The Pennsylvania State University
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IMPACT ABSORPTION AND TRACTION CHARACTERISTICS
OF TURF AND SOIL SURFACES

A Thesis in
Agronomy

by

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Abstract
Impact Absorption and Traction Characteristics of Turf and Soil Surfaces
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This study investigated the effects on impact absorption and traction characteristics of turf and soil surfaces. A portable device (a combination of the Clegg Soil Impact Tester and the Bruel and Kjaer LS 2515 Vibration Analyzer) was used to measure impact absorption, while traction was measured with the Eijkelkamp field shear test apparatus. Impact absorption was measured with 0.5, 2.25 and 4.5 kg hammers. These devices were used to investigate differences in impact absorption and traction characteristics in agronomic factors and turfgrass maintenance practices such as soil moisture, soil bulk density, soil compaction, aeration (core cultivation), vegetation and thatch.

Soil moisture was the most important factor in determining impact absorption characteristics of surfaces. Decreasing soil moisture was associated with higher peak deceleration values (peak deceleration is the point of maximum deceleration). The presence of vegetation and use of aeration lowered peak deceleration values only during periods of low soil moisture. Higher soil bulk densities were associated with higher peak deceleration values. Thatch absorbed more of the impact created with the 0.5 kg hammer than with the 2.25 kg hammer. In general, the lighter the hammer, the greater the differences in peak deceleration values among the agronomic factors and turfgrass maintenance practices studied. The presence of roots was the most important factor in determining traction levels. Higher traction was associated with turf covered surfaces as compared to bare surfaces.
ABSTRACT

Playing quality of athletic fields is important to an athlete from both performance and safety standpoints. Two important interactions between the player and the surface involve the impact energy created by the player that is absorbed by the surface (hardness) and the type of footing a playing surface provides (traction). No method for quantitative assessment of athletic fields has been established. There is a need for a portable apparatus to measure impact absorption on athletic fields that can be used in conjunction with a portable shear vane apparatus to measure traction. The objectives of this study were to develop a portable system to measure impact absorption and to use this apparatus in conjunction with a shear vane apparatus to determine the effects of several management practices and agronomic factors on hardness and traction of turf and soil surfaces.

Impact absorption was measured with a combination of the Clegg Impact Soil Tester (CIT) and the Bruel and Kjaer LS 2515 Vibration Analyzer. An accelerometer attached to an impact hammer (dropped from a set height) sends a voltage output upon impact to the LS 2515, where the signal is displayed as a deceleration-time curve. This portable system can store and average impact data and is reliable to the nearest 1 g (g = acceleration due to gravity). The stored impact curves are transferred from the LS 2515 to a microcomputer (a program was written to analyze several impact characteristics of the impact curve) for analysis. Three impact hammers (4.5, 2.25 and 0.5 kg) were evaluated in this study. The 4.5 kg hammer is standard equipment for the CIT, while the 2.25 kg hammer
approximates the impacting energy (force/unit area) of a hammer used in the American Society for Testing and Materials standard (F355-86), and the 0.5 kg is the same as that used by researchers in Europe.

The study included measurements utilizing the combination of the CIT and the LS 2515 Vibration Analyzer and the three hammers, along with the shear vane to assess factors such as vegetation, cutting height, soil compaction, aeration, thatch and soil moisture. Impact characteristics measured included peak deceleration, total duration of impact, time to peak deceleration, rate of change in deceleration, deformation, severity index, and rebound ratio. Correlations among impact characteristics and among hammers were also determined.

Cutting height of Kentucky bluegrass (Poa pratensis L.) and tall fescue (Festuca arundinacea Schreb.) did not affect impact absorption characteristics measured with the 2.25 or 4.5 kg hammers. With the 0.5 kg hammer, increasing cutting height increased the impact absorbing ability of tall fescue. The presence of vegetation decreased impact values with a more dramatic effect evident during sampling dates of low moisture. Under certain conditions there was no difference in peak deceleration values between turf covered and bare surfaces. However, the time to peak deceleration was shorter on bare than turf-covered surfaces.

Compacted soil increased impact values in both Kentucky bluegrass and tall fescue turf. This was evident with all three hammers. The differences between compaction levels increased with decreasing soil moisture. Aeration of compacted soil tended to decrease the impact values of Kentucky bluegrass but not to the level of undisturbed turf.
This trend was not as pronounced for tall fescue turf. Again, the effects of aeration were more pronounced at lower soil moisture levels.

Thatch decreased impact absorption values on fine fescue (*Festuca rubra* L.), Kentucky bluegrass, and zoysiagrass (*Zoysia japonica* Steud.) turf. Verdure did not significantly reduce the impact values over that of thatch alone. This trend was consistent both in situ and with turf plugs on a pad. Increasing thatch thickness was associated with decreasing peak deceleration values of fine fescue and zoysiagrass turf. The presence of roots increased traction values regardless of species. Overall, traction levels were lower for tall fescue than Kentucky bluegrass turf and for aerated turf.

The range of peak deceleration values in this research was 59-394 g with the 0.5 kg hammer respectively. Maximum peak deceleration value difference due to compaction was 53, 32, and 19 g with the 0.5, 2.25, and 4.5 kg hammers. The peak deceleration range on bare soil was 72-394-, 41-165, and 27-126 g with the 0.5, 2.25, and 4.5 kg hammers, respectively, while the range on turf was 59-215, 43-131, and 27-92 g. Traction values ranged from 27-79 kPa.

