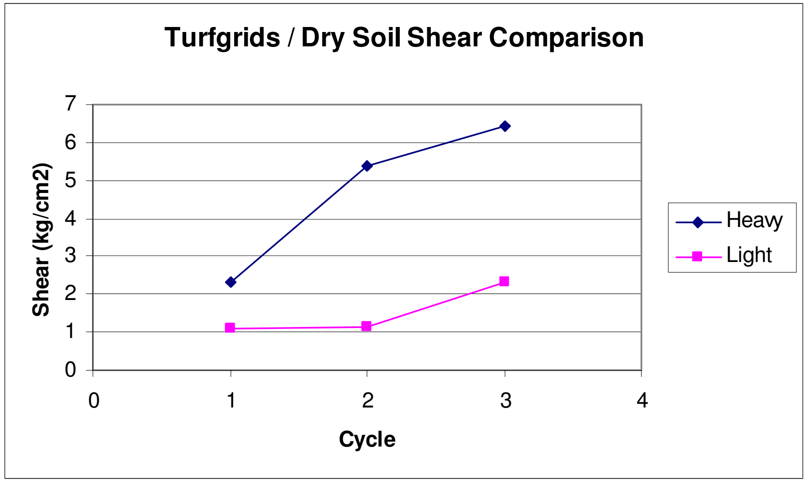
Comparison Graphs


Turfgrids / Dry Soil Bulk Density Comparison
Bulk Density (g/cm3)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
1
2
3
4
Cycle
Heavy
Light

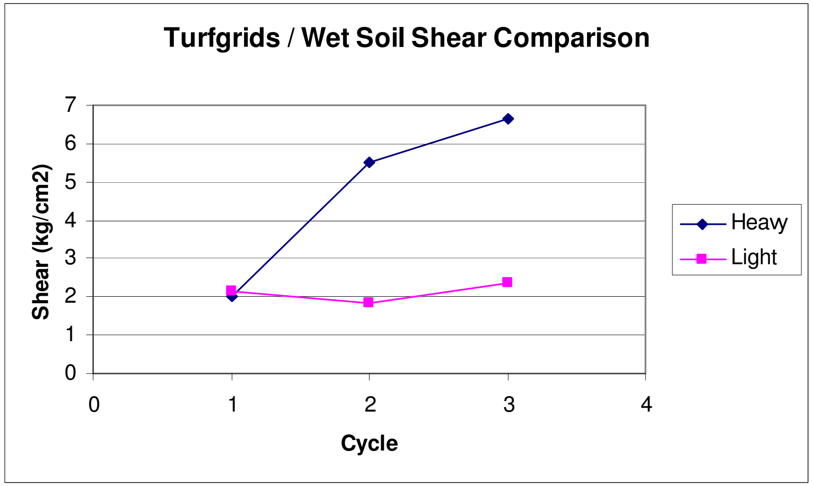

Turfgrids / Wet Soil Bulk Density Comparison
Bulk Density (g/cm3)
2
1.8
1.6
1.4
1.2
1
0
1
2
3
4
Cycle
Heavy
Light


Hydrocells / Dry Soil Bulk Density Comparison
Bulk Density (g/cm3)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
1
2
3
4
Cycle
Heavy
Light

