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THE OPTIMIZATION OF GOING MANAGEMENT ON UK RACECOURSES USING CONTROLLED WATER APPLICATIONS

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Abstract

Non-uniform surface rating (going) on a racecourse increases the potential for risk of injury to competing horses and their riders. Variability in soil type and strength are the primary cause of inconsistent going. This research aimed to produce guidelines for Racecourse Managers to help them achieve uniform going by influencing the strength of the different soil types encountered on a racecourse using controlled water applications.

Two models were developed, a soil-water balance to predict the mean going for a given soil type (MEGPREM), and a determination of effective irrigation model (DEFFIM) that establishes how much water is required to change a hard level of going to a preferred softer level. MEGPREM was found to provide poor predictions of going. DEFFIM was shown to be a valid model, and potentially provides Racecourse Managers with a useful tool to aid their decision making with regards to watering.

A further study to determine whether different irrigation regimes affected the structure of two different soil types concluded that a regime that allows the soil to dry to a pre-determined soil-water deficit and then re-wet to field capacity produced better soil physical properties than soils maintained at field capacity. Utilizing a simulated irrigation regime, directed by DEFFIM, that achieved wet/dry cycles as described, a cost analysis was carried out to compare the simulated irrigation with the actual irrigation practices at a racecourse for the 2004 and 2005 flat racing seasons. The results suggested that potentially significant savings in water consumption could be achieved with the use of DEFFIM, satisfying the requirements of the Water Act 2003, whilst still maintaining a preferred level of going.

The findings of this research suggest that going management on a racecourse could be optimized with controlled water applications, potentially reducing the risk of injury to competing horses and jockeys.

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Nomenclature and abbreviations

$<$	Less than.
$\geq$	Equal to or greater than.
%	Percentage.
θ_V	Soil volumetric moisture content.
°C	Degrees centigrade.
µm	Micrometre (10^{-6} m).
ρ_b	Bulk density (mass of soil per unit bulk volume of soil).
ANOVA	Analysis of variance.
ASTM	American Society for Testing and Materials.
AWSET	Automatic weather station evapotranspiration program.
C3	Cool season grass.
C4	Warm season grass.
CIH	Clegg impact hammer.
DEFFIM	Determination of effective irrigation model.
DU	Distribution uniformity.
EA	Environment Agency.
EAWC	Easily available water content.
EF	Modelling efficiency.
Effective irrigation	Net total of irrigation after addition of rainfall and deduction of water losses through ET.
ET	Evapotranspiration.
ET_a	Actual evapotranspiration.
ET_c	Evapotranspiration of the crop.
$ET_{c\ adj}$	Evapotranspiration of the crop under non-standard conditions.
ET_o	Reference crop evapotranspiration.
FC	Field capacity (maximum water content of a soil after gravitational drainage has occurred).
F pr	F probability.
F Test	To test if the standard deviations of two populations are equal.
Going	Surface rating of a racecourse.
Going-stick	Device used to measure the going on a racecourse.
H_2S	Hydrogen sulphide.
HOC	Height of cut.
HRA	Horseracing Regulatory Authority.
I_p	Plasticity index (of soil).
IMS	Irrigation management services irrigation scheduling program.
IO	Innovation offsets.
IT	Information technology.
K	Hydraulic conductivity.
K_c	Crop coefficient.

Nomenclature and abbreviations

kg	Kilogram (10^3 g).
kPa	Kilopascal (10^3 N m^{-2}).
K_s	Stress coefficient.
K_{sat}	Saturated hydraulic conductivity.
kW	Kilowatt (unit of power equal to 1000 watts).
LAI	Leaf area index.
LSD	Least significant difference of means (at the 5% level) determined by ANOVA.
LTA	Long term average.
m	Metre.
m^2	Square metre (unit of area).
m^3	Cubic metre (unit of volume).
mm	Millimetre (10^{-3} m).
MEGPREM	Mean going prediction model.
MPa	Megapascal (10^6 N m^{-2}).
nm	Nanometer (10^{-9} m).
Nm	Newton metres.
PSD	Particle size distribution of a soil.
PSMD	Potential soil moisture deficit.
PWP	Permanent wilting point (soil water content at which plants are unable to extract water).
r	Sample correlation coefficient.
r^2	Coefficient of determination (in regression analysis).
Rzone def	Rootzone deficit (mm).
Sat	Saturated.
SCL	Sandy clay loam.
SPR	Soil penetrative resistance.
SWB	Soil water balance.
SWD	Soil water deficit.
TAWC	Total available water content.
TDR	Time domain reflectrometry.
UK	United Kingdom.
UK CIP	United Kingdom Climate Impact Programme.
USGA	United States Golf Association.
WaSim	Water Simulation program.
W_l	Liquid limit (of soil).
W_p	Plastic limit (of soil).
x-inefficiencies	Costs that are greater than the minimum attainable.

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1.0. INTRODUCTION

The health and safety of the horse and its rider are paramount during racing. The degree of risk of injury to the horse and rider are influenced by the surface rating (Henley *et al*., 2006), referred to as the going. Going primarily relates to the surface hardness. In the United Kingdom (UK) going is categorized as, heavy, soft, good-to-soft, good, good-to-firm, firm, and hard, where heavy is a slow wet surface, and hard is a fast dry surface. However, the terms used to express going are subjective and are not related to formal soil science descriptions of soil strength A high correlation between race times and the hardness of the racecourse surface was shown by Zebarth and Sheard (1985); race times increased (i.e. horses ran more slowly) as the surface became softer.

Plate 1.1: Typical scene at a horserace in the UK

The ideal going varies depending on the type of racing. The Horseracing Regulatory Authority (HRA) stipulate in the HRA General Instructions no. 3.2, that under Rule 80 (ii) of the Orders and Rules of Racing (HRA, 2005) that '*National Hunt courses* (jump courses) *should aim to produce good ground (and no firmer than Good to Firm)*,' and that '*Flat courses should aim to provide good to firm ground*'. This is echoed by Winter (1998), who also suggests that flat racing should have good-to-firm surfaces, and that jump racing (National Hunt) should have good surfaces.

Most races take place on surfaces that are good-to-soft, good, or good-to-firm (Williams *et al*., 2001a). Racetracks that are excessively wet typically also have low soil strength, which hinders a horse's propulsion through sinkage and sliding, and can cause stress injuries on the horse's hind quarter muscles (Field, 1994). Conversely, racetracks that are hard produce a high impact force on contact with a horses hoof, with a high peak force occurring very quickly. This results in a high rate of loading, and therefore strain, experienced by the horse's leg bones (Pratt, 1984). This can lead to micro damage and gradual weakening of the leg bones. When the racetrack is wetter than heavy, or harder than hard, the race is cancelled, primarily for the horse's welfare.

The going can, however, vary around the racetrack. This can be due to variations in many factors, including soil texture, soil water content, compaction, (particularly on the racing line), grass cover, drainage, topography, orientation, shading and poorly adjusted irrigation sprinklers or leaking irrigation pipes. These factors can lead to a non-uniform surface rating (inconsistent going) around the length and across the width of the racecourse. A greater potential for the risk of injury to horses occurs when the surface rating goes from relatively hard to significantly softer over a short distance (Chivers, 1999). The ideal racecourse has uniform going along the length and across the width, so that the risk of injury to horses is reduced.

In racecourse management, the application of water is the primary method used to reduce a hard level of going to a softer level that is conducive to racing. Water applications are generally required during the summer months as a result of the prevailing weather conditions at that time. However, the soil texture and soil variability across the racecourse is rarely considered when irrigation regimes are developed. This can result in excessive unnecessary amounts of water being applied in some areas.

The Water Act 2003 (HMSO, 2003) requires users of water to reduce water consumption, where possible, and to use water effectively so that waste is minimized. Failure to do so could lead to the revocation of any water abstraction license (Weatherhead, 2004), which could result in a racecourse being unable to achieve a suitable surface rating through the summer months if an alternative source of water is not found. This could result in potentially dangerous racing surfaces or, where surface conditions are deemed too dangerous, the abandonment of racing. Clearly this would have financial implications for the racecourse and its stakeholders. Controlled water applications, to influence the surface rating (going), could significantly reduce the total annual water consumption on a racecourse, in accordance with the Water Act 2003. This is because specific measured amounts of water are applied to the various parts of the racecourse to create uniform going conditions around the racecourse as a whole

1.1. Aims of the Research Project

The aim of this project is to produce robust and practical guidelines for the optimization of going management on racecourses through the use of controlled water applications, such that consistent surface conditions can be achieved.

1.1.1. Objectives

To achieve the aim of the research, two key objectives are addressed. The objectives are:

1) To develop methodologies that enable individual racecourses to construct a user-friendly empirical model that predicts the average going, for the different soil textures around the racecourse, based on the racecourses unique weather and going data.

2) To develop methodologies that enable individual racecourses to create a user-friendly empirical model that provides an objective determination of the depth of water application needed to manage going (provide a depth of water amount in mm required to change going by half a class) from the racecourses unique weather and soils data.

1.2. Statement of Approach

The approach taken in this thesis reflects the multidisciplinary nature of the research carried out. Chapter 2.0. reviews the incidence and nature of horse injuries in a racecourse environment and looks at the way the surface rating of a racecourse is assessed. The impact that poor surface conditions on a racecourse can have on the stakeholders of the racing industry is also discussed. The relationships between the soil, grass plant and water and their influence on going are considered. The methods used to determine water losses and subsequently apply supplemental water and the impact environmental regulation may have on water use in a racecourse situation is also detailed.

The methodology, results and analysis of a questionnaire survey that provides a contextual framework on which the experimental work of this research project was based is described in Chapter 3.0. and this work forms part of the work to achieve Objectives One and Two. The survey also provides some wider context to the research. From the results of the questionnaire survey, eight racecourses were identified for further study. Chapter 4.0. details the methodologies used and results obtained from an audit of the eight selected racecourses, which further contributes to Objectives One and Two.

Validation of a method chosen to measure going is provided in Chapter 5.0. The going measurement method is used to aid the construction of a soil-water balance (SWB) model that predicts mean going for known soil textures on a racecourse at any given time throughout the year. The SWB model is described in detail in Chapter 6.0. and relates to Objective One.

Objective Two, the development of methodologies to produce a user-friendly model that determines the depth of water required to change a high measured level of going (a harder going) to a preferred lower level (a softer going), is described in Chapter 7.0. The chapter details and explains the methodologies developed to measure, record and analyse the data required to construct the model, as well as detailing the validation process of the model developed.

A study to show the effects that two different irrigation regimes can have on the development of soil structure is described and explained in Chapter 8.0. The study was carried out on the two predominant soil textures found on UK racecourses (sandy loam and clay loam, based on the results of the questionnaire survey). This work links the development of Objective Two to the potential benefits that controlled water applications can have on soil structure.

Chapter 9.0. combines the models developed in Chapters 6.0. and 7.0. to conduct an illustrative cost analysis. The cost analysis looks at the difference, both financially and environmentally, between an irrigation regime directed by the combined SWB mean going prediction and determination of effective irrigation models and an irrigation regime that reflects current practices on a UK racecourse.

A summary of the key findings of the research and the conclusions drawn from it are given in Chapter 10.0. All recommendations for required further work are also presented in Chapter 10.0.

2.0. LITERATURE REVIEW.

2.1 Horse Injuries.

A major cause of horse injury and fatality is musculoskeletal injury (Vaughan and Mason, 1976, cited in Williams *et al*., 2001a). Research by Williams *et al*. (2001b) showed that during a three-year period (1996-1998) a total of 2,358 post race clinical conditions, including injuries and fatalities, from 222,993 racing starts were reported (10.57 per 1,000 of all starts).

The type of racing held – Flat, Hurdle, Steeplechase – has an influence on the risk of injuries to horses. Jump racing, both hurdle and steeplechase, has a higher risk of injury than flat racing (Henley *et al*., 2006; Parkin *et al*., 2006). This is supported by Pinchbeck *et al*. (2002) who reported that steeplechase racing, which accounts for 14% of all racing in the UK, accounted for approximately 31% of all equine fatalities on UK racecourses. Further supporting evidence was presented by Wood *et al*. (2001), who showed that the equine fatality rates in the UK for flat racing were 0.1 per 100 starts, 0.52/100 starts for hurdling, with steeplechase racing having 0.71 fatalities per 100 starts. Table 2.1 categorizes the mechanisms of bone fractures in horses.

Table 2.1
Categories of the mechanisms of bone fracture in horses (Taken from Riggs, 2002).

Type of Fracture	*Description*
1) Monotonic Fracture	A bone that is momentarily loaded beyond its ultimate strength will fail; this may result from the extraordinary high forces associated with an accident, such as a collision or fall.
2) Pathological Fracture	A bone that is weakened by pathology, such as neoplasia or osteoporosis, may have such reduced ultimate strength that it becomes unable to withstand the normal loads of day-to-day life.
3) Fatigue Fracture	A bone that is subjected to cyclical loading will undergo fatigue and its material properties will be progressively eroded. If the rate of accumulation of fatigue damage is sufficiently rapid, the bone may be so weakened that it becomes unable to withstand the normal loads of day-to-day life.

Bone fractures – in the lack of any traumatic incident – that affect racehorses were originally termed "spontaneous" (Bathe, 1994; Ellis, 1994). These spontaneous catastrophic fractures are the culmination of pre-existing fatigue related events, more commonly known as "stress fractures" (Riggs, 2002; Davidson and Ross, 2003). Stress fractures are a common cause of lameness in racehorses. The age of the horse has also been shown to be a factor to the risk of injury occurring, with a greater likelihood of moderate to severe injuries occurring on horses older than four years (Clanton *et al*., 1991; Wood *et al*., 2001; Henley *et al*., 2006).

It is suggested however (Bathe, 1994) that more than 90 percent of horse injuries occur during training, and not during a race, although catastrophic injuries are more prevalent during racing than they are during training (Estberg *et al*., 1996). Injuries that occur more often during training are described by Stover (2003) as fractures of the proximal phalanx and humerus, whereas fractures of the carpal bone are more common during racing.

Additionally the risk of injury was found by Pinchbeck (2004) to be associated with the speed of a race, and foot conformation. The race time (speed of the race) can be influenced by the surface characteristics, particularly traction. Foot conformation and limb loading are also affected by the surface characteristics, as a horse's musculoskeletal structure must adapt to the loading circumstances brought about by the surface characteristics. It is during adaption that horses are most susceptible to injury (Stover, 2003); therefore the potential for musculoskeletal injury can be influenced by the surface characteristics. This is reinforced by Williams *et al*. (2001b) who reported that horse fatalities decreased as racing surfaces became softer, and that a reduction in the overall rate of musculoskeletal injuries in all types of racing (flat, hurdles and chases) also occurred as surface conditions became softer (as can be seen in Figures 2.1 and 2.2 overleaf). This is supported by Verheyen *et al*. (2001), Wood *et al*. (2001), Oikawa and Kusunose (2005) and Henley *et al*. (2006), although surface conditions have not been significantly associated with fatal musculoskeletal injury (Hill *et al*., 1986; Bailey *et al*., 1997; Estberg *et al*., 1998).

[1]*All Weather Track*

Figure 2.1: Injured horses in flat races by type of going as a percentage of runners for the period 2000 to 2002 (data supplied by The Jockey Club).

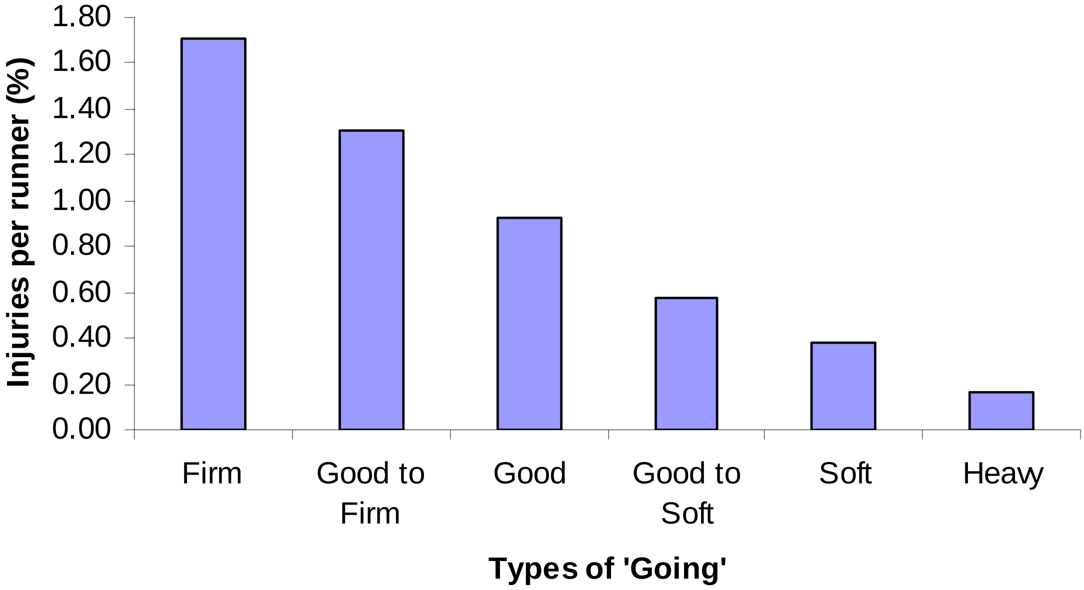


Figure 2.2: Injured horses in jump races by type of going as a percentage of runners for the period 2000 to 2002 (data supplied by The Jockey Club).

It is suggested by Stover (2003) that racecourses adopt uniform racing surfaces so that when competing horses race at different venues, the need to re-adapt to a different surface condition is reduced, therefore minimizing the potential for injury. However, serious injuries to horses occur when the going changes rapidly from hard to soft in one stride length (Chivers, 1999). It is also difficult for the jockey to retain control of the horse in such circumstances, which Hughes (1998) likens to "*trying to regain the equilibrium of a car after it has travelled from tarmac to shingle at speed*". Therefore the development of uniform conditions (consistent going) within a racecourse – as opposed to between racecourses – would reduce the need for a horse to adapt to potentially changing surface conditions during a race, and therefore minimize the potential for serious injuries to occur.

2.2. Determining the Rating of a Racecourse's Surface Conditions.

The assessment of a racecourses surface condition (going) has several functions. The level of going on a given day can be used to determine the suitability of the surface for racing and as a tool to guide management regimes on a racecourse – primarily irrigation – to achieve the optimum level of going. This has a vital role in maintaining the welfare of the competing horse and reducing the risk of injury.

The declaration of the level of going prior to a race meeting also has financial implications for a racecourse, as the number of race entries attracted can be influenced by the declared and/or predicted level of going, which in turn can affect the number of spectators and level of consumption of on-site services, such as catering and betting. Therefore the correct determination of going is vital if the production of a consistent surface at the optimum level of going and the viable sustainability of a racecourse is to be achieved.

There are numerous methods employed by the racecourse industry to assess the going on a racecourse. The methods vary from subjective to objective measurements; Table 2.2 highlights some of these methods.

Table 2.2
Subjective and objective methods to assess going.

Subjective Measurement	***Objective Measurement***
Weather conditions	Penetrometer
Knowledge of the racecourse	Clegg Soil Impact Tester
Walking stick	Going Stick

2.2.1. Subjective measurements of going.

The UK racing industry has not had an objectively measured standard of going until recently. Instead, the industry has relied on subjective measurements based on a person's judgement and experience. Subjective analysis of the going varies from monitoring the weather forecast and predicting the affects of any rainfall or sunshine, to personal knowledge of the racecourse and its nuances, such as areas of the racecourse that drain quickly or slowly.

The most commonly used assessment is that of a stick, whether it is a walking stick or staff. The size and shape of the stick varies from course to course, as does the user of the stick. The stick is pushed into the ground and levered back to make an assessment of the surface conditions (Plate 2.1). The general rule of thumb is the greater the resistance to penetration, the harder the going.

Plate 2.1: Subjective determination of going with a walking stick.

Misjudgements in assessment occur from the variation in size and shape of the stick and its user, as a larger person using a stick with a small diameter would find it easier to push the stick into the ground than a smaller person using a large diameter stick. The larger person might declare the going as good-to-soft, whereas the smaller person may declare the going as good-to-firm. However, problems only arise where different users assess the same racecourse, or compare the going between racecourses. Where the same person uses the same method on the same course, there is usually a reasonable level of consistency in going declarations made.

2.2.2. Objective measurements of going.

The use of a walking stick is a very subjective method to determine the going, relying on the user's knowledge and experience; however there are several objective methods available that allow inexperienced users to determine the level of going.

The Penetrometer method is used in many countries, including Australia, France, India, and South Africa (Field *et al*., 1993). The Penetrometer measures the penetrative resistance of the surface, and is related to the depth of penetration into the surface that a horse's hoof will achieve. A "*moderate to good correlation*" between race times and penetrometer measurements exists (Neylon and Stubbs, 1999), which enabled Murphy *et al*. (1996) to construct a calibration chart to calibrate different racecourses to a standard penetrometer scale. However, race times can also be influenced by the topography and layout of the track, or the condition of the horse and the jockey's willingness to make the horse run faster, therefore race times are dependent on more than just the penetrative resistance of the soil.

The Clegg impact hammer (CIH) measures the hardness of the surface through the deceleration of a 0.5 kg weight on impact with the surface (Clegg, 1976), and is used to assess many sports surfaces, including racecourses. However, Neylon and Stubbs (1999) suggest that the CIH is unsuitable for racecourses as it is a lightweight device that is disrupted by surface irregularities that may not be experienced by the horse. Baker (1995) and Baker *et al*., (1999) found that the larger 2.5 kg CIH gave some indication of potential variations in surface hardness on a racecourse, but they did not relate their findings to a level of going.

The use of the Clegg Shear Tester (CST) (Aldous *et al*., 2005), also known as the Turf Shear Tester, has been alluded to as a measurement of surface conditions on a racecourse (Chivers, pers. comm.). The device is essentially an 'A' frame with a pendulum type tine that is inserted into the ground, and levered back, so that it rotates around the 'A' frame. This method provides an index of the shear strength for soil or turf at the surface in a horizontal direction (Chivers and Aldous, 2003), with measurements recorded in Newton metres (Nm). However, a relationship between shear strength recorded with the CST and the surface rating of a racecourse has not been established; an understanding of this relationship will need to be ascertained before widespread acceptance of this device as a measurement of going can be achieved.

A self-propelled racetrack hardness measurement and analysis system was developed by Oikawa *et al*. (2000), and comprised a vehicle with a one metre long arm connected to a piezoelectric type accelerometer – fitted with a six kg horse-hoof shaped hammer that struck the ground with a fixed force at intervals of five or ten metres whilst the vehicle moved, enabling the determination of surface hardness around the entire racecourse. The impact deceleration of the weighted accelerometer was determined in a similar manner to the CIH. This system was primarily developed for dirt and sand (non-turf) racecourses, and would be of limited use on a natural turf racecourse when the going is softer than good, as it is likely the hammer action of the system would either damage the surface of the racecourse, or dependent on the level of grip on the vehicles tyres, the vehicle itself would either create too much disturbance to the surface (ruts) or become immobilised due to a loss of traction.

The 'Going-Stick' (TurfTrax, 2004) mimics the appearance (vaguely) and application method of an ordinary walking stick – the method favoured by many Clerks of the Course – but unlike a walking stick the going-stick measures the penetrative resistance of the surface, to a depth of 100 mm, and the translational shear strength of the rootzone (Plate 2.2).

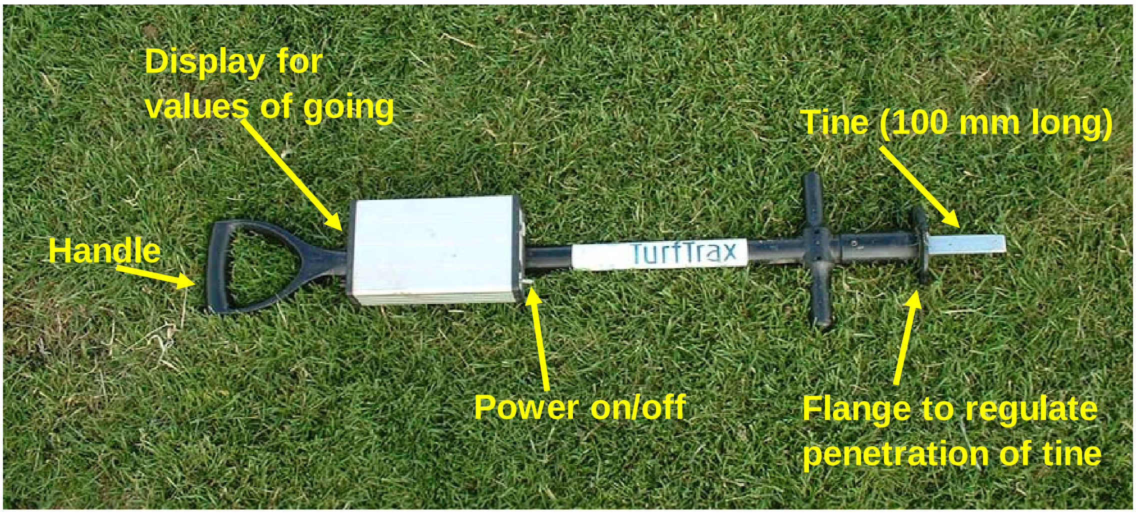


Plate 2.2: Going-stick.

The going-stick determines a mean value of three measurements of soil penetrative resistance, and soil translational shear strength, and converts the mean to a value of going based on a 15 point index (Figure 2.3) that has been calibrated to values of going expressed by senior race inspectors of the Jockey Club. This allows some correlation with the average opinion of going within the racing industry in the UK.

The going-stick has different settings for flat and jump racing, in line with the different levels of going for the two disciplines, and is used in conjunction with a waypoint system (Figure 2.4). The waypoint system enables the assessment of specific sections of the racecourse, and could be used to pinpoint management activities specific to one location on the course to produce more consistent going. The going-stick has been endorsed as an official measurement of going by the Jockey Club, and is currently used by 25-30 of the 59 racecourses in England, Scotland and Wales.

13+	Hard
12	Firm
10	Good to Firm
8	Good
6	Good to Soft
4	Soft
2	Heavy

Figure 2.3: 15 point index of going expressed by the going-stick.

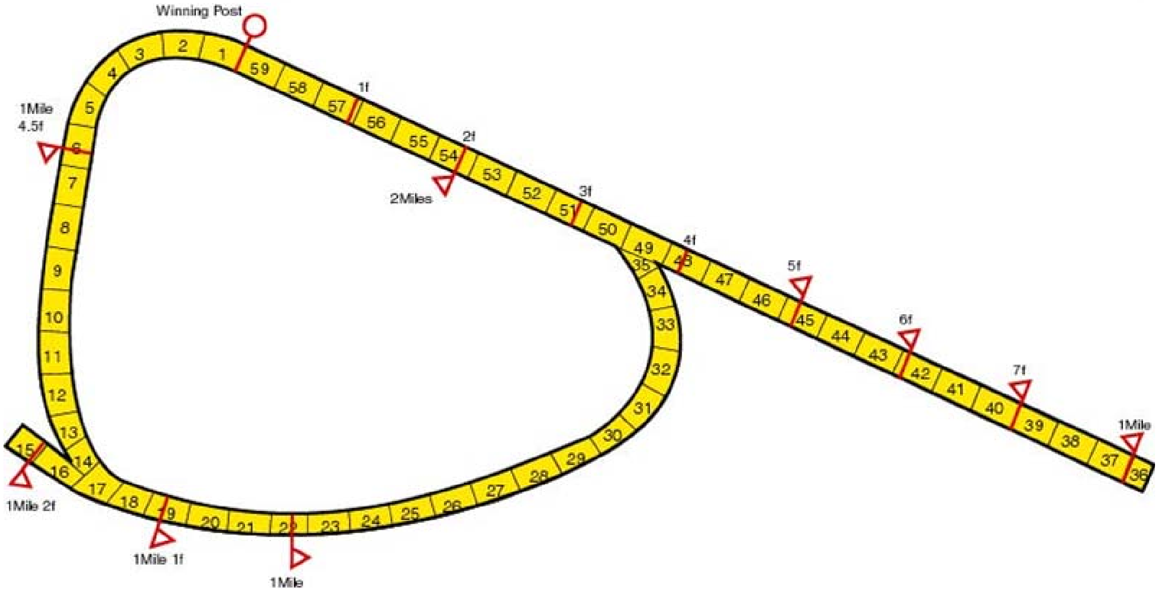


Figure 2.4: Going-stick waypoint system for the flat course at Newcastle racecourse.

2.2.3. Potential impact of incorrect going determinations.

The incorrect determination of going around a racecourse can lead to inappropriate management decisions and practices that may result in poor surface conditions. The knock-on effect of poor surface conditions – apart from the risk for serious injuries to horses – is the potential impact on the market value of the racing industry and its stakeholders (Figure 2.5).

The value of horseracing to the constituent parts of the horseracing industry for the year 2004 is stated by Mintel (2005) to be worth:

- £9 billion in turnover to the betting industry, with two thirds of its total profits arising from horseracing.
- £400 million in tax revenues for the government derived from £250 million in betting duty receipts, with the remaining tax from racing and breeding activities.
- £101.3 million in prize money available to the owners of racehorses.
- £100 million in funding for the levy board.

However the value of revenue generated for individual racecourses was not given, owing to the differing scale and scope of activities at each racecourse.

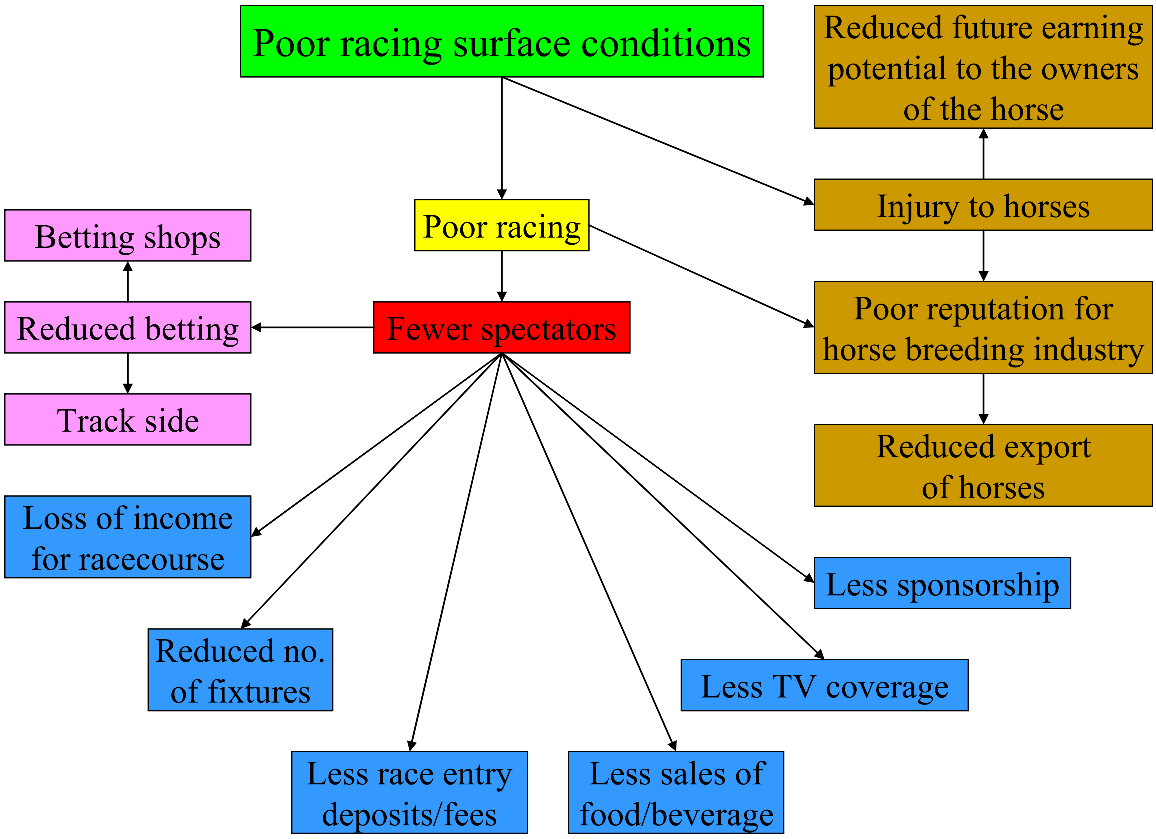


Figure 2.5: Implications of poor surface conditions on racecourses.

2.3. Management Issues.

The management issues associated with the production of optimum surface conditions revolve around the grass plant, the medium it is growing in (soil), and the use of water. The relationships and inter-relationships between these components are complex. Figure 2.6 (overleaf) has been developed by the author to illustrate these relationships. The following sections (2.2.1. to 2.2.5.) consider, in turn, these three key factors (grass plant, soil and water).

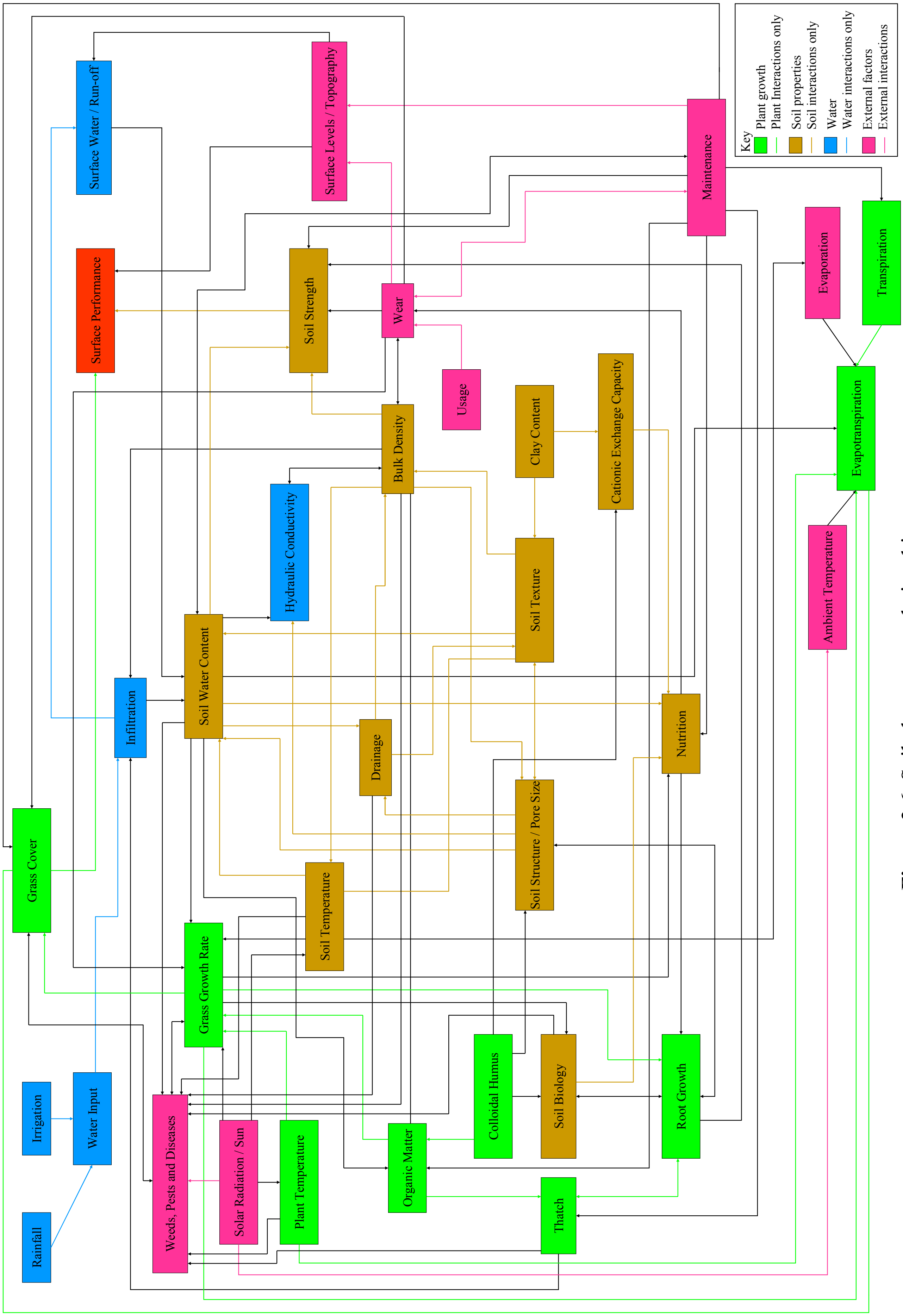


Figure 2.6: Soil plant water relationships

2.3.1. Turfgrass.

Turfgrass racecourses have a faster racing surface than a bare ‘dirt’ racecourse (Joe King, quoted in Westbrook-Dominick, 1992). A good overall cover of a suitable, high quality sward grass is important, as it will help to prevent the horse from changing its stride and injuring itself, which can occur if there are changes in the appearance of the grass cover. In good growing conditions, mature turf will recover almost immediately from the wear and tear imposed on it from racing horses. If over used however, the turfgrass cover can be destroyed (Lodge and Shanks, 1999).

In England, Scotland and Wales the turfgrass species typically found on a racecourse will be cool season grasses (C3 grasses). The composition of the turfgrass species varies dependent on the level of use the racecourse receives. Perris (1999) found that if Fescue (*Festuca sp*) was present in the sward, it was “*invariably strongest*” in less intensively used sections of the racecourse, for example, off the racing line. Perennial Ryegrass (*Lolium perenne*) is a wear tolerant pasture type species that usually dominates areas of greater wear (Field, 1994). In high wear areas with compacted soils, an increase in Meadow Grass (*Poa sp*) occurs, with a resultant decrease in Perennial Ryegrass (Field and Murphy, 1991, cited in Harrington 1994).