All of the impact characteristics were strongly correlated with each other except for rebound ratio. The poorest correlation between hammers existed between the 0.5 and 4.5 kg hammers while the strongest was between the 0.5 and the 2.25 kg hammers.
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0.5 kg Hammer
2.25 kg Hammer
4.5 kg Hammer

Traction

Experiment 3

Impact Absorption on Kentucky Bluegrass Turf

0.5 kg Hammer
2.25 kg Hammer
4.5 kg Hammer

Traction on Kentucky Bluegrass Turf

Impact Absorption on Tall Fescue Turf

0.5 kg Hammer
2.25 kg Hammer
4.5 kg Hammer

Traction on Tall Fescue Turf

Experiment 4

Impact Absorption on Kentucky Bluegrass Turf

0.5 kg Hammer
2.25 kg Hammer

Traction on Kentucky Bluegrass Turf

Impact Absorption on Tall Fescue Turf

0.5 kg Hammer
2.25 kg Hammer
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Traction on Tall Fescue Turf

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0.5 kg Hammer
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INTRODUCTION

A high quality athletic field surface should be a smooth, even, well-drained surface covered with a dense, highly wear tolerant grass. Certainly the soil type and grass species best suited for an area will vary widely; however, the basic requirements for maintaining a high quality turf are similar.

A wide range of conditions exists for athletic fields. The conditions vary not only in agronomic factors, but also in maintenance levels (Harper et al., 1984) and construction methods. This variance can lead to differential effects on player performance and on the behavior of balls in sports such as baseball and soccer.

With recent increases in "free" time (Peterson, 1973), and a growing concern for physical fitness, outdoor sports are gaining popularity. Many of these sports are played on fields that already receive intense use from various community events.

The natural versus artificial turf debate has focused attention on the safety of natural as well as artificial turf. As with any sporting activity, injuries occur. However, there is a big difference when the injury is due to player/player contact as compared to player/field related injury. If the injury is due to the field conditions, either poor construction methods or maintenance practices, the possibility of personal liability by the field owners and/or operators exists.

The effect a field has on player safety and player performance as well as ball performance may be termed as the playing quality of a field. Fields that are hard can be dangerous to players, while a soft spongy field may create early fatigue in the leg muscles of a player.
Similarly, uneven, bumpy, sparsely covered playing surfaces can cause the ball bounce and roll to be unpredictable and also adversely affect footing.

Playing quality of athletic fields involves three different but related interactions (Bell et al., 1985). They are the effects a field has on the ball and two player/surface interactions: the effect the surface has on absorbing impact energy created by a player (this effect is also referred to as hardness) and the type of footing a playing surface provides (traction). While the description of these interactions seems both logical and simplistic, characterization of these interactions on different surfaces depends on the number of extrinsic and intrinsic factors associated with the particular athletic field. In order to compare surfaces, quantitative means for measuring these characteristics are necessary.

In the following pages, a literature review on research dealing with the quantification of the above interactions will be presented. It will include the research conducted on ball interactions and hardness and traction of athletic fields, along with the effects of maintenance practices and agronomic factors on these interactions. From this review a justification for this dissertation will be presented along with the objectives of this research.
LITERATURE REVIEW

While the demand for top playing quality of athletic fields is prevalent, means for assessing this quality are not widespread. Researchers have investigated several methods for evaluation of athletic fields that have included both qualitative and quantitative tests.

Qualitative Assessment of Athletic Fields

The hardness of an athletic surface affects the player as well as ball bounce. Boeckel (1977) suggested a qualitative method for evaluating field surfaces known as the heel method. Top soil stability was rated from 1 to 9 by pushing the heel of a shoe into the soil. A rating of 1 was unstable while a 9 was a stable surface. A rating of 7 indicated an ideal surface while above or below was unacceptably hard or soft. The author noted that "this method works very quickly but requires some experience."

Injury Rate Comparison as an Assessment of Athletic Fields

Another method for evaluating athletic surfaces has been to compare the number of injuries received on each surface. The majority of research has been done comparing football injuries on artificial turf versus natural grass. Comparisons have been made at high school, college, and professional levels. Results from these studies are quite varied based on a number of factors. In a comparison of injuries in high
school football, Bramwell et al. (1972) reported that injury rates for games played on synthetic surfaces were significantly higher than grass. This difference was mainly a function of the even higher injury rate on the artificial surface in the dry condition. A further expansion of this study compared several different synthetic surfaces to natural grass (Adkinson et al., 1974). A significant difference in number of injuries existed between natural and synthetic surfaces and also between synthetic surfaces. In reports involving comparisons of injuries at the professional level, there was a higher probability of injury occurring on an artificial field than on a natural grass field (Macik, 1987). The number of injuries that occurred on synthetic fields in domed stadiums was less than the number on exposed synthetic fields.

A comparison of intercollegiate football injuries occurring on natural grass and synthetic turf resulted in no significant difference in the number of injuries between surfaces (Keene et al., 1980). However, the type and severity of injuries that occurred on synthetic surfaces were significantly different. More sprains and torn ligaments occurred on the natural surface while a greater number of abrasions (minor injuries) occurred on synthetic turf. A concurring report by the National Collegiate Athletic Association (NCAA) in 1987 of 15 football teams stated that artificial surfaces did not cause more injuries than natural surfaces. Although the age of the synthetic turf has been reported to affect the ability to absorb impact (Bowers and Martin, 1974), the results of Keene et al. (1980) indicated age did not affect the number or types of injury.
There are problems associated with comparisons of surfaces using injury data. In terms of the surface, the question of characterization of the field must be considered. The surface type will vary depending on several factors. For synthetic surfaces the variance will increase with age, the shock-absorbing padding underneath the surface (Bowers and Martin, 1974), and the surface fabric itself (Adkinson et al., 1974). Natural surfaces can differ in many ways also. Kretzler (1972) recognized this in rebuttal to some of the early injury/surface comparison work. He questioned the use of the words "natural turf." The meaning of this term could encompass any field that was not covered by synthetic fabric. This could range from a well-constructed and well-maintained field to a stone laden field that was void of grass. Characterization of natural fields in relation to soil type, moisture, and bulk density as well as grass species and density is imperative when making comparisons between surfaces.