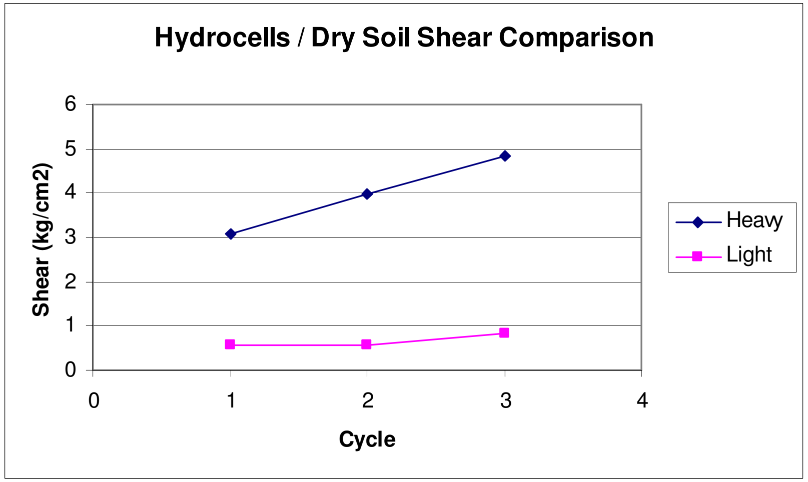

Hydrocells / Wet Soil Bulk Density Comparison
Bulk Density
1.8
1.6
1.4
1.2
1
0
1
2
3
4
Cycle
Heavy
Light