Certain meadow grasses, such as Annual Meadow Grass (*Poa annua*), and Rough Stalked Meadow Grass (*Poa trivialis*), are undesirable because they are shallow rooting (Field, 1994). Good rooting is important for water and nutrient uptake to sustain the grass plant, and because of the reinforcing influence of roots on soil strength. Perris (1999), suggests the use of Smooth Stalked Meadow Grass (*Poa pretensis*) in the establishment of a turf sward on a racecourse as it is a hard wearing grass that quickly fills-in bare areas, such as recently repaired divots, due to its rhizomatous growth habit. Other grass species found on racecourses are Timothy (*Phleum pratense*), particularly on wet sites, and Cocksfoot (*Dactylis glomerata*). Growth of C3 grasses is limited at temperatures below 5°C, and the optimum temperature range for their growth is 15-22°C (Aldous and Wilson, 1999). Excessive growth and/or poor management of the turfgrass can lead to a build-up of thatch, which is described in Section 2.3.1.1.

2.3.1.1. Thatch accumulation.

If the turfgrass is not managed properly, excess organic matter known as 'Thatch' can develop. Shildrick (1985) defines thatch as "*an intermingled organic layer of dead and living shoots, stems, and roots that develop between the zone of green vegetation and the soil surface*". Several specific factors lead to the formation of thatch on a racecourse, which Catrice (1993) lists as:

- Height of cut
- Aeration techniques
- Fertilizer use
- Microbiology of the soil
- Grass species
- Non-collection of arisings
- Intensity of use of the racecourse
- Composition of the soil
- Climate

A certain amount of thatch that has a weak water retention capacity and has an inert organic pad with few adsorbed cations is desirable (Pierrang and Catrice, 1989), and is thought to act as a shock absorber in the soil. However Zebarth and Sheard (1985) reported that thatch did not have a significant effect (P <0.05) on surface hardness, and that turf management should be carried out to optimize turf growth and recovery. Excess thatch can, however, lead to poor infiltration of water, poor soil aeration, low soil strength / poor structure and shallow root growth. Root growth is important to the strength characteristics of a soil and is explained in the following section.

2.3.1.2. Root growth.

Roots have an important role as they enable the take-up of soil water and nutrients thereby ensuring the survival of the grass plant and anchor the grass plant to the surface reducing the likelihood of it being pulled or kicked out of the ground. Root growth is influenced by several factors, such as the height of cut (HOC) of the turfgrass, severity and depth of any soil compaction, nutrient status and moisture content of the soil (Borg and Grimes, 1986).

Rooting depth of the turfgrass dictates the depth of water held in the soil that is available to the grass plant. Seasonal changes in root length can occur, especially if the

HOC is adjusted (see Figure 2.7). Therefore the monthly rooting depth needs to be established to determine the plant available water (PAW). Mown cool-season grass rarely roots deeper than 0.3 metres (Emmons, 2000).

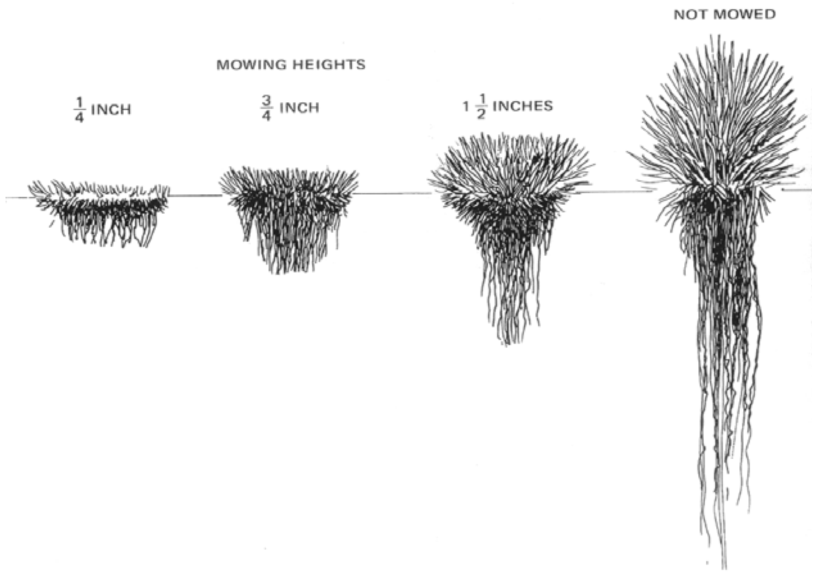


Figure 2.7: Changes in turfgrass root depth with height of cut (Emmons, 2000).

“Mechanical impedance” is stated by Whalley *et al*. (2005) to be one of the most often cited physical stresses that affects root growth. Although Bengough and Mullins (1990) state that virtually all roots growing through soil experience mechanical impedance to some degree. Large mechanical resistance to root growth occurs in dense regions of high soil strength, which occur in naturally compacted soil horizons or where soil compaction is caused by heavy vehicles or excessive wear.

Rooting can influence soil strength and stability and can improve soil shear resistance at depth (Waldron and Dakessian, 1982). The shear resistance of sandy rootzones were shown by Adams *et al*. (1985) to increase by a factor of 2-3 when grass roots were present. The effects of rooting on shear strength is, however, dependent on the species of turfgrass, as Adams and Jones (1979) found that the roots of *Agrostis tenuis* ‘Highland’ (Brown Top Bent grass) had an insignificant effect on shear resistance, whereas greater shear resistance was found with the roots of *Lolium perenne* ‘Majestic’ (Perennial rye grass) which is the grass species favoured on most racecourses. Rooting depth is not affected by soil texture itself (Borg and Grimes, 1986), which is described in Section 2.3.2.

2.3.2. Soil texture.

Soil texture is classified by the relative components of a soils particle size distribution (PSD), which is separated into sand, silt and clay fractions (2.0-0.05, 0.05-0.002 and <0.002 mm diameter respectively). Soil texture classes identified in England and Wales are as follows:

- Sand
- Sandy loam
- Sandy clay loam
- Sandy clay
- Clay loam
- Clay
- Silty clay
- Silty clay loam
- Silt loam
- Sandy silt loam

following the classification developed by the Soil Survey of England and Wales (Avery, 1980).

Soil texture can have an influence on the performance of a racing surface. Zebarth and Sheard (1985) found that turfgrass had higher resistance to shear (i.e. higher resistance to hoof rotation) and lower impact resistance (i.e. lower shock loading of the horses leg) when grown on natural soil material, compared to turf grown on sand materials. This implies that safer racing surfaces are achieved on soil-based surfaces; however the relative strengths of soil and sand based surfaces would be dependent on their moisture content, which has a considerable influence on the strength characteristics of both soil and sand materials, as described in Section 2.2.8.

Variation in soil texture occurs on both a macro and micro scale (Figures 2.8 and 2.9). Perris (1999) stated that research by the Sports Turf Research Institute (STRI) in 1995, to assess six racecourses in the United Kingdom (UK), found that it was rare for the majority of the ground of a racecourse to be consistent with regards to the soil type and depth. Wrigley *et al*. (1994) attributes such variation to the extensive area of land that racecourses cover. Soil variability is further compounded by the use of sandy rootzones during routine maintenance to repair surface damage by horses' hoofs. Inconsistency in soil type and depth may be a factor in the variability of racecourse going, due to the diverse drainage characteristics and water-holding capacities of the different soils. The water holding capacity, and therefore soil-water content, has a large influence on the soil strength properties of a soil and is described in Section 2.3.3.

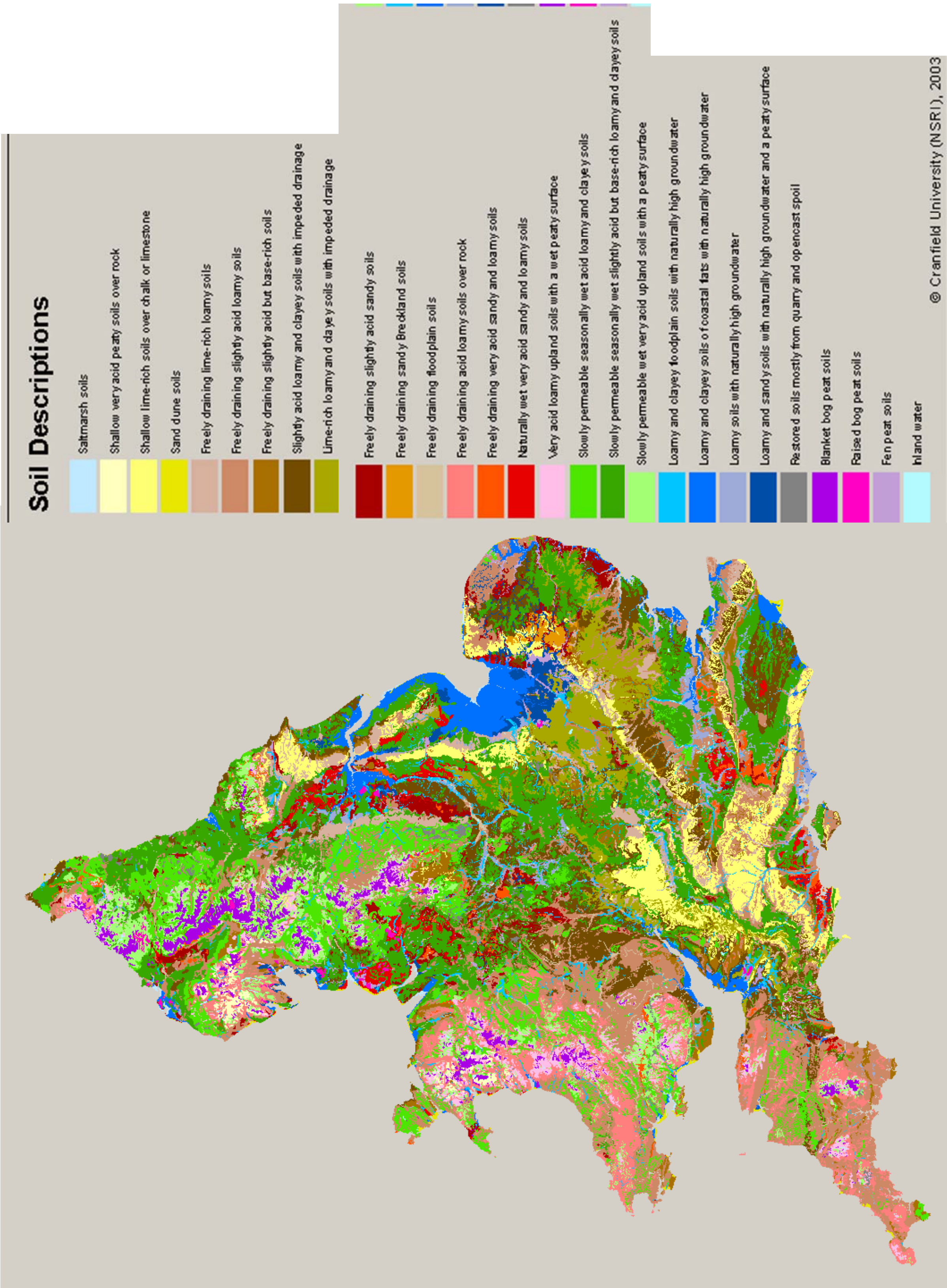


Figure 2.8: Soil variation on a macro scale (simplified version of the national soil map supplied by the National Soil Resources Institute. © Cranfield University, 2003).

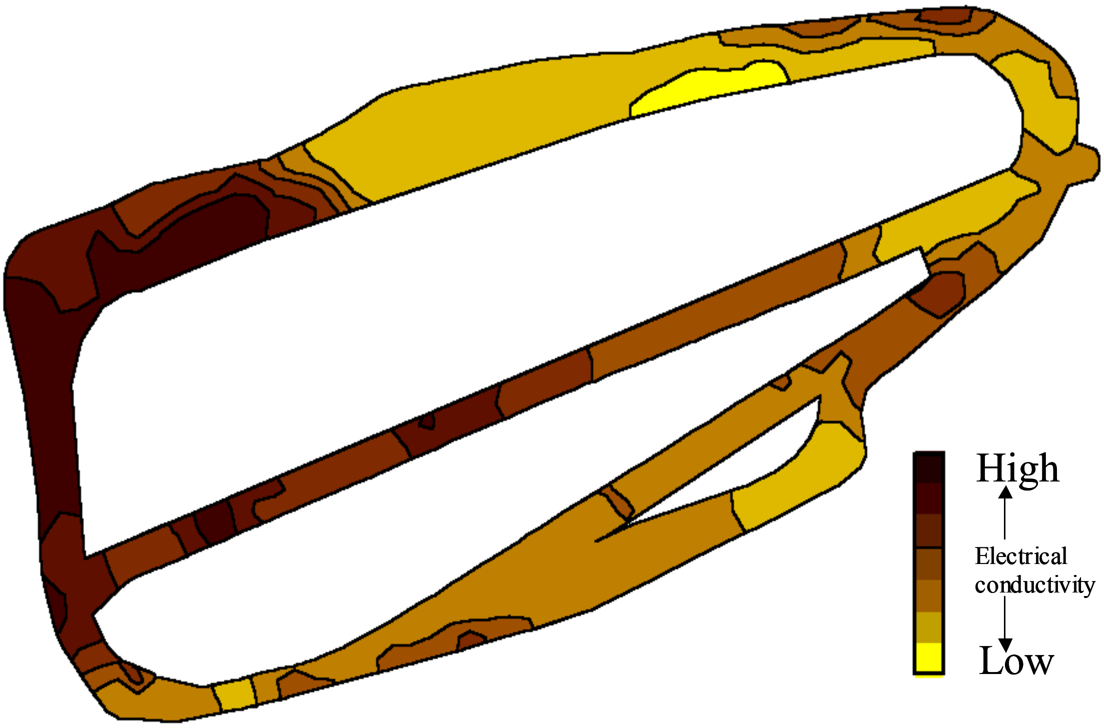


Figure 2.9: Soil variation on a micro scale denoted by changes in colour on a map of Sandown Park Racecourse (MagnaScan soil map of Sandown Park Racecourse © TurfTrax, see Appendix 1.1 for an explanation of the magnascan).

2.3.3. Soil structure

The way in which soil particles and aggregates are held together, termed the 'Soil Structure,' is as important as soil texture in regulating the movement of air and water in the soil, both of which impact greatly on the soils suitability for plant root growth (Brady and Weil, 2002). Dexter (1988) defines soil structure as "*the spatial heterogeneity of the different components or properties of the soil*," where the 'components' range from, amongst others, the arrangement of colloidal clay particles in a floculе, the arrangement of clods on the surface of a tilled layer, an array of earthworm tunnels and the variability of soil strength from one point to another. Dexter (1988) further explains that "*spatial heterogeneity = spatial variability = structure*".

Soil structure influences most factors that affect plant growth in soil, but it is not a plant growth factor itself (Scott, 2000). The processes associated with the development of structure are listed by Rowell (1994) as:

1. *Physical:*
   (a) drying and wetting which causes shrinkage and swelling with the development of cracks and channels;
   (b) freezing and thawing which create spaces as ice is formed.
2. *Biological:*
   (a) the action of roots, which remove water resulting in the formation of spaces by shrinkage, release organic materials, and leave behind organic residues and root channels when they die;
   (b) the action of soil animals which move material, create burrows and bring mineral and organic residues into close association;
   (c) the action of micro-organisms which break down plant and animal residues, leaving humus as an important material binding particles together.

Soil structure is often evaluated with the determination of bulk density (ρ_b). A compacted soil will have a high ρ_b and lower porosity. ρ_b values are generally lower at or near the surface and, dependent upon the soil formation processes, usually increase with depth to some maximum value (Scott, 2000).

2.3.3.1. Shrink-swell cycles.

Racecourses on clay dominated soils that irrigate during the summer may create swollen soil that is prone to compaction, when it should ideally be shrinking as it dries to maintain and renew its structure. If jump racing in winter is held on the same racecourse, and remedial action has not been taken to alleviate compaction and structural damage, poor drainage can occur. This exacerbates the tendency for the soil to compact and damages the soil structure further, leading to further drainage and compaction problems. Waterlogged surfaces are one of the main causes for cancellations of flat and jump racing.

Changes to the soil structure can be brought about through wetting and drying cycles. Wetting can cause compression and air entrapment through differential swelling. Soil particles and aggregates reorientate upon drying due to changing surface tension forces, leading to the development of structural units where repeated wet/dry (shrink-swell) cycles occur (Hussein and Adey, 1995). Wet-dry cycles were shown by Pillai and McGarry (1999) to be a mechanistic method of repairing compaction, with six wet-dry cycles producing the greatest improvements in structure in the soils they considered.

2.3.3.2. Soil compaction.

Compacted soil is a major component of poor racing surfaces. The compaction is caused by traffic, both horse and machine, when the soil is at its optimal water content for compaction to occur and culminates in poor drainage, shallow root growth, and low surface resilience. A compacted layer 70-150mm below the surface is not unusual on racetracks (Field, 1994), but on excessively soft tracks, horses hooves can sink as deep as 200 mm into the ground (Plate 2.3). Compaction at depth as a result of such severe damage can have significant repercussions on winter racing, when good drainage is essential.

A

B

Plate 2.3: Typical wear on a racecourse when raced on heavy ground (A), resulting in hooves penetrating the soil down to a depth of 200 mm (B), which can cause severe compaction.

Variation in the severity of compaction can occur around a racecourse. Most compaction occurs on the jockeys preferred racing line, which can be alleviated to a degree by moving the rails of the racecourse to spread the wear (traffic). Other areas that are prone to greater levels of compaction are the take-off and landing points on jumps, which are usually used in the winter months when the ground is soft.

2.3.4. Soil strength.

The ideal racecourse surface is stated by Field (1994) to have an '*elastic and resilient surface, which will provide adequate cushioning and then return to its original state'* and is further defined by Magni *et al*. (2005) as a racecourse that provides '*good traction, high shock absorbency and minimal surface deformation*'. Soil elasticity is the intermediate state between viscosity, which is caused by too much water, and plasticity, where maximum shock absorption by friction occurs (Catrice, 1993). A viscous soil will result in slippage without compressing the soil; plasticity will cause significant surface deformation, resulting in a reduction in porosity and an increase in the soils bulk density and compaction. Therefore the water content and porosity of the soil have a large affect on soil strength and deformation, which Clothier (2001) states are key characteristics of racecourse performance. Knowledge of the relationship between soil strength, deformation and the soil water content is therefore important.

Cohesive soils (a soil with a clay content greater than 15%) have two components of soil strength a) electrostatic forces between the water in the capillary pores and clay surfaces and between clay platelets, and b) the soil particles frictional resistance to movement (Brady and Weil, 2002). When cohesive soils become compacted or dry, the soil particles come into closer contact and increases in strength occur as a result. Conversely a decline in strength occurs as the soil becomes wet and the pores fill, forcing the particles apart, which reduces the frictional and cohesive components.

Non-cohesive soils, such as sand, rely on frictional forces between the particles for their strength when dry. When the water content of a non-cohesive soil bridges the gaps between the particles, the soil strength increases through the electrostatic attraction of the mineral surface and the water. However water will act as a lubricant, as opposed to a binding force, if the particles become surrounded by water, resulting in a loss of soil strength (Brady and Weil, 2002).

2.2.4.1. Soil water release characteristics.

More water is retained by clay, at a given water potential, than a loam or sand, as shown in Figure 2.10 which illustrates the idealised relationship between the moisture content and water potential for three different soil textures. Soil texture has a large influence on the retention of soil moisture as the proportion of micropores that hold water tightly are largely determined by the amount of clay in the soil.

The soil water content – energy relationship is influenced by the soil structure, where greater overall water-holding capacity is achieved with a well granulated soil that has more total pore space than a poorly granulated or compacted soil. Bullock *et al*. (1985) showed that compaction can decrease macro porosity (pores >60 µm diameter) by over half. A compacted soil is likely to have a high proportion of medium and small pores, which will hold less total water than a well structured soil, but will hold more of that water more tightly than the large pores, found in well structured soils, that hold water at relatively low potentials. Therefore the water release characteristics of a soil are predominantly influenced by soil structure at potentials between 0 and approximately 100 kPa, the remainder of the water release is influenced by the soil texture (Brady and Weil, 2002).

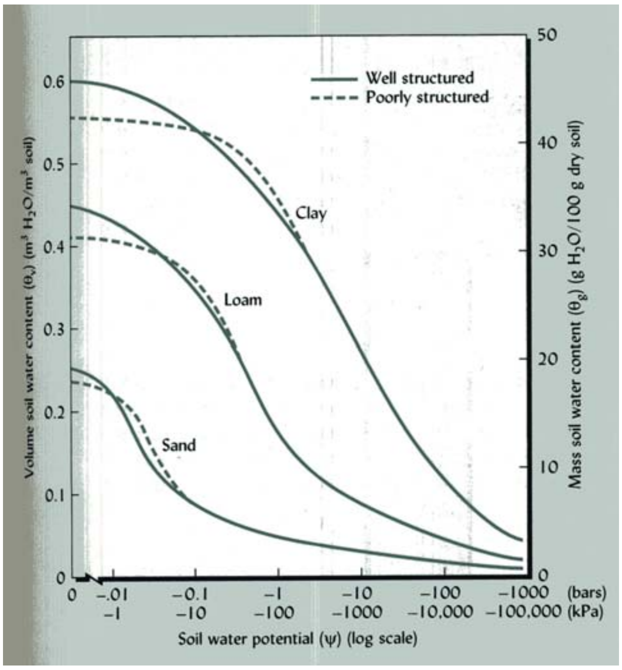


Figure 2.10: Moisture release characteristic curves for three different soil textures (taken from Brady and Weil, 2002).

Taylor *et al*. (1972) state that decreasing soil water potential or water content often increases soil strength. This is echoed by Terzaghi *et al*. (1996) who state that the degree of compaction and stiffness of a cohesive soil increases as its water content approaches the lower limit of the plastic range. Further evidence is provided by Spoor and Godwin (1979) who found that clay soils deformed by either brittle fissuring or in a compressive way, depending upon the relative values of moisture content, spherical pressure and dry density. However, the relationship between pore-water pressure deficiency and tensile strength during drying was shown by Haines (1927, cited in Snyder and Miller 1985) to differ markedly from the corresponding relationships during wetting, due to hysterisis effects, which is explained in the following section.

2.3.4.2. Hysterisis.

A drying soil is used to determine the relationship between soil water content and potential. When the same soil is wetting (as opposed to drying) the relationship is different, as a drying soil will retain more water than a wetting soil at the same potential (Figure 2.11). This phenomenon is termed ‘hysterisis’, and is due to several factors which Brady and Weil (2002) describe as the non-uniformity of pores, as some smaller pores can be bypassed as the soil is wetted, which prevents water penetration due to trapped air. Micro pores surrounding macropores can also create a bottleneck effect as the macropore cannot lose its water until the potential is low enough to empty the smaller pores surrounding it.

Changes to the soil structure brought about by shrink-swell cycles of clays can also occur as the soil wets up and dries out, leading to a change in the pore size and distribution. However soil structure is likely to be constantly changing throughout the wetting phase, dependent on the clay content and rate of wetting, as the swelling soil will be continually changing the size and distribution of pores. Therefore the amount of water held in a wetting soil at a given potential is likely to be influenced by the rate at which a soil reaches that potential.

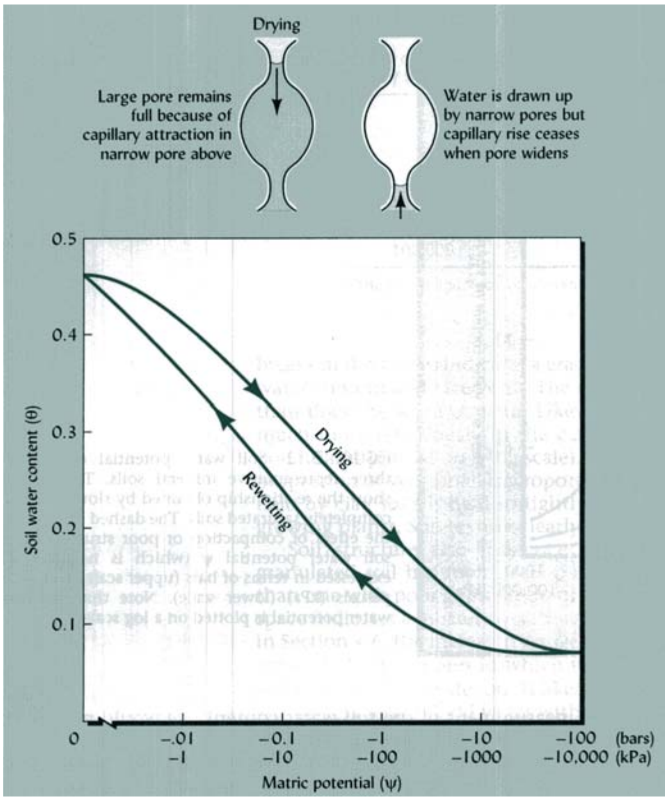


Figure 2.11: Graphic representation of the difference in water held in a drying and wetting soil at a given potential (taken from Brady and Weil, 2002).

2.3.4.3. Atterberg limits.

An indication of the degree of deformation that will occur for a given soil when subjected to a load can be taken using the 'Plasticity index' (I_p), which is the numerical difference between the different states of soil consistency (liquid limit and plastic limit) and their corresponding water contents referred to as the 'Atterberg limits' (Terzaghi *et al*., 1996). The liquid limit (W_l) corresponds to shearing resistance of approximately 1.7 to 2.0 kPa for all fine-grained soils (Mitchell and Soga, 2005), whereas the plastic limit (W_p) is the range of water content where the soil has plastic behaviour and an undrained shear strength (for different clay minerals) between 100 to 300 kPa (Sharma and Bora, 2003 cited in Mitchell and Soga 2005).

The plasticity index (I_p), is calculated as:

$$I_p = W_l - W_p \quad (1)$$

and is represented in a plasticity chart (Figure 2.12) which shows the I_p as a function of W_l for clays and silts.

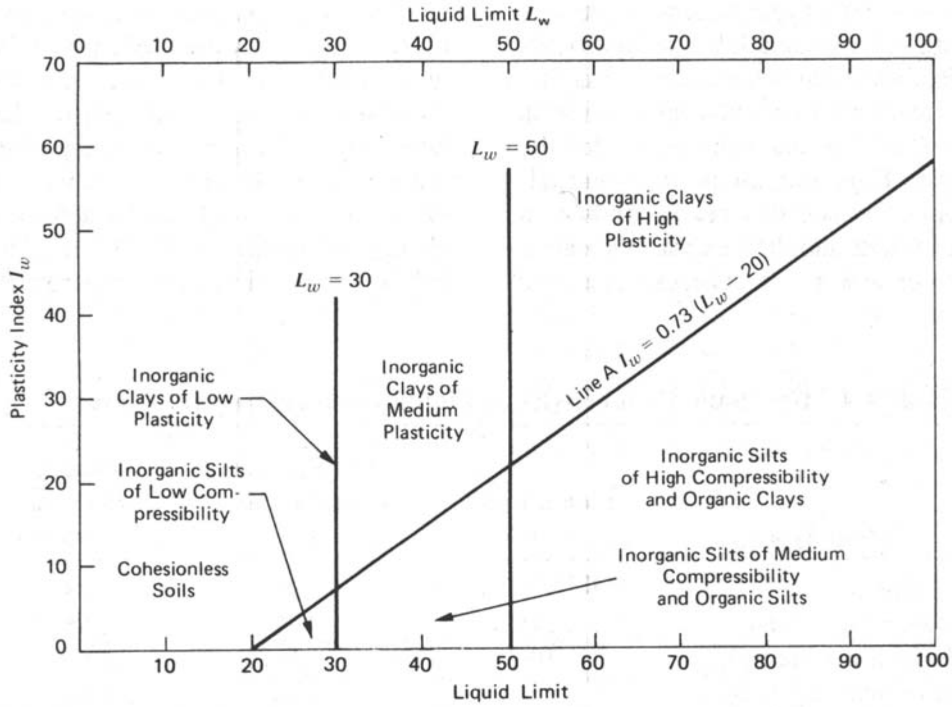


Figure 2.12: Plasticity chart (taken from Mitchell and Soga 2005).

As the rating of a racecourses surface (going) relates to how hard the surface is, it can be associated to the lower and upper plastic limits of the Atterberg limits, where a hard surface has low plastic behaviour with high strength characteristics and a soft surface has high plastic behaviour and low strength characteristics. Given the strong influence that water has on soil strength properties, the management of soil water is fundamental to the management of going on a racecourse. This is supported by Baker *et al*. (1999) who suggest that irrigation practices to reduce the firmness of the racing surface are more important than aeration methods. However Field and Murphy (1990) state that direct measurements of wetness are not indicative of the surface conditions as it is difficult to measure the water content of only the layer of soil that reacts with the horses hoof. Although Bullock *et al*. (1985) suggest that monitoring soil water potential is useful to establish the frequency of wet-dry cycles, which may be of value due to their important role in the regeneration of soil structure.

There is a need to relate the soil water content, for different soil types, to a level of going, to be able to determine the level of soil water required for a specified level of going. The calculation of water losses from racecourse surfaces is also important in order to be able to make the correct management decisions with regards to the application of supplementary irrigation.

2.3.5. Determination of water loss from the surface.

Grass plants, like all plants, require water to sustain life. Water is lost by the grass plant through the stomata on its leaves during the process of transpiration (Beard, 1973). Further water losses occur from evaporation from the surface of the soil, which is influenced by the surface shading produced by the turf cover; evaporative losses are greater when there is poor coverage of turfgrass. The combined effect of water loss through transpiration from the plant, and evaporation from the soil is termed Evapotranspiration (*ET*) (Fry and Huang, 2004) (Figure 2.13). A determination of water losses through *ET* has to be made in order to establish the correct amount of irrigation water the turfgrass requires to survive.

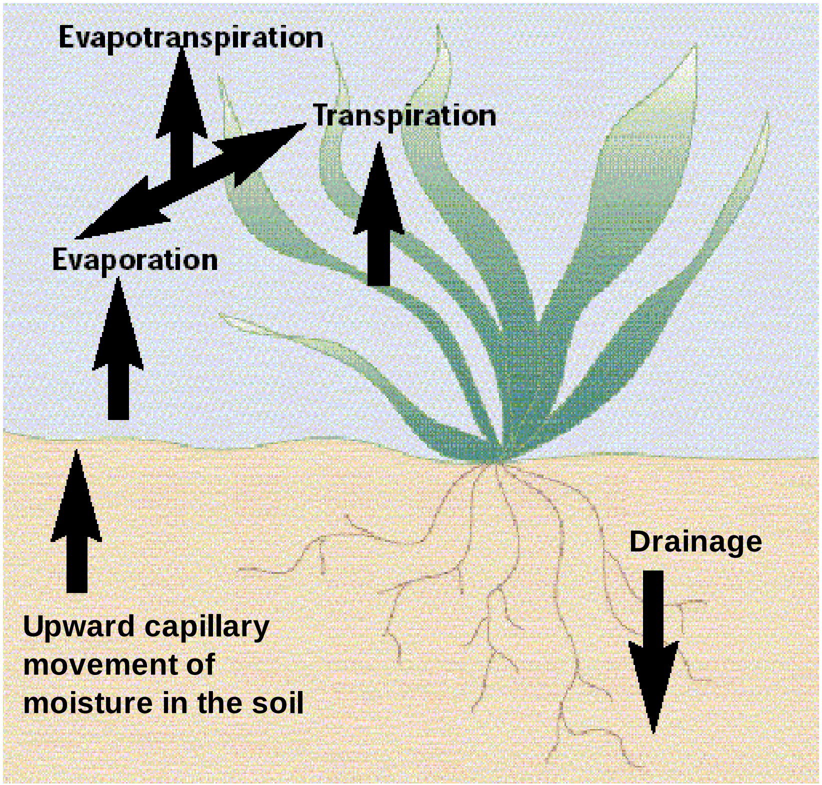


Figure 2.13: Water loss through evapotranspiration (adapted from Mitra, 2000).

2.3.5.1. Establishing ET rates for racecourse turfgrass.

Before the actual *ET* for the turfgrass (ET_c) can be determined, a reference crop *ET* (ET_o) has to be calculated from weather data and multiplied by the crop coefficient (K_c) that is specific to the turfgrass maintained in the chosen area. The reference crop is described in Allen *et al*. (1998) as "*A hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23*". This description closely resembles an actively growing and adequately watered stand of grass of a uniform height, similar to that found on a racecourse. The K_c coefficient incorporates the averaged effects of evaporation from the soil and the characteristics of the turfgrass, and is the ratio between ET_c and ET_o (Aronson *et al*., 1987).

ET rates have been shown by Jiang *et al*. (1998) to vary on similarly maintained turf on a golf course due to differing microclimates across the site. Little or no work has been carried out to establish *ET* rates for sports turf with the climatic conditions and turfgrass species found in the UK. Lodge and Baker (1992) showed that the mean value of ET_c was 65% of the value of ET_o (a K_c of 0.65) on a UK golf putting green. However the height of cut (HOC) on a golf putting green is significantly lower than the HOC found on a racecourse, therefore the 65% value is unlikely to be relevant to a racecourse. Others (Richie *et al*., 1997; Ervin and Koski, 1998; Brown *et al*., 2001) have reported K_c values between 0.5 to 0.9 for cool-season turfgrass across a range of climatic conditions in the United States of America (USA). Table 2.3. shows an example of K_c values for the southwest of the USA.

Table 2.3.
Crop coefficients for cool-season turfgrass in the arid southwest of the USA (adapted from Richie *et al*., 1997).

Month	***Monthly***	***Quarterly***	***Semi-annually***	***Annually***
January	0.61			
February	0.64	0.67	0.68	
-[1]	-[1]			
April	1.04			
May	0.95	0.96		
June	0.88		0.90	0.80
July	0.94			
August	0.86	0.85		
September	0.74			
October	0.75			
November	0.69	0.68	0.68	
December	0.60			

[1] *Not given*

2.3.5.2. Determination of reference crop ET (ET_o) for racecourse turfgrass.

A value of ET_o can be achieved from direct measurement of evaporation using methods such as a Class-A pan or porous ceramic atmometer (Qian *et al.*, 1996). Alternatively an estimate of ET_o can be derived from an empirical model that incorporates weather data for a given area, such as the FAO Penman-Monteith equation (Allen *et al.*, 1998), where:

$$ET_o = \frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma \frac{900}{\mathrm{T} + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (2)$$

Where
ET_o = reference evapotranspiration [mm day^{-1}],
R_n = net radiation at the crop surface [Mj m^{-2} day^{-1}],
G = soil heat flux density [Mj m^{-2} day^{-1}],
T = mean daily air temperature at 2 m height [°C],
u_2 = wind speed at 2 m height [m s^{-1}],
e_s = saturation vapour pressure [kPa],
e_a = actual vapour pressure [kPa],
e_s-e_a = saturation vapour deficit [kPa],
Δ = slope vapour pressure curve [kPa °C^{-1}],
γ = psychrometric constant [kPa °C].

2.3.5.3. Determination of actual ET (ET_c) for racecourse turfgrass.

Previous research (Devitt *et al.*, 1992; Brown *et al.*, 2001) has shown that it takes two to three years to develop satisfactory ET_c and K_c values. The generally accepted method to measure ET_c values is with Lysimeters (Connellan, 1999), although Carrow (1995) used Time-Domain Reflectrometry (TDR) to measure ET_c.

Brown *et al*. (2001) determined ET_c using the equation:

$$ET_c = I + P - \Delta S - D \qquad (3)$$

Where
I = irrigation,
P = precipitation,
ΔS = the daily change in soil moisture storage,
D = the amount of drainage.

The above methods are time consuming and would be beyond the time frame of this research project. However, a value of ET_c can be achieved if the K_c for the turfgrass is known, by using the equation:

$$ET_c \quad = K_c \times ET_o \qquad (4)$$

2.3.5.4. Determination of crop coefficient (K_c) for racecourse turfgrass.

Values of K_c are usually achieved by dividing the ET_c by the ET_o:

Hence $$K_c \quad = \frac{ET_C}{ET_O} \qquad (5)$$

Although this method requires knowledge of the ET_c, it may be possible to determine an estimate of the K_c from the leaf area index (LAI) – which is a ratio of the total leaf area to the unit area of ground beneath the leaves (Connellan, 1999) – with a HOC gradient (Burgess, pers. comm.). This would enable a back-calculation of ET_o to be made to arrive at an estimate of K_c, which will allow the calculation of ET_c.

Various factors affect K_c values such as grass type i.e. cool season (C3) or warm season (C4), height of cut, stage of development, and quality of the turf. K_c values are generally higher for C3 grasses than C4 grasses (Table 2.4.). During cold periods K_c values are lower, and appropriately higher in the warmer months (Brown and Kopec, 2000).

Table 2.4.
Typical K_c values for C3 and C4 grasses from a California site (Emmons, 2000).

Grass Type	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Bermuda (C4)	0.55	0.54	0.76	0.72	0.79	0.68	0.71	0.71	0.62	0.54	0.58	0.55
Rye (C3)	0.61	0.64	0.75	1.04	0.95	0.88	0.94	0.86	0.74	0.75	0.69	0.60

K_c values have been calculated and documented for agricultural crops by Allen *et al*. (1998), including basic estimates of K_c values for turfgrass in certain conditions. K_c values for sports turf, particularly racecourse turf, have not been calculated however.

Additionally, the calculation of K_c assumes that the soil is maintained at field capacity, which is unlikely to occur in reality due to natural drying periods or intervals between water applications. Therefore ET_c under non-standard conditions ($ET_{c\ \mathrm{adj}}$) is calculated by using a stress coefficient (K_s) and/or by adjusting K_c (Allen *et al*., 1998). Additionally, it would be preferable to calculate monthly K_c values as Carrow (1995) showed that K_c changed substantially over a growing season.