Another problem with using the number of injuries in comparing surfaces is classifying the type or nature of the injury itself. Football is a contact sport; as long as there is contact, there will be injuries (Kretzler, 1972). The key here is to evaluate injuries that may be related to the field surfaces, which vary in characteristics due to maintenance practices, construction methods, or a combination of both. A report on injuries in 12 Pennsylvania high schools (Harper et al., 1984) stated that 20.9% of all injuries reported were either definitely or possibly field related. In this study, each school's athletic trainer was asked their opinion on the cause of the injury. Before comparisons of surface types are made using injuries rates or types, a characteriza-
tion or a method to evaluate the field is necessary. One means for characterizing surfaces is through a procedure that quantitatively measures the impact energy a surface can absorb.

Quantitative Assessment of Athletic Fields

Quantitative comparisons among fields can be very useful. These comparisons remove subjectivity from the analysis if the testing method is consistent throughout the study. Several types of quantitative comparisons have been developed to evaluate athletic field surfaces.

Impact Absorption

The ability of a surface to absorb the impact energy of an object hitting that surface is known as the shock absorbing or attenuating ability of that surface. The measurement of this shock absorbing ability is the measurement of the impact absorption or hardness of the field.

When an object of mass $m$ at height $h$ is at rest, it has a potential energy

$$E = mgh$$

where $g$ is the acceleration due to gravity. If dropped from height $h$ the potential energy is converted to kinetic energy, or energy of motion. The kinetic energy of a mass $m$, moving with a velocity $v$, is

$$E = \frac{1}{2}mv^2$$

The velocity of a freely falling object just prior to impact varies with the height above the surface when released $v = (2gh)^{1/2}$. Upon impact,
the energy is either absorbed by the surface or returned to the object. These forces at impact can be measured using an accelerometer. Following the equation $F = ma$, and by impacting a surface with the same mass, $m$, the deceleration or negative acceleration, $a$, is an indication of the reactive force, $F$, returned to the dropped object.

A piezoelectric accelerometer (Figure 1) mounted on a missile (object) senses the change in velocity (deceleration) caused by the impact and sends a signal (voltages or charges generated in the discs or crystals) corresponding to the applied acceleration (Allocca and Stuart, 1984). Piezoelectric accelerometers are used in the cases where dynamic acceleration is to be measured because no external power is required. When force is applied, an electrical charge $Q$ is produced by the crystal as a function of the piezoelectric strain constant ($d$) and the force ($F$);

$$ Q = dF $$

The force is a product of the mass $m$ and the applied acceleration ($a$);

$$ Q = dma $$

It is assumed that the pre-stress force is greater than any force that may be generated by the mass due to external acceleration; and therefore, the varying force on the crystal will be proportional to acceleration. The more force that is applied, the more voltage the accelerometer produces. Upon impact the accelerometer is measuring the negative acceleration (deceleration, $g$) of the object. The harder the surface, the faster the object decelerates and the higher the peak deceleration ($g$-max). The energy created during the fall is either in part absorbed by the surface or returned to the missile. The more energy
Figure 1. A typical piezoelectric accelerometer.
returned to the missile, the faster the deceleration and the higher the voltage signal from the accelerometer.

Consider the following impact curves in Figure 2. Curve a is formed when an object hits a hard surface. Curve b is created when the same mass hits a soft surface. The curves are a measure of deceleration with the peak of each curve indicates g-max. With curve a the time of collision is small and the deceleration is rapid. With curve b, the surface is more yielding, the impact time is longer, and the maximum deceleration is less. Since the same mass is dropped from the identical height for both curves, the areas under those curves must be equal (Sears and Zamansky, 1970). It is on this basis that hardness comparisons of surfaces can be made. As long as the same weight is dropped from the same height, the object will have created the same amount of energy on impact. The harder surfaces will absorb less energy and cause rapid deceleration while the softer surfaces will remain in contact with the object longer during the impact and will have a lower maximum deceleration.

Research on the impact absorption of surfaces has been mainly conducted in the late 1970's and 1980's. However, the earliest work involving impact energy for determining playing quality of athletic surfaces was done in 1968 by Gramckow (1968). Impact absorption was measured using an accelerometer attached to a 3.64 kg (8 lb) weight dropped from a height of 183 cm. An impact curve was measured using an oscilloscope, and pictures of the curve were recorded with a camera. The effects of grass species, soil type, soil moisture, soil amendment, and height of cut on impact absorption were evaluated. Bermudagrass (Cynodon
Figure 2. Simulated acceleration-time impact curves for hard (a) and soft (b) surfaces.
dactylon (L.) Pers) absorbed more energy than either tall fescue (Festuca arundinacea (L.) Schreb) or Kentucky bluegrass (Poa pratensis L.). Sand mixed with 50% sawdust (by volume) had the lowest peak deceleration or g-max values while the loam soil treatment had the highest readings. Increasing soil moisture caused a decrease in peak deceleration values.

The utilization of synthetic surfaces for playing surfaces generated comparisons between synthetic and natural surfaces. A study designed to evaluate the impact energy absorbed by old and new AstroTurf, Kentucky bluegrass, and asphalt surfaces was conducted by Bowers and Martin in 1974. A 7.3 kg (16 lb) weight was dropped from a 31.8 cm height. A signal from an accelerometer was expressed on an oscilloscope. Results showed the Kentucky bluegrass to have superior impact absorbing qualities followed closely by new AstroTurf. Five-year-old AstroTurf had much less poorer shock absorbing characteristics. The study showed the importance of the underpadding for artificial surfaces.

Another method for quantifying playing surfaces is by measuring deformation of a surface during or following impact. From a turfgrass or soil standpoint, there is more deformation with a softer surface, due to more energy being absorbed by the softer surface. Gramckow (1968) measured deformation on both compacted and noncompacted soil. Loam had greater deformation than sand, and both soils increased in deformation with increasing moisture. As soil moisture increases to a certain point (this point being a function of the properties of each soil), the compactability and consequently the amount of deformation increases (Craig, 1983). Beyond this point of soil moisture, the soil porosity is filled with water making compression more difficult.
The amount of soil deflection and the time for the compacted area to return to its original state are definitions of resiliency and elasticity as defined by Thomas and Guerin (1981). They evaluated the quality of sports turf using an apparatus known as the Sports Simulator. Of the three soil systems evaluated (calcined clay, silica sand, and silica sand + polyurethane foam), calcined clay had the least resiliency and elasticity. The sand + polyurethane treatment maintained its elasticity when subjected to several compactions while the other treatments showed a significant loss in elasticity.