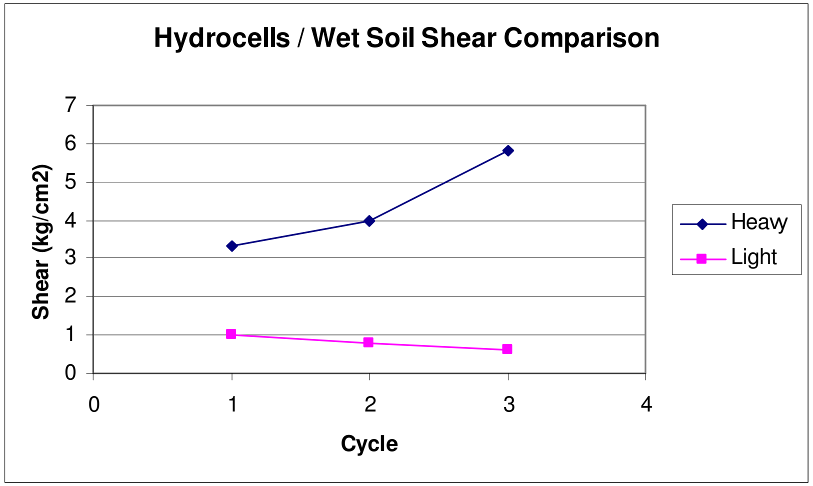
Turfgrids / Dry Soil Shear Comparison



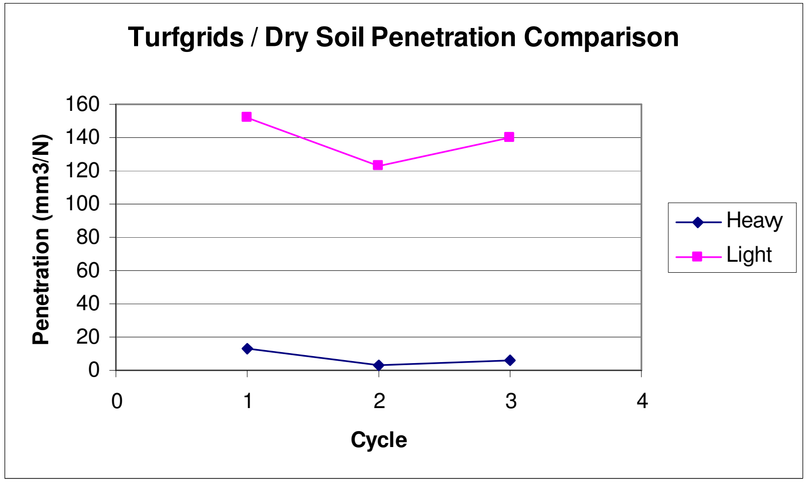
Turfgrids / Wet Soil Shear Comparison

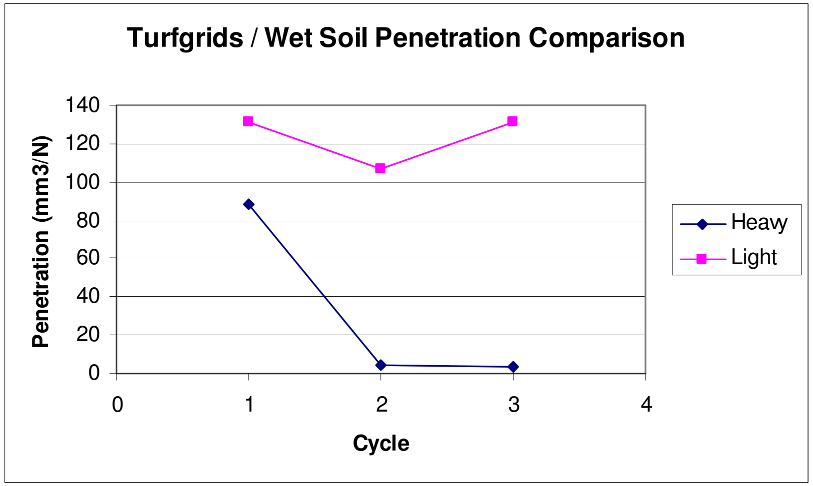


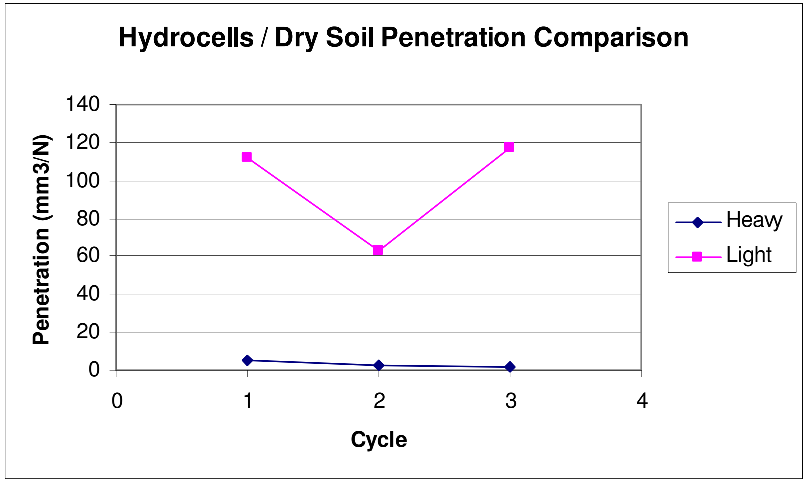
Hydrocells / Dry Soil Shear Comparison

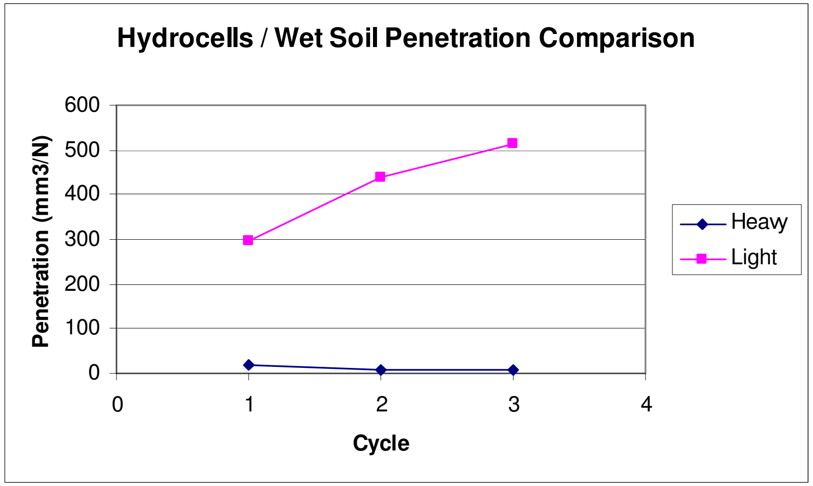


Hydrocells / Wet Soil Shear Comparison


Turfgrids / Dry Soil Penetration Comparison


Turfgrids / Wet Soil Penetration Comparison


Hydrocells / Dry Soil Penetration Comparison


Hydrocells / Wet Soil Penetration Comparison