Assuming that ET_o, ET_c, K_c, K_s and $ET_{c\ \mathrm{adj}}$ can be determined for turfgrass on a racecourse, the correct application of water is important. The ability of the water application method to apply uniform amounts of water over the whole area serviced by it – referred to as the distribution uniformity (*DU*) of the water application system – can have a large effect on the quantity of water required to irrigate the turfgrass. Rainfall is assumed to have 100% uniformity as an equivalent depth of water would, in most cases, be applied over all areas of a given site. Richie *et al*. (1997) suggest that the *DU* of many turfgrass sites range from 50 to 70%, and that more irrigation water needs to be applied as the *DU* decreases, even though the turfgrass water use remains the same, which Richie *et al*. (1997) describes as:

$$\text{Actual irrigation need} = \frac{ET_O \times K_C}{DU} = \frac{ET_C}{DU} \tag{6}$$

Therefore the correct determination and uniform application of the amount of supplementary water required to replace water lost to *ET* is important. Incorrect determinations and poor *DU* can result in excessive amounts of water being applied to the surface, which could have a detrimental effect on the soil structure and strength properties, leading to poor surface characteristics.

2.3.5.5. Irrigation.

Irrigation is a management tool to supplement water applications in the absence of rainfall and has a dual purpose on racecourses; to promote good grass growth, and to soften hard surfaces. This concurs with Baker *et al*. (1999) who suggest that the effects of aeration practices to reduce hardness are secondary to irrigation. Overhead irrigation (as opposed to sub-surface irrigation) in the form of either pop-up sprinklers, tow lines, boom irrigators, rain guns, static or hand moved sprinklers, or a combination of two or more methods is generally used to apply water on a racecourse.

Adams and Gibbs (1994) state that in the UK in summer the maximum anticipated *ET* is approximately 25 mm per week and that irrigation systems should be able to achieve that amount of input. However no explanation as to how a value of 25 mm *ET* per week, which would equate to approximately 3.5 mm per day, was arrived at is given. It is possible that it is based on a 30 year average of *ET* for the summer months, but this could not be verified. Although an irrigation system that has the capacity to apply a greater volume of water than the 30 year average monthly *ET* (i.e. excess capacity) will allow for exceptional dry periods and/or the expansion of the irrigation system. However Catrice (1993) suggests that the amount of water that is thought to be sufficient for the turfgrass is usually considered excessive for the production of a surface rating that is suitable for horseracing, yet a method that associates a measure of soil-water to a measured level of going has not been established, therefore this suggestion should be viewed with caution.

Opinions on the ideal surface conditions vary from person to person, although water and its use / misuse is a consistent theme. Laxon (1998) believes that racecourses should not water within six to seven days of racing. Where irrigation within six to seven days prior to a race has occurred, many racecourses in the event of rainfall post irrigation go straight to soft going, which creates track bias in favour of horses that prefer softer conditions. Extremes of wet and dry surfaces through the over or under use of irrigation should not exist on the racecourse. Hughes (1998) asserts that irrigation, or lack of knowledge of irrigation use, has created as many problems as it has solved, especially when it is used to only irrigate sections of the racecourse, leading to changes in surface conditions.

In some circumstances, poorer racing surfaces have been produced with the installation of an irrigation system (Wrigley *et al*., 1994). This is likely to be due to excessive amounts of water being applied, which has led to a soil that is prone to compaction. Murphy and Field (1994) state that in some instances automated irrigation has led to an increase in the meadow grass (*Poa* sp) content of the racecourses sward composition. On one racecourse they recorded an increase in *Poa* content from 26% in 1989 to 45% in 1993, noting that an extensive irrigation system had been installed between their sampling times.

However it is suggested by Chivers (1999) that irrigation could help create more uniform conditions on dry parts of the racecourse by matching the moisture content of the drier and wetter areas of the racecourse. To achieve this would require an irrigation system that is capable of precise applications of water, in conjunction with a system to measure the soil conditions. Advances in precision agriculture have seen the development of digital crop water stress maps (Meron *et al*., 2003) and variable rate irrigation (Perry *et al*., 2003) to achieve spatially variable irrigation in a field environment. Adaptation of this technology may enable precision irrigation in a racecourse situation. Although it has been known that increased soil repellency (dry patch) may occur on high sand content soils where the use of a precise irrigation system has been used to replace the grass plants *ET* (Cisar, 1994).

Irrigation to replace water lost to ET_o will enable efficient water use to maintain grass plant survival in a racecourse environment. However, the amount of water required to change the going (i.e. water that may be needed in addition to that needed for grass plant survival) has not been established. Consequently, another (new) factor/coefficient that calculates the amount of additional water necessary to change a measured level of going from that which is deemed unsuitable for horseracing to a preferred going class on a particular soil type needs to be constructed.

2.4. Environmental Regulation.

The gross annual cost for a firm to decrease pollution output in line with environmental regulations is described by Venu (2002) as being "*equal to the sum of operating costs attributable to pollution abatement and payments to the government for sewage services and solid waste collection and disposal*". In the United Kingdom (UK) environmental regulation exists for many sectors of industry, ranging from agriculture, chemical and machinery manufacture, through to the textiles and clothing industry (Netreg, 2005).

The Water Resources Act 1991 controls the abstraction and impounding of water. To modernise water management the government introduced the Water Act 2003, which received Royal Assent in November 2003 (Environment Agency, 2005). The act introduced significant changes to the legislation governing water abstraction and impoundment licences currently contained in the Water Resources Act 1991, and will be brought into effect in stages over a period of six to eight years (see Appendix 1.2).

There will be three types of licence, full, transfer and temporary, where full licences are required for large abstractions, and transfer licences for large scale transfer from one source to another (HMSO, 2003). To protect the environment in water stressed areas the Environment Agency (EA) is attempting wherever possible to issue time limited licences, which will be issued on a first come, first served basis (dependant on the merits of the application), until the maximum allowable abstraction for a given area has been reached (Burges Salmon, 2003).

The EA shall also look closely at a firms water efficiency when issuing new abstraction licences or when reviewing/renewing existing licences. Water users should be able to show that they can economise on water use and avoid wastage of water as much as possible, in order to strengthen any application for a water abstraction licence.

2.4.1. The impact of the Water Act 2003 on water use on racecourses.

Horse racing in the UK mainly takes place on a natural turfgrass surface over a large area of land. A large number of the 59 racecourses in the UK abstract water for irrigation purposes. Irrigation is used for two purposes, a) grass plant survival, and b) the going. To achieve the required going for racing – good and good-to-firm going for jump and flat racing respectively – it is necessary in dry periods of the year to apply irrigation water to supplement rainfall. Failure to do so can result in going that is too firm, which has implications for the safety and welfare of the competing jockey and horse. Additionally, poorer racing surfaces will become apparent if water use is restricted through limited abstraction rights, the knock-on effect of poor surface conditions to the racing industry and its stakeholders was shown in Figure 2.5.

2.4.2. The Porter hypothesis.

In his essay "America's Green Strategy" Porter (1991) proposed that environmental regulations enhanced a firm's competitive advantage. Porter and Van der Linde (1995) further argued that the costs of complying with environmental regulation can be more than fully offset by the innovations they trigger, which they termed "innovation offsets". Strict environmental regulations stimulate innovation, leading to enhanced competitiveness.

However others (Campbell, 2003; Frohwein and Hansjürgens, 2005) maintain that firms will invest in new technology regardless of any environmental regulations placed upon them, and that stricter regulation will have a negative effect on innovation and competitiveness in certain segments of industry. In addition, results conforming to Porter's hypothesis that are driven by an environmental policy do not mean that the policy is optimal (Mohr, 2002).

Innovation offsets (IO) arrive in two distinct ways, firstly through learning, whereby the firm becomes more efficient and reduces waste (i.e. less packaging), improves a process, or converts waste into a secondary good, for example waste coconut fibre into a composting material (Greeneem, undated). The second method of IO derives from actual changes to a product in response to an environmental impact. IO are further divided by Porter and Van der Linde (1995) into two separate categories, 'product offsets,' and 'process offsets'. Where 'product offsets' result in safer, better quality products incorporating recyclable materials, and 'process offsets' achieve material savings, better use of by-products, lower energy consumption and reduced waste, any of which can reduce pollution in line with environmental regulation.

Costs that are greater than the minimum attainable are referred to as “x-inefficiencies” (Parkin *et al*., 1997). Through IO – not necessarily driven by environmental regulations – a firm is likely to achieve improved manufacture processes, lower product costs, and a safer working environment. These would result in efficient, and therefore cheaper, methods of operation, reducing x-inefficiencies, which would enable the firm to be more competitive whilst still reducing pollution which Klein and Rothfels (1999) refer to as a ‘double dividend’. Appendix 1.3 shows some examples of product and process offsets.

Racecourses need to show that they are managing their water use efficiently and effectively, in order for them to retain any existing abstraction licences, or for any successful future applications for an abstraction licence, under the Water Act 2003. Technology transfer is currently producing more efficient and effective irrigation strategies on racecourses. Section 2.5.3. highlights the technology available to racecourses that will enable them to comply with the requirements of the Water Act 2003.

2.4.3. Technologies available to racecourses to improve irrigation strategies.

2.4.3.1. Weather stations.

Small self-contained weather stations have been installed on some racecourses, allowing the manager to determine rainfall occasions and amounts, and other useful information such as solar radiation, wind speed and relative humidity. These measurements, in conjunction with computer software will allow the determination of a soil water balance that can be used to provide an objective determination of when and how much irrigation is required. This minimises unnecessary excessive use of irrigation that wastes water.

2.4.3.2. Soil moisture sensors.

Soil moisture measurement methods such as tensiometers, time domain reflectometry and capacitance sensors allow direct measurements of the soils moisture status, enabling the manager to make informed decisions on whether to irrigate or not. Unfortunately, due to the high contact forces that horses have with the ground on a racecourse, it is not possible to permanently install soil moisture sensors within the top 150 mm of the soil profile. Installation would result in either damage to the sensor, or worse still, injury to the horse and its rider. However, hand held versions of the soil moisture sensors can still be used to good effect.

2.4.3.3. Computer software.

Computer software to control irrigation systems is commonplace on many sports surfaces. However computer programmes to schedule irrigation, based on water losses through evapotranspiration, are not common on sports surfaces. These programmes, such as Daily ET, WaSim, and AWSET are generally used in the agriculture sector, and could be transferred to the sports surface sector. These programmes work in conjunction with site-specific data collected from a weather station.

2.4.3.4. Valve in head sprinkler control.

Currently, of the racecourses that use pop-up sprinkler systems, most use a block method to control the system. This is, one valve to control many sprinkler heads. This can result in wastage from surface water run-off if the soil does not have a high enough infiltration rate to cope with the high volumes of water that many pop-up type sprinklers deliver. Neither does the block method allow for individual control of sprinkler heads where adjustment of several sprinkler heads for high wind may be necessary. Valve-in-head sprinklers are independently controlled, allowing greater control over the area to be watered, and should reduce overall water applications if used correctly.

2.4.3.5. Travelling boom.

Travelling boom irrigators enable the entire width of a racecourse to be irrigated in one pass, achieving more consistent surface conditions (assuming the soil texture does not vary). Many racecourses are beginning to favour boom irrigators over pop-up sprinkler heads, as they also tend to use less water. However they are very expensive to purchase, and require greater labour inputs to operate.

2.4.3.6. Variable valve control.

Advancements in precision agriculture have seen the development of digital crop water stress maps (Meron *et al*., 2003) and variable rate irrigation (Perry *et al*., 2003) to achieve spatially variable irrigation in a field environment. Adaptation of this technology may enable precision irrigation in a racecourse situation.

2.4.4. Acceptance of technology in the racecourse industry.

However, even though advancements in technology have enabled more precise management of water, Canillas and Salokhe (2002) describe how information technology (IT) has not been embraced to any great extent in the farming industry. They explain that the lack of interest in IT by farmers is due to factors such as their relatively high age and low level of education. Many of the IT applications available do not seem to give significant benefits to the most experienced farmers (Ascough *et al*., 1999 cited in Canillas and Salokhe, 2002); a lack of agricultural competence is the driver for using IT.

The author does not envisage a similar situation occurring in the racecourse industry, mainly due to the potential constraints that the Water Act 2003 imposes on the managers of racecourses. To fully satisfy the obligations of the Water Act 2003 and to ensure safe racing surfaces are produced, it is likely that the racecourse industry will have to embrace innovation in order to achieve process offsets that will improve water use whilst at the same time reducing water consumption; a double dividend.

2.4.5. Porters hypothesis in relation to racecourses.

Porter's hypothesis that environmental regulations enhance a firms competitiveness through the innovations they stimulate may be correct for competing markets. However racecourses are unique in that they are not in direct competition with other racecourses, as the fixture list for UK racing is designed, in the main, to prevent clashes between adjacent courses. The innovation offsets that racecourses could achieve would be 'process innovations' achieved through embracing new and developing technologies to improve the way they manage their water supplies.

Racecourses need to use water more efficiently if they are to retain their abstraction licences. Technology is available, but is costly and beyond the resources of many racecourses. However racecourses cannot afford not to embrace this technology, as the alternative is to lose their abstraction licence, and no licence effectively means no business if the racecourse relies on summer racing. Therefore in the context of a racecourse environment, Porter's hypothesis should be interpreted such that environmental regulation leads to changes in management style that could lead to the sustained health of the competing horse and savings, both environmental and financial, in the long term.

2.5. Summary of the Literature.

The potential for musculoskeletal injury to a horse can be influenced by the surface characteristics of the racecourse. Uniform conditions (consistent going) would minimize the potential for serious injury to horses to occur. An objective determination of going aids the racecourse manager in pinpointing management activities to produce more consistent going. Poor management decisions may result in poor surface conditions which can have considerable impact on the welfare of the horse and the market value of the racing industry and its stakeholders.

Racecourses rarely have consistent soil texture along their length and across their width. Soil structure is as important as soil texture in regulating the movement of air and water in the soil. Wet-dry cycles can improve soil structure and repair compaction. The water content and porosity of the soil have a large effect on soil strength. More water is retained by clay, at a given potential, than loam or sand. Decreasing soil water potential or water content often increases soil strength. The soil water content, for different soil types, needs to be related to a level of going to enable the determination of the water required to achieve a specified level of going to be made.

Water lost from the racing surface can be determined with the calculation of ET_o. Little work has been carried out to establish ET for sports turf with the climatic conditions and turfgrass species found in the UK. Irrigation is a management tool to supplement water applications in the absence of rainfall and has a dual purpose on a racecourse; to promote good grass growth, and to soften hard surfaces. Mismanagement of irrigation has led to poorer surface conditions in some cases. A soil water balance can be used as an objective determination of when and how much irrigation is required. The Water Act 2003 requires users of water to economise on water use and avoid wastage, failure to do so could lead to the loss of any abstraction licence held by the racecourse, potentially leading to poor surface conditions as a result.

2.6. Conclusions.

None of the methods to measure going, described in Section 2.1, take into account the spatial variability of the soil texture and the relative moisture holding capacity of the soil, or the rooting depth of the turfgrass present; the very elements that contribute to the strength properties of the surface, as shown in Section 2.2. The need for a user-friendly, robust, objective determination of going based on the soil type, its water content, and the rooting depth of the turfgrass present will enable more accurate decision making with regard to water applications, which currently can be very subjective. Soil-water balance (SWB) models have been used for, amongst other things, determining water requirements for agricultural crops, therefore modelling going using a SWB would give the manager of a racecourse greater information as to the water status of the soil.

The relative amount of water required to change the going from a hard surface to a softer going condition that is more suitable for racing needs to be established. More uniform surface conditions – therefore safer for the competing horse – could be achieved with knowledge of the water requirements for the specific soil types encountered around the length and across the width of the racecourse. More accurate determination of the soil-water status would also aid irrigation practices in general, and should prevent excessive unnecessary applications of water, in accordance with the Water Act 2003.

3.0. CONTEXTUAL FRAMEWORK OF THE EXPERIMENTAL PROGRAMME.

There are 59 racecourses in England, Scotland and Wales. To help develop a framework around which to plan the experimental programme and also to provide some wider context for the research, a postal questionnaire survey was conducted in tandem with a revue of the potential soil moisture deficit for each racecourse. The results of this work were then used to identify eight racecourses, which would form the focus of further study. This work forms part of the work to achieve Objectives One and Two.

3.1. Potential Soil Moisture Deficit.

To identify the typical climatic conditions of each racecourse, the racecourses were categorized using the Environment Agency 'Agroclimatic Zones' (Weatherhead *et al*., 2002). The agroclimatic zones are rated from one to seven and relate to the potential soil moisture deficit (PSMD) at the end of one year (Table 3.1) for the area in which the racecourses are located (see Appendix 2.1).

Table 3.1
Agroclimatic zones and their potential soil moisture deficit after one year.

Zone 1	0 – 75mm	**Zone 2**	76 – 100mm	**Zone 3**	101 – 125mm
Zone 4	126 – 150mm	**Zone 5**	151 – 175mm	**Zone 6**	176 – 200mm
Zone 7	>200mm				

The agroclimatic zones were determined by converting the postal address of each racecourse to Easting and Northing coordinates, using the internet website 'Multimap.com' (Multimap, undated). The coordinates were then checked against the Environment Agency (EA) regional maps for agroclimatic zones. The EA maps only give agroclimatic zones for England and Wales however.

The agroclimatic zones for racecourses in Scotland were determined by using the methodology of Knox *et al*. (2006a) to estimate the PSMD for each racecourse location (Figure 3.1). This was carried out using the UK Climate Impact Program (UK CIP) dataset (Met Office, undated), which is the baseline climatology database for the period 1961 to 1990.

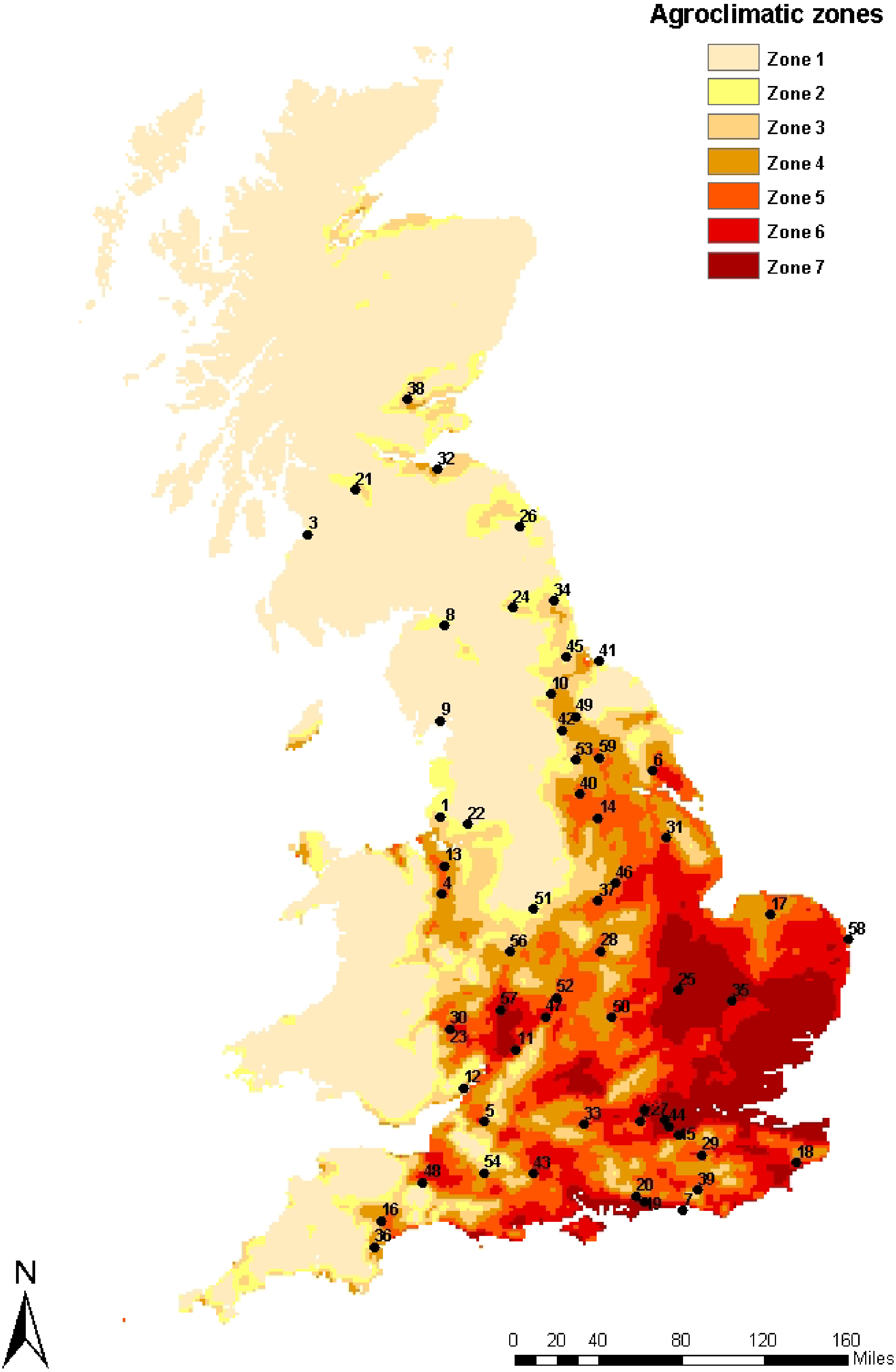


Figure 3.1: Agroclimatic zones for England, Scotland and Wales with racecourse locations indicated by numbers; see key overleaf (adapted from Weatherhead *et al*., 2002).

Key to racecourse locations

1	Aintree	21	Hamilton Park	41	Redcar
2	Ascot	22	Haydock Park	42	Ripon
3	Ayr	23	Hereford	43	Salisbury
4	Bangor-on-Dee	24	Hexham	44	Sandown Park
5	Bath	25	Huntingdon	45	Sedgefield
6	Beverley	26	Kelso	46	Southwell
7	Brighton	27	Kempton Park	47	Stratford
8	Carlisle	28	Leicester	48	Taunton
9	Cartmel	29	Lingfield Park	49	Thirsk
10	Catterick	30	Ludlow	50	Towcester
11	Cheltenham	31	Market Rasen	51	Uttoxeter
12	Chepstow	32	Musselburgh	52	Warwick
13	Chester	33	Newbury	53	Wetherby
14	Doncaster	34	Newcastle	54	Wincanton
15	Epsom Downs	35	Newmarket	55	Windsor
16	Exeter	36	Newton Abbot	56	Wolverhampton
17	Fakenham	37	Nottingham	57	Worcester
18	Folkestone	38	Perth	58	Yarmouth
19	Fontwell Park	39	Plumpton	59	York
20	Goodwood	40	Pontefract		

3.1.1. Agroclimatic zones of racecourses.

The 59 racecourses throughout England, Scotland, and Wales were grouped into seven zones according to their agroclimatic conditions (Table 3.2). Only one racecourse (Ayr) is in the zone one category (PSMD 0-75 mm), and two racecourses (Huntingdon and Kempton Park) fall within the parameters of zone seven (PSMD >200 mm). The majority of racecourses are categorized as zone four or five, with 15 and 21 racecourses respectively. A full list of the racecourses in the seven agroclimatic zones is given in Appendix 2.2.

Table 3.2
The number of racecourses in the different agroclimatic zones.

Agroclimatic zone	***Potential soil moisture deficit** (mm)*	***No. of racecourses***	***Percentage** (%)*
1	0-75	1	2
2	76-100	7	12
3	101-125	8	14
4	126-150	15	25
5	151-175	21	36
6	176-200	5	8
7	>200	2	3
	Total	59	100.0

Mean rainfall per agroclimatic zone cannot be calculated due to the spatial and weather pattern variation between racecourses. The long term average (LTA) rainfall for each racecourse can be used for comparison with rainfall data for a given year, to determine whether the year was drier, wetter, or similar to the LTA. Table 3.3 shows listed rainfall data for several racecourses for 2001 compared to the LTA, a full list of racecourses with comparisons between 2001 rainfall and the LTA are given in Appendix 2.3.

Table 3.3
Comparison of rainfall data for 2001 to the long term average rainfall.

Racecourse	***Annual rainfall for 2001** (mm)*	***30 Year average rainfall** (mm)*	***Difference to the 30 year average** (mm)*
Ascot	958.00	693.50	+264.50
Bangor-on-Dee	724.00	755.55	-31.55
Cartmel	1258.00	1219.10	+38.90

The results in Table 3.3 indicate that the actual rainfall in a given year can vary quite dramatically from the LTA. Ascot had a wetter than average year, with a difference of +264.5 mm from the LTA, whereas Bangor-on-Dee had a drier than average year, with a deficit of 31.55 mm rainfall in 2001. This variation is typical of the short-term temporal variation associated with many climatic datasets.

3.1.2. Discussion of the results of the potential soil moisture deficit for each racecourse.

The agroclimatic zones provided the mechanism to separate the racecourses objectively into groups, based on the PSMD they could expect at the end of one year. These groups identify the potential water requirements of each racecourse to maintain field capacity in one year. Racecourses in Agroclimatic Zone One would require less irrigation on average – at the end of a year – to recharge the soil back to field capacity, than a racecourse in agroclimatic zone seven. Thirty six out of the fifty nine racecourses in England, Scotland and Wales fell within agroclimatic zones four and five (61% of all racecourses).

However, the agroclimatic zones represent average values of PSMD that can be expected. Therefore it is possible that the PSMD could be higher in a zone one location than a zone seven in a given year, although on average, most years, zone seven would be higher than zone one.

3.2. Questionnaire Survey.

A questionnaire survey of the 59 racecourses was conducted in January 2003 to identify the following:

- Dimensions of the racecourse (Flat, Hurdle and Chase)
- Grass sward composition
- Predominant soil type present
- Whether irrigation is used
- How the manager decides when to irrigate
- Source of irrigation water
- Methods of irrigation water application

An alternative method to a questionnaire survey would be to conduct separate interviews with the Clerk at each course, but this would be time consuming and expensive, given the large number of racecourses, and their geographic spread throughout England, Scotland and Wales. Additionally there would be no guarantee that the quality of the answers would be any better than those received in a questionnaire survey. Plus there is the risk of bias due to leading the interviewee in the course of asking and explaining the questions.

The questionnaire was sent to the Clerk of the Course, and the Head Groundsman at each racecourse to ensure that someone who had expert knowledge of the racecourse and its management received it. A copy of the questionnaire is given in Appendix 2.4. A response rate of five percent is regarded as a typical rate of returned questionnaires for most postal surveys (Hague, 1993). A response rate greater than five percent was anticipated however, as the Jockey Club (industrial sponsors of the project) notified all 59 racecourses that they would be receiving the questionnaire and that they should complete it. This was followed with reminders to complete the questionnaire several weeks later.

The questionnaires contained qualitative categorical questions (questions that required a yes or no answer), and quantitative questions, for example the length of the racecourse (Appendix 2.5). In parallel with the questionnaire survey, a review of current agronomy reports for all 59 racecourses was also conducted to compare with the findings of the questionnaire survey. Particular emphasis was given to the reported soil texture and grass species present on the racecourse, as mistakes in their identification can be easily made.

3.2.1. Analysis of questionnaire data.

Analysis of the data generated by the returned questionnaires was carried out using Statistical Package for the Social Sciences (SPSS, 2001) computer software. Where questions had not been answered, discrete missing values were entered and coded to show if the answer was not applicable, not known, or illegible (Miller *et al*., 2002).

Descriptive and frequency tests were conducted to summarise the data. Cross tabulation was carried out to examine the relationship between two variables, for example soil texture and agroclimatic zone, and multi-response analysis was carried out to determine predominant soil texture and irrigation evaluation methods. Analysis of Variance (ANOVA) was carried out to determine whether any statistically significant relationships existed between the variables.

3.3. Questionnaire survey results.

There were 49 responses to the questionnaire survey accounting for 83% of all racecourses in England, Scotland, and Wales (see Appendix 2.5). Not all responses were fully completed; therefore there was variation in the number of responses to each question.

3.3.1. Predominant soil type.

The predominant soil texture was reported by 48 racecourses; as expected there was a considerable range between courses. Sandy loam and Clay loam were the two most commonly reported soil texture, with 23 and 27% of all cases respectively (Figure 3.2). The agronomy reports that stated a soil texture supported the reported types in the survey with the exception of Kempton Park (reported – sand, Agronomy report – sandy clay loam), Ripon (reported – clay loam, Agronomy report – silty soil), Stratford-on-Avon (reported – clay, Agronomy report – high sand content), and Worcester (reported – sandy silt loam, Agronomy report – silty clay loam).

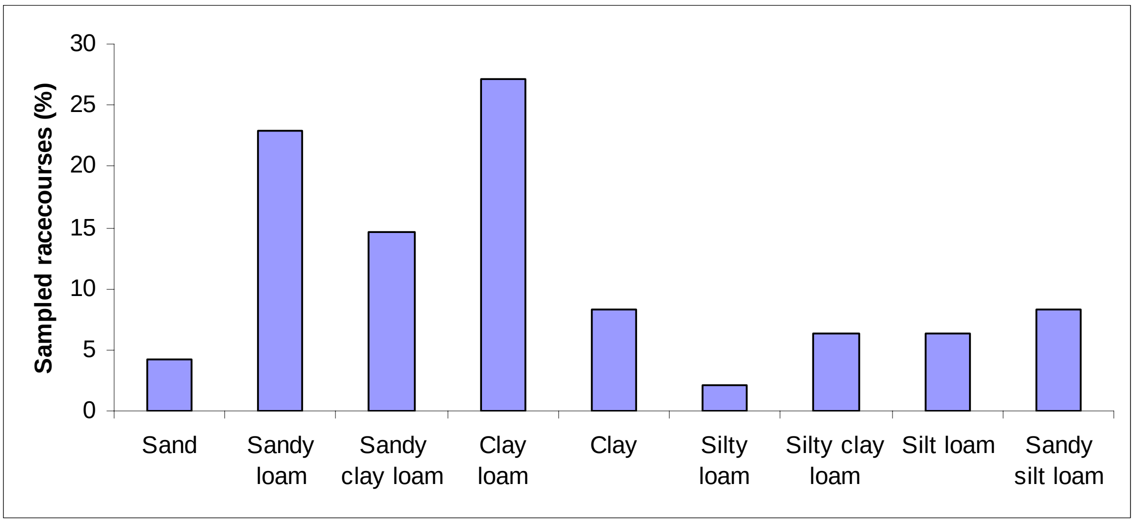


Figure 3.2: Predominant soil types found on the racecourses of England, Scotland and Wales.

3.3.2. Grass species.

As expected Rye Grass (*Lolium perenne*) was the dominant grass species with 65% of all reported grass types (Table 3.4). This is because Rye Grass is the grass type that Groundsman favour for over-seeding and renovation work due to its fast establishment and higher wear tolerance (Adams and Gibbs, 1994). Annual Meadow Grass (*Poa annua*), an invasive weed grass, was not as dominant as expected.

Table 3.4
Mean percentage of grass species present on UK racecourses.

	Bent (%)	*Fescue (%)*	*Rye (%)*	*Timothy (%)*	*Annual meadow grass (%)*	*Rough stalked meadow grass (%)*	*Smooth stalked meadow grass (%)*	*Other grass (%)*
Mean	3.93	10.33	65.20	1.02	9.78	1.57	5.85	1.90
S.E.	0.58	1.28	2.42	0.35	1.76	0.58	1.59	0.64

3.3.2.1. Influence of soil texture on sward composition.

Some of the reported soil textures had a significant relationship with the population of certain grass species. Sand content had a significant relationship with Bent Grass species (*Agrostis sp*) and Timothy (*Phleum pretense*) (F pr 0.025 and 0.016 respectively). This was not unexpected for the Bent Grass species, as the majority of Bent Grasses prefer drier soils, which a sand dominant soil would usually imply. Timothy is shallow rooting, and as a consequence is usually found on moist soils (Hubbard, 1984), and was not expected to have a significant population on a sand dominated soil.

Sandy clay loam had a significant relationship with the populations of Fescue (*Festuca sp*) (F pr 0.028), Rye Grass (F pr 0.021), and Smooth Stalked Meadow Grass (*Poa pretensis*) (F pr 0.001). Rye Grass was expected to be significant as it thrives in soil of this type. Smooth Stalked Meadow Grass was not expected to have a significant population, as it is very slow to establish (Aldous and Chivers, 2002). A full list of the reported populations of grass species for each soil texture is given in Appendix 2.5.

3.3.3. Irrigation of the racecourse.

Of the 49 respondents to the questionnaire, 47 racecourses used irrigation, two racecourses, Bath and Taunton, did not (Table 3.5).

Table 3.5
Number of racecourses that use irrigation.

		No. of racecourses	***Percent** (%)*	***Valid Percent** (%)*
Valid	Yes	47	79.7	95.9
	No	2	3.4	4.1
Missing data		10	16.9	
Total		59	100.0	100.0

3.3.3.1. Determination of irrigation requirement.

Methods used to determine the need for irrigation varied between objective measurements e.g. penetrometer, and subjective measurement such as a visual inspection. Three methods were reported more than any other measurement, these were, visual inspection (33% of all responses), weather forecast (29% of all responses), and hard going (21% of all responses), this was expected as these methods are quick and easy to carry out, and do not require expensive instrumentation. Full details of the methods used to determine irrigation requirements are given in Appendix 2.5.

3.3.3.2. Sources of water and method of application.

There were four different sources of water reported in the questionnaire survey. The two most common sources being surface water e.g. reservoir (44% of all responses), and ground water e.g. borehole (39% of all responses), (see Figure 3.3). This was expected, as these two sources are generally cheaper per cubic metre of water used (after initial capital costs) than conventional mains water. See Appendix 2.5 for breakdown of water sources by racecourse type.

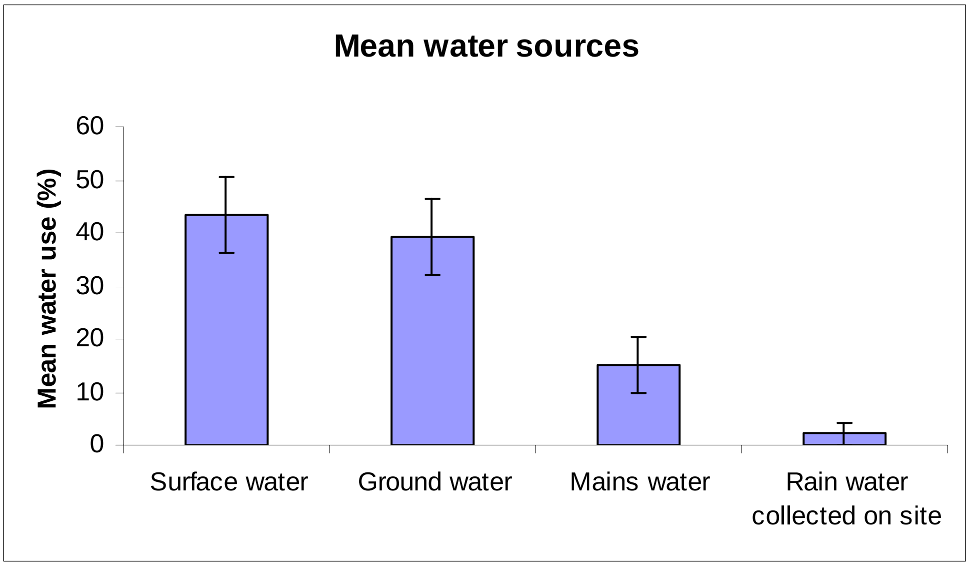


Figure 3.3: Sources of irrigation water on racecourses, with standard error.

The use of different methods to apply water also varied between the racecourses. The mean total use of static or hand moved sprinklers was 42% of all water applications carried out on racecourses (Figure 3.4). Hose reels and booms accounted for 35% of water applications.

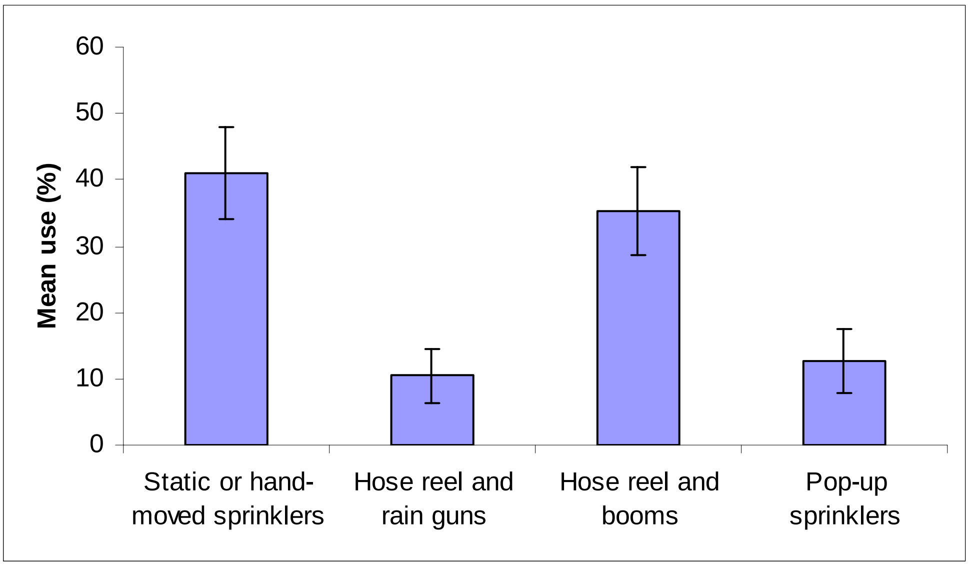


Figure 3.4: Water application methods used on racecourses, with standard error.

3.3.3.3. Irrigation use in 2001.

At the time of the questionnaire survey the irrigation data for 2002 was not available; therefore all results refer to 2001. From the 47 racecourses that use irrigation, 43 used irrigation in 2001 (Table 3.6). The rainfall data for Carlisle, Exeter, Fakenham, and Kelso were not reported, therefore it cannot be ascertained whether they had above average rainfall in 2001, which would be a contributing factor to them not irrigating.

Table 3.6
Number of racecourses that irrigated in 2001.