Impact absorption in field surfaces research has been conducted not only on surfaces for human athletes, but on those for the thoroughbred horse as well (Zebarth and Sheard, 1985). The impact absorption (referred to as impact resistance by the authors) was measured by vertically mounting an accelerometer to a simulated hoof. They concluded that the performance of race horses showed a strong negative correlation with impact absorption measurements. Longer race times were associated with lower impact absorption measurements. Studies on surfaces as to the best grass species for racing horses have also been assessed subjectively (Chevigny and Dujardin, 1981).

The American Society for Testing and Materials, ASTM, (1986), has developed a standard test method for shock (impact) absorbing properties of playing surface systems and materials. The procedure involves attaching an accelerometer to a circular, flat or rounded, metal impacting missile with a specified mass, geometry, and impact velocity. The acceleration-time history of the impact is recorded with the aid of an oscilloscope or other recording device. This method suggests
calculating severity index as well as other parameters. The severity index is equal to the integral of a 2.5 dt over the total duration of impact, where $a = $ acceleration. The severity index was developed to predict the probability of cerebral concussions due to head impacts (Gadd, 1971). Henderson (1986) used the ASTM method to evaluate effects of different soil types, depth of soil, and turf on impact absorption. A 9.1 kg (20 lb) cylindrical missile was dropped from a height of 61 cm onto the different surfaces. He concluded that the depth of soil affected by the impact was between 7.5 and 15 cm.

Another device used for measuring impact absorption is the Clegg Impact Soil Tester (CIT) (Clegg, 1976, 1978). Developed in Western Australia for testing dirt road base surfaces by Baden Clegg, it has been used for evaluating turf surfaces in both Europe and Australia (Lush, 1985 and Canaway, 1985a). Unlike previously described apparatuses, which are bulky and cumbersome, the CIT is lightweight (11.8 kg) and portable. The readout box provides only the peak deceleration (g-max) as a LCD readout. The design is essentially the same as other instruments; an accelerometer is mounted on a missile (4.5 kg and several lighter missiles) and dropped from a set height (45 cm) through a guide tube. The CIT can be operated by one person and up to 100 measurements can be made in 15 minutes (Lush, 1985).

Among the surfaces evaluated (using a 0.5 kg hammer dropped from a 30 cm height) have been cricket pitches (Lush, 1985), tennis courts (Holmes and Bell, 1986b), bowling greens (Holmes and Bell, 1986c), and soccer fields in both England (Holmes and Bell, 1986a) and Saudi Arabia
Baker, 1987). The effect of rootzone composition on player performance was examined on soccer fields (Baker and Isaac, 1987).

Several factors affect the impact absorption characteristics of a natural surface. Gramckow (1968) showed a negative correlation between soil moisture and surface hardness. The presence, type, and amount of ground cover has been shown to affect the peak deceleration values of a surface. Holmes and Bell (1986a) reported that peak deceleration values increased as ground cover decreased. However, Zebarth and Sheard (1985) found a greater impact resistance on turf than bare soil. Gramckow (1968), Henderson (1986), Holmes and Bell (1987), and Baker and Issac (1987) reported a wide variation of impact values depending on soil type. Impact absorption measurements varied depending upon grass species (Gramckow, 1968).

The bulk density (mass of soil/unit volume, g/cm³) of a soil affects the hardness of a surface. Zebarth and Sheard (1985) concluded that a positive correlation between impact resistance and bulk density existed. When the soil is compacted the surface absorbs less impact energy. Areas of playing fields that are more intensively used, and therefore more compacted with less turf cover, have been shown to have higher impact values (Holmes and Bell, 1987). Additionally, Holmes and Bell (1986c) produced a contour map of surface hardness of a bowling green showing the soil compaction at the edge of the green caused by player traffic.

Thatch levels and cutting height did not affect impact absorption levels in association with race horses (Zebarth and Sheard, 1985). Granckow (1968) found that peak deceleration values increased as cutting height decreased. The height of cut seems to be more a function of
ball/surface interaction. The CIT has shown a strong positive correlation to rebound resilience, measured by the height of bounce (Holmes and Bell, 1986a). Nitrogen levels have been shown to influence the hardness of a surface. Canaway concluded that surface hardness (as measured with the 0.5 kg hammer) decreased as nitrogen level increased (1985a).

Standards of playing quality for natural turf have been proposed by researchers in the United Kingdom (Holmes and Bell, 1987). Their report linked together quantitative data obtained with the CIT (as related to field hardness) and subjective data obtained from players on their perception of the surface following play. The proportion of players rating a field "hard" or "unacceptably hard" increased with increasing impact values. They concluded that the preferred limits of surface hardness for running on a surface is 20-80 g, as determined with a 0.5 kg hammer dropped from 30 cm. The same range was found to be acceptable for falling or diving onto the surface.

Since there are many different parameters to be considered when measuring the hardness of natural surfaces, Bell et al. (1985) outlined the following factors that must be measured simultaneously in order to fully determine the impact absorbing capabilities of a surface:

(a) the total duration of impact;
(b) the time to reach maximum deceleration;
(c) the peak deceleration;
(d) the average deceleration;
(e) the rate of change of deceleration;
(f) the area under the curve of deceleration vs. time;
(g) the peak force;
(h) the deformation of the surface;
(i) the time for the surface to return to its original state.

Holmes and Bell (1987) noted that no research program has measured all these factors together. One machine that is capable of measuring the first seven parameters from impact curves is the Bruel and Kjaer LS 2515 Vibration Analyzer. It can replace the readout box on the CIT, and is lightweight enough so that the system remains portable (Figure 3). The LS 2515 is equipped with a battery-powered oscilloscope; and therefore, produces an impact curve. Up to 50 curves can be stored into memory, and the LS 2515 is computer adaptable. The deceleration readout on the LS 2515 is to the nearest 0.1 g. The CIT readout is to the nearest 10 g. Henderson (1986) found significant differences as low as 3 g for peak deceleration values among different soil depths.

Traction

The other interaction between the player and the surface is referred to as traction. Traction is the property which allows players to move on the field without excessive slipping or falling (Bell et al., 1985). Traction is the term used when discussing footwear with studs or cleats, while friction refers to smooth-soled footwear. Another term for traction is shear resistance or shear strength. However, forces other than resistance to shear are involved and the term traction is more appropriate (Bell et al., 1985).
Figure 3. Diagram of Clegg Impact Soil Tester and Brueel and Kjaer LS 2515 Vibration Analyzer.
Traction has been measured several different ways on natural turf and has been measured simultaneously with impact absorption since 1968. Gramckow (1968) measured shear strength for several different soils, grass species, and cutting heights. An aluminum plate with four 1.9 cm football cleats fastened to the plate were secured into the turf. The amount of force applied linearly to tear the cleats and the plate out of the ground was measured. In their work sand had a lower shear strength than clay or loam soils. Torg et al. (1974) studied player-surface friction and traction and determined values for friction on various turf and natural surfaces.

Canaway (1975) used a studded disk apparatus with studs arranged on the disk at 60° intervals but different radii from the center of the disc. He measured the torque necessary to shear different turf species and cultivars. The device was modified so that all six studs were 4.6 cm from the center of the disc (Canaway and Bell, 1986), and this modified apparatus was used to measure traction by Canaway (1985 a,b), Holmes and Bell (1986a), Baker and Issac (1987), and Baker (1987).

Other tractions measurements were made by van Wijk (1980). His shear vane apparatus consisted of four blades (each 1 x 4 cm) at 90° intervals around a central shaft. The vane is pushed 4 cm into the top layer and the torque required to overcome the strength or resistance to shear of the soil is measured. Wijk (1980) noted that the torque can be converted to shear strength by applying the equation:
\[
S_v = \frac{T}{2\pi r^2(u + 1/3 r)}
\]

where \(S_v\) = vane shear strength (Pa)

\(T\) = torque applied (Nm)

\(r\) = radius of cylinder sheared (m)

\(u\) = height of cylinder sheared (m)

Zebarth and Sheard (1985) measured the resistance to shear as it relates to race horses. A 8 cm wide steel plate adjusted to project 6.0 cm into the surface was mounted on a rotating arm. The arm was electrically driven and strain gauges were attached to measure the torque. Henderson (1986) measured traction with a field shear test apparatus, type 1B supplied by Eijkelkamp. This apparatus consisted of 12 fins welded at right angles to a cutting head (7.0 cm diameter). The fins were 1.0 and 2.0 cm long and alternatively placed around the cutting head. They had a penetration depth of 1.6 cm. Torque was applied and the maximum torque was read from the calibrated gauge on top of the apparatus.

Traction levels are a function of several parameters. One of these factors is the presence or absence of ground cover. Traction was found to be positively correlated to ground cover (Holmes and Bell, 1986a), and increases in turf roots contributed to an increase in shear resistance (Zebarth and Sheard, 1985). Roots of 100-day-old perennial ryegrass (Lolium perenne (L.)) increased by almost threefold the resistance to shear in fine sand (Adams and Jones, 1979). The height of cut has not been shown to influence traction, although differences due to species have been presented (Gramckow, 1968).
Bulk density has had mixed effects on traction measurements. On bare soils, increasing bulk density and/or soil moisture tension increased traction (Zebarth and Sheard, 1985, Wijk, 1980). On a turf covered soil, bulk density was not significantly correlated with shear resistance (Zebarth and Sheard, 1985).

Nitrogen levels influence traction. Canaway (1985) concluded that traction levels for sands were at their highest at a yearly nitrogen rate of 225 kg/ha. The difference in traction in response to nitrogen fertility was quite wide between sand and soil. The soil response was limited, and traction levels of the soil were significantly lower than the sand system. The presence of fine material in sand mixes increases the resistance to shear of the surface, but the extent of the effect depends upon compaction and water pressure potential (Adams, 1981).

Standards have been proposed for traction levels on natural athletic fields. Researchers in the United Kingdom concluded that the preferred minimum traction level, as measured with the modified apparatus (Canaway and Bell, 1986), is 30 Nm (131.3 Pa) while the lowest acceptable minimum should be 20 Nm (87.5 Pa). From their survey, 75% of the players stated that the surface footing was poor at levels less 20 Nm (Holmes and Bell, 1987). They noted that it is difficult to set maximum levels of traction because of the limited knowledge on the relationship between high traction and injuries.
Penetration Resistance

Another method for measuring or quantifying playing quality of an athletic field surface has been through the use of a penetrometer. Penetration resistance is measured in terms of the force per square centimeter. A cone is attached to a rod which leads up to a handle and gauge. The cone is pushed into the soil at a constant rate, such as 2 cm per second. The penetrometers used by most researchers have been similar except for a variation in cone size.

Bulk density and soil water pressure potential have major influences on penetration resistance (Wijk, 1980). Increasing bulk density or soil water potential increases soil penetration resistance. Holmes and Bell (1986a) reported a negative correlation between moisture content and penetration resistance. Wijk (1980) set limits for playability on soccer fields using a 1 cm² cone. On moderately trafficked parts of the field, a penetration resistance of 10 kg/cm² was recommended while 14 kg/cm² was the level on intensively played areas.