		Frequency	*Percent*	*Valid Percent*
Valid	Yes	43	72.9	91.5
	No	4	6.8	8.5
Missing	Not applicable	2	3.4	
	Missing data	10	16.9	
Total		59	100.0	100.0

The responses to the amount of water used in 2001 were given in m^3, this is probably a measurement taken directly from a water meter attached to the irrigation system. The mean total amount of water used in 2001 was 9,687 m^3 on flat courses, 5,118 m^3 on hurdle courses, and 4,610 m^3 on steeplechase courses. These values were converted to a depth of water for the average sized flat, hurdle and steeplechase course, based on the dimensions given in the questionnaire responses, and are presented in Table 3.7. Tables 3.8 and 3.9 show the mean water use for flat and jump (hurdle and steeplechase) courses during the winter (October-April) and summer (May-September) for each agroclimatic zone. The mean monthly water use in winter was greater on jump courses (1,105 m^3) than flat courses (4 m^3), which was expected. Flat racing does not generally take place in the winter, therefore irrigating for grass plant survival or to soften surface conditions is not necessary.

Table 3.7
Mean total water use in 2001.

	Flat course *(mm)*	***Hurdle course*** *(mm)*	***Steeplechase course*** *(mm)*
Mean	143	97	95
N	16	13	14
S.E.	29	28	28

Table 3.8
Mean monthly depth of irrigation per agroclimatic zone for an average sized flat racecourse in 2001.

Agroclimatic zone of racecourse		***Winter mean monthly irrigation Oct-Apl*** *(mm)*	***Summer mean monthly irrigation May-Sept*** *(mm)*
Zone 2	Mean	XX	7
	N	XX	2
	Std. Dev	XX	7
Zone 3	Mean	<1	<1
	N	1	1
	Std. Dev	N/A	N/A
Zone 4	Mean	<1	30
	N	2	7
	Std. Dev	<1	9
Zone 5	Mean	XX	25
	N	2	6
	Std. Dev	XX	15
Zone 6	Mean	XX	64
	N	1	2
	Std. Dev	N/A	81
Total	Mean	<1	28
	N	6	18
	Std. Dev	<1	27

Note: XX = missing data N/A = not applicable

Table 3.9
Mean monthly depth of irrigation per agroclimatic zone for an average sized jump racecourse in 2001.

Agroclimatic zone of racecourse		***Winter mean monthly irrigation Oct-Apl** (mm)*	***Summer mean monthly irrigation May-Sept** (mm)*
Zone 2	Mean	XX	2
	N	XX	1
	Std. Dev	XX	N/A
Zone 3	Mean	10	20
	N	2	2
	Std. Dev	14	28
Zone 4	Mean	21	78
	N	3	4
	Std. Dev	36	49
Zone 5	Mean	34	70
	N	2	4
	Std. Dev	7	26
Zone 6	Mean	XX	162
	N	XX	1
	Std. Dev	XX	N/A
Zone 7	Mean	XX	XX
	N	XX	XX
	Std. Dev	XX	XX
Total	Mean	22	66
	N	7	12
	Std. Dev	24	51

Note: XX = missing data N/A = not applicable

The summer mean monthly water use was greater on jump courses (66 mm) than flat courses (28 mm). The differences in water use between agroclimatic zones (shown in Tables 3.8 and 3.9) were expected, and demonstrate that, in general, greater amounts of water were used as PSMD increased. Details of the amount of water used in 2001 on individual racecourses that supplied water use data are presented in Appendix 2.5.

3.3.3.4. Influence of soil texture on water use.

All soil textures were analysed with ANOVA to determine whether they had a significant relationship with water use in 2001 on racecourse types. Only sandy silt loam had a significant relationship with water use for hurdle courses (F pr 0.024) and steeplechase courses (F pr 0.017). Appendix 2.5 details the complete ANOVA results for soil textures and their relationship with water use for the different racecourse types.

3.3.4. Cancelled race days.

Responses to the number of cancelled days over the period 1991 to 2001 were sporadic, and some racecourses did not have records for the whole period; therefore data presented may not be representative of the facts. The mean number of cancelled flat racing days per racecourse due to frozen ground was very low (0.44 days), this was expected as frozen ground is less likely during the time of year that flat racing is held. Conversely, the mean number of cancelled jump race days (hurdle and steeplechase) due to frozen ground was greater (6.39 days), as the occurrence of frozen ground is more probable during the period of the jump season (Table 3.10).

Table 3.10
Mean total cancelled days over period 1991-2001 for all racecourse types.

	Flat race days due to frozen ground	***Jump race days due to frozen ground***	***Flat race days due to water logging***	***Jump race days due to water logging***	***Flat race days due to other reasons***	***Jump race days due to other reasons***
Mean	0.44	6.39	3.79	6.00	3.13	3.82
N	9	23	24	23	15	17
S.E.	0.44	0.99	0.72	1.11	1.21	0.85

The mean number of flat race days cancelled due to water logging (3.79 days) was greater than the mean number of cancelled flat race days due to frozen ground (0.44). Water logging could be indicative of either excessive water applications through the year that have resulted in a poorly structured soil that has a low hydraulic conductivity, or that the drainage system present is inadequate to facilitate the removal of excess water. Water logging also caused a mean of six cancelled race days per jump course. This probably reflects the time of year that the majority of jump racing is carried out.

Sandy silt loam was the only soil texture that had a significant relationship (F pr 0.005) with the number of cancelled race days due to water logging on flat racecourses. Doncaster, Redcar and Windsor, are the only racecourses that have flat racing on a predominantly sandy silt loam. Redcar reported 13 cancelled days for the period 1994-2001, Doncaster and Windsor did not report any cancellations. See Appendix 2.5 for full analysis of cancelled race days.

Other reasons for cancelled race days, 3.13 days and 3.82 days for flat and jump courses respectively, included a bomb scare (Ascot), flooding of a river adjacent to the racecourse (Bangor-on-Dee), and a roadway washing away (Epsom Downs). However, the main reasons for other cancelled race days on both flat and jump courses were fog / poor visibility, and the foot and mouth outbreak in 2001. By their very nature, the majority of cancelled race days of this type are unforeseeable and difficult to counteract.

3.4. Discussion of the Results of the Questionnaire Survey.

The questionnaire survey had a good response rate (83%) as expected, due to the Jockey Clubs insistence that the racecourses should fill-in and return them, however the quality of the answers on some returned questionnaires was poor, illegible or missing, therefore the response rate to individual questions varied. The analysis of the questionnaires took into account the missing and/or illegible answers, separating the results as a percentage of the number of responses.

3.4.1. Predominant soil type.

As expected, the predominant soil texture varied across all the racecourses that reported their predominant soil texture (48 courses). In certain cases, the reported soil texture and the soil texture given in the agronomy report for the racecourse differed. It is possible that both answers are correct, as soil type will vary spatially, but it depends on the sampling locations and number of samples taken as to which answer is correct for the predominant soil. True identification of a soil type is difficult without a particle size distribution (PSD) analysis; therefore it is unlikely that the reported types or the agronomy reports are completely reliable. The racecourses are listed by their reported soil type, agroclimatic zone, and race type in Appendix 2.5.

3.4.2. Grass species.

Rye grass dominated the sward composition on the racecourses (65%), as it is the favoured grass species for divot repair and overseeding. However, sward composition varies according to the soil texture, nutrient status, pH, drainage, level of compaction and wear, all of which are different from racecourse to racecourse.

Poa dominance was expected, but this was not the case. This could be due to the higher heights of cut that racecourses receive (75-120 mm), compared to other sportsturf surfaces, as *Poa annua* is less competitive at high heights of cut.

3.4.2.1. Influence of soil texture on sward composition.

The racecourse that reported the high level of Timothy on a sand dominated soil (Great Yarmouth) is located in agroclimatic zone six. This has a high PSMD, and it is possible that either excessive amounts of water have been applied through the irrigation system to ensure survival of all grass species present and to produce going more conducive to good racing surfaces, and/or that compaction has resulted in a poorly drained soil profile that retains water. Water use for this course was not reported however, so this hypothesis is difficult to verify. Excessive water use could also contribute to the high Bent Grass population, as it may be Velvet Bent (*Agrostis canina*), which is a Bent Grass species that prefers moist conditions (Hubbard, 1984).

3.4.3. Irrigation of the racecourse.

96% of the racecourses that gave a response use irrigation. With such a high rate, this shows the importance of irrigation in the maintenance of a racecourse, whether it be for turfgrass survival, or influencing the level of going.

Two racecourses (Bath and Taunton) stated they do not use irrigation. Bath racecourse is located in agroclimatic zone four and holds flat racing, which is carried out in the summer; therefore it is surprising that it does not use irrigation. Taunton, however, holds jump racing during the winter months, thus reducing the importance of irrigation in track management of this course.

3.4.3.1. Determination of irrigation requirements.

A combination of methods is employed to determine the irrigation requirements of a racecourse. The three most reported methods were a visual analysis (33% of all responses), weather forecast (29% of all responses) and hard going (21% of all responses). Visual analysis and hard going are both subjective measurements. It could be argued that weather forecasting is both a subjective and an objective measurement, as its accuracy varies with how far into the future the forecast is made.

Managing irrigation requirements in response to a weather forecast could be construed as a predictive method, whereas irrigating in response to hard going may be considered a reactive method. The suitability of managing irrigation based on a visual analysis would be dependent on the skill and experience of the person managing the racecourse, although the indicators that the turfgrass requires irrigation are usually wilt, reduced growth and/or die back. These symptoms indicate that the grass plant is already stressed and not in a phase of healthy growth, which is crucial for recovery from wear.

The use of objective methods – such as the going stick or penetrometer – as carried out at some racecourses, does allow unbiased, repeatable, independent measurements to be achieved, minimizing the human errors often associated with subjective methods.

3.4.3.2. Sources of water and method of application.

Reservoirs and boreholes were the most commonly reported source of irrigation water on a racecourse (44 and 39% of all responses respectively). With the enactment of the Water Act 2003, the need for good water management is crucial, if abstraction licences are to be retained. Reservoirs and boreholes offer cheap sources of water; after initial capital costs. Mains water is expensive, with a cubic metre costing approximately £0.80 (Water UK, 2006), hence the low number of mains water users.

Static or hand moved sprinklers were the most commonly reported method of water application (42% of responses), although this does not mean it is the preferred method. Many racecourses are switching to travelling boom systems, which was the second most commonly reported method (35% of responses); however boom systems are expensive, relative to a static sprinkler.

Pop-up sprinklers only accounted for 13% of all water applications. This was expected as their fixed nature does not achieve a uniform coverage over the entire racecourse, unlike mobile sprinklers, due to the fact that they cannot be installed under the racing surface for safety reasons. Additionally, high wind speeds can affect the water distribution of a pop-up sprinkler; whereas a mobile sprinkler can be moved to counter the effects of strong winds, therefore pop-ups are generally used mainly when quick applications of water are required.

3.4.3.3. Irrigation use in 2001.

91.5% of respondents that use irrigation, irrigated in 2001. Four racecourses, Carlisle, Exeter, Fakenham and Kelso (8.5% of respondents that use irrigation), did not use irrigation in 2001. Carlisle is the only racecourse of the four that holds flat racing, the other three racecourses hold only jump racing (predominantly carried out in the winter months). This may explain why these courses did not require irrigation, as ground conditions are usually wetter, therefore softer, at this time of year. Unfortunately these racecourses did not provide rainfall data; therefore it is difficult to determine whether they experienced higher rainfall than the LTA, which would explain the non-use of irrigation.

The mean monthly water use in winter was greater on jump courses (1,105 m^3) than flat courses (4 m^3), which was expected. Flat racing does not generally take place in the winter, therefore irrigating for grass plant survival or to soften surface conditions is not necessary.

Jump racing is primarily carried out in the winter months, however some racecourses do have jump racing during the summer, and larger quantities of water are needed to achieve the good going that is preferred for jump racing, as opposed to the volume of water required to achieve good-firm going on flat courses. This is supported by the results of the questionnaire survey, which indicated that the mean monthly water use in the summer was greater on jump courses (3,358 m^3) than flat courses (1,880 m^3).

3.4.3.4. Influence of soil type on water use.

Sandy silt loam was the only soil texture to have a significant relationship with water use on hurdle courses (F pr 0.024) and steeplechase courses (F pr 0.017). However, only two racecourses (Doncaster and Worcestor) have jump racing on a predominantly sandy silt loam soil, both of which are located in agroclimatic zones with relatively high PSMD (agroclimatic zones five and six respectively). The high water use could be attributable to the time of year that the racing took place e.g. in the summer, when greater water applications are generally required to achieve good going. Therefore the weather, and not the soil texture, may be the reason for the significance measured. No significant relationships with water use were evident for the other soil textures. Full analysis of water use by soil texture is presented in Appendix 2.5.

3.4.4. Cancelled race days.

Data for cancelled race days were incomplete for the majority of racecourses therefore firm conclusions are difficult to arrive at. The majority of cancellations caused by frozen ground or poor visibility due to fog are beyond the control of the racecourse manager, and are difficult to prevent. Bomb scares, flooding and disease were rare occurrences, but they highlight the vulnerability of racecourses to factors outside the normal range of problems faced by other sports surfaces.

Cancellations due to water logging can, however, be a result of excessive rainfall, over use of irrigation, poor drainage due to compaction, the predominant soil texture or interactions of all of these factors. One course (Redcar) reported 13 cancelled days due to water logging between the period 1994 to 2001. Further investigation is required to determine whether the high number of cancelled race days at Redcar is a result of poor drainage due to the soil texture (sandy silt loam), compaction, or the loss of soil structure from excessive irrigation use.

Water applications (excluding rainfall) are controlled by the manager of the racecourse. Management practices that reduce water applications could lessen the effects that contribute to water logging. Therefore a new approach to water management, encompassing new techniques, may be necessary to minimize the number of cancelled race days due to water logging.

3.4.5. Limitations of the questionnaire survey.

Overall the response to the questionnaire was very good (83% returned). Not all responses were completed fully, and some data was not available from the majority of racecourses, for example the amount of irrigation water used per month, making any inferences on irrigation use in terms of amount of water used per month impossible. This was surprising given the important role irrigation has in the management of surface conditions on a racecourse.

The author recognises that there was some error in the design of the questionnaire, as the structure of the questions led to vital information being missed in some cases. Racecourses that did not use irrigation, or did not irrigate in 2001 were asked to go directly to the last section of the questionnaire, which meant that questions such as predominant soil type and monthly rainfall were not answered. Any future questionnaire survey should be structured to avoid this weakness in questionnaire design.

3.5. Conclusions.

Characterizing the racecourses by agroclimatic zone is a quick and easy way of determining the potential water requirements of a racecourse for a given year, and can aid in developing the argument for retaining an abstraction license for future water use. The results of the questionnaire survey reinforced the increased need for water to manage racecourses in the drier agroclimatic zones. Given the large quantities of water required for racecourse management indicated in the questionnaire survey, better management practices to minimize water use will have potential economic and environmental savings.

The questionnaire survey provided a useful review of the current state of racecourses in England, Scotland and Wales. The survey also provided a large dataset on which to carry out various analysis methods, ranging from the physical properties of the racecourse, through to specific management techniques. The results of the questionnaire provide a good grounding for similar surveys on racecourses in the future, although the overall aim of any such survey should be clearly defined, otherwise data of only general interest will be forthcoming.

4.0. AUDIT OF EIGHT RACECOURSES.

Eight racecourses were selected for a more detailed audit. They were identified from the results of the questionnaire survey (Section 3.2) and were audited to characterise the soil variability, soil strength characteristics and the type of racing carried out. This work contributes towards Objective One.

The audit was designed to determine whether penetrative resistance and bulk density varied around a racecourse, and to what extent they differed between flat and chase tracks on the same racecourse. Soil textural variation was also determined to check whether differences in compaction and penetrative resistance were due to racing type or changes in soil texture. From this work two racecourses typical of the eight selected were identified for more detailed assessment.

4.1. Identification of Eight Racecourses for Further Research.

The results from the questionnaire survey were used to identify typical racecourses (within set parameters) for further study. This would enable the research project to characterise and take account of the typical range of variation in physical and environmental conditions that might be present on UK racecourses. The criteria for identifying suitable racecourses were based on the following three elements:

- **Agroclimatic zone**: The racecourse agroclimatic zone should be in either zones 2-3 or 5-6. – This would enable the research to be carried out on racecourses that have environmental conditions towards either end of the agroclimatic zone range, excluding the extreme ends of the range (zones 1 and 7) as only a few racecourses fall within them.

- **Soil type**: The predominant soil type of the racecourse should match one of the two most commonly reported soil types in the questionnaire survey. – This would enable the research to be carried out on racecourses that have a soil type that is typical of the majority of racecourses.

- **Type of racing**: The racecourse should host both flat and jump racing. – Racecourses with year-round racing have more severe wear issues than racecourses with a single season of racing, and subsequently incur more damage to their racing surface and soil structure. This will ensure this research focuses on some worse case scenarios within the racing industry.

The racecourses meeting these criteria were then split into the categories shown in Table 4.1.

Table 4.1
Categories of racecourses for further research.

Category	*No. of Racecourses*	*Agroclimatic Zone*	*Predominant Soil Type*
1	2	2-3	Sandy loam
2	2	5-6	Sandy loam
3	2	2-3	Clay loam
4	2	5-6	Clay loam

4.1.1. Selected racecourses for further analysis.

The racecourses selected for further research (Table 4.2) are based on the results of the agroclimatic zones and questionnaire survey, and their fulfilment of the criteria outlined in Section 4.1., with the exception of Uttoxeter, Newton Abbot and Newcastle racecourses.

Table 4.2
Racecourses selected for further analysis.

Soil Type	*Racecourse*	*Agroclimatic Zone*
Sandy Loam:	Catterick	3
	Mussleburgh	3
	Newton Abbot	5
	Sandown Park	5
Clay Loam:	Newcastle	2
	Uttoxeter	3
	Leicester	5
	Lingfield Park	5

The selection of Uttoxeter, Newton Abbot and Newcastle racecourses for further research was due to the following:

Uttoxeter didn’t return a completed questionnaire, but the senior race inspector and other representatives of the Jockey Club prior knowledge of the course suggested Uttoxeter would fall within the criteria laid out for further research, with the exception that it is a jump only course (chase and hurdle).

Newton Abbot reported clay as the predominant soil texture (which later transpired to be a combination of clay loam and sandy loam), but the Jockey Club were keen to include Newton Abbot, as it would provide information about summer jump only courses, and would provide good comparative data to Uttoxeter.

Newcastle reported its predominant soil texture as sandy clay loam. However, a combination of Newcastle’s busy racing calendar (both flat and jump racing), as well as being located in an agroclimatic zone two meant that it offered valuable information.

4.2. Methodology of the Audit of Eight Selected Racecourses.

The audit consisted of on-site measurements and the removal of soil samples for laboratory analysis from 11 corresponding points on the chase and flat course at each racecourse during the period January to March 2004. All locations sampled were areas outside the take off and landing areas associated with jumps. The measurements carried out were:

- Soil particle size distribution analysis
- Soil dry bulk density analysis
- Soil penetrative resistance

The sampling locations for each racecourse are given in Appendix 3.1.

4.2.1. Particle size distribution analysis.

Soil textural variation around the racecourse was measured to determine whether differences in bulk density and soil penetrative resistance were due to racing type or changes in soil texture. The soil samples were taken to a depth of 150 mm from a 6 x 6 m area at each location, using a 25 mm diameter soil auger in accordance with BSI (1991, BS7370) methodology. Soil textural classification was then determined using particle size analysis by Pipette Method (Bascomb, 1982, BS7735).

4.2.2. Dry bulk density analysis.

Dry bulk density measurements (ρ_b) were carried out to determine whether or not differences in ρ_b existed between corresponding locations on flat and jump courses, or between locations within the flat and jump courses. Undisturbed soil samples collected with density rings from the top 30 mm of the soil profile were used to determine ρ_b. The density ring dimensions were 20 x 54 mm (45.81 cm^3); three samples per location were collected. ρ_b was determined using the method described by Smith and Thomasson (1982).

4.2.3. Soil penetrative resistance.

A Findlay Irving Soil Penetrometer, fitted with a 12 mm diameter cone, was used to measure soil resistance to vertical penetration. Five penetrometer tests were taken at each location. Each test consisted of 15 readings taken at 35 mm intervals to a depth of 0.52 m. The readings, given in Kg, were adjusted from a calibration curve, and then converted to kPa (see Appendix 3.2 for calibration and conversion of pentrometer results).

4.2.4. Analysis of results.

Measurements were not compared between the different racecourses, owing to their different geographic locations, management practices, topography, orientation and climatology. The aim was to characterise variability at individual racecourses. This would form the basis of determining how to divide a course when it comes to irrigation strategy later in the project.

All penetrometer and dry bulk density results were analysed by analysis of variance (ANOVA). Anova was chosen as it allows simultaneous analysis of the effect of more than one factor on population means (Zar, 1996) which negates the need to perform a one-way ANOVA for each factor. Two-way ANOVA will also test for interaction amongst the factors. The 'Least Significant Difference,' (LSD) test (Clarke and Kempson, 1997) was carried out to ascertain the values of differences between sample means that achieve significance.

4.3. Results of the Audit of Eight Racecourses.

The hurdle course was sampled and measured in the absence of a flat course at Newton Abbot and Uttoxeter. The hurdle course at Catterick was sampled and measured instead of the jump course, to allow a comparison between a hurdle and flat course.

4.3.1. Soil textural classification.

Results from the particle size distribution analysis indicate that soil textural classification varied between the locations on each individual racecourse, as expected. All racecourses had a variety of soil textures, with the exception of Catterick, which comprised a sandy loam in all but one location, which was a sandy clay loam (Table 4.3 overleaf).

Table 4.3
Soil textural classification of the sampling locations on the eight racecourses.

Location	*Catterick*[1]	*Leicester*	*Lingfield Park*	*Musselburgh*	*Newcastle*	*Newton Abbot*[1]	*Sandown Park*	*Uttoxeter*[2]
A – Flat	SL	SCL	SSL	LS	SCL	SSL	LS	SL
A – Jump	SL	SL	SCL	S / LS	SCL	SL	LS	CL
B – Flat	SL	SCL / SL	SSL	SL / LS	SCL	CL	LS	SCL / SL
B – Jump	SL	SL	CL / SSL	S	SCL	CL	SL	CL
C – Flat	SL	CL	SSL	SL	SL	CL / SSL	LS / SL	SCL
C – Jump	SCL	CL	SSL	S	SCL	CL	LS	SCL / CL
D – Flat	SL	SCL	SSL	LS	SCL	CL	SL	SSL / CL
D – Jump	SL	SCL	SSL	*S*	SCL	SL	SL	*SL*
E – Flat	SL	SCL	SSL	LS	SCL	SL	*SL / LS*	*SL*
E – Jump	SL	CL	SSL	*S*	SCL	SCL	LS	*SL*
F – Flat	SL	CL	SSL	LS	SCL	SL	SL	*SL*
F – Jump	SL	CL	*StL*	SL	SCL	SL	SL	*SCL / CL*
G – Flat	SL	SCL	SSL	LS	SCL	CL	LS	*SL*
G – Jump	SL	SCL	SSL	SL	SCL	SL	SL	*SL*
H – Flat	SL	SL	SSL	SL	SCL	CL	SL	*SL / SCL*
H – Jump	SL	SL	SSL	SL	SCL	CL	SL	*CL*
I – Flat	SL	*C*	SSL	LS	SCL	SL	LS	*CL*
I – Jump	SL	CL	SSL	LS	CL	CL	*SL / LS*	*CL*
J – Flat	SL	CL	SSL	LS	SCL	SL	LS	*SL*
J – Jump	SL	SL	SCL	LS	CL	CL	LS	*CL*
K – Flat	SL	SCL	SSL	LS	SCL	SL	LS	*SCL*
K – Jump	SL	SCL	SSL	LS	SL	CL	LS	*SCL / CL*

Key *SL = sandy loam, SSL = sandy silt loam, SCL = sandy clay loam*
StL = Silt loam, LS = loamy sand, CL = clay loam, S = sand

4.3.2. Soil dry bulk density.

All ρ_b values were lower than expected (<1 Mg m^3, with the exception of Cattericks' hurdle course) which is probably a reflection of the sampling method. However the same method was used for all samples taken, therefore there is consistency in the samples taken which, although lower than established soil science theory would expect, does allow comparisons to be made. All racecourses, except Newton Abbot, had significantly different mean ρ_b values between either their flat and chase courses (Leicester, Sandown Park, Lingfield Park, Mussleburgh and Newcastle), their flat and hurdle courses (Catterick), or their hurdle and chase courses (Uttoxeter) (Table 4.4).

Table 4.4
Mean dry bulk density for flat and chase courses with least significant difference of means at the 95% level.

Racecourse	***Flat course mean bulk density** (Mg m^3)*	***Chase course mean bulk density** (Mg m^3)*
Catterick (LSD = 0.0439)	0.831	1.003*
Leicester (LSD = 0.0485)	0.698	0.882
Lingfield Park (LSD = 0.0767)	0.940	0.829
Musselburgh (LSD = 0.0725)	0.914	1.074
Newcastle (LSD = 0. 0396)	0.621	0.706
Newton Abbot (NS)	0.624*	0.597
Sandown Park (LSD = 0.0425)	0.762	0.956
Uttoxeter (LSD = 0.0574)	0.797*	0.687

** Hurdle course*

The chase course had greater mean ρ_b on five of the eight racecourses. Of the remaining racecourses, Lingfield Park had greater mean ρ_b on its flat course, which has been reconstructed in parts, and had only held one race prior to sampling. The greater mean ρ_b could be attributable to the surface becoming consolidated during reconstruction, which may not have been alleviated sufficiently (at the time of sampling), with aeration. Alternatively there could have been less thatch in the newly established surface, as the very low ρ_b values indicate the presence of organic matter, not mineral material.

Differences in ρ_b between locations around each racecourse showed no clear patterns despite the differences being significant at the 95% level for Catterick, Leicester, Lingfield Park, Musselburgh and Sandown Park. In some locations there were clear differences on the straights, for example locations I and J on the flat course at Catterick, and on some courses the differences were on the bends, for example locations D and E at Leicester on the chase course (see Appendix 3.1.2).

Further (larger) samples were collected from Leicester Racecourse during January 2006. The samples were 100 mm diameter by 130 mm deep and taken from areas previously identified as clay loam and sandy loam soils. All samples were taken at a distance of 1.0 to 1.5 m from the running rail of the flat course. The mean ρ_b for clay loam and sandy loam was 1.08 Mg m^3, which was still lower than expected, but greater than the smaller samples taken previously. Appendix 3.3 details the results of the larger samples.

4.3.3. Soil penetrative resistance (SPR).

Only two racecourses – Leicester and Musselburgh – had significant differences in mean SPR between their respective flat and chase courses (Leicester F pr <0.001, Musselburgh F pr <0.001), although all eight racecourses had significantly different mean SPR values between their sampling locations (F pr <0.001). Depth had a significant effect on SPR too (F pr <0.001); this was expected, as soil will consolidate with depth and less organic matter, although the depth of the topsoil was not measured, nor was the textural classification of the underlying subsoil determined. Full results are given in Appendix 3.1.

A pattern of SPR values emerged at every racecourse, except Musselburgh where all racecourses had greater mean SPR values on the chase course in the upper layer of the soil profile, the depth of which varied from course to course, than the flat course. However three racecourses – Newcastle, Sandown Park and Uttoxeter – had a threshold depth, which varied between the courses, where the subsoil had consistently higher SPR values on the flat course (Figure 4.1).

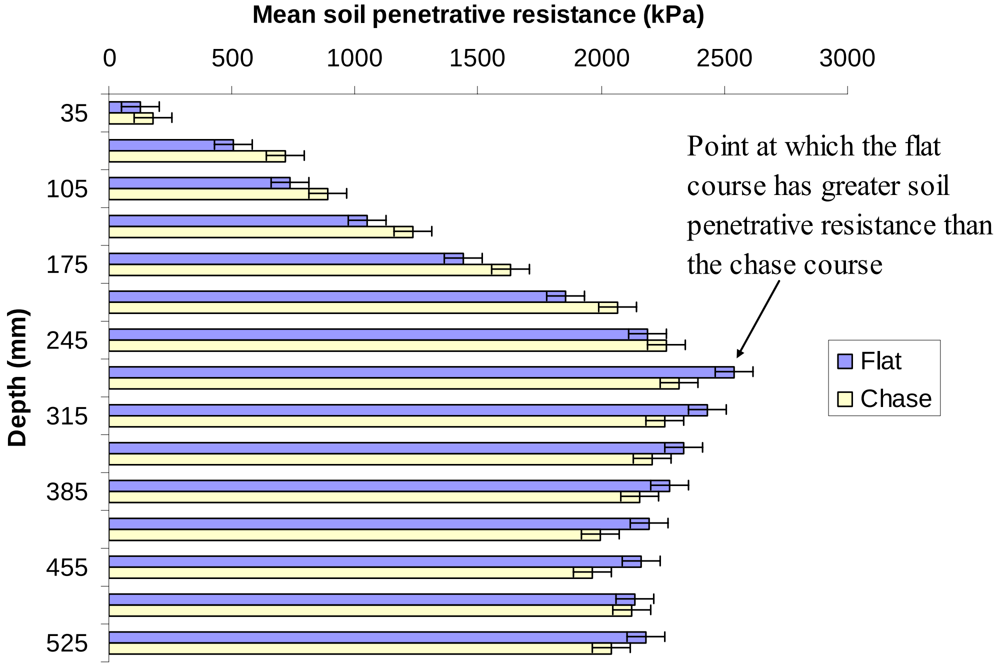


Figure 4.1: Crossover of greater soil penetrative resistance from chase course to flat course at Sandown Park racecourse, with least significant difference of means at the 95% level.

The flat course having greater SPR at depth than the chase courses was not expected, although the differences were not significant, aside from Sandown Park (F pr <0.001) and Uttoxeter (F pr <0.001), which was a comparison between a hurdle and a chase course (Figure 4.2).

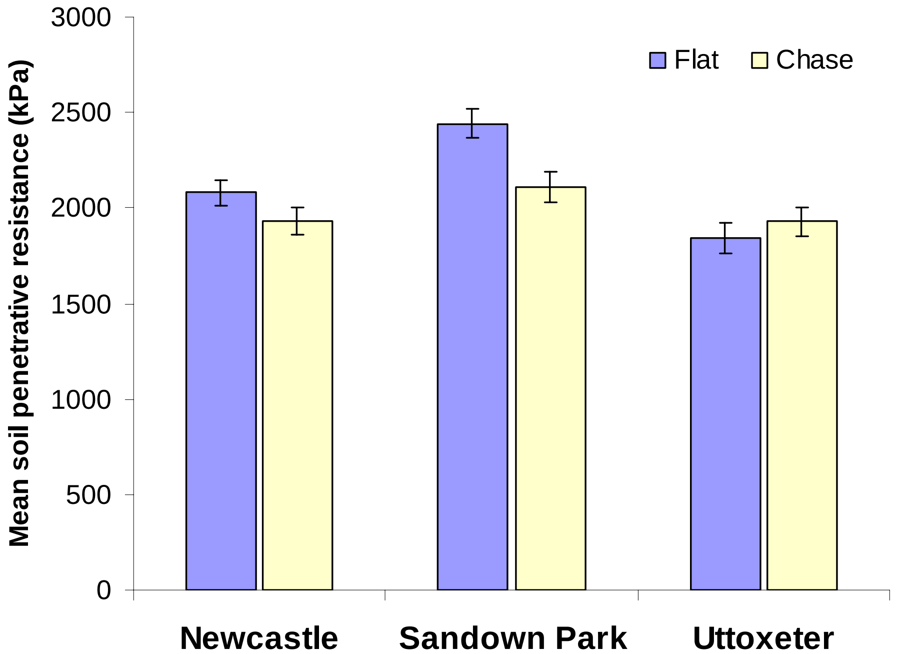


Figure 4.2: Mean soil penetrative resistance below a depth of 175 mm for three racecourses, with least significant difference of means at the 95% level.

4.4. Discussion of the Results of the Audit of Eight Racecourses.

4.4.1. Selection of the eight racecourses for further analysis.

Five racecourses (Catterick, Leicester, Lingfield Park, Musselburgh and Sandown Park) matched the criteria for selecting these courses for further analysis. The selection of the remaining three racecourses was influenced by the Jockey Club, as they were keen to include a summer jump course in the audit stage, to broaden the scope of the research project. This led to the inclusion of Newton Abbot and Uttoxeter. The Jockey Club also desired the inclusion of Newcastle due to its busy racing calendar, and that it met two out of the three criteria for selection.

It could be argued that the preferences of the Jockey Club compromised the selection process. However, the three courses met two out of the three criteria for selection. All three fell within the agroclimatic zones required; Newcastle had both flat and jump racing, and a soil texture (sandy clay loam) close to the preferred textures of clay loam and sandy loam. Newton Abbot and Uttoxeter had soil textures matching the criteria, but only had jump racing. In addition, with the inclusion of Newcastle, Newton Abbot and Uttoxeter, it ensured a broad geographical spread amongst the racecourses audited.

4.4.2. Audit of eight selected racecourses.

The ρ_b and penetrative resistance measurements are representative of the day on which they were recorded. The measurements are dynamic, and would vary from day-to-day, but give a good indication of the soil condition at the time of testing. Soil textural classification is unlikely to change on a short or medium term basis.

4.4.3. Soil textural classification.

Particle size distribution analysis showed that soil textural class varies around and between racecourses. Different soil textures will retain varying amounts of moisture, as they have disparate volumes of macro-pores, resulting in variability in soil moisture content around the entire racecourse. The propensity of different soil textures to compact will depend on the levels of applied load and the soil strength as influenced by soil water content and bulk density. As racing takes place in a wide range of conditions, this is likely to give rise to inconsistent going around any of the eight racecourses, with the possible exception of Catterick as it had consistent soil texture. Soil textural classification did not have an influence on ρ_b in this study, with the exception of Leicester racecourse.

4.4.4. Dry bulk density.

All ρ_b values were lower than expected, and this was due to the samples being taken from the top 30 mm of the soil profile, where there was a high proportion of organic matter from grass plant stems and roots. The samples collected were small (54 x 20 mm) and it is possible that larger, deeper samples may have shown greater differences in ρ_b values, as the high organic matter content that was present in the samples collected would have diminished with depth, and therefore had less of an effect on the overall ρ_b.

The ρ_b results reveal that seven courses had significantly different ρ_b values between their flat and chase courses in the top 30 mm of the soil profile, five of which had significantly greater ρ_b on their chase. This can be explained to some extent by the fact that jump racing is usually carried out in the winter months when wetter soil conditions are more likely and, as the ground conditions that are most suitable for jump racing are softer than those for flat racing, the soil is in a condition that is more likely to compact under load and wear. Five of the eight racecourses studied had significant differences in ρ_b between sampling locations, due to the spatial variability of applied wear loading they receive from racing horses. The variability in ρ_b around the length of a racecourse (either flat or chase) could result in going that is inconsistent and therefore potentially dangerous to the health of the competing horse.

Given the way horses tend to bunch more closely together around bends to shorten the effective distance travelled it might have been expected that the main differences in density around a flat or chase course would have occurred in these locations. This is not the case and suggests the practice of moving the rail to spread wear across the track is effective in reducing compaction on the racing line around bends. None of the ρ_b values recorded would indicate compaction issues.

Soil textural classification did not have an influence on the ρ_b in this study, with the exception of Leicester racecourse. The locations on the jump course at Leicester racecourse that were identified as sandy loam soils tended to have greater ρ_b values than locations identified as clay loam soils. The differences are partly due to the unique fact that Leicester does not irrigate its jump course, which allows some regeneration of aggregate structure to occur in the clay dominated locations as a result of natural shrink-swell cycles associated with wetting and drying. In addition, sandy loam soils tend to be more prone to compaction than clay loam soils (National Soil Resources Institute, 2002).

The subsequent larger samples taken from Leicester Racecourse at a later date showed that the ρ_b was greater than the original smaller samples, but still lower than expected (1.08 Mg m^3) based on anecdotal evidence (Cranfield University, undated) which suggests that the average ρ_b on undisturbed grassland would be 1.12 Mg m^3. The lower values could be attributable to the time of year the samples were collected (January) which was outside the racing season, when restoration and repair of the flat course had been conducted, such as vert-draining to alleviate compaction. January was the only time that permission was given to remove the large samples due to the surface disturbance created and the potential for injury to competing horses if the area had not been repaired appropriately if carried out during the racing season.

4.4.5. Soil penetrative resistance.

Given the differences between flat and jump racing revealed by the bulk density results, it could be expected that all racecourses would have significantly different mean soil penetrative resistance (SPR) values between their flat and chase courses. This was not the case with mean SPR being significantly different between race types on only two racecourses (Sandown Park and Uttoxeter), although the location where SPR was recorded was significant on all eight racecourses. Depth has a significant effect on SPR; chase courses had greater SPR in the upper soil profile than flat courses. With increasing depth, the reverse occurred; flat courses had greater SPR than chase courses.

The greater SPR values in the upper profile on the chase courses were expected, due to the seasonality of jump racing (winter months) and the softer ground conditions required. These would increase the likelihood of compaction occurring, and therefore increase ρ_b values, which Zebarth and Sheard (1985) found increased impact resistance. This is reinforced by the greater SPR values found on the chase course in the upper soil profile at each racecourse and supports the reasoning used to explain the higher ρ_b results for the chase course compared to the flat course found earlier.

Racetracks that are hard produce a high impact force, with a high peak force occurring very quickly, resulting in a high rate of loading (Pratt, 1984). As most flat racing is carried out in the summer, at the time of racing, courses are likely to be harder than chase courses are during their peak racing period (winter months). This could result in compactive forces being transferred through the soil profile to greater depths, creating a compacted layer deeper in the soil in comparison to chase courses. The effect of soil conditions at the time of racing may therefore be highly significant on the location of any compaction caused, with wet, soft conditions prevalent during chase meetings resulting in compacted and poached topsoil layers, but harder soil conditions at the time of flat racing resulting in deeper compaction under flat courses. However it should be noted that many flat courses look to develop a firmer subsoil to the course to provide a base for the surface when the topsoil is soft / heavy, which could also explain the greater SPR found at depth on the flat courses.