Henderson (1986) reported differences in penetration resistance in parameters such as cover and soil type. The presence of turf roots increased penetration resistance as did soils with higher levels of fine textured particles (< 0.05 mm). A positive correlation exists between traction levels and penetration resistance (Holmes and Bell, 1986a, Wijk, 1980). The soil particles and their arrangement will dictate the penetration and traction levels in soil systems. Although the forces applied on these tests were not similar, the measured levels of these parameters correlate quite well with others (Wijk, 1980).
OBJECTIVES

From this literature review, it is obvious that the techniques and methodology used for assessing playing quality of athletic fields are incomplete. A standard method for assessment of these fields must be established. Except for the CIT, the apparatuses used for evaluating impact absorption were for the most part bulky and cumbersome. There is no doubt for this work to be successful that a portable lightweight device is necessary. The CIT has proven that it can be used as a reliable indicator of impact absorption. However, if the criteria set forth by Bell and coworkers (1985) are to be met, the Bruel and Kjaer LS 2515 Vibration analyzer (or some other lightweight battery operated portable oscilloscope) must replace the readout box on the CIT.

Another reason for the need for this research is that little information on impact absorption exists for athletic fields in the United States. Further, information on how management practices such as core cultivation affect field hardness are limited. Results from researchers on parameters such as cutting height and turf cover have varied. The effect of thatch on impact absorption is not well documented.

Traction measurements are more standardized than hardness measurements. However, the same lack of information exists on such management practices as listed earlier.

There is a need for methods to quantitatively assess athletic field surfaces. Measuring field hardness and traction are two excellent means for such assessment. After outlining methodology, research on the effects of different parameters such as soil moisture, bulk density, soil
type, and grass species should begin. With this information, predictions of impact absorption and traction can be made. The next step is to gather a team of scientists from both the medical and life sciences to determine what impact or traction levels may have a high probability of producing injury. The first step is still, however, the development of methods suitable for on-site quantitative evaluations. With this in mind the objectives of this research were as follows:

(1) To develop a portable system for evaluating impact absorption on turfgrass and soil surfaces via a combination of the Clegg Impact Soil Tester and the LS 2515 Vibration Analyzer.

(2) To evaluate the effect of hammer weight on impact absorption characteristics.

(3) To determine the effects of soil moisture, compaction, core cultivation, vegetation, and cutting height on impact absorption characteristics and traction.
MATERIALS AND METHODS

This section has been divided into a general section that describes the apparatuses used in this research, and individual experiment sections describing the objectives and treatments of each experiment.

General

This section describes the apparatuses used to measure impact absorption and traction. Also included is a brief description of the computer program used to analyze the impact absorption data.

Impact Absorption Measurements

The following materials were purchased from Lafayette Instrument Company, Lafayette, IN:

1 Guide tube (5.1 cm diameter)
1 4.5 kg hammer equipped with accelerometer
1 Readout box (nearest 10 g) with connecting cable
1 Carrying case

The following materials were purchased from Bruel & Kjaer:
1 LS 2515 vibration analyzer (height 17.7 cm, width 43.0 cm, depth 32.0 cm)
3 15.3 m lengths of accelerometer cable
2 Accelerometers: type BK 4382
3 BNC connectors
1 MM0012 Photoelectric probe
1 ZG0249 Power supply

The following materials were either made or purchased locally.

1 0.5 kg hammer
1 2.25 kg hammer
3 Martin 24 fly fishing reels (to store accelerometer cable)
3 76.1 cm length x 5.1 cm diameter PVC Pipe
1 circular bubble level (attached to guide tube and used to insure vertical positioning during impact measurements.)

An accelerometer is mounted in the top of each hammer. A metal cup is mounted on top of each hammer to protect the accelerometer. To each hammer a 15.3 m cable is attached, threaded through the handle, and attached to a Martin 24 fly fishing reel. The reel is essential for convenient maintenance and storage of the wire. The reel is attached to the PVC pipe, and the hammers are stored in the pipe when not in use. The other end of the cable is attached to the LS 2515 vibration analyzer during measurements (Figure 3).

The settings for the LS 2515 vibration analyzer are as follows:

Input: pC
Gain: 150 g or 474 g (g = gravity)
Parameter: Accelerometer
Low freq. range: 3.0 Hz
Calibration: 3.16 pC/ms^{-2}
Horizontal Multiscale: 20 MHz
Time mode depressed
Trigger: internal

Trigger delay: -3.13 ms

Three hammers were included in this study. A 4.5 kg hammer is standard with the purchase of a CIT. A 2.25 kg and 0.5 kg hammer were manufactured by The Pennsylvania State University Engineering Shop Service following blueprints from the manufacturers of the CIT. The 4.5 and 2.25 kg hammers were made from cold rolled steel and had metal pipe "T" handles while the 0.5 kg hammer was constructed with solid PVC and had a plastic tube handle. All hammers were 5.0 cm in diameter.

Measurements were made with this apparatus from a drop height of 0.45 m. With the above settings, the "start single" measurement button and the linear average button were engaged. To average successive impacts, the linear averaging button must be engaged. Averaging of impacts continued until these buttons were depressed again. To store an impact curve in the LS 2515, the memory store button was pressed.

Computer Program

The data collected in the LS 2515 were transferred to a microcomputer via an IEEE 488 bus cable, a multiwire cable providing for byte-serial, bit-parallel communication. Use of the IEEE-488 bus is dependent upon the existence of a GPIB interface board within the microcomputer. The interface board in this system was a National Instruments Model GPIB-PC IIA board installed using the default settings specified in the literature of the manufacturer. The computer program used to analyze the deceleration-time impact curves was written by W. W.
Moyer and M. J. Bregar, The Pennsylvania State University, University Park, PA 16802. The Impact Analysis program was written in BASICA to carry out analysis of data recorded during the impact of an instrument of known mass from a set height. The continuous signal generated by the accelerometer was sampled by the LS 2515 and stored in the memory of the analyzer. A threshold value of one-tenth peak deceleration was used to define the beginning and end of the deceleration-time impact value. The microcomputer had high resolution graphics capability. The program provided the following information:

- Maximum deceleration - (g)
- Time to maximum deceleration - (ms)
- Total duration of impact - (ms)
- First rate of change (threshold to point of maximum deceleration) - (g/ms)
- Second rate of change (threshold to 0.5 point of maximum deceleration) - (g/ms)
- Third rate of change (0.5 to point of maximum deceleration) - (g/ms)
- Surface deformation - (integral of velocity (v) curve, which is the integral of the deceleration curve, from v at impact to v = 0) - (cm)
- Severity index - (the integral of $g^{2.5} \, dt$ over the total duration of impact) - (s)
- Rebound ratio - (the area under the deceleration curve after v = 0 divided by the area prior to v = 0)
Impact Velocity Determination

The velocity with which the hammer impacted the surface was determined by two methods. The first method utilized the LS 2515 and the MMO012 photoelectric probe. A 0.9 cm diameter hole was drilled 8.0 cm from the base of the guide tube. A 2.5 cm strip of "chrome" reflective tape was attached 5.5 cm from the base of each hammer. The time the reflective tape took to pass by the probe was recorded on the LS 2515. Each hammer was dropped 20 times. Operator variability was tested using this method. Another series of impacts was recorded with each hammer dropped from a height of 44.4 cm.

The second method involved the use of high speed motion picture film. The film speed was 1000 frames/s and the shutter speed was 0.0002 s. The guide tube was mounted 5.0 cm above a rubber pad. The hammer was photographed as it exited the tube. To improve visibility of the black hammer, a 1.9 cm strip of orange reflective tape was attached at the base of the hammer. The velocity recorded was calculated using the number of frames counted per distance traveled.

The average impact velocity using the photoelectric probe was 2.91 m/s, while the impact velocity was 2.79 m/s as measured with the high speed film. There was no difference in impact velocity between the hammers, and the average velocity was determined to be 2.85 m/s. No difference in impact velocity between heights of drop 45.0 and 44.4 cm was detected.
Hammer weights

The weights utilized in this study simulate different activities involved in sporting activities. The 4.5 and 0.5 kg hammers were built to the specifications outlined by Clegg (1976), while the 2.25 kg hammer was manufactured to simulate the energy/unit area of the ASTM method (F355-86). The ASTM method utilizes a 9.09 kg hammer, which has an impacting area of 129 cm² and is dropped from a 61 cm height. The hammers used in this study had impacting surface areas of 20.25 cm² and were dropped from a height of 45 cm. Impacting energies/unit area (0.5 \( mv^2/A \), where \( m = \) mass, \( v = \) impact velocity, and \( A = \) surface area) calculated using measured impact velocities of hammers (2.85 m/sec for 0.5, 2.25, and 4.5 kg as determined in this research, and 3.39 m/sec for the 9.09 kg hammer as determined by C. A. Morehouse, (personal communication)), were 1003, 4512, 9025, and 4049 N/m for the 0.5, 2.25, 4.5 and 9.09 kg hammers, respectively.

Both the 4.5 kg and 2.25 kg hammers simulated a player running on or falling to the ground. The 0.5 kg hammer simulated the action of a ball. The heavier hammers made larger indentations into the ground. This action was similar to a heavier object such as a foot or elbow contacting the soil-turf interface. Our studies with these heavier hammers have shown that 4.5 kg hammer can exaggerate the action when high moisture conditions are present. For an overall purpose, the 2.25 kg hammer is best suited for player simulation and the 0.5 kg hammer is optimum for ball simulation.
Traction Measurements

Traction was measured with a field shear test apparatus, type 1B, Eijkelkamp, The Netherlands (Figure 4). This apparatus consisted of 12 fins welded at right angles to a cutting head (7.0 cm diameter). The fins were 1.0 and 2.0 cm long and alternatively placed around the cutting head. They had a penetration depth of 1.6 cm. Torque was applied and the maximum torque was read from the calibrated gauge on top of the apparatus. Averages of either four or six measurements were recorded. Traction (shear strength) was calculated as the quotient of the maximum torque (Nm) and the constant of the apparatus (2.285 x 10^{-4} m^3).

The equipment described above was also used to assess surface conditions on 24 high school football fields (J. N. Rogers, III, D. V. Waddington, and J. C. Harper, II. Relationships between field hardness and traction, vegetation, soil properties, and maintenance practices on high school football fields (manuscript submitted for publication). Peak deceleration, as measured at various times during the year, ranged from 50 to 286 g with the 0.5 kg hammer and from 33 to 167 g with the 2.25 kg hammer. Shear resistance ranged from 39 to 123 kPa. Treatments imposed in this thesis research produced peak deceleration and shear resistant values within similar ranges.
Figure 4. Eijkelkamp type 1B field shear test apparatus.
Experiment 1

Experiment 1 was begun in April, 1986 at the Center for Landscape Management and Water Quality Research on a 'Kentucky-31' tall fescue site. The objective of this experiment was to determine the effects of cutting height and vegetation on impact absorption and traction. The soil was a Hagerstown silty clay loam (8.2% sand 65.6% silt and 26.2% clay). There were seven treatments, three cutting heights (7.6, 5.1, and 2.5 cm), with each cutting height evaluated both with and without top growth, and bare soil. The design was a randomized complete block with three replications. Data were analyzed for this experiment and all subsequent experiments using analysis of variance and the least significant difference (lsd) test at the 0.05 level. The lsd was not calculated when the F-ratio was not significant at the 0.05 level. In such cases NS has been inserted in tables in place of the lsd value. The plot area was mowed weekly. Fertilizer and herbicides were applied as needed. Moisture received was through natural precipitation.

Impact, shear, and soil moisture data were recorded on 14 May and 20 September 1986 and 9 April, 15 July, and 15 October 1987. An average percent soil moisture was recorded for each date in this experiment and all subsequent experiments. Impact values for all three hammers were recorded for each date except for 14 May 1986 (only the 4.5 kg hammer was available). Impact values were registered with the CIT on 14 May 1986 and with the combination CIT + LS 2515 for the other dates. In 1987, the impact measurements were averaged in the LS 2515. Shear resistance was measured with the shear vane apparatus with four measurements averaged
for each treatment. Percent soil moisture in the surface 5.0 cm was measured on a dry weight basis.