4.5. Conclusions to the Audit of Eight Racecourses.

The results of the racecourse audit show that the chase course has a greater influence on i) ρ_b in the top 30 mm of the soil profile and ii) SPR in the upper soil profile, than the flat course. Significant differences in ρ_b and SPR were found between sampling locations on most courses (both flat and chase). These differences show that the conditions on a racecourse can be quite variable along its length, which can result in inconsistent going and therefore can be dangerous to the welfare of the competing horse and its jockey.

It could be inferred from these results that any methodology developed to subjectively predict the mean going on a racecourse or to determine the irrigation requirements to influence going would need to be specific to discrete sections of the racecourse, rather than the whole racecourse, to take into account the variability found. However, the measurements were taken during the jump racing season, when the flat courses were left fallow. Sampling during the flat season when the jump courses are left fallow may give different results, therefore additional sampling during the flat season should be carried out.

4.6. Selection of Two Racecourses for Further Research: Criteria for Selection.

Two of the eight audited racecourses were selected for further study. The criteria in selecting the two racecourses were that the courses had to be at either end of the agroclimatic scale i.e. within zones 2-3 and 5-6 to enable the research to span either end of the agroclimatic zone spectrum. Both racecourses should have year round racing, accommodating both flat and jump seasons, and ideally should have a large number of fixtures in their racing calendar, so that worst case scenarios were encountered. The predominant soil texture should also be similar between the courses, to allow for temporal comparisons.

In addition, the two racecourses should ideally have a weather station on site, or access to accurate weather records, to assist the development of the research project, and have available historical data relating to going. The willingness of the Clerk of the Course for further research to be conducted at their racecourse was also considered.

4.6.1. Selected racecourses for further study.

The two racecourses selected for further research were Newcastle Racecourse and Leicester Racecourse. These courses were chosen as they fulfilled the criteria specified in Section 4.6. with the exception of matching predominant soil textures. Only certain points around each racecourse had matching soil textures, therefore temporal comparisons would not be possible. Additionally, the availability of weather data at

Leicester was limited, but this was rectified with the installation of a weather station in August 2005.

Leicester and Newcastle had the two busiest racing calendars of all eight racecourses. Historical weather data and going data – as measured with the going-stick – was also available for Newcastle racecourse. Furthermore the willingness of the Clerks of the Course at Newcastle and Leicester was important, as it was critical to have good accessibility to the courses throughout the duration of the research project. The Clerks of the Course at Newcastle and Leicester were also agreeable to additional disruption to their surfaces (from soil sampling) for an extended period.

4.6.2. Discussion of the selection of two racecourses for further study.

The selection of Leicester and Newcastle racecourses for further research reflects their compatibility with the criteria laid out in Section 4.6., even though their predominant soil textures were not identical. However, given that the majority of racecourses have differences in layout, topography, soil variability, orientation, grass species and light levels, it is unlikely that realistic comparisons could be made between racecourses, even if they were in the same agroclimatic zone and had the same predominant soil texture.

5.0. VALIDATION OF THE GOING-STICK.

To achieve Objectives One and Two, an objective method to determine going needs to be employed. From the objective methods described in Section 2.1.2. the going-stick was chosen as the measure of going for the development of the models to predict the mean going on a racecourse (Objective One, Section 6.0). It was also used to provide data to determine the amount of effective irrigation required to reduce a high level of going to a desired level (Objective Two, Section 7.0). The going-stick was chosen because it relates going to two separate soil strength properties that are intrinsically linked to soil moisture and it has been endorsed by the Jockey Club as an official measuring device for going.

To ensure that the results obtained by the going-stick were reliable three tests were conducted on the stick. The tests comprised a repeatability test of penetration and shear strength properties with known loads, a comparison test of going values – as measured with the going-stick – with a penetrometer in a soil environment at different densities, and an analysis of the relationship between going-stick values and volumetric soil moisture content.

5.1. Methodology.

5.1.1. Going-Stick penetration and shear repeatability test.

The going-stick was switched to 'Engineering mode' which displays peak penetration and shear values, as opposed to a integrated value of going. Different loads were applied to the tip of the going-stick blade to simulate vertical (penetration) forces, and to the side of the blade to simulate translational shear forces (Plate 5.1).

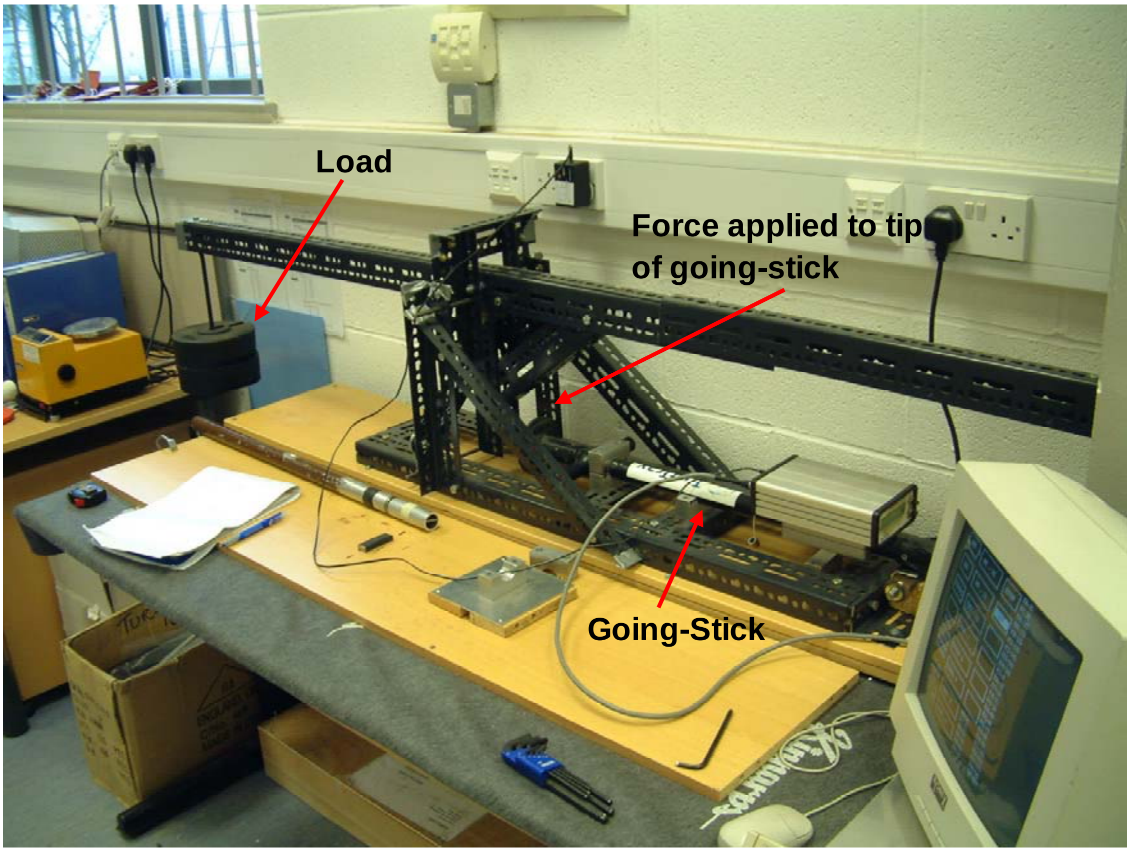


Plate 5.1: Test apparatus for going-stick penetration repeatability test.

The loads for penetration were 5, 10, 15, 20, and 25 kg applied in a random order, the load for shear was 5 kg. Loading for penetration was repeated three times, loading for shear was repeated five times, as only one weight was used. The going-stick was reset at the end of each set of loads to ensure that the reading displayed was at zero prior to applying loads. The values of penetration and shear were recorded directly from the digital display of the going-stick.

5.1.2. Going-Stick comparison test.

An evaluation of the performance of the going-stick compared to a penetrometer in a controlled soil environment was conducted in the soil dynamics laboratory at the Silsoe campus of Cranfield University. The soil in the soil dynamics test bin (soil bin) was a sandy loam and was prepared with four passes of the soil processor machinery. The soil bin was divided into a 3 x 3 grid layout and undisturbed soil samples were collected with density ring's from the top 30 mm of the soil profile from each grid point for determination of the dry bulk density. The dimensions of the density rings used were

20 x 54 mm (45.81 cm^3) and one sample per location was collected. Dry bulk density was determined using the method of Smith and Thomasson (1982) as described in Section 4.2.2.

Three measures of penetration and shear were taken within each grid point with the going-stick to arrive at a value of going in accordance with the operators instructions (TurfTrax, 2004). A copy of the operators instructions is provided in Appendix 4.1. A measurement of penetration resistance was carried out with a soil penetrometer fitted with a 12 mm diameter cone. The measurements were taken in 10 mm increments to a depth of 150 mm to allow comparison with the results obtained from the going-stick. The penetration measurements were repeated three times in each grid, adjacent to where the measurements with the going-stick were taken. The length of the soil-penetrating blade on the going-stick is 100 mm; therefore only the values of soil penetration resistance to a depth of 100 mm were used to arrive at a mean value of soil penetration resistance for each grid.

5.1.3. Determination of the relationship between Going-Stick values and volumetric soil moisture content.

The measurement and recording of values of going and the volumetric soil moisture content for each point at which the going was measured was carried out at the locations identified on the flat course at Leicester and Newcastle Racecourses (Section 4.3.1.). Going values were determined with the going-stick and volumetric soil moisture content was determined with a Theta Probe (Charlesworth, 2000).

5.1.4. Analysis.

The results of the three tests were analysed using linear regression to determine whether significant relationships existed between the values of going, as determined by the going-stick and the respective test values of vertical and shear loading, soil penetration resistance and volumetric soil moisture content.

5.2. Results.

5.2.1. Going-Stick penetration and shear repeatability test.

Linear regression was used to analyse the results for the penetration resistance repeatability tests. A significant relationship (F pr = <0.001) exists between the loading applied to the going-stick and the values of penetration expressed by the going-stick. The coefficient of determination (r^2 = 0.99) shows that 99% of the variation of penetration readings can be explained by changes in the loading applied to the going-stick (Figure 5.1).

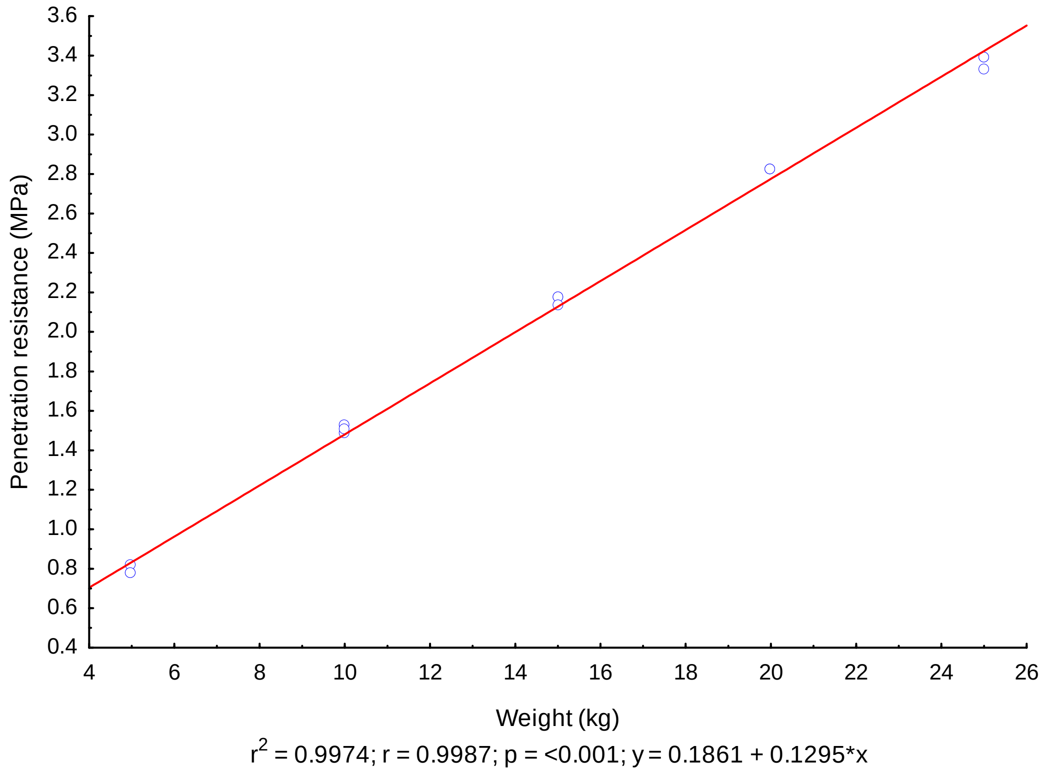


Figure 5.1: Linear regression analysis of the relationship between weights to the tip of the going-stick and the determination of penetration resistance by the going-stick.

The going-stick consistently achieved shear readings of 1.56 MPa every time the 5 kg load was applied to the tip of the going-stick during the determination of the repeatability of the shear component of the going-stick. The results of the shear test suggest that the going-stick is a reliable method for the determination of shear, although only one weight (5 kg) was used. It would be preferable to measure the shear component with several different loads, similar to the penetration repeatability test, to ensure the repeatability of the going-stick at different loads. But this was not possible as the test apparatus did not have the facility for additional weights to be applied to the tip of the going-stick during the test of the shear component of the going-stick.

5.2.2. Going-Stick comparison test.

5.2.2.1. Going.

The values of going varied across the width and along the length of the soil bin. The values of going ranged from 8.8 (good going) to 12.6 (firm going) on the going-stick index of going (Table 5.1).

The values of penetration resistance taken with the going-stick were converted to MPa using a calibration curve, developed by Dresser and Stranks (pers. comm.), for comparison with the values of penetration resistance recorded by the penetrometer. The going-stick consistently recorded higher values than the penetrometer, although the values did follow the trend of the penetrometer results. The calibration chart is presented in Appendix 4.2.

Table 5.1
Summary of going comparison test.

Grid point	**A**	**B**	**C**
Dry bulk density (Mg m^3)	1.44	1.36	1.30
Mean penetrative resistance (MPa)	1.18	1.14	1.05
Going-stick: going	10.5	10.1	10.1
mean penetreation (MPa)	3.52	3.09	3.27
mean shear (MPa)	0.78	0.93	0.83
Grid point	**D**	**E**	**F**
Dry bulk density (Mg m^3)	1.52	1.47	1.31
Mean penetrative resistance (MPa)	1.37	1.12	0.87
Going-stick: going	12.5	10.3	8.8
mean penetreation (MPa)	4.15	3.21	2.79
mean shear (MPa)	0.95	0.93	0.77
Grid point	**G**	**H**	**I**
Dry bulk density (Mg m^3)	1.32	1.46	1.27
Mean penetrative resistance (MPa)	1.40	0.92	0.84
Going-stick: going	12.6	8.9	9.2
mean penetreation (MPa)	4.18	2.73	2.91
mean shear (MPa)	0.98	0.84	0.81

Plate 5.2: Evaluation of the going-stick in the soil bin (note surface disturbance where measurements with the going-stick have taken place).

5.2.2.2. Dry bulk density.

Dry bulk density (ρ_b) varied across the width and along the length of the soil bin, with values ranging from 1.27 Mg m^3 to 1.53 Mg m^3. Linear regression analysis suggested that there was no significant relationship between ρ_b and going (F pr = 0.4089), with only 10% of the variation in going accounted for by changes in the ρ_b (r^2 = 0.0993). Linear regression analysis also implies that the mean soil penetrative resistance (SPR) had no significant relationship with ρ_b (F pr = 0.2683), changes in bulk density accounted for 17% of the variation in mean SPR (r^2 = 0.1712) (Figures 5.2 and 5.3).

It can be inferred from these results that in this study soil density was not a governing factor in the value of going expressed by the going-stick, although this contradicts the known science relating to soil strength. However, the large variation in ρ_b could be attributed to the sampling method, as the density rings were small, and any losses of soil from the density ring would have a large influence on the determination of the ρ_b. Larger samples would be preferable to reduce the effects that small losses of soil have on the ρ_b.

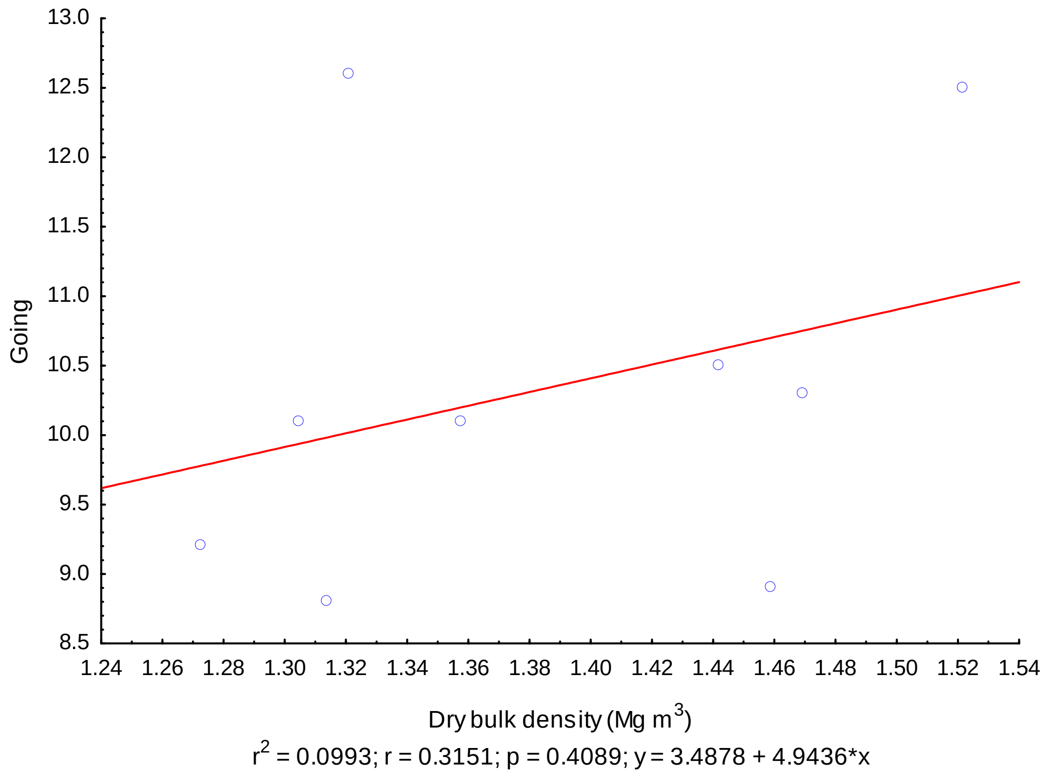


Figure 5.2: Linear regression analysis of the relationship between going, as measured by the going-stick, and the dry bulk density of a sandy loam.

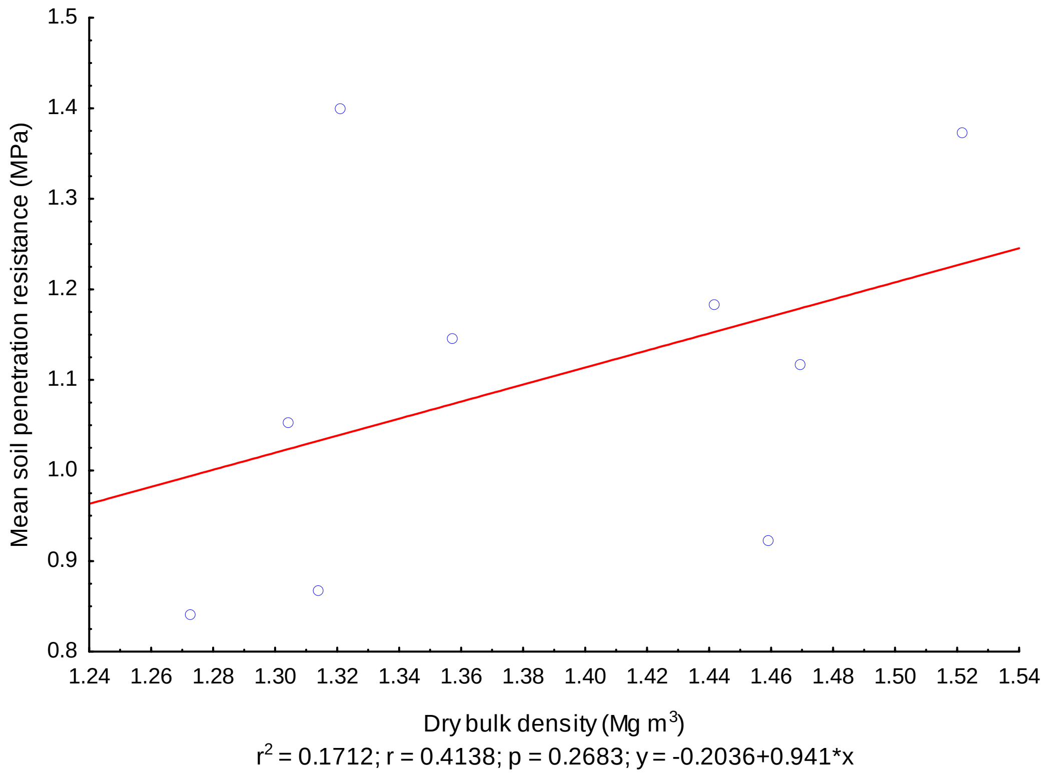


Figure 5.3: Linear regression analysis of the relationship between mean soil penetrative resistance and the dry bulk density of a sandy loam.

5.2.2.3. Penetration.

There was a significant relationship (F pr = <0.001) between going and the mean soil penetrative resistance to a depth of 100 mm. Linear regression showed that changes in the mean soil penetrative resistance to a depth of 100 mm accounted for 93% (r^2 = 0.93) of the variation in going (Figure 5.4)

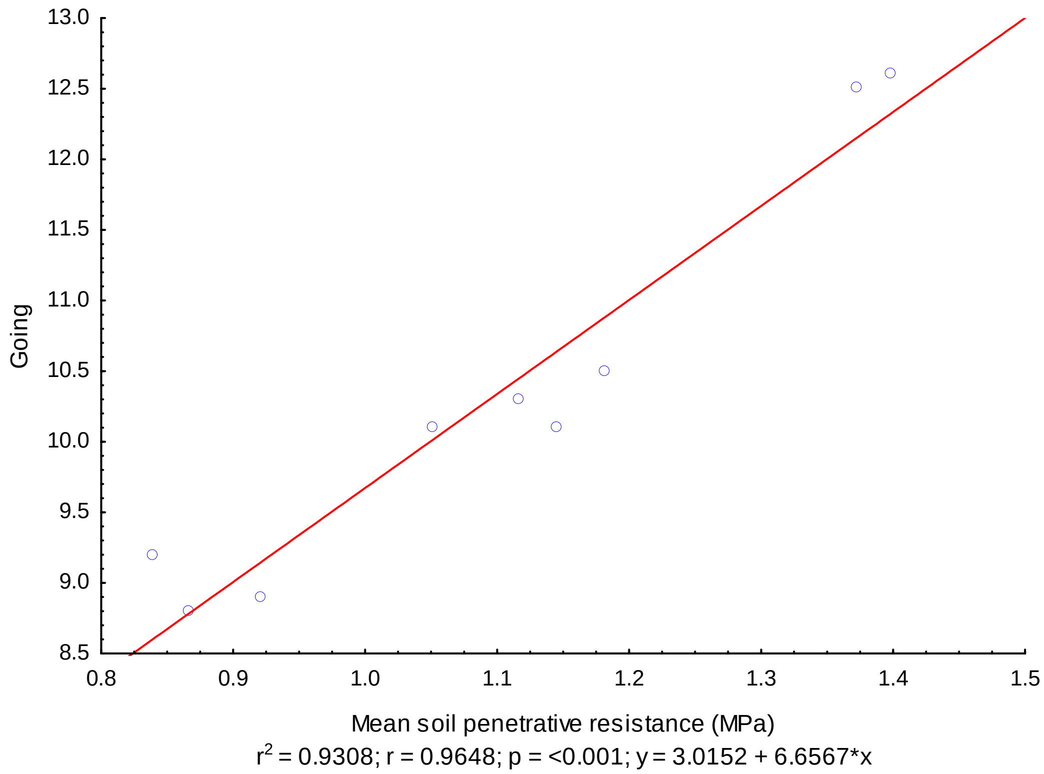


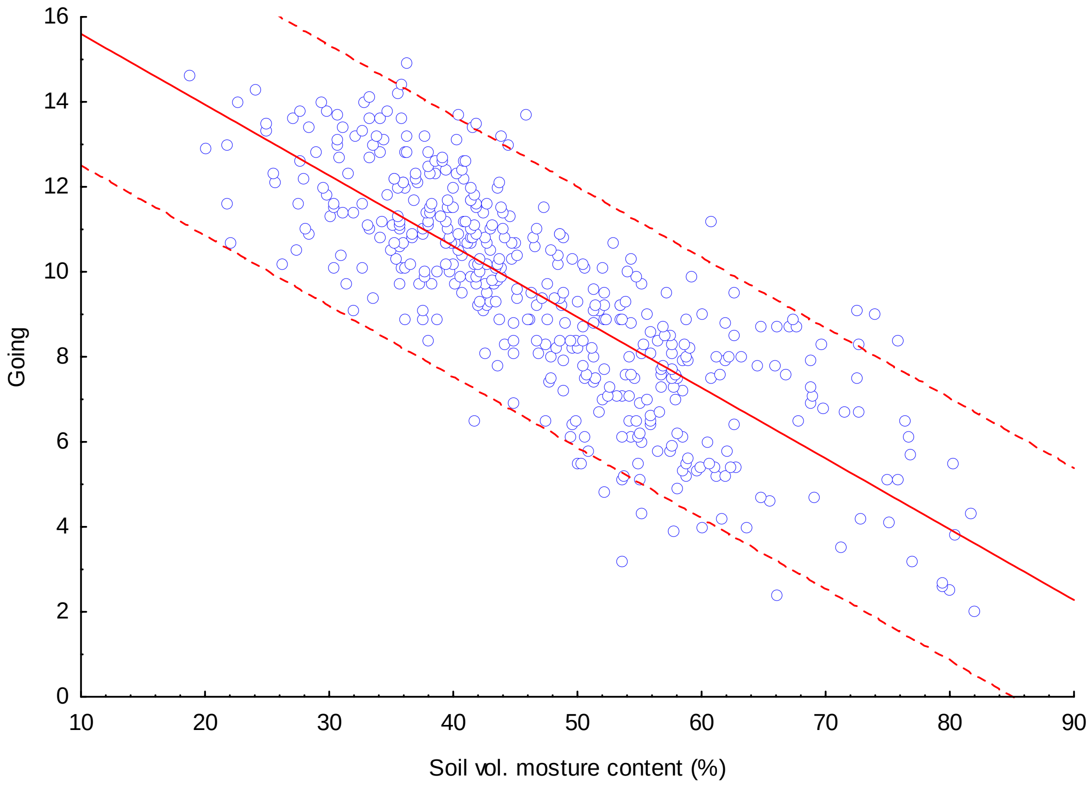
Figure 5.4: Linear regression analysis of the relationship between going, as measured by the going-stick, and the mean soil penetrative resistance of a sandy loam.

5.2.3. Determination of the relationship between Going-Stick values and volumetric soil moisture content.

A strong relationship exists between the values of going expressed by the going-stick and the volumetric soil moisture content on the soil types found on the flat course at Leicester Racecourse and Newcastle Racecourse. Changes in the volumetric soil moisture content accounted for 64% (r^2 = 0.64) of the variation in going on the sandy loam soil at Leicester and Newcastle Racecourses (Table 5.2). Changes in volumetric soil moisture content accounted for 93% and 71% of the variation in going on the sandy clay loam and clay loam soil types at Leicester and Newcastle Racecourses (Figure 5.5).

Table 5.2
Coefficient of determination and significance values for linear regression analysis between going and volumetric soil moisture content for the soil types found on the flat course at Leicester and Newcastle Racecourses.

Soil Type	***Coefficient of Determination*** *(r^2)*	***Significance*** *(at the 95% level)*
Sandy loam	0.64	<0.001
Sandy clay loam	0.93	<0.001
Clay loam	0.71	<0.001



r^2 = 0.6406; r = -0.8004; p = <0.001; y = 17.2646 - 0.1665*x

Figure 5.5: Linear relationship between going and volumetric soil moisture content for sandy loam soil on the flat course at Leicester Racecourse and Newcastle Racecourse.

5.3. Summary of Going-Stick Validity Tests.

The results of the repeatability test show that the going-stick consistently achieves the same value of penetration resistance for a given load, and that there was zero variation for repeated shear loading with a five kilogram weight. The comparison test in the soil bin revealed that a significant relationship (F pr = <0.001) exists between the going-stick and mean soil penetrative resistance of the top 100 mm of a sandy loam soil profile. However, the soil bin was void of any plant life; therefore there were no roots present to aid the shearing strength of the soil, as would be the case in a racecourse environment. The results also suggest that it is soil strength, rather than ρ_b that accounts for going, and support the results of the Shrink-Swell trial (Section 8.8.1) that indicated that high bulk densities do not necessarily confer good soil strength properties.

This is at odds with established strength theory as density is an integral component in the strength of non-cohesive soils. This apparent contradiction may be partly explained by the difficulties in obtaining reliable density measurements using small cores. In retrospect, it may have been beneficial to have used bigger cores that gave a measure of bulk density through the top 100 mm as against the top 30 mm as was the case in this experiment.

Soil moisture is strongly associated with soil strength. The analysis of the relationship between going and the volumetric soil moisture content show that as the volumetric soil moisture content increases, the level of going decreases. The opposite effect occurred as the soil became less wet. This was expected because the water potential of the soil increases as the soil becomes drier, which results in an increase in the tension of the water that surrounds the soil particles, pulling them closer together so that they make better contact. This creates greater binding strength between the soil particles, which at the same time increases the frictional resistance between them, creating a stronger soil that is less pliable (plastic) and has a greater bulk density, which therefore confers a harder surface and an increase in going. These results suggest that the going-stick is a repeatable method of arriving at an objective determination of soil penetrative and shear resistance values.

6.0. MODELLING GOING USING A SOIL WATER BALANCE: DEVELOPMENT, CALIBRATION AND VALIDATION.

Racecourses occupy a large area of land. Based on the results of the questionnaire survey an average flat course spans an area 67,604 m^2 (see Appendix 2.5) As a consequence the current techniques to determine going can take many hours to carry out, as they require the person measuring the going to traverse the entire racecourse, taking many measurements along the way. The ability to predict the going for specific locations on a racecourse would be a valuable tool to assist the manager to identify where surface management practices need to be targeted in order to achieve a consistent racing surface.

Using the going-stick as a method to provide values of going (Section 5.0), a soil-water balance was used to determine whether going could be modelled to enable the prediction of going for the different soil types encountered on a racecourse to be made. Methodology to produce an empirical model specific to individual racecourses was developed, the model considers the irrigation and soil water aspects; not the soil strength characteristics. This work relates to Objective One of the research project. A flow diagram of the processes involved to produce the model is given in Figure 6.1.

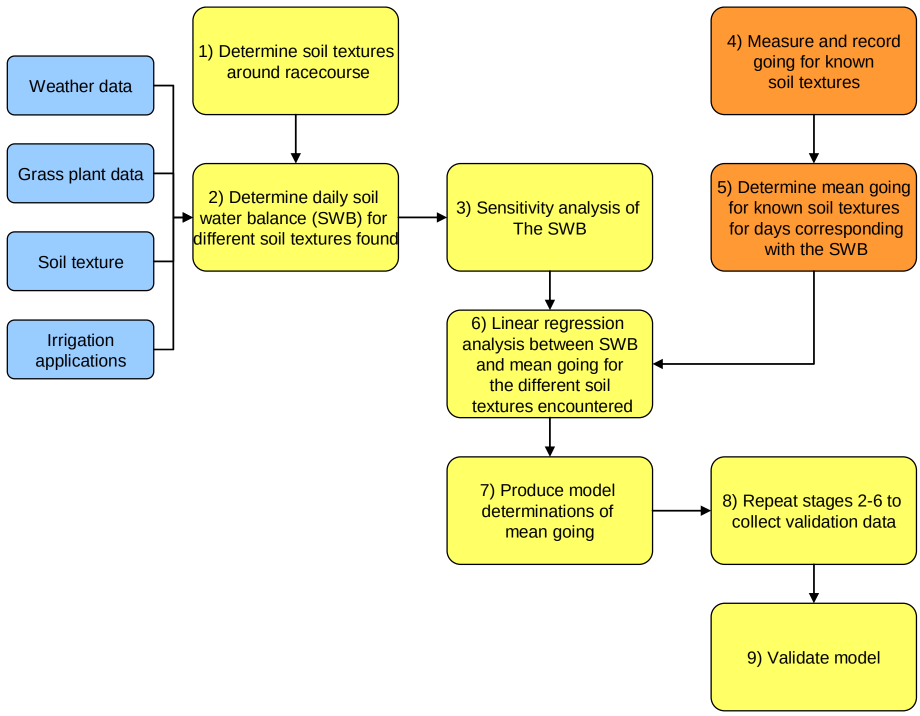


Figure 6.1: Flow diagram of processes to produce the mean going prediction model

6.1. Soil-Water Balance Modelling.

Soil-water balance (SWB) models have been developed to aid irrigation scheduling for farmers and growers. Typical crops irrigated in the UK are potatoes, sugar beet and vegetables grown between April and September (Stewart and Nielson, 1990). The determination of water losses and therefore, water requirements enables the farmers and growers to optimize water usage, produce high quality crops, maximize yields and achieve better water management in line with the requirements of the Water Act 2003.

There are several different types of SWB model, the complexity and purpose of which differs from model to model. Singh (undated) groups the different types of model into three categories,

1) *Agroclimatic models: The models are usually single layer models used for characterization of environments for soil water availability.*
2) *Management models: The soil profile is divided into two or three layers and the information generated by these models is used for soil and crop management.*
3) *Physical process models: The soil profile is divided into many layers for studying the flow processes in the soil more precisely.*

The use of empirical or theoretical descriptions or processes differs between the models. Therefore the data required for each model varies, as does the accuracy of the prediction of various water balance components. Singh (undated) states that generally the agroclimatic models require the least input data, whereas process models require the most input data, particularly soil property data.

6.1.1. Simple soil-water balance model requirements.

A simple SWB model will require the determination of water losses through evapotranspiration, and water additions through rainfall and supplementary irrigation, to arrive at the SWB. Hess (1994) lists the three main components of a simple SWB model to aid irrigation scheduling as;

1) *The calculation of a daily reference crop evapotranspiration value from local meteorological data*

2) *The adjustment of the reference crop evapotranspiration to an actual evapotranspiration, taking account of crop cover and soil water content*

3) *The calculation of a soil water deficit value*

6.1.2. Determination of reference crop evapotranspiration.

Reference crop evapotranspiration (ET_o) is the evapotranspiration rate for a theoretical reference crop, as described in Section 2.3.5.1., that all empirically estimated crop *ET* rates are calculated from with the use of an appropriate crop coefficient (K_c). Many empirical models have been constructed to determine estimates of ET_o, such as the Modified Penman (Doorenbos and Pruitt, 1977), Kimberly-Penman (Allen *et al*., 1989), Heat Energy Balance (Jensen *et al*., 1990), Priestly-Taylor (Fry *et al*., 1997) and the Penman-Montieth (Allen *et al*., 1998). There are also direct measurements to derive values for ET_o such as Class-A pan (Doorenbos, 1976) and porous ceramic atmometers (Qian *et al*., 1996).

The calculation of daily reference evapotranspiration (ET_o) using the Penman-Montieth Method has been selected, as it is an equation recommended by the Food and Agriculture Organisation of the United Nations (FAO) for use with factors for a reference surface (Allen *et al*., 1998), which the turfgrass on a racecourse closely matches.

The calculation of the Penman-Montieth Method requires certain meteorological data;

1) Maximum air temperature (°C)
2) Minimum air temperature (°C)
3) Mean daily vapour pressure (kPa)
4) Net radiation (MJ m^{-2} d^{-1})
5) Wind run (km d^{-1}).

The Penman-Montieth equation for ET_o is summarised as,

$$ET_o \quad = ETrad + ETaero \tag{7}$$

Where

$$ETrad \; = \frac{\Delta}{\Delta + \gamma *} \frac{(R_n - G)}{\lambda} \tag{8}$$

$$ETaero = \frac{86.4}{\lambda} \frac{1}{\Delta + \gamma *} \frac{\rho cp}{ra} (ea - ed) \tag{9}$$

Definitions of the symbols in Equations (8) and (9) are given below. All equations associated with the Penman-Montieth Method are presented in Appendix 5.1.

Symbol	Description	Unit	Value
λ	latent heat of vaporisation	MJ kg^{-1}	
Δ	slope of vapour pressure curve	kPa $°C^{-1}$	
γ	psychrometric constant	kPa $°C^{-1}$	
ρ	atmospheric density	kg m^{-3}	
γ*	modified psychrometric constant	kPa $°C^{-1}$	
cp	specific heat of moist air	kJ kg $°C^{-1}$	1.013 kJ kg-1 $°C^{-1}$
ea	mean saturation vapour pressure	kPa	
ed	actual vapour pressure	kPa	
ETaero	aerodynamic term	mm d^{-1}	
ET_o	reference crop evapotranspiration	mm d^{-1}	
ETrad	radiation term	mm d^{-1}	
G	soil heat flux	MJ m^{-2} d^{-1}	
ra	aerodynamic resistance	s m^{-1}	
R_n	net radiation	MJ m^{-2} d^{-1}	

(Taken from Hess, 2002)

6.1.3. Adjustment of the reference crop evapotranspiration to an actual evapotranspiration.

The calculation of actual evapotranspiration (ET_a) is carried out to make adjustments for the crop type and any soil water deficit limitations. However the estimate of ET_a is not necessary if the crop is well watered, maintains good surface coverage and does not reach a point where transpiration is reduced due to limitations of soil water in the rootzone. Therefore it is the author's view that the adjustment of ET_o to ET_a is not necessary on a turfgrass sward found in a racecourse environment – assuming the turfgrass cover remains at a level ≥85%. Since racecourses are currently well watered through the summer racing season to maintain surface conditions conducive to racing, and the racecourses turfgrass sward closely matches the description of the reference crop; any differences are likely to be negligible.

6.1.4. Calculating a soil-water deficit.

The calculation of the soil water deficit for a simple single layer SWB relies on a number of assumptions. The Irrigation Management Services (IMS) scheduling programme (Hess, 1994), lists the assumptions for a single layered water balance model as,

1) *The soil has a high hydraulic conductivity and no drainage impediment.*
2) *There is no temporary storage of water in excess of field capacity beyond one day.*
3) *The water table is deep and there is no significant contribution from groundwater to the root zone.*
4) *At the end of each day, the water content of the root zone is uniformly distributed.*
5) *Soil below the root zone is at field capacity.*
6) *Rainfall and irrigation systems do not apply water at such high application rates as to exceed the infiltration capacity of the soil.*

Using the calculation of ET_o (Section 6.1.2.) and the assumptions listed above, a soil water deficit can be derived from the following equation,

$$SWD_i = SWD_{i-1} + ET_{oi} - (R_i + I_i) \tag{10}$$

Where SWD_i = soil water deficit on day i (mm)

ET_{oi} = reference crop evapotranspiration on day i (mm)

R_i = rainfall on day i (mm)

I_i = irrigation on day i (mm)

6.1.5. Rainfall balance model.

Based on Equation (10) a simplified rainfall balance was generated to determine whether the effects of water on going could be generally described. The rainfall balance was determined with the following equation:

$$RB = inputs - outputs \tag{11}$$

Where RB = rainfall balance (mm)

$inputs$ = rainfall (mm d^{-1})

$outputs$= ET_o (mm d^{-1})

A monthly rainfall balance was generated for Newcastle Racecourse and the daily mean going for the whole of Newcastle Racecourse was plotted against the corresponding days for that month. The Rainfall balance showed that when water inputs are greater than water outputs softer surface ratings are achieved. When water outputs are greater than water inputs, firmer surface ratings of the racecourse occur.

From the results of the rainfall balance a simple model that predicted the mean going for the whole racecourse (described in Appendix 5.2) was developed. The model highlighted that the prediction of mean going for an entire racecourse would not assist a racecourse manager in managing the racecourse. The model would enable the manager to determine if irrigation was likely to be needed to the whole racecourse, but would not specify whether specific locations had a higher or lower mean surface rating, which would dictate the irrigation regime. This was not unexpected due to the variation in soil characteristics around a racecourse, highlighted in the audit of eight racecourses (Section 4.3.1). Therefore the development of a more complex soil-water balance model that would predict the mean going for the different locations and soil types encountered on a racecourse was necessary, so that location specific irrigation practices could be taken into account.

6.2. Complex Soil-Water Balance Models.

The level of sophistication of the SWB can be increased in two ways; the incorporation of a layer regulating function, or the optimization of a parameter. The incorporation of a layer regulating function, whereby the soil profile is separated into layers to enable the calculation of the soil water status in each layer, is useful where known changes in the soil type occur at depth, or where knowledge of particular zones of the soil profile is required (Figure 6.2). Layered SWB models generally assume that drainage from one layer to the next only occurs when the upper layer is above field capacity.

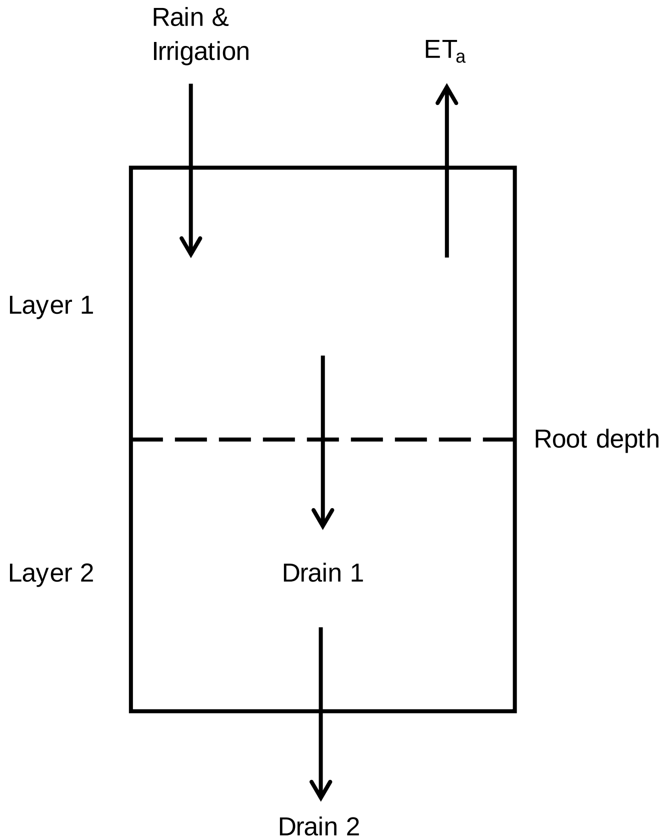


Figure 6.2: Example of a two layer soil water balance model (Taken from Hess, 1996a).

The optimization of a parameter usually involves the inclusion of the root development of the turfgrass, referred to as a 'Root Constant' function. The root constant function enables the determination of the water available to the turfgrass, and capacitates the SWB model to adjust the potential evapotranspiration to a determination of actual evapotranspiration (ET_a); the ratio of actual to potential evapotranspiration. SWB's of this type are referred to as 'Optimized' models.

In a study of the relative performance of 35 different soil moisture deficit models, Calder *et al*. (1983) found that using parameter optimization, best model fits were obtained. Soil moisture deficit models that incorporated the layer regulating function were the most successful when parameter optimization was excluded, and that an optimized layer function often gave the best fit within the optimized models, although the introduction of a layer gave only a small improvement.

6.2.1. Available water capacity.

Both models (layered and optimized) require knowledge of the available water capacity for a given soil type. The total available water capacity (TAWC) can be calculated from the determination of a soils moisture release characteristics. The moisture release characteristics describe the fraction of the soil water volume held at saturation (Sat), field capacity (FC) and permanent wilting point (PWP). Figure 6.3 shows typical moisture release characteristics for clay loam and sandy loam soils, which were determined using the methods of Smith and Thomasson (1982).

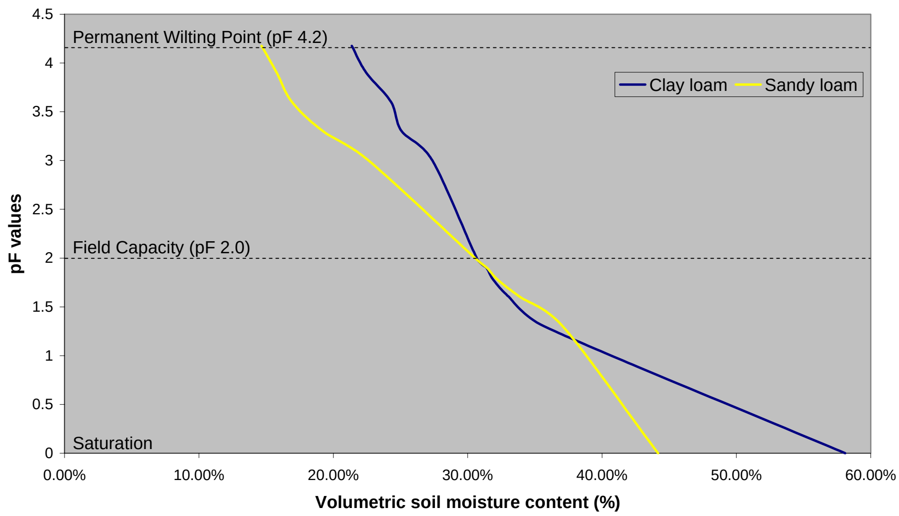


Figure 6.3: Moisture release characteristics for sandy loam and clay loam soils.

With knowledge of the rooting depth of the turfgrass, the water volume that is most easily available to the turfgrass (EAWC) can be established. Evapotranspiration rates are reduced when the turfgrass expends more energy trying to extract the tightly bound water that is not easily available, although this normally only occurs when the soil water status is approaching PWP. The calculation for TAWC is expressed by Hess *et al.* (2000) as,

$$TAWC = FC - PWP \tag{12}$$

$$FC = \theta_{FC} \, x \, r_i \, x \, 1000 \tag{13}$$

$$PWP = \theta_{PWP} \, x \, r_i \, x \, 1000 \tag{14}$$

$$EAWC = TAWC \, x \, p \tag{15}$$

Where $TAWC$ = total available water capacity of root zone (mm)

$EAWC$ = easily available water capacity of root zone (mm)

FC = water content of root zone at field capacity (mm)

PWP = water content of root zone at permanent wilting point (mm)

θ_{FC} = volume water fraction at field capacity

θ_{PWP} = volume water fraction at permanent wilting point

p = fraction of total available water that is easily available (dimensionless)

r_i = root depth on day i (m)

6.3. Developing the Methodology for a Soil-Water Balance Model to Predict the Mean Going for a known Soil Type.

An optimised SWB model that incorporated a layer function, as mentioned in Section 6.2., was chosen as the best method to determine the status of the soil water at Newcastle Racecourse, as a sufficient amount of information regarding the physical characteristics (soil type) and factors affecting turfgrass growth (crop type, weather and irrigation regime) was known. The SWB model used was the computer software program 'WaSim' (HR Wallingford and Cranfield University, 2002).

6.3.1. The WaSim soil-water balance model.

WaSim is a one-dimensional daily SWB model that simulates changes in the watertable position and root zone soil water content in response to water applications from rainfall and irrigation (Hess *et al*., 2000). A three-layer SWB model is used to estimate daily changes in the soil water content, with inputs (rainfall and irrigation), outputs (evapotranspiration and drainage) and deep percolation taken into consideration. The upper and lower boundaries of the model are the soil surface and impermeable layer respectively (Figure 6.4), which the water is stored between in five compartments. A description for each compartment is given in Table 6.1.

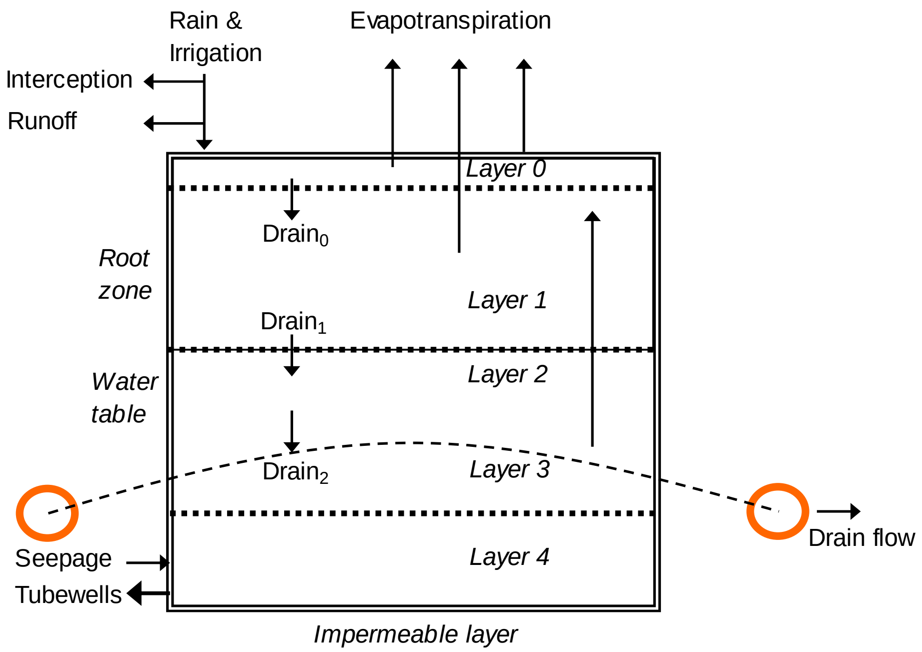


Figure 6.4: Schematic representation of the WaSim SWB model (Taken from Hess *et al*., 2000).

Table 6.1
Descriptions of the five compartments in the WaSim SWB model (adapted from Hess *et al*., 2000).

Compartment 0	The surface (0 – 0.15 m) layer
Compartment 1	The active root zone (0.15 – root depth)
Compartment 2	The unsaturated compartment below the root zone (root depth – water table)
Compartment 3	The saturated compartment above drain depth (water table – drain depth)
Compartment 4	The saturated compartment below drain depth (drain depth – impermeable layer)

The determination of going relates to the upper layers of the soil profile, therefore the soil water deficit in compartments zero and one are of primary interest. As the grass plant roots grow, the boundary between compartments zero and one will change. Compartment one will have zero thickness until the grass plant roots reach a depth of 0.15 m.

The flat racing season takes place during a period of active grass growth (summer), where it is likely that rooting depths will be in excess of 0.15 m (see Section 2.3.1.2), therefore the determination of the root zone deficit, which takes into account the rooting depth, shall form the basis of the generation of a SWB to predict the mean going on a known soil type. WaSim calculates the root zone deficit (Rzone def) as,

$$SWD = (\theta_{FC} - \theta) \times r \times 1000 \tag{16}$$

Where SWD = soil water deficit of root zone (mm).

r = root depth (mm).

θ_{FC} = volume water fraction at field capacity (dimensionless).

θ = volume water fraction of root zone (dimensionless).

(Taken from Hess *et al*., 2000).

Analysis of the relationship between the Rzone def, for the different soil types identified on the flat course at Newcastle Racecourse, and the mean going on the flat course at Newcastle Racecourse was conducted to determine whether an improved model to predict the mean going for a given soil type could be achieved. The results of the analysis are presented in Section 6.3.4.3.

6.3.2. Parameterization of the WaSim soil-water balance model.

The WaSim soil-water balance model software required certain parameters to be entered into the program before any determination of a SWB could be achieved. The parameters used were site specific to Newcastle Racecourse.

Owing to the irrigation regime at Newcastle, whereby water is applied to three distinct sections of the track on different days, due to the time required to water such a large area and/or the racing distance of a given race meeting, it was necessary to divide the racecourse information (soil, root depth, irrigation) into the relevant sections – chute, straight and round (Figure 6.5) – to reflect the irrigation practices.

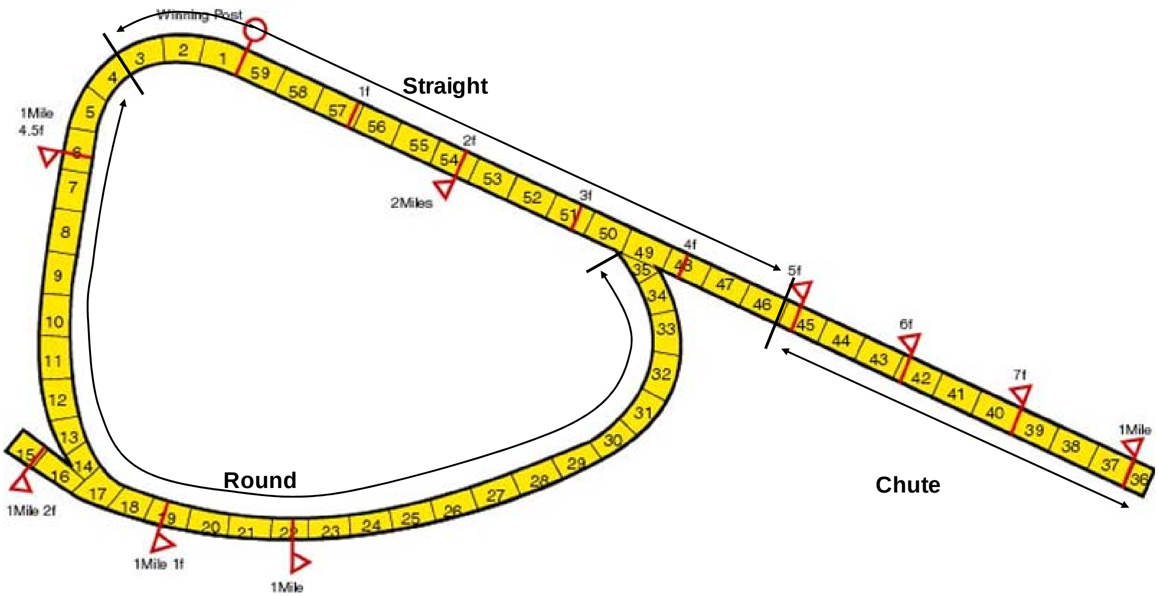


Figure 6.5: Newcastle Racecourse separated into three sections to reflect the irrigation practices conducted on the flat course © Turftrax.

6.3.2.1. Soil type.

Soil types identified during the audit of Newcastle Racecourse – sandy loam and sandy clay loam (Section 4.3.1.) – were used to create a SWB specific to each soil type encountered. In addition, the soil texture for each waypoint on the chute was identified, using the methods described in Section 4.2.1., as they were not determined during the audit.

6.3.2.2. Crop.

The crop was identified as turfgrass. The date the turfgrass was sown and achieved full cover was set as the 1st January as it is a pre-existing native stand of turfgrass. The WaSim program reduces crop cover linearly from maturity to harvest, to allow for senescence, which is unlikely to occur in a sports surface environment, therefore the maturity and harvest of the turfgrass was set as 31st December.

6.3.2.3. Root depth.

Root samples were collected at monthly intervals from Newcastle Racecourse at the locations identified in the audit (Section 4.2.), to determine the mean rooting depth for each soil type. The core-break method (Böhm, 1979) was carried out to establish the mean depth of the root mass; five samples per waypoint were collected. Monthly mean rooting depths for each soil type on the flat course were determined. The difference between the rooting depth for each soil type was not significant, therefore the values of rooting depth for all soil types were used to determine the mean monthly rooting depth (Figure 6.6).

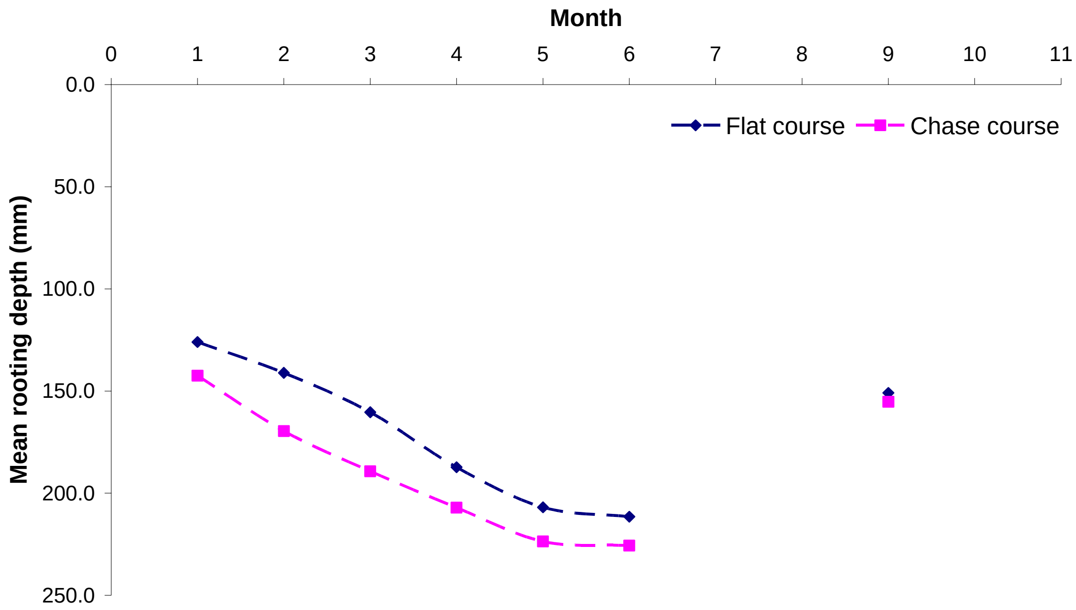


Figure 6.6: Mean rooting depth for all soil types at Newcastle Racecourse for the year 2005.

Beard (1973) Turgeon (2002) and Fry and Huang (2004) describe how roots decline in the mid to late summer months. WaSim does not take into account root decline as it assumes that rooting depth remains constant until harvest. This is supported by Borg and Grimes (1986) who state that established perennials do not have significant changes in root depth during one growing season. It would have been preferable to establish whether or not root decline occurred on the racecourse and whether or not it was significant, as it may have an influence on the determination of the Rzone def. But as the WaSim program does not facilitate the measurement of root decline it was not determined. Although root sampling in September showed that root decline did occur, but the rate at which it occurred was not established. The mean root depth for January (126 mm) was entered as the rooting depth on the 1st January. The maximum mean root depth (220 mm) and the day that maximum root extension was achieved (15th June) was also entered.

6.3.2.4. Weather data.

Weather data generated by a weather station situated at Newcastle Racecourse was provided by TurfTrax Ground Management Systems Limited. The data dates from mid April 2004 to December 2005. The location of the weather station is not central to the racecourse, but is clear of any structures that may influence the data collected. This is important otherwise misleading information could be recorded. Anecdotal evidence of the impact incorrect positioning of a weather station can have was described by Bonfield (pers. comm.), who stated that the weather station at Goodwood Racecourse recorded wind speeds in excess of 100 mph on race days. The reason for this was that the weather station had been located adjacent to the helicopter landing area. See Appendix 5.3 for an example of the parameters measured by the weather station at Newcastle Racecourse.

Given the large area of land a racecourse covers, it would be preferable to have several weather stations located along the length of the racecourse to identify any variations in microclimates. This is reinforced by Jiang *et al*. (1998), who showed that microclimates can vary significantly in a study to determine the variability of turfgrass water requirements on a golf course. Due to the financial situation at most racecourses, this is economically impractical however.

Data from the weather station was entered into the Automatic Weather Station Evapotranspiration (AWSET) program (Cranfield University, 2002) to calculate an estimate of daily ET_o values using the Penman-Montieth Method, as described in Section 6.1.2. However AWSET can only calculate an estimate for sun hours and net radiation (MJ m^2), based on solar radiation (kW m^2) values, as sun hours are not measured by the Newcastle Racecourse weather station. The processed weather data was entered into the WaSim program in a spreadsheet format.

6.3.2.5. Irrigation data.

Irrigation data for the period 2004-2005 at Newcastle Racecourse was supplied by the Clerk of the Course, James Armstrong. The data was provided as a depth of water applied in millimetres per day. The data for 2004 was divided into two sections, the round section, and the straight section which incorporated the chute. However, the data for 2005 was more specific to the waypoints – which were introduced in late April 2004. This required the 2004 data to be further divided into the sections identified in the 2005 data, to ensure consistency (see Figure 6.4).

6.3.2.6. Start data.

The SWB start date was taken from the first full day of weather data (20th April 2004). As the WaSim program does not take into account root decline during periods of the year the SWB was run for each year separately to avoid having maximum mean rooting depth on the 1st January. The values for the moisture content in the soil profile calculated by WaSim at the end of the first year where used at the beginning of the second year to ensure initial conditions were consistent with the end of the previous year.

6.3.3. Calibration and error of the going data.

The calibration of the going data, as described in Appendix 5.4, was applicable to the SWB. The values of going for the waypoints with known soil textures were selected and separated into their corresponding sections of the racecourse, and were further separated by their soil type for the SWB model. A mean value of going was determined – after the removal of any outliers – for each soil type in order to arrive at a mean value of going for a known soil type on a section of the racecourse on a given day.

6.3.4. Analysis of the soil-water balance model to predict the mean going for known soil types at Newcastle Racecourse.

Determination of the rootzone deficit (Rzone def) in the SWB model began on the 20th April 2004. It was assumed that the initial condition of the soil moisture status was field capacity (FC). However, without historical weather data prior to the 20th April 2004 it is difficult to determine the initial conditions, as the soil could have been either saturated or below FC on the day before readings began, which would have a knock-on effect on the output of the SWB by skewing the determination of the Rzone def by ± x-amount. Therefore a sensitivity analysis was conducted to identify when the SWB reached equilibrium; the point at which the Rzone def was not influenced by the initial conditions.

6.3.4.1. Sensitivity of the soil-water balance.

SWB's with different initial conditions on day one were constructed for each soil type. The initial conditions were soil moisture fractions for saturated (Sat) conditions, FC and permanent wilting point (PWP). The default values of WaSim for each soil type were used for the soil moisture fractions at saturation, FC and PWP (Table 6.2), as they were similar to values achieved on a sand table and pressure membrane apparatus when determining the soil moisture release characteristics of typical sandy loam and clay loam soils (Section 6.2.1).

Table 6.2
Soil moisture fractions for saturation, field capacity and permanent wilting point of three soils.

Soil Type	***Sat***	***FC***	***PWP***
Sandy loam	0.453	0.245	0.095
Sandy clay loam	0.398	0.241	0.148
Clay loam	0.464	0.321	0.197

All three SWB were plotted together to enable a graphical analysis of extreme initial conditions (Figures 6.7, 6.8 and 6.9) to identify the point at which they merged and maintained the same value for the rootzone deficit.

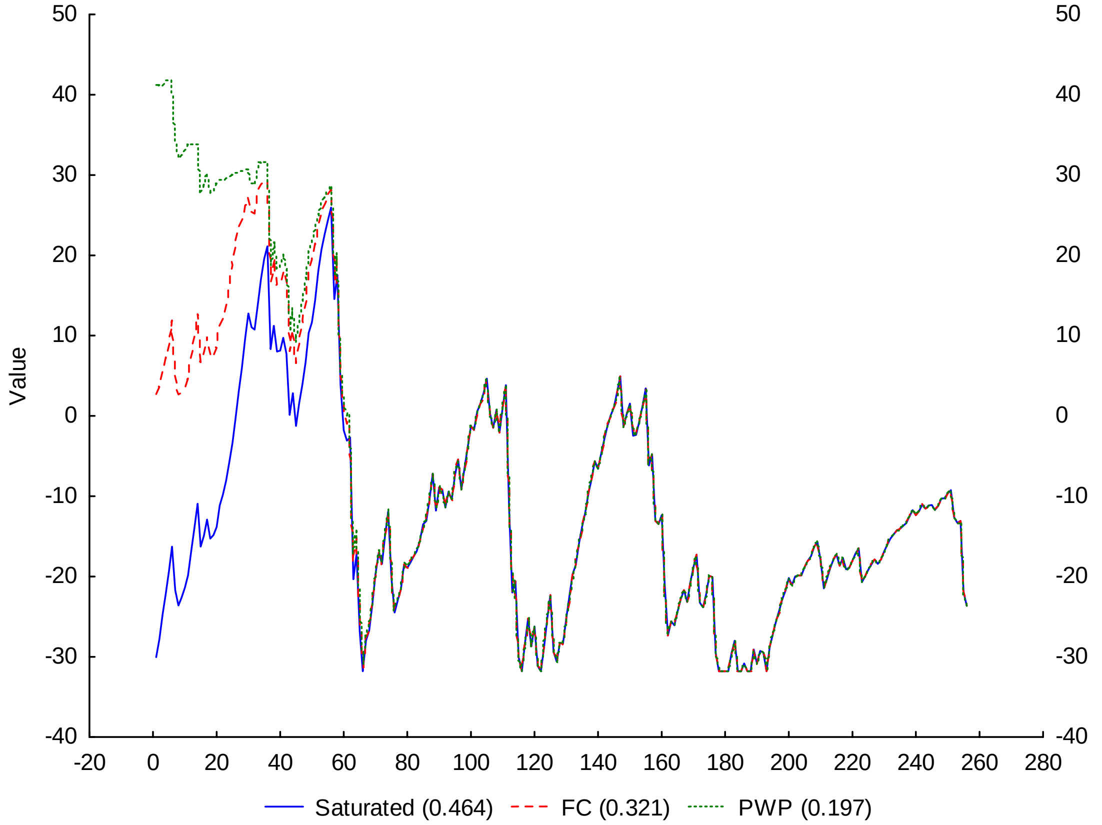


Figure 6.7: Clay loam Rzone def with three different initial soil moisture conditions.

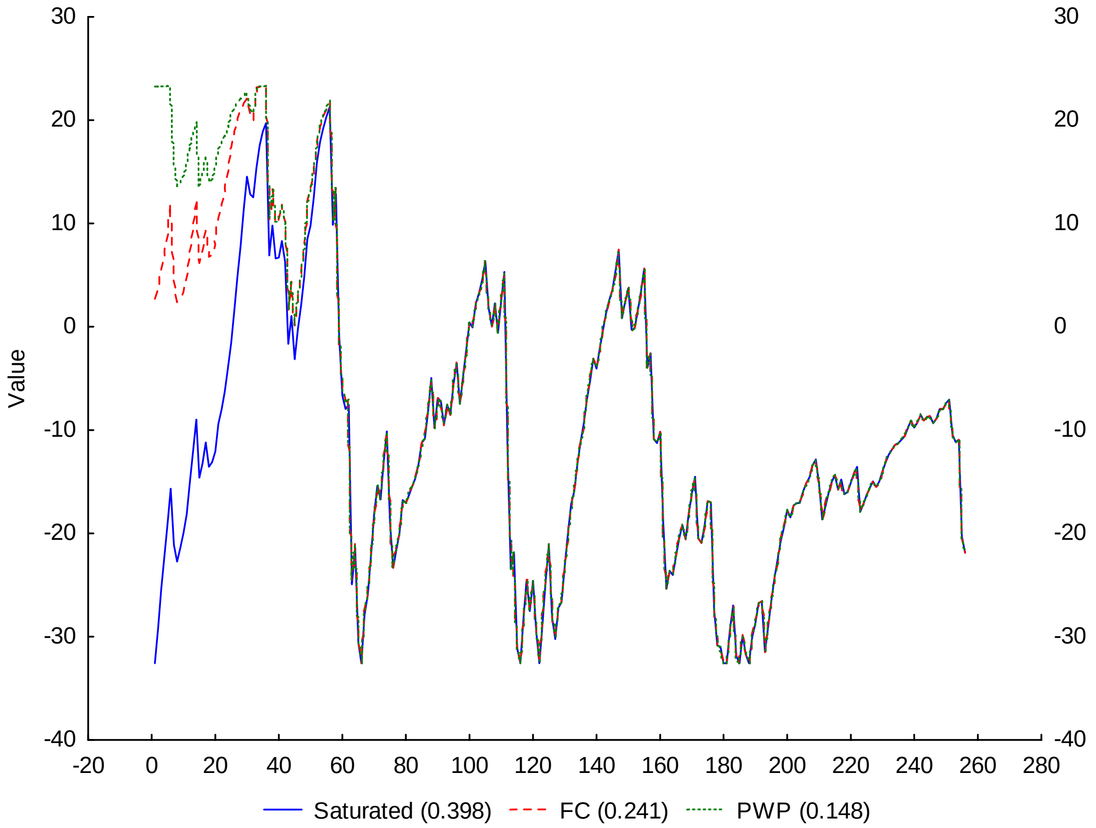


Figure 6.8: Sandy clay loam Rzone def with three different initial soil moisture conditions.

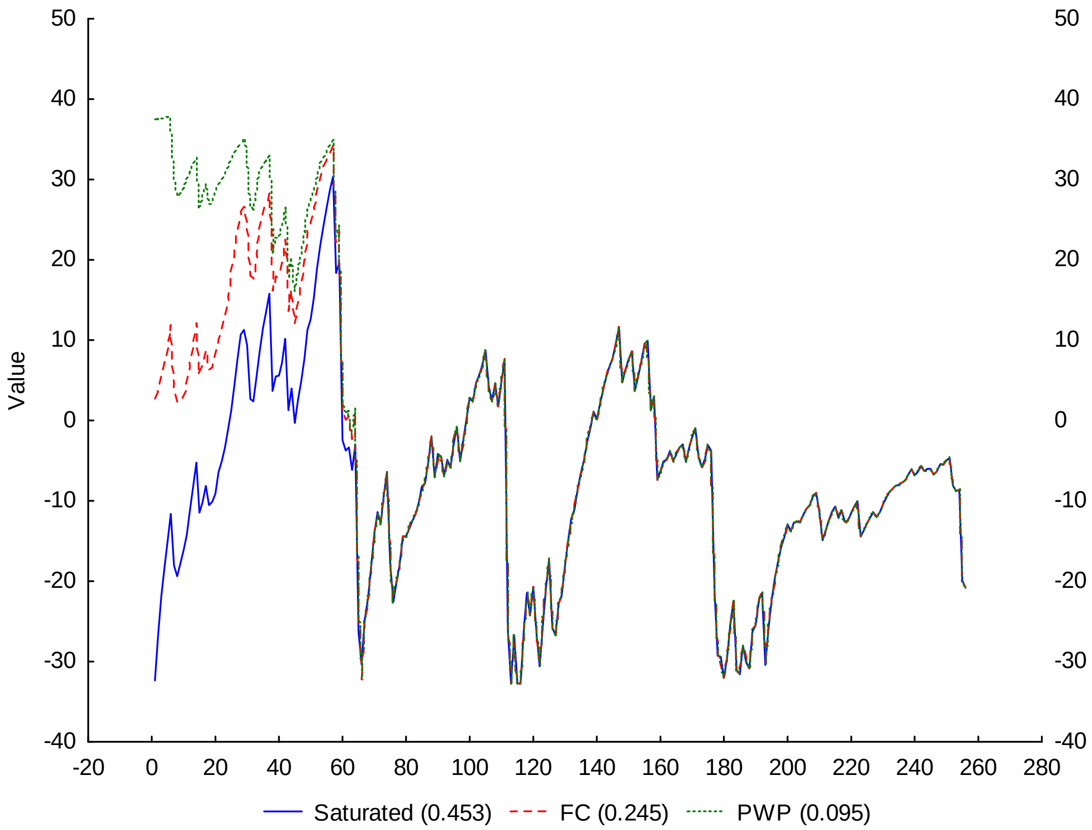


Figure 6.9: Sandy loam Rzone def with three different initial soil moisture conditions.

The three different Rzone def's for each soil type merged together at or around a 20 mm deficit ± 1 mm. To further improve the reliability of the Rzone def, only data that occurred after a significant wetting event – that resulted in the Rzone def having a negative rootzone deficit – were analysed, as it is assumed that the soil will return to FC within one to three days in the absence of rainfall or irrigation (Brady and Weil, 2002). Therefore the first values of the Rzone def that were used for the model development have a value that is ≤0.00 mm, and occurred on the 18th June 2004 ± 1 day, dependent on the soil type.

6.3.4.2. Selection of WaSim soil-water balance model data.

The Rzone def displayed obvious wetting and drying cycles (Figure 6.10) over the period 2004 to 2005, as expected. It was thought that the change in going for a defined value in the Rzone def would be dependent on whether the Rzone def was experiencing a wetting cycle or a drying cycle, due to the effect of hysteresis, as described in Section 2.2.4.2. To determine whether or not the wetting and drying cycles needed to be separated, analysis was conducted to determine whether the values of going on a wetting cycle were significantly different to the values of going on a drying cycle.

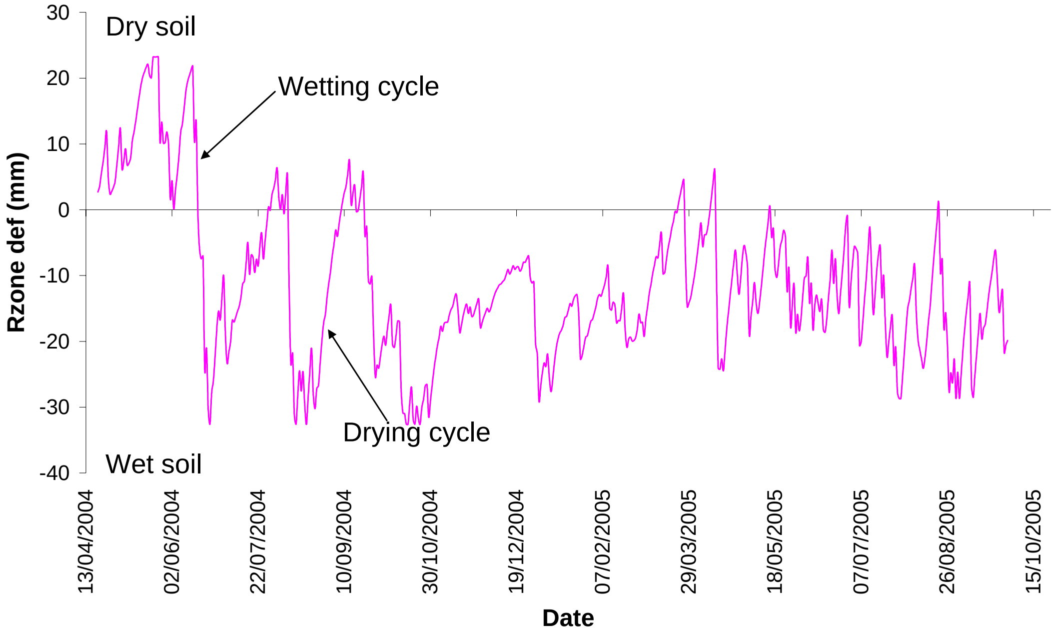


Figure 6.10: Wetting and drying cycles of the rootzone deficit for sandy clay loam on the straight section of the flat course at Newcastle Racecourse.

The analysis was carried out using Statistica statistical software (StatSoft, Inc, 2004). The wetting and drying cycles for the Rzone def were plotted against their corresponding values of going on a given day. A comparison between the two slopes and intercepts for the wetting and drying cycles respectively was carried out using the confidence interval of the slopes and intercepts, which showed that the going derived on wetting and drying cycles were not significantly different to each other (Figure 6.11). Therefore the wetting and drying cycle values of the Rzone def were combined for the overall analysis of the Rzone def and its relationship with the mean going for a known soil type on a given section of the racecourse (Figure 6.12).