The size of each plot was 0.9 by 4.4m. This tract was divided into seven subplots, 0.9 by 0.6m, which were randomized for dates of data collection. On each data collection date, the top growth was clipped and removed from a portion of the subplot prior to impact and shear measurements. To prepare the bare area treatment, glyphosate (4.4kg/ha) was applied on 25 April 1986.

**Experiment 2**

Experiment 2 was initiated in July 1986 at the Joseph Valentine Turfgrass Research Center to study the effect of cutting height and compaction on hardness and traction in Kentucky bluegrass turf. The test was conducted on a Hagerstown silt loam soil (19.2 % sand, 56.6 % silt, and 24.2 % clay).

The original design for this experiment was a 2 by 4 factorial. There were two levels of compaction (with and without) and four cutting heights (0 (bare), 1.9, 3.8, and 5.7 cm). The zero cutting height represented plots on which vegetation had been killed using 4.4 kg glyphosate/ha. Fertilizer and herbicides were applied as needed. The turf was mowed once per week. Compaction was applied periodically (30 times) from July to November, 1986 and April to August, 1987 when soil moisture conditions were most conducive to enhancing soil compaction. The plots were compacted with a clay tennis court roller (364 kg) with the front roller 71 cm wide and the back roller 86 cm wide. Turfgrass on
this site was not irrigated during the experimental period. Data were collected on 20 September, 1986.

For 1987, the design was changed to a split plot 2 by 4 factorial design. The split was three surfaces; full turf cover, turf cover with no top growth, and bare ground (sod stripped). Due to the design of the experiment, readings on bare soil with thatch residue remaining were repeated. Data were collected on 14 May, 22 July, and 16 November 1987. Readings with all three hammers were recorded on each date except for the 4.5 kg hammer on 16 November 1987. An average of four impact values was recorded in 1986, while the impact values were averaged by the LS 2515 in 1987. The average of six traction measurements and % soil moisture for each main plot were entered for each date. Bulk density was measured on 22 July and 16 November 1987. Ten soil cores 5.0 cm long by 1.9 cm in diameter were weighed and an average bulk density from samples taken was determined.

Experiment 3

Experiments 3a and 3b were initiated in April, 1986 at the Joseph Valentine Turfgrass Research Center to evaluate the effects of compaction and core cultivation on impact absorption and traction. Experiment 3a was conducted on a tall fescue site while experiment 3b was on Kentucky bluegrass turf. The experiments were located adjacent to each other and had the same treatments. These experiments were conducted on a Hagerstown silt loam soil (17.2 % sand 62.2 % silt and 20.6 % clay).
Fertilization and herbicides were added as needed. The turf was mowed at a height of 2.5 cm and received no water other than rainfall.

The design was a split plot with four treatments and three replications. There were two levels of aerification (with and without) in combination with compacted versus noncompacted soil. The areas were aerated on 27 May and 9 November 1986 and 4 June 1987, by using 8 to 10 passes with a pull behind Ryan Renovaire Model No 544317 aerifier with 1.9 cm tines. The turf was compacted with a clay tennis court riding compactor as described earlier. Approximately 40 passes were made from May through November 1986, plus another 30 passes from April through July 1987, when soil moisture conditions were conducive to soil compaction.

Measurements were made 28 May, 20 September, and 16 November 1986 and 14 April, 1 July, 25 August, and 16 October 1987. Impact values were collected with all three hammers except on 28 May (only the 4.5 kg hammer was available). The six impact values recorded for each date in 1987 were averaged by the LS 2515. An average of six shear resistance measurements was recorded for each treatment. Percent soil moisture of the surface 5.0 cm was recorded. Bulk density of the surface 5.0 cm was measured on 13 June, 1986, and 28 August, 1987. Ten cores 5.0 cm long by 1.9 cm in diameter were weighed and an average bulk density was determined. Root weight was measured at three depths (0-4, 4-8, and 8-12 cm) on 20 November 1987.
Experiments 4 and 5

Experiments 4 and 5 were conducted on four separate sites to determine the effect of thatch on impact absorption. The first site was a fine fescue (*Festuca rubra* L.) plot located in a residential lawn in Centre County. Sites two and three were on Kentucky bluegrass turf at the Joseph Valentine Turfgrass Research Center, with one site being a 5-year old stand (Kentucky bluegrass-a) and the other site a 3-year old stand (Kentucky bluegrass-b). The final site was a zoysiagrass (*Zoysia japonica* Steud.) plot also located in a residential lawn in Centre County. For each site the design was the same. Experiment 4 was a randomized complete block with three treatments and four replications. Impact measurements were made on an undisturbed turfgrass site, the turfgrass site with top growth removed, and the turfgrass site with top growth and thatch removed. The LS 2515 recorded an average of two impact measurements for each treatment. Measurements were made with the 2.25 kg and 0.5 kg hammer on all sites. Soil moisture was recorded for each replication for all sites.

Experiment 5 was also conducted at the sites described for experiment 4. The thatch + topgrowth plugs removed in experiment 4 served as the treatments for this experiment. The plugs were removed from each site with a putting green cup cutter. The plugs were placed on a section of running track padding for measurement. The three treatments in this randomized complete block design with four replications were grass + thatch on the pad, thatch on the pad, and the pad alone. For all measurements the pad was placed on a concrete surface. The LS 2515
recorded an impact measurement for each treatment. Measurements were recorded for both the 2.25 and 0.5 kg hammers.

Data for both experiments at the fine fescue, Kentucky bluegrass-a and -b and zoysiagrass sites were recorded on 3 September, 25 September, 12 October, and 10 September 1988, respectively.

Correlations Among Impact Characteristics

After an analyses of variance had been calculated for each experiment, correlations between the impact characteristics of each hammer and among hammers were determined to establish relationships between these parameters. Pearson's correlation coefficients were determined significant at the 0.05 level. Comparisons were not made across experiments.