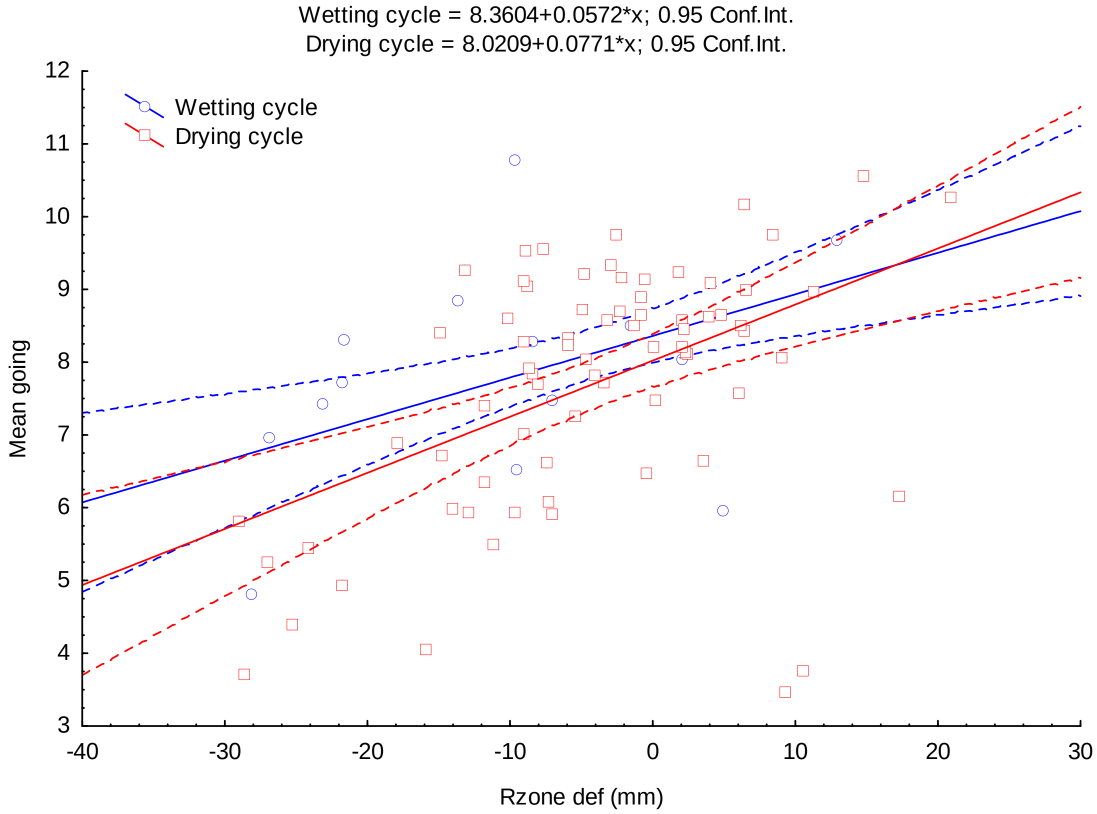


Figure 6.11: Comparison of the slope and confidence intervals for the wetting and drying cycles of the soil-water balance for a sandy clay loam at Newcastle Racecourse

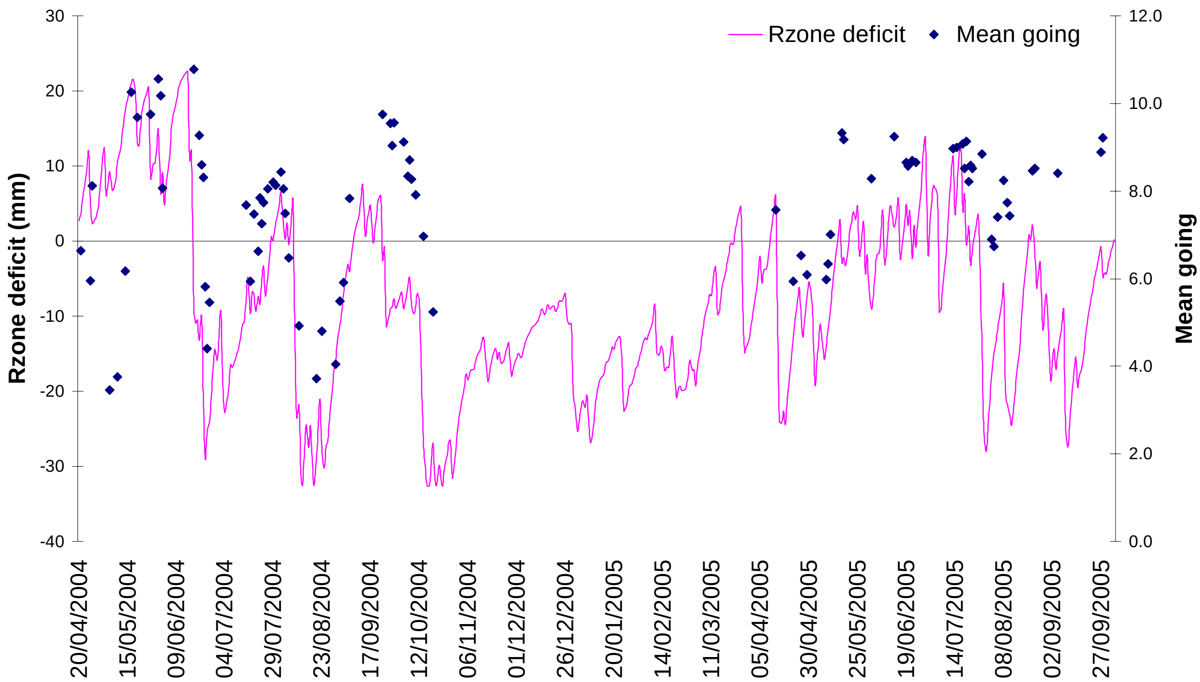


Figure 6.12: The rootzone deficit for sandy clay loam on the round section of the flat course at Newcastle Racecourse, with mean going for the period 2004-2005.

6.3.4.3. Analysis.

Due to the different soil types identified and the separation of the racecourse into three defined sections on the basis of differing irrigation practices, the data available for analysis for each combination of soil and section was reduced, relatively, in comparison to the amount of data available for the analysis of the simple rainfall balance model. Greater variation around the mean was, therefore, expected.

As a consequence the range of values in each dataset was limited; therefore linear regression was used – as opposed to non-linear regression for the rainfall balance model – using Statistica, to determine whether a relationship existed between the rootzone deficit, generated by the SWB model, and the mean going for each soil type in each section of the flat course.

There appeared to be a time lag, visually, (see Figure 6.12) between the Rzone def and the mean going, whereby the mean going appeared to respond to changes in the Rzone def over the next one to three days, dependent on the soil type, after the change in the Rzone def occurred. This can be explained to some extent by the fact that the WaSim programme calculates daily inputs and outputs to determine the Rzone def at the end of each day. In reality it is likely that the soil requires at least 24 hours or more to enable the Rzone def to be evenly distributed throughout the soil profile (layer 0 and 1 of the SWB model in the case of the Rzone def). Therefore the analysis of the relationship between the Rzone def and the mean going took into account the apparent time-lag, by shifting the Rzone def forward by increments of one day, to a maximum of three days, to achieve the best fit between the Rzone def and the mean going.

The sandy clay loam on all sections of the racecourse achieved best results with a one-day shift in the Rzone def, whereas the sandy loam and clay loam soils required two and three day shifts in their respective Rzone defs. The difference in the number of days shift in the Rzone def between the different soil types is likely to be due to the rate at which the different soil types achieve equilibrium in their Rzone defs owing to the architecture of each soil type (see Section 2.2.3), whereby the different soils have distinct pore size distribution, bulk density and hydraulic conductivity rates.

There was a significant relationship (F pr = <0.001) between mean going and the Rzone def for a sandy loam soil on the round section of the flat course at Newcastle Racecourse. Linear regression showed that changes in the Rzone def accounted for 38% of the variation in mean going, when a two day shift in the Rzone def was incorporated (Figure 6.13). The description of the slope (Y = 7.8101 + 0.0921 x X) for the interaction between the mean going and the Rzone def gives the equation to predict the mean going for the sandy loam soil on the round section of the flat course, assuming the Rzone def is known.

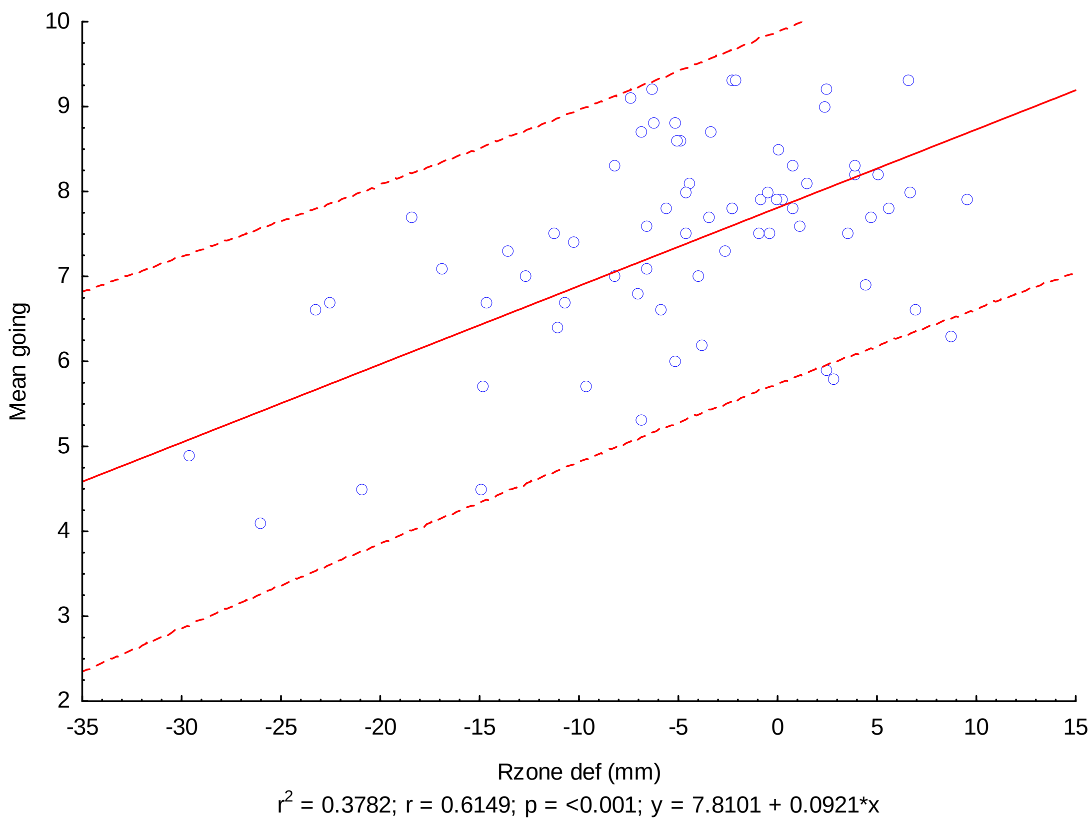


Figure 6.13: Linear regression analysis of the relationship between the Rzone def – with a two day shift – and mean going, for sandy loam soil on the round section of the flat course at Newcastle Racecourse, with prediction intervals at the 95% level.

A significant relationship (F pr = <0.001) exists between the Rzone def and mean going expressed by the going-stick for the sandy clay loam soil on the round section of the flat course at Newcastle Racecourse. The optimum coefficient of determination (r^2 = 0.5172) was achieved with a one day shift in the Rzone def, and shows that 52% of the variation in mean going can be explained by changes in the Rzone def (Figure 6.14).

The slope of the interaction between the mean going and Rzone def is:

$$Y = 8.4263 + 0.1 \times X \qquad (17)$$

where Y is the mean going and X is the Rzone def. This equation is the predictive model to determine the mean going for a sandy clay loam soil on the round section of the flat course at Newcastle Racecourse.

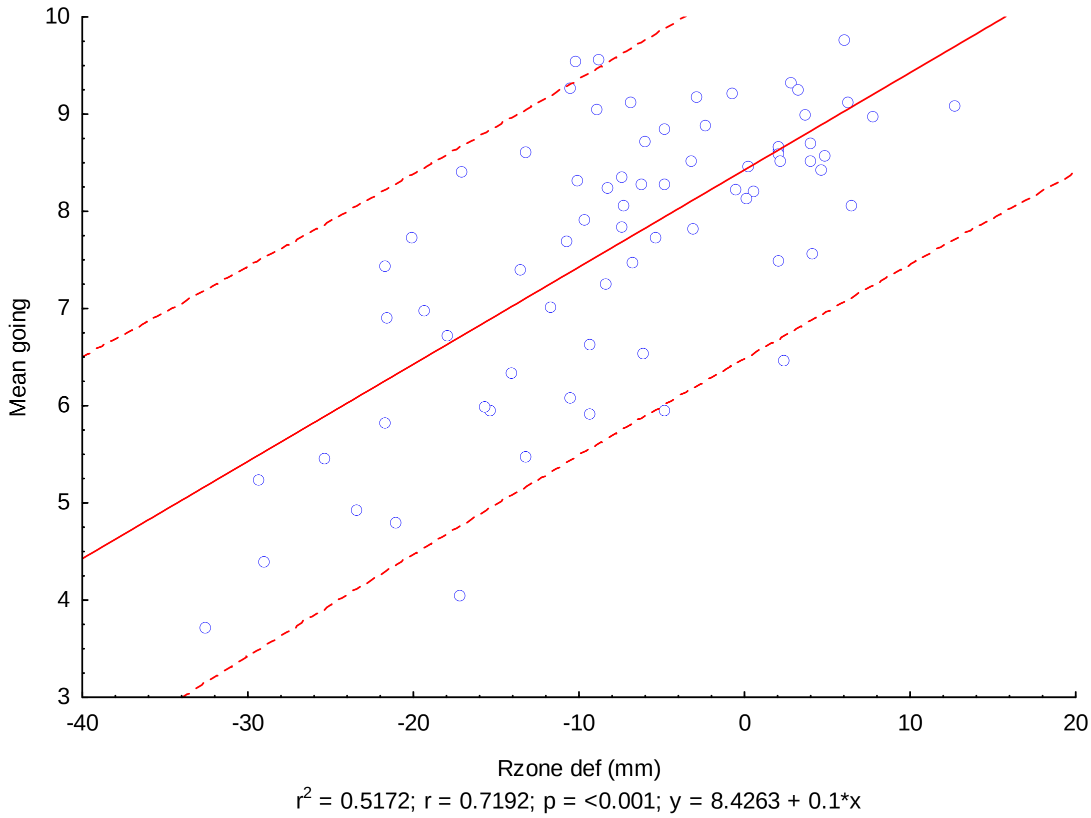


Figure 6.14: Linear regression analysis of the relationship between the Rzone def – with a one day shift – and mean going, for sandy clay loam soil on the round section of the flat course at Newcastle Racecourse, with prediction intervals at the 95% level.

Changes in the Rzone def – shifted by one day – accounted for 28% of the variation in mean going for sandy clay loam soil on the straight section of the flat course at Newcastle Racecourse (Figure 6.15). The relationship between the mean going and Rzone def was significant (F pr = 0.001).

The equation for predicting the mean going on sandy clay loam in the straight section of the flat course at Newcastle Racecourse is derived from the slope of the interaction between the mean going and Rzone deficit (Y = 8.8614 + 0.0883 x X).

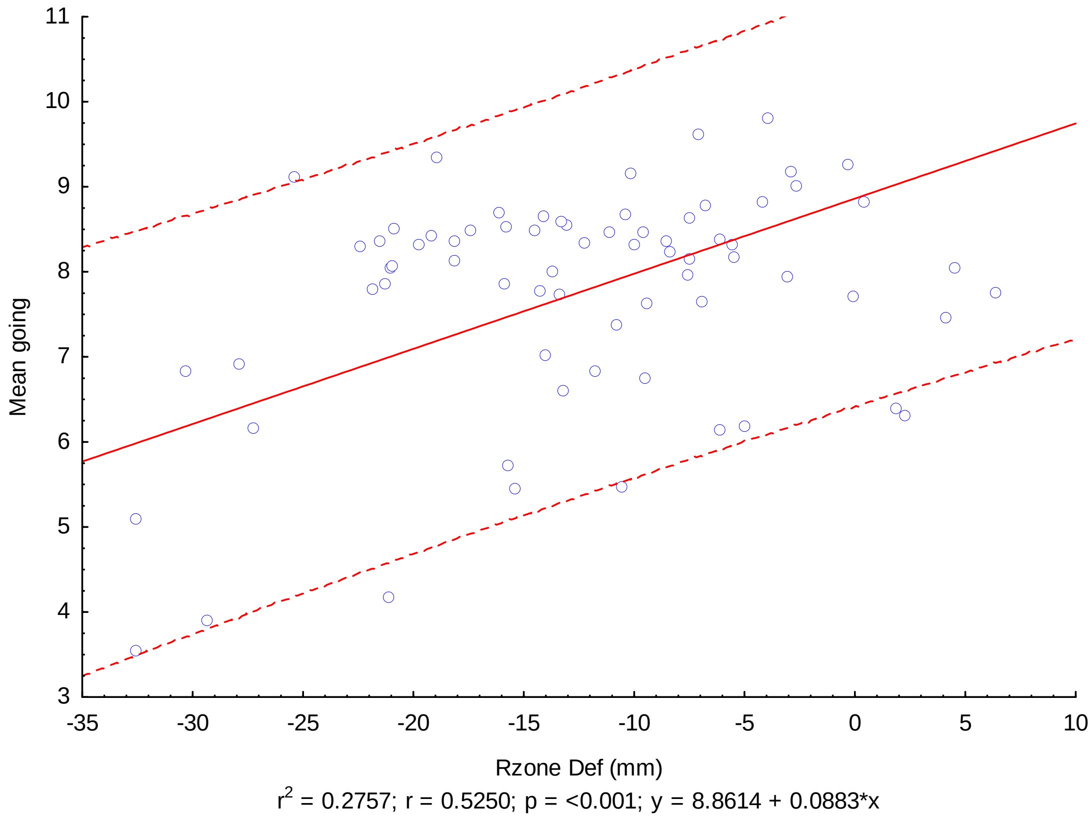
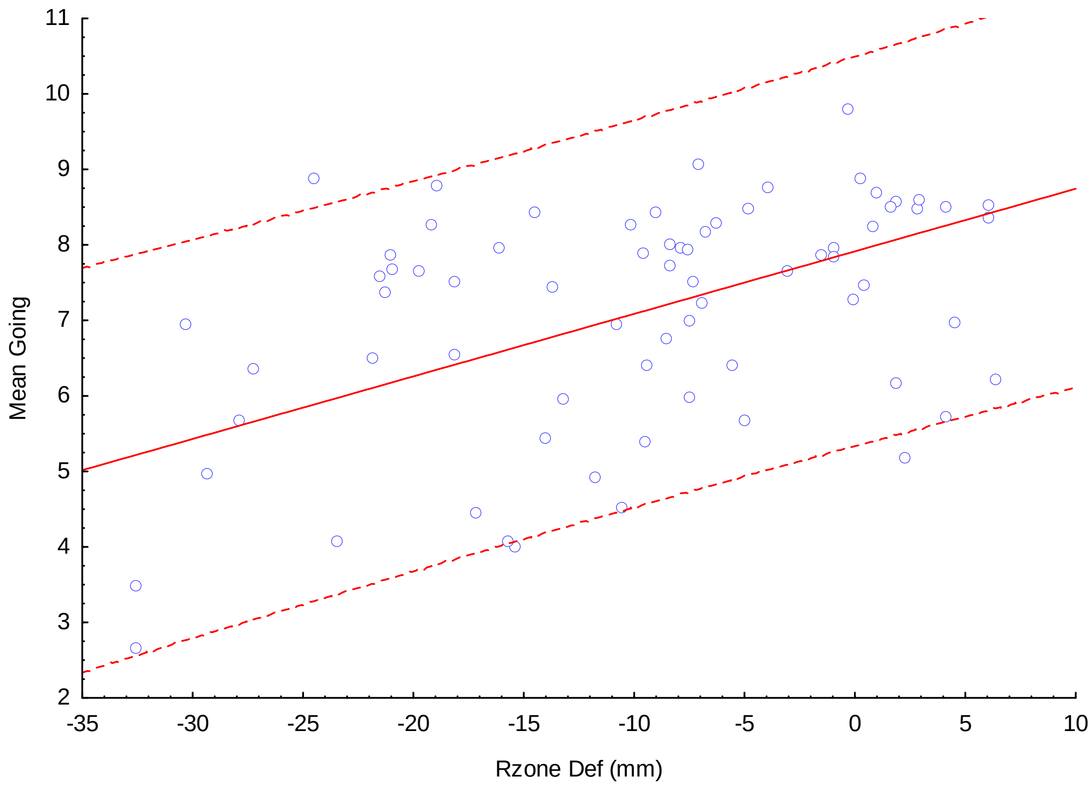


Figure 6.15: Linear regression analysis of the relationship between the Rzone def – with a one day shift – and mean going, for sandy clay loam soil on the straight section of the flat course at Newcastle Racecourse, with prediction intervals at the 95% level.

There was a significant relationship (F pr = <0.001) between mean going and the Rzone def for a sandy clay loam soil on the chute section of the flat course at Newcastle Racecourse. The coefficient of determination (r^2 = 0.3040) showed that 30% of the variation in mean going could be accounted for by changes in the Rzone def. The Rzone def had a one day shift (Figure 6.16).

The description of the slope (Y = 7.9149 + 0.0828 x X) for the interaction between the mean going and the Rzone def gives the equation to predict the mean going for the sandy clay loam soil on the chute section of the flat course at Newcastle Racecourse.



r^2 = 0.3040; r = 0.5514; p = <0.001; y = 7.9149 + 0.0828*x

Figure 6.16: Linear regression analysis of the relationship between the Rzone def – with a one day shift – and mean going, for sandy clay loam soil on the chute section of the flat course at Newcastle Racecourse, with prediction intervals at the 95% level.

A significant relationship (F pr = <0.001) exists between the Rzone def and mean going expressed by the going-stick for the clay loam soil on the chute section of the flat course at Newcastle Racecourse. The optimum coefficient of determination (r^2 = 0.3267) was achieved with a three day shift in the Rzone def, and shows that 33% of the variation in mean going can be explained by changes in the Rzone def (Figure 6.17). The equation for predicting the mean going on clay loam in the chute section of the flat course at Newcastle Racecourse is derived from the slope of the interaction between the mean going and Rzone deficit (Y = 8.0129 + 0.0883 x X).

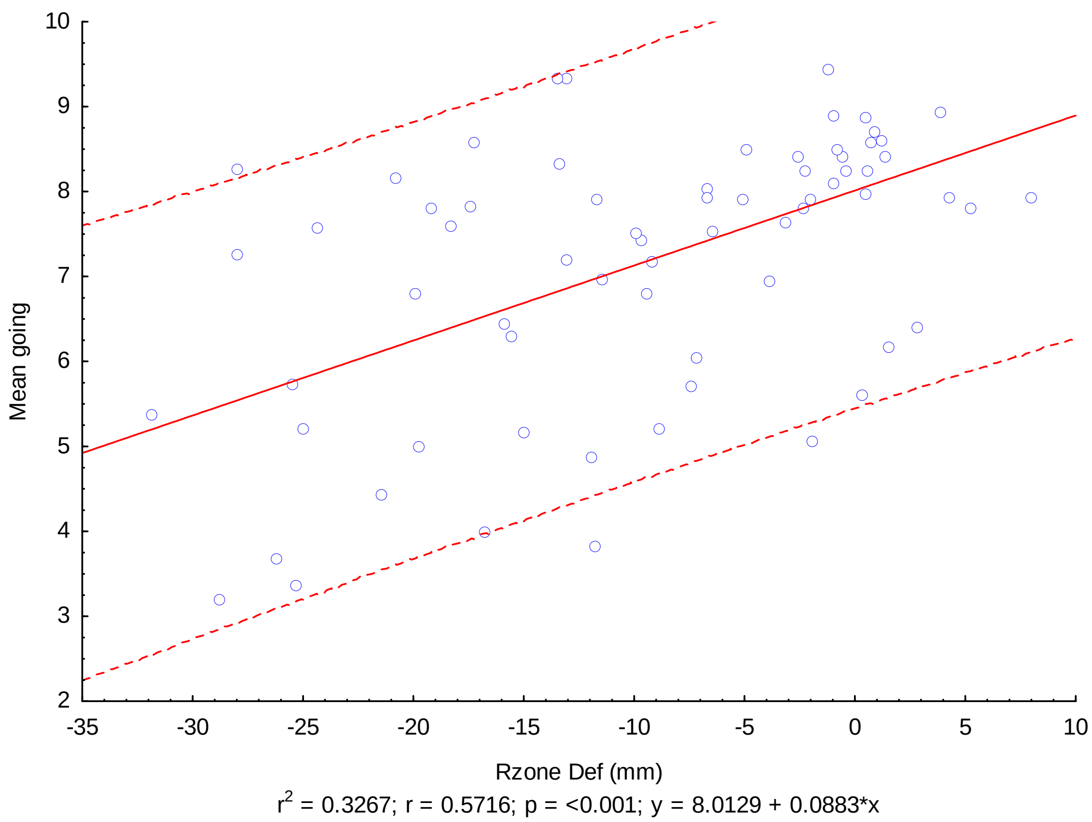


Figure 6.17: Linear regression analysis of the relationship between the Rzone def – with a three day shift – and mean going, for clay loam soil on the chute section of the flat course at Newcastle Racecourse, with prediction intervals at the 95% level.

All five SWB models had a time lag effect which differed depending on the soil type. Sandy loam achieved best results with a one day lag, whereas sandy clay loam and clay loam achieved best results with a two and three day lag respectively. A possible explanation for the time lags is given in the discussion of the SWB model (Section 6.6.4).

The prediction models also have the dual purpose of identifying the value of Rzone def required for a desired level of going on a given soil type within each section of the racecourse. This information will contribute to the manager's knowledge of the racecourse, and enable them to make informed decisions with regards to the amount of irrigation to apply.

6.4. Validation of the Soil-Water Balance Model.

Validation of the SWB mean going prediction model (MEGPREM) comprised two stages, 1) validity of the model to predict the going at Newcastle Racecourse, 2) validity of the model to predict the going at other racecourses with the same soil types found at Newcastle Racecourse.

6.4.1. Validation of the soil-water balance model for predicting the mean going at Newcastle Racecourse.

Weather data collected from the weather station at Newcastle Racecourse for the period 1st January 2006 to 30th September 2006 was used to validate the model. The weather data was summarised using AWSET software and inserted into WaSim to generate a SWB, as described in Section 6.3.2.4. The initial conditions were taken from the results of the SWB for the 31st December 2005.

The author measured and recorded the going on the flat course at Newcastle Racecourse with a going-stick on the 12th, 13th and 14th September 2006 – towards the end of the flat racing season – as going values were not determined with a going-stick at Newcastle Racecourse throughout the 2006 flat racing season, with the exception of two days measurements taken by the Clerk of the Course on the 20th and 26th September; therefore a limited dataset was available to validate MEGPREM. The running rail had recently been relocated from its summer position to minimize wear adjacent to it, therefore the author measured the going at the points he interpreted as the locations where the Clerk usually measured prior to the repositioning of the running rail.

Additionally, two waypoints (17 and 32) had recently had sand bands installed to improve the surface drainage characteristics at those locations. The bands were very close to one another (approximately 75 mm) and may have influenced the values of going recorded at those locations. However the value expressed by the going-stick is representative of the going experienced by racing horses at those locations. It is unlikely that the going values at waypoints 17 and 32 would have a significant affect on the outcome of the determination of actual mean going.

All recorded going measurements were transformed to arrive at an actual mean going for each combination of racecourse section and soil type, using the methodology described in Section 6.3.3. The values of the rootzone deficit – generated in WaSim – for the different soil types on the dates on which going was recorded were incorporated into the equations derived in Section 6.3.4.3. for the prediction of the mean going on sandy loam, sandy clay loam and clay loam soil types.

The difference between predicted and actual (observed) mean going was greater for the measurements of going recorded by the author, than those recorded by the Clerk of the Course. This could be due to the author taking measurements at locations that are not consistent with the locations where the Clerk of the Course measures going, as the author assumed that the clerk measured the going at random locations within each waypoint. Later discussion with the Clerk of the Course (Armstrong, pers. comm.) revealed that the clerk measures the going at set locations, two metres from the inner running rail, on the round section of the flat course and deviates across the track on the straight section (straight and chute combined). Therefore the clerk has consistency in where he takes his measurements. The predicted and observed data is given in Table 6.3.

Table 6.3
Predicted and actual mean going for the flat course at Newcastle Racecourse.

	Chute				***Straight***		***Round***			
	Clay loam		Sandy clay loam		Sandy clay loam		Sandy clay loam		Sandy loam	
Date	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual
12/09/06[1]	6.8	9.6	7.0	9.9	7.9	9.0	7.3	9.5	7.3	8.7
13/09/06[1]	7.0	9.7	7.2	9.9	8.1	9.5	7.5	10.1	7.1	10.6
14/09/06[1]	6.8	9.4	7.3	10.3	8.2	9.4	7.7	10.0	7.2	9.4
20/09/06[2]	7.4	8.1	7.9	9.0	8.8	9.6	8.4	9.0	7.8	7.8
26/09/06[2]	7.1	7.2	6.7	7.8	7.6	7.4	7.0	7.4	6.6	7.1

[1] *Dates when actual measurements of going were recorded by the author*
[2] *Dates when actual measurements of going were recorded by the Clerk of the Course*

Linear regression analysis was conducted to show if a significant relationship existed between the predicted and actual mean going. A sample correlation coefficient test was carried out to determine whether the predicted mean going and actual mean going had a strong positive or negative correlation; the significance of the correlation coefficient was assessed using an F-test. Modelling efficiency was conducted to assess the accuracy of the predicted values.

6.4.1.1. Linear regression.

Linear regression analysis showed that the coefficient of determination (r^2) ranged between 0.007 and 0.599 for all combinations of soil type and section of the flat course, with the exception of the 0.599 value (straight section, sandy clay loam). These results suggest that a strong relationship does not exist between the predicted mean going, using the equations in Section 6.3.4.3, and the actual (observed) mean going for any combination of soil type/section of the flat course at Newcastle Racecourse. Figure 6.18. (overleaf) shows an example of the linear regression analysis for one of the soil type/section combinations. The r^2 for the various combinations of soil type and section of racecourse are presented in Table 6.4.

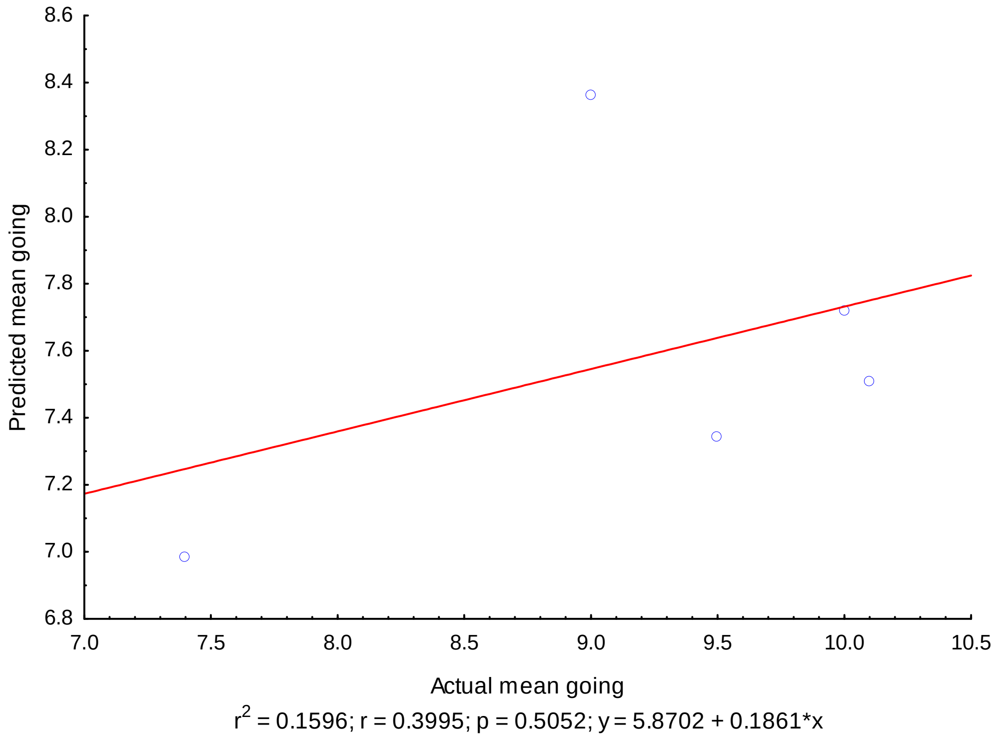


Figure 6.18: Linear regression analysis to establish the relationship between the predicted and actual mean going for sandy clay loam on the round section of the flat course at Newcastle Racecourse.

6.4.1.2. The sample correlation coefficient of the soil-water balance model.

An estimate of p, the correlation coefficient for the whole population, is provided by the sample correlation coefficient (r) (Draper and Smith, 1998). Values of r lie between +1 and -1, where +1 is a perfect positive correlation, and -1 is a negative correlation between the predicted and observed values (Smith *et al*., 1996). When r = 0 no correlation exists, and therefore there is no relationship between the predicted and observed datasets. The equation to determine the sample correlation coefficient is given by Smith *et al*. (1996) as,

$$r = \frac{\sum_{i=1}^{n}(o_i - \bar{o})(p_i - \bar{p})}{\left[\sum_{i=1}^{n}(o_i - \bar{o})^2\right]^{1/2}\left[\sum_{i=1}^{n}(p_i - \bar{p})^2\right]^{1/2}} \tag{18}$$

Where o_i = the observed values

p_i = the predicted values

$\bar{o}$ = the mean of the observed values

$\bar{p}$ = the mean of the predicted values

n = the number of samples

The sample correlation coefficient (r) for all combinations of soil type and section of the racecourse ranged from 0.08 to 0.77. This indicates that MEGPREM does not provide a perfect positive correlation with the observed values of going, but does show a good association with the observed values, with the exception of the 0.08 value (round section, sandy loam). The significance of r was assessed using an F-test (Fleming and Nellis, 2000); r was not significant (F pr >0.05) for any combination of soil type/section of racecourse. The values of r and significance of r (*F test*) are presented in Table 6.4.

6.4.1.3. Modelling efficiency of the soil-water balance model.

The accuracy of the predicted values was assessed using modelling efficiency methodology (*EF*) by comparing the variance of predicted from observed values to the variance of observed values from the mean of the observations (Smith *et al*., 1996). This uses a simple predictive model – the mean of the observations – as a method to test the efficiency of MEGPREM. The modelling efficiency equation is presented by Smith *et al*. (1996) as,

$$EF = \frac{\left(\sum_{i=1}^{n}(o_i - \bar{o})^2 - \sum_{i=1}^{n}(p_i - o_i)^2\right)}{\sum_{i=1}^{n}(o_i - \bar{o})^2} \qquad (19)$$

Where o_i = the observed values

p_i = the predicted values

$\bar{o}$ = the mean of the observed values

n = the number of samples

Where the predicted values are identical to the observed values, the *EF* will achieve a maximum value of +1. If the value of *EF* is negative (less than 0), the prediction model values are less accurate than just using the mean of the observations as a predictive method (Loague and Green, 1991). The *EF* values for the different combinations of soil type and section of the racecourse ranged between -0.60 to -5.73. This means that the predicted values of mean going are less accurate for the prediction of mean going than using the mean of the actual (observed) going.

The *EF* results support the coefficient of determination (r^2), sample correlation coefficient (r) and significance of r (*F test*) findings that the predicted and actual mean going determinations do not have a significant relationship. All results for the various combinations of soil type and section of racecourse are presented in Table 6.4. However, the data presented in Table 6.3 would suggest that MEGPREM is likely to be more accurate than the validation process would imply, as the predictions of mean going for the days on which the Clerk of the Course measured the going are modelled more accurately. Unfortunately the clerk did not measure the going with a going-stick during the 2006 flat racing season at Newcastle, except the two previously mentioned occasions on the 20th and 26th September. Therefore the lack of going data available to validate the model was due to circumstances beyond the author's control. Additional data collected by the clerk and repetition of the validation process would determine conclusively whether or not the SWB mean going prediction model is valid, however there was not enough time available to carry out this additional work as part of this study.

Table 6.4
Results of validation tests for the SWB to predict the mean going for known soil types on the flat course at Newcastle Racecourse.

Section	*Soil type*	r^2	r	*F test*	*EF*
Chute	Clay loam	0.3776	0.6145	0.2701	-3.49
	Sandy clay loam	0.0903	0.3005	0.6233	-5.73
Straight	Sandy clay loam	0.5998	0.7745	0.1241	-0.60
Round	Sandy clay loam	0.1596	0.3995	0.5052	-2.56
	Sandy loam	0.0076	0.0873	0.8890	-1.60

6.4.2. Validation of the soil-water balance model as a generic going prediction model.

The determination of whether the SWB models to predict the mean going on the soil types found at Newcastle Racecourse could be transferred to other racecourses with the same soil types was carried out. The collection of weather, irrigation and going data for York Racecourse was conducted due to its similar soil types to those found at Newcastle Racecourse.

To verify the soil types at York Racecourse, soil samples were collected and analysed for particle size distribution (PSD) using the methods described in Section 4.2.1. The methodology to produce daily weather summaries, the SWB and a determination of the actual mean going was carried out in accordance with Section 6.3.2. The predictions of going were carried out using the equations developed in Section 6.3.4.3. The irrigation regime dictated whether or not the racecourse needed to be split into different sections, and the variation in soil texture around the courses influenced the waypoints used. The validation of the prediction model for York Racecourse was carried out in the same manner as the validation of the model for Newcastle Racecourse (Section 6.4.1).

6.4.2.1. Particle size distribution analysis.

The PSD analysis of the soil found at York Racecourse was carried out on 24 of the waypoints (Figure 6.19). The PSD showed that the soil types ranged from clay through to sand. Thirteen of the 24 waypoints had soil types that corresponded with the soil types at Newcastle Racecourse; eight sandy clay loam and five sandy loam. Table 6.5 lists the waypoints measured and the determination of the soil types within them. Full PSD analysis results for the 24 waypoints is given in Appendix 5.5.

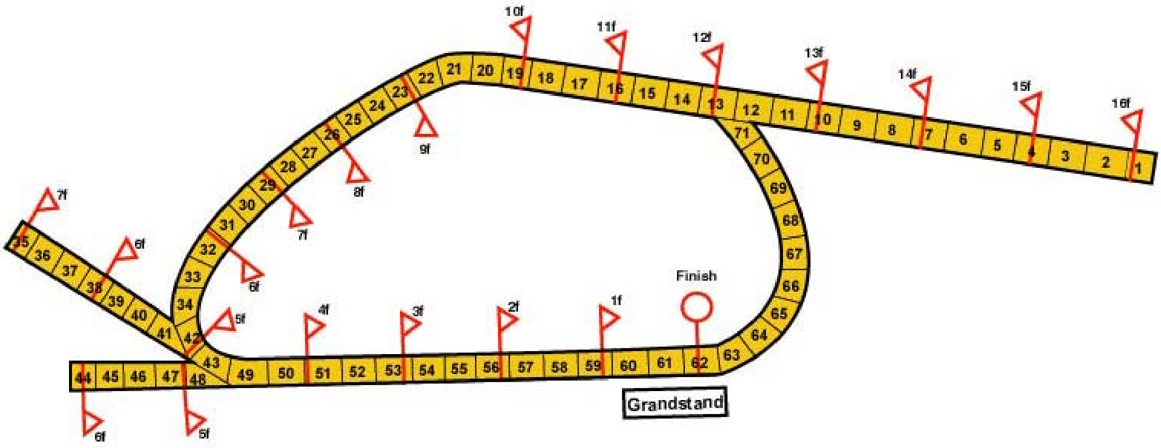


Figure 6.19: Waypoint map of York Racecourse © Turftrax.

Table 6.5.
Waypoints sampled at York Racecourse and the soil types within them (waypoints with soil types compatible with Newcastle Racecourse are highlighted).

Waypoint	***Soil Type***	***Waypoint***	***Soil Type***
3	Sandy clay loam	39	Loamy sand
6	Sand	42	Loamy sand
9	Sandy clay	45	Sandy clay loam
12	Sandy clay loam	48	Sandy loam
15	Sandy loam	51	Sandy clay loam
18	Sandy clay loam	54	Loamy sand
21	Sandy clay loam	57	Sandy loam
24	Sand	60	Sandy silt loam
27	Clay	63	Loamy sand
30	Sandy loam	66	Sandy silt loam
33	Sandy loam	69	Sandy clay loam
36	Loamy sand	71	Sandy clay loam

6.4.2.2. Irrigation and going data.

The irrigation and going data was collected by the Grounds Manager. Going was determined with a going-stick. The irrigation data was a combination of differing pop-up sprinkler and boom irrigator applications. Some days one method was used, other days both methods were used. Where irrigation using both methods took place, the depth of water applied by each method was combined to arrive at a daily total of water applied for each individual waypoint.

The depth of water applied was calculated automatically for the pop-up sprinklers by the computer controlling them, the depth of water applied by the boom irrigator was determined from the forward speed and nozzle jet sizes fitted to the boom. Therefore the determinations of the depth of water applied by both methods are theoretical. The determinations do not take into account any occurrence of spray drift caused by strong winds, non-target specific applications due to poor alignment of the pop-up sprinklers, the wrong selection of forward speed for the boom irrigator, blocked nozzles, or a general drop in water pressure that would reduce the flow rates of both methods. However, in the absence of any other method to measure the depth of water applied, the theoretical values give a useful indication of the amounts of water applied.

As a consequence of the dual application methods, not all waypoints had the same amount of water applied to them. Therefore no two waypoints received the same total amount of water (Appendix 5.6 details all water applications at York Racecourse during 2006). As a result the waypoints had to be assessed individually, unlike Newcastle Racecourse where irrigation data was, for example, 10 mm applied to waypoints 4-35, which enabled several waypoints with the same soil type to be clustered together for analysis. Therefore instead of analysing each individual waypoint only two of the available waypoints, for each soil type representative of Newcastle Racecourse, were analysed to determine whether the SWB mean going prediction model for Newcastle Racecourse could be used as a generic model. The waypoints were selected at random and waypoints 18 and 51 for sandy clay loam and 30 and 57 for sandy loam were chosen.

6.4.2.3. Rootzone deficit.

The Rzone def was initiated on the 1st January 2006 and was assumed to have reached equilibrium prior to the first measured going on the 5th May 2006, based on the results of the sensitivity analysis of the Rzone def (see Section 6.3.4.1). An example of the

Rzone def and measured going is given in Figure 6.20. The Rzone def and corresponding going for all four waypoints are given in Appendix 5.6.

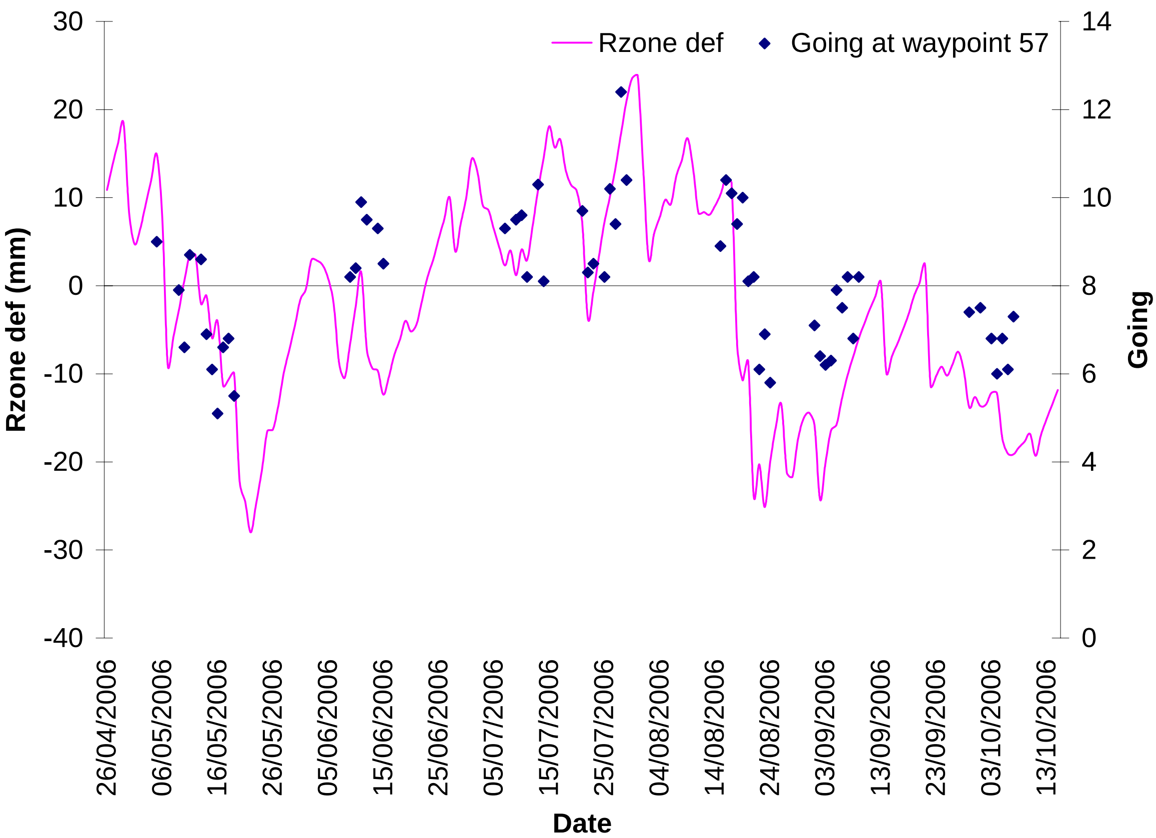


Figure 6.20: Rzone def and going for waypoint 57 at York Racecourse during the 2006 flat racing season.

6.4.2.4. Linear regression analysis (r^2).

Going at each waypoint was measured on 57 occasions in 2006. Predictions of going corresponding to the dates going was measured were produced for the four selected waypoints. All predicted and observed going values for the selected waypoints are given in Appendix 5.6. Linear regression analysis for the four waypoints produced r^2 values ranging between 0.0010 and 0.4556. These results suggest that a strong relationship does not exist between the observed and predicted values of going for the four waypoints, with the possible exception of the 0.4556 value (waypoint 57). Figure 6.21 (overleaf) shows an example of the linear regression analyses. All r^2 values are presented in Table 6.6.

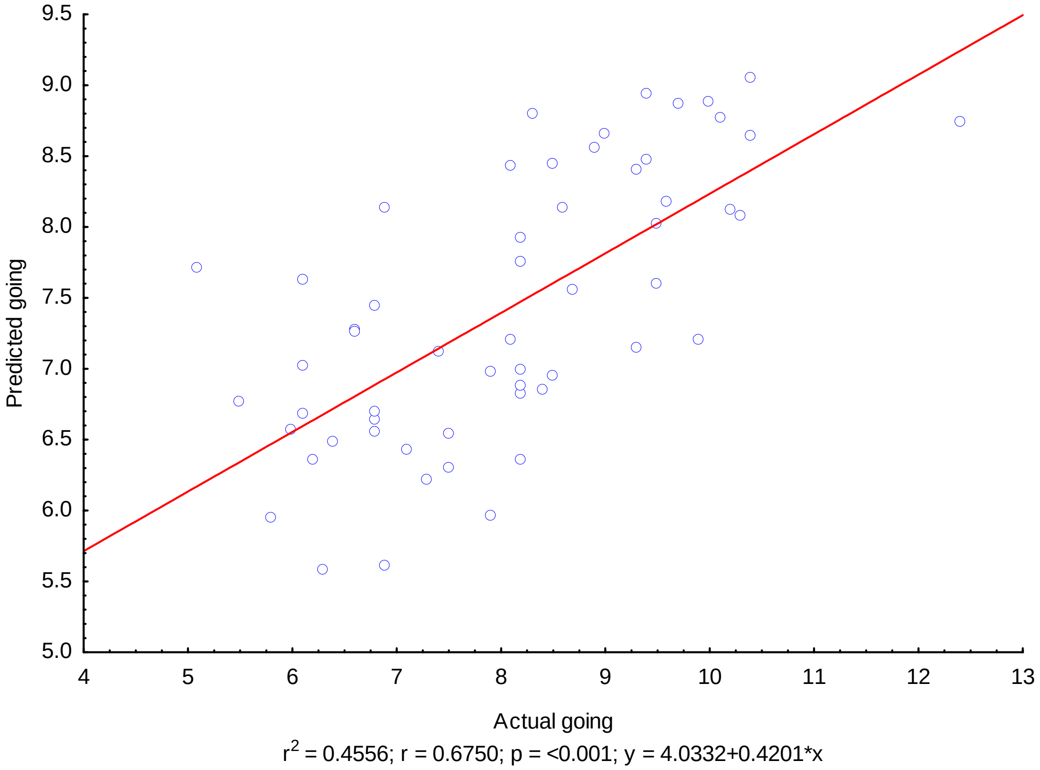


Figure 6.21: Linear regression analysis to determine the relationship between the predicted and observed going values for waypoint 57 at York Racecourse.

6.4.2.5. Sample correlation coefficient (r).

Waypoint 30 (sandy loam) had an *r* value of -0.03. This indicates that there was no correlation between the predicted and observed values of going for that waypoint. The remaining three waypoints had *r* values of 0.25, 0.48 and 0.68 for waypoints 18, 51 and 57 respectively. These values show that the predicted values of going for these waypoints have a low to good association with their equivalent observed values. However, only Waypoints 51 and 57 had significant values of *r* (F pr <0.05). See Table 6.6 for all *r* values.

6.4.2.6. Modelling efficiency (EF).

Waypoints 18 and 30 had negative *EF* values (-0.04 and -0.59 respectively). This suggests that the mean of the observed going would provide a more accurate prediction of the going at these waypoints than the predicted values themselves. Waypoints 51 and 57 however had *EF* values of 0.02 and 0.27 respectively. These results suggest that the predicted values give a more accurate prediction of going than the mean of the observed going for those waypoints. Although the value of 0.02 for Waypoint 51 is negligible as it is only just a positive number. The value of 0.27 for Waypoint 57 is more acceptable. The *EF* values for all four waypoints are presented in Table 6.6.

Table 6.6
Results of validation tests for the SWB to predict the mean going for known soil types on the flat course at Newcastle Racecourse.

Soil type[1]	*Waypoint*	r^2	*r*	*F test*	*EF*
SCL	18	0.0649	0.2548	0.0558	-0.04
SCL	51	0.2299	0.4795	0.0002	0.02
SL	30	0.0010	-0.0321	0.8125	-0.59
SL	57	0.4556	0.6750	<0.001	0.27

[1] *SCL = sandy clay loam; SL = sandy loam*

The *EF* values support the findings of the coefficient of determination (r^2), sample correlation coefficient (r) and significance of r (*F test*) whereby better results were obtained with the model predictions for Waypoint 57. Waypoint 51 also achieved good results; Waypoints 18 and 30 did not. These results suggest that the use of the SWB model to predict the going at Newcastle Racecourse cannot be used as a generic model for racecourses with the same soil types. Although in some cases (Waypoint 57) good estimates of going can be achieved.

6.5. The Use of MEGPREM to Determine the Amount of Irrigation Required to Change Going.

The equation for the SWB model to predict the mean going for a known soil type is Y = 8.4263 + 0.1 x X (Equation 17) for the sandy clay loam on the round section of the flat course at Newcastle Racecourse, shown in Figure 6.22. The amount of irrigation applied to change going by one index point could be considered equal to a change in the Rzone def of the same amount

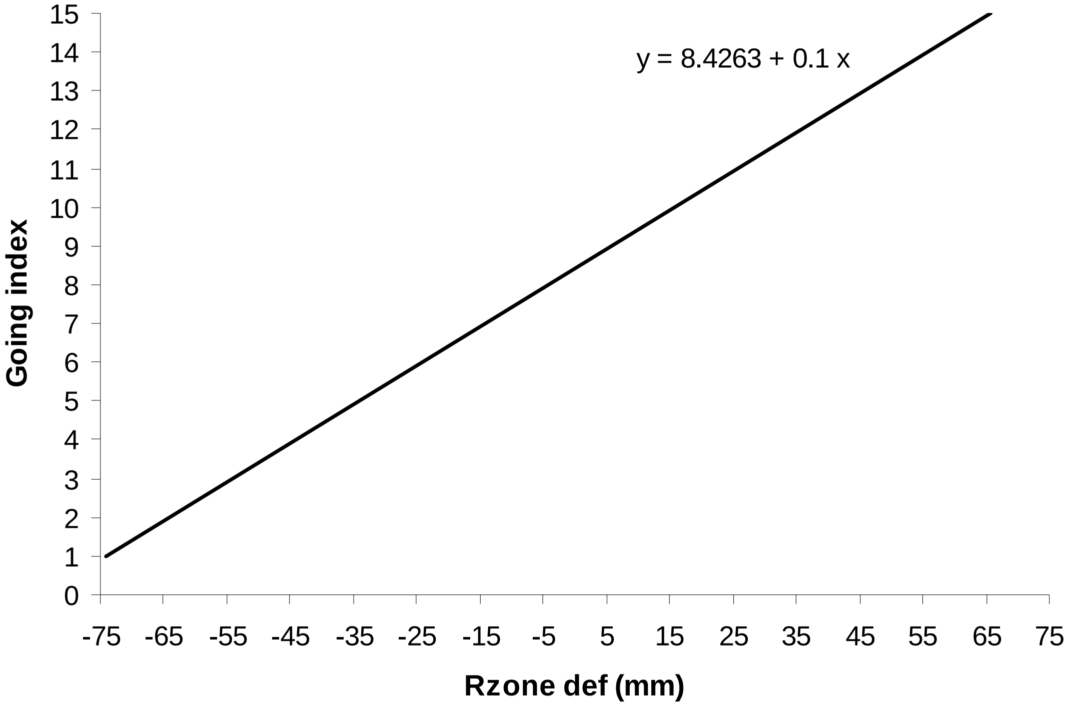


Figure 6.22: Straight line for the SWB model to predict the mean going for the sandy clay loam soil on the round section of the flat course at Newcastle Racecourse.

Hence $R_I - R_F = I$ (20)

Where R_I = root zone deficit at the initial going (mm)

R_F = root zone deficit at the final (desired) going (mm)

I = amount of irrigation required to change going (mm)

Rewriting Equation 19 at initial and final going gives

G_I = (8.4263 + 0.1 x R_I) (21)

G_F = (8.4263 + 0.1 x R_F) (22)

Subtracting Equation (22) from Equation (21) gives

$$G_I - G_F = 0.1\ (R_I - R_F) \tag{23}$$

Substituting from Equation (20) gives

$$G_I - G_F = 0.1 \text{ x } I \tag{24}$$

The amount of irrigation required to change the going index by one point can be calculated as: (using Equation 19)

$$1 = 0.1 \text{ x } I \tag{25}$$

Hence $I = 10$ mm

Equation (25) shows that to change the going by one index point requires 10 mm of irrigation water, using the SWB mean going prediction model (Figure 6.22). When the change in going required is greater than one index point, the model would imply that for each additional index point a further 10 mm of irrigation water is required. However, it is unlikely that the same rate of change in going for a given amount of irrigation water can be achieved when the initial going is at either a low soil plastic state, or a high soil plastic state.

Water applied to a soil with a high plasticity index value (a relatively high water content) will begin to weaken the soil due to the soil pores filling with water which, acting like a lubricant, reduces inter-particle contact as the soil approaches the liquid limit, this decreases the friction generated by the contacting particles and as a result diminishes shear resistance. Conversely water applied to certain soils such as poorly aggregated sands with an extremely low soil-water content can improve the contact between soil particles as it attracts the soil particles to each other and therefore increases the friction and inter-locking between particles, leading to an increase in shear strength. Therefore the initial soil-water content has a large influence on the change in soil strength that an input of 10 mm of water would bring about, it cannot be assumed that the amount of irrigation water required to change going is equal to the change in the Rzone def for the corresponding levels of going (initial and final). This suggests that MEGPREM is inappropriate for the determination of the amount of irrigation water required to bring about specific changes to the level of going, and that an alternative model is required.

6.6. Discussion.

There are a number of potential sources of variation in the data used to develop the rainfall balance and MEGPREM models. The sources relate to the method of determination of going, the environmental conditions at Newcastle Racecourse and the SWB itself.

6.6.1. Determination of going.

The measurement of going with the going-stick produces a final value based on a mean value of three measurements of soil penetration and translational shear resistance. A going determination is conducted at each waypoint to arrive at a value of going for that waypoint. However it is extremely unlikely that the locations within the waypoint are the same for each subsequent determination of going. If all going determinations were carried out at the exact same location, the destructive nature of the going-stick method (see Plate 5.2) would alter the soil structure and affect future readings. Therefore natural soil variability will be reflected in going-stick readings, adding variability to the overall model results, but reflecting more accurately the real conditions on the racecourse.

The going data provided does not state whether the determination of going was conducted before or after rainfall or irrigation events. It is likely that the values are a mixture of both, as the Clerk of the Course would measure the going to know if irrigation was necessary, and then measure the going after the application of water to see if the surface had reached the desired level of going. This does, however, make the going measurements recorded difficult to tie in with specific SWB values.

The soil collected for the identification of the predominant soil type in a given waypoint was collected in the manner described previously (Section 4.2.1), but owing to the inherent variability of soil, it is possible that the predominant soil type within a waypoint is different to the results obtained from this sampling exercise. Therefore the going value used may not be specific just to one soil with the texture described but may possibly cover soils with a range of soils textural classifications depending on the distribution of those soils and the locations at which going was determined.

The rooting depth of the turfgrass has been shown to differ throughout the year (Section 6.3.2.3). It is likely that root density will also change throughout the year. In addition, recently repaired areas of the track will have juvenile grass plants, compared to less disturbed areas that will have more mature, established, grass plants. These turfgrass factors are likely to affect the shear strength properties of the soil, which is measured in the determination of going using the Going Stick.

Cultural practices on the racecourse tend to favour deep aeration with a verti-drain type machine to relieve compaction prior to, during and at the end of the race season. This results in the ground having a variable volume of macro-pores, which aids drainage and encourages root growth. Therefore the soil structure at the beginning of the race season can be quite open and free-draining, without a high level of compaction, resulting in the penetration and shear resistance values measured by the going-stick being potentially lower for a given SWB, than they would be toward the end of the race season.

The values of going measured at Newcastle do not have a wide spread, (ranging between 2.3 to 10.78), although these values were the exception rather than the norm, and the maximum and minimum value varied between soil types. This is due to the fact that the Clerk of the Course does not allow the ground conditions to dry to such an extent that hard ground conditions would occur. Additionally, the flat season occurs during the summer, and in the absence of high rainfall the surface rating rarely gets as low as heavy going. Therefore the values of going measured at Newcastle Racecourse do not express the whole range of going levels that might be found on other racecourses.

6.6.2. Environmental factors.

Due to the large area of land that Newcastle Racecourse occupies, the localised environmental conditions can vary around the length of the track. The audit of Newcastle Racecourse (Section 4.3.) identified three predominant soil types at various points around the racecourse, demonstrating that variability in soil type – as described in Section 2.3.2. – does occur. This results in a range of different moisture holding capacities, and therefore different soil strengths occurring round the racecourse, leading to inconsistent going. However Newcastle, like Catterick Racecourse (Section 4.3.1), is comprised of soils with a relatively consistent soil textural classification compared to the other racecourses audited.

It is assumed that the irrigation data provided is accurate, although the degree of accuracy in the determination of the amount of irrigation applied may be poor. The Clerk of the Course measured the water applied by placing simple rain gauges on the ground at either end of a travelling boom irrigator to collect the irrigation and determine the depth of water applied in millimetres (mm). This method only gives a determination of the amount of water being applied towards either end of the irrigator, and does not measure the rate of application at the centre of the boom.

The forward travelling speed of the irrigator is regulated by a tractor that tows the boom. The forward speed of the tractor, and therefore the boom, is dependent on the tractor driver and the correct gear selection for a desired rate of application. Incorrect gear selection will have an effect on the amount of water applied.

It is assumed that the water pressure, and therefore delivery rate of the water, is consistent around the length of the racecourse. Differences in water pressure will also affect the rate of water applied to the surface. Additionally, the irrigation data does not state whether water was applied in the morning or afternoon, therefore the time-step in changes to the soil properties are difficult to determine.

Rainfall data is collected from a single weather station, located towards the North-west of the racecourse. It is assumed that the rainfall recorded at the weather station is representative of rainfall over the entire racecourse. However, given the large area that the racecourse covers, it is possible that recorded rainfall has not fallen on all parts of the racecourse, or that rainfall has fallen on areas of the racecourse where the recording of rainfall is not carried out.

Reference crop evapotranspiration (*ET_o*) was used to determine the combined moisture losses for evaporation from the soil and transpiration of the grass plant. This was due to the turfgrass sward closely matching the description of the reference crop (Section 2.3.5.1). It is possible that changes in the rate of evapotranspiration for the crop (*ET_c*) occurred around the racecourse due to minor changes in the localised environmental conditions, such as lower light levels due to shade at various locations. It is unlikely that any changes had a significant effect on the rate of *ET_c*; therefore it was assumed that *ET_c* was constant and equal to *ET_o* around the racecourse. However, the sward composition was a mixture of Perennial Rye Grass interspaced with undesirable weed grasses, particularly Annual Meadow Grass (see Appendix 2.5). It is likely that individual grass species have different rates of water loss through transpiration, owing to their unique anatomical, morphological and physiological development. Therefore the *ET_c* per unit area could be dependent on the predominant grass species, and therefore could be different for locations where changes in the predominant species occur.

High wear areas, such as bends where concentrated wear can cause surface destruction and reduced grass cover will cause changes in the rate of water loss through *ET* per unit area. However the practise of moving the rails on bends to spread the wear ensured that good grass cover was maintained (see Section 4.4.4), therefore adjustments to the *ET_o* were not made.

The collection of root length data showed that the mean root depth varied during the year, which was taken into account with the WaSim program. However, the rooting depth for individual grass species was not determined. It is possible that the mean rooting depth per unit area is dependent on the predominant grass species – *Poa annua* is renowned as a shallow rooting turfgrass (Aldous and Chivers, 2002) – therefore the assumed amount of water available to the predominant grass plants in a given area could be incorrect. Although given the number of replicates used to determine the mean rooting depth, and the low standard error associated with the these results (Appendix 5.7), it is unlikely that any differences in rooting depth for different grass species in a given area will have a significant effect on soil strength.

The initial conditions at the start of the WaSim SWB model were assumed to be at field capacity. As there was no weather data prior to 19th April 2004 available for the site, it is possible that the initial conditions were either drier or wetter than field capacity. However the determination of the point at which to select data for analysis (Section 6.3.4.1) showed that the SWB reached equilibrium regardless of the initial conditions. Therefore the SWB can be assumed to be reasonable for the date (18th June 2004) at which correlation between mean going and the Rzone def began.

6.6.3. The MEGPREM model.

The relationships between recorded going and the Rzone def in a wetting or drying cycle was analysed (Section 6.3.4.2) to determine whether or not significant differences between the two cycles existed. No significant differences were found however, and therefore the wetting and drying cycle data were combined to create a larger dataset for the Rzone def component.

The different irrigation regimes on the three sections of the flat course are due in part to time management and other factors such as changes in the topography, orientation, levels of wear and localised environmental conditions. As a result, owing to the combinations of soil types and irrigation regimes, five prediction models were produced. This not only reflects the variability in soil type around the flat course, but the need to manage distinct sections of the racecourse differently.

Linear regression analysis revealed that the five models achieved coefficient of determination values (r^2) between 27 to 51%. Considering the size of each section of the flat racecourse and therefore the potential variability of the soil type in the waypoints tested, the r^2 values are reasonable. The linear regression analysis provided the equations on which the MEGPREM models are based.

6.6.4. Validation of MEGPREM.

WaSim is a published SWB method (HR Wallingford and Cranfield University, 2002), yet there are no published papers that examine its validity or accuracy. The validity and accuracy of the WaSim model needs to be established as any errors in WaSim will be inherited by any subsequent model built on it. However Hess (pers. comm.) argues that it is impossible to say how accurate a model such as WaSim is, stating that in one situation it may give good results, but in another it may behave very poorly. Bearing this in mind, the WaSim model enables the generation of a SWB for large datasets of historical data, so that a Rzone def for several consecutive years can be established. This was important in the case of Newcastle Racecourse which required the generation of a Rzone def for three consecutive years; with years one and two being used to build the model and year three to validate the model.

The dataset of going observations available to validate the SWB model was small. A larger dataset would have been preferable to minimize the influence any unusual data may have had on the outcomes of the validation process. The data was collected from the flat course at Newcastle Racecourse towards the end of the flat racing season; therefore the surface had undergone virtually a full season of racing along with the associated wear before any measurements were taken. Despite this, the racecourse had very good grass cover at the time of sampling.

A large number of juvenile grass plants establishing in repaired divots was apparent as a result of the management practices used to repair the wear caused by racing. Owing to the sandy nature of the rootzone used to repair the divots some measurements of going were lower than expected. This could be because the sandy rootzone is inherently weaker than the natural soil due to the differences in the strength characteristics of the soil materials, resulting in the sandy rootzone being less cohesive than clay, which could contribute to a lower shear strength in the rootzone material. Additionally, the juvenile grass plants were unlikely to have established a good root system. An established root system would reinforce the rootzone and therefore improve its shear strength properties, leading to a higher measurement of going.

Theoretically there would be less surface damage/wear at the beginning of the flat racing season and therefore less likelihood of the going measurements being influenced by repaired divots. Therefore validation data collected throughout 2006 would not only have increased the size of the dataset to validate MEGPREM it may also have minimized the influence of any excessively high or low going values on the outcome of the validation process. Although repaired divots with juvenile/semi-mature grass plants give, on average, a lower measurement of going and could be referred to as rogue readings, they [the divoted areas] are representative of the surface that the horses run on and therefore going values taken from such areas should not be considered as errors or rogue readings, even though such readings may occur as outliers in the dataset.

The time of day that the measurements were taken by the author and the Clerk of the Course may have been different and could partly explain why the measurements recorded by the author were not as close to the predicted values of going as the Clerks measurements of going. The author recorded measurements of going in early to mid morning. The time the Clerk measured the going could not be verified, nor could it be ascertained which of the Clerks measurements of going were taken before or after a rainfall/irrigation event, as the Clerk stated that he carried out going measurements both to determine if irrigation was necessary and to determine the change in going after an irrigation/rainfall event.

However the time lag indicated by the model results (Section 6.3.4.3) seems to suggest that an irrigation or rainfall event will only influence going after a certain period of time had elapsed between the addition of water and the measurement of going itself. On this basis, and not knowing which measurements of going recorded by the Clerk were taken before or after irrigation/rainfall, then the evident time lag in the relationship between the Rzone def and going could be explained. If going is measured on day_i and then an irrigation/rainfall event occurs later that day, the Rzone def at the end of day_i will be lower than expected for the going measured and as a result the following day (day_{ii}) the going is likely to be lower. If there is no irrigation/rainfall on day_{ii} the Rzone def at the end of day_{ii} would have increased (relatively due to losses through *ET*) even though it would appear that the going has decreased in comparison to the previous day.

The WaSim program calculates the Rzone def on a daily basis, midnight to midnight. If the determination of the Rzone def was synchronised with the measurement of going, (i.e the Rzone def and going were determined at 08:00 hours), the Rzone def would bear more relation to the measurement of going. Any irrigation or rainfall event later in the day would then be accounted for in the following day's measurement of going, and would also be included in the Rzone def for that period.

It is likely that the reason for the large differences between the author and the Clerks measured going values and the predicted values of going is due to a combination of errors in the model itself and the differences in sampling method between the author and the Clerk. Because the author chose points at random within the waypoint, it is probable that areas unlikely to be raced on were included in the assessment. In addition, sampling in a wider area inevitably increases the likelihood of a wider range of soil conditions being encountered and incorporated into the measurements. The Clerk, however, consistently measured going at the same locations within a given waypoint and therefore a much narrower range of soil conditions and patterns of wear were likely to be included in any measurements.

When the Clerk's measurements of going are compared with the prediction of going in isolation, the going values measured by the Clerk are very close to the predicted measurements of mean going. This suggests that there is a need for consistency in the method and approach used to collect the data to both construct and validate the SWB mean going prediction model. Using only the values of going obtained by the Clerk, it is possible that the validation results indicate that the SWB mean going prediction model may be more reliable than the validation exercise initially suggests. Obtaining further data from the Clerk would allow a more thorough validation exercise to be undertaken.

6.6.5. Validation of MEGPREM for Newcastle Racecourse as a generic model to predict the mean going at racecourses with the same soil types.

Given the indication that the SWB model developed to predict the mean going at Newcastle Racecourse may be valid when only the Clerks going assessments are used (Section 6.6.4), the determination of whether or not the SWB models could be used as a generic model on racecourses with the same soil types was carried out. York

Racecourse was used for this exercise as it was known that all the relevant data (weather, going and irrigation) to perform the analyses was available at that racecourse. Data pertaining to the 2006 flat racing season was used. Going was measured on 57 occasions by the Head Groundsman during 2006 providing a large dataset.

The values of the depth of water applied supplied by the Head Groundsman could be criticized, as they were theoretical depths. The values were generated by the computer control system for the pop-up sprinklers, and calculated from the forward speed and nozzle sizes of the boom irrigator. It is possible that the accuracy of the values is erroneous as not all of the water may have reached its intended target due to drift, wrongly aligned sprinkler heads, incorrect selection of forward speed or nozzle size (boom irrigator), or a reduction in water supply through pressure drops in the irrigation system caused by leaks or worn pumps. Determining the depth of water applied with catch-cans (see Section 7.1.2) would have given more accurate values. Despite this, the theoretical values still provide a useful indication of the amounts of water applied.

The two different methods of water application meant that individual waypoints had to be assessed because no two waypoints received the same amount of water on any given day which could affect their respective Rzone def to some degree. This differs from the analysis of multiple waypoints at Newcastle Racecourse, as the irrigation regime at Newcastle Racecourse was not as precise for individual waypoints. Analysis of individual waypoints was not difficult to carry out for this validation process as only two randomly selected waypoints per soil type were tested. Should the whole of York Racecourse have been modelled, however, up to 71 individual waypoints would have needed to be assessed, adding another layer of complexity to the prediction process. Any predictions derived from such an approach would be specific to individual waypoints, as opposed to a mean value generated from several waypoints which was the case for Newcastle Racecourse. Therefore predictions of separate waypoints would arguably be more useful, enabling more precise management of the individual parcels of land occupied by each waypoint.

Waypoints 51 (sandy clay loam) and 57 (sandy loam) consistently achieved the best results in all validation analyses. These two waypoints are situated on the home straight adjacent to the grandstand (see Figure 6.18.) and are therefore subjected to wear at every race meeting. The other waypoints tested (18 and 30) do not necessarily receive wear at every race meeting, as the sections of track used are generally dictated by the length of the races being held. The equations used for the prediction of going were derived from the model developed at Newcastle Racecourse, which has a busy racing schedule. This means most of the waypoints are raced on at regular intervals. This could explain why Waypoints 51 and 57 achieved better predictions, as they receive a similar amount of wear and may, as a result, be a closer reflection of those assessed at Newcastle.

Overall, but with the exception of Waypoint 57, modelling efficiency analysis (*EF*) of the waypoints chosen suggests that the model is a poor predictor of going at York Racecourse. Therefore it is unlikely that the Newcastle Racecourse MEGPREM could be used as a generic model for other racecourses with the same soil types. It is more probable that SWB models – developed using the methodologies described in Section 6.3. – which are unique to individual racecourses will achieve better results. This is because although two racecourses may have the same soil types, the differences in land management practices, topography, orientation and/or racing schedule are likely to be such that a generic model is unable to take these into account effectively.

6.6.6. MEGPREM as a method to determine irrigation requirements to change going.

MEGPREM implies that the average amount of water required to reduce a measured level of going by one point of the going-stick going index is 10 mm and that for each additional index point another 10 mm on average is required (Section 6.5). It is unlikely that increments of 10 mm will bring about set changes in going due to the influence water has on soil strength. In some very dry, particulate type soils such as sands, the addition of water may increase soil strength initially, up to a threshold point, by improving soil cohesion, due to surface tension effects in the soil water which improves the contact between soil particles. Beyond such a threshold point, which will differ between soil types, any additional water is most likely to weaken the soil due to the connecting soil particles being forced apart by the water that is attracted to their surfaces.

The rate of change in soil strength will be different for cohesive and non-cohesive soils due to the size and shape of their particles, which affects the ability of soil water to improve inter-particle contact. In addition, the initial soil-water potential will also affect the amount of water present in pores of a given size. This helps to determine whether the soil is in a brittle, lower plastic, upper plastic or liquid state. As the pores fill with water, air is driven out of the soil and as a consequence, at a threshold point, the soil becomes weaker. This eventually leads to the soil becoming fluid (liquid) and less able to compress under load. Therefore the soil texture and its initial soil strength characteristics will have a large influence on the subsequent changes to soil strength that the application of 10 mm of water would bring about.

The MEGPREM approach is more appropriate for the prediction of the mean going for a known soil type, but less so for the determination of the amount of irrigation water required to change a measured level of going. The determination of the amount of water required to change a measured level of going to a desired level requires the development of an alternative model dealing specifically with this element. Any such model should take into account the initial conditions on a racecourse prior to rainfall or watering.

6.7. Conclusions.

A SWB model to predict the mean going at Newcastle Racecourse was developed. The model validation process suggests that the model is not reliable. However the dataset used to validate the model was small. The model may be more effective than the validation analysis would initially suggest if the predictions of going are looked at on the basis of whether the Clerk of the Course provided the measurements or whether the author did. A larger dataset comprised of measurements by the Clerk only is required to determine whether this is true or not.

Use of the model as a generic model to predict the going on racecourses with the same soil types was shown to be invalid. The results suggested that models unique to individual racecourses developed using the methodology described in Section 6.3. would be needed if this approach is to be adopted.

The model does not provide an accurate determination of the amount of water required to change a measured level of going. This is because it does not take into account the initial soil conditions. Therefore a model that takes into account initial soil conditions in the determination of the amount of water required needs to be developed. This will be discussed in Chapter Seven.

Overall the SWB modelling approach has provided a reasonable basis for the prediction of going which, with further development, will potentially provide the racecourse manager with a positive useful tool. The SWB approach has also informed additional research into the development of a model that determines how much water is required to change a measured level of going to a desired level. This will be discussed in the following chapter.

7.0. A MODEL TO DETERMINE THE IRRIGATION REQUIREMENTS TO REDUCE MEASURED GOING TO A SPECIFIED LEVEL.

The ability to predict the going based on a SWB (Section 6.4) is a useful tool for the manager of a racecourse. Where the prediction of going meets the standard required for a satisfactory racing surface (good-to-firm for flat racing), the manager will endeavour to keep that level of going by maintaining the desired Rzone def prior to a race meeting through supplemental irrigation – when necessary – to replace water lost to ET_o. Where the prediction of going is greater than the level required, the manager will usually apply water to allow the soil to reach a plastic state, therefore reducing the hardness of the surface. However this can potentially result in over-watering, leading to a surface that is too soft for racing.

The correct amounts of water required to change a hard surface to a surface conducive to racing need to be established, as at present determinations are generally based on the tacit knowledge of the manager, which may or may not be effective depending on the knowledge and experience of the person in question. A model that determines the amount of water required to alter a given soil type, from hard going to a desired level of going, would establish more accurate application rates for the irrigation required, aiding managers – both experienced and inexperienced – in their decision making processes with regards to water applications to achieve consistent going around the length of a racecourse. More accurate application rates would minimize unnecessary over-watering, in accordance with the directives of the Water Act 2003. The correct determination of the amount of water required will also potentially reduce water consumption, which will enhance the future retention of any water abstraction license, moreover the associated costs for potable mains water usage would be reduced too.

This chapter describes the development of an empirical model to determine the amount of effective irrigation required to reduce the going on a given soil type to a desired level. The model deals with only the irrigation aspect of influencing going, not the strength characteristics of the soil. A flow diagram of the processes involved to produce the model is given in Figure 7.1. This work relates to Objective Two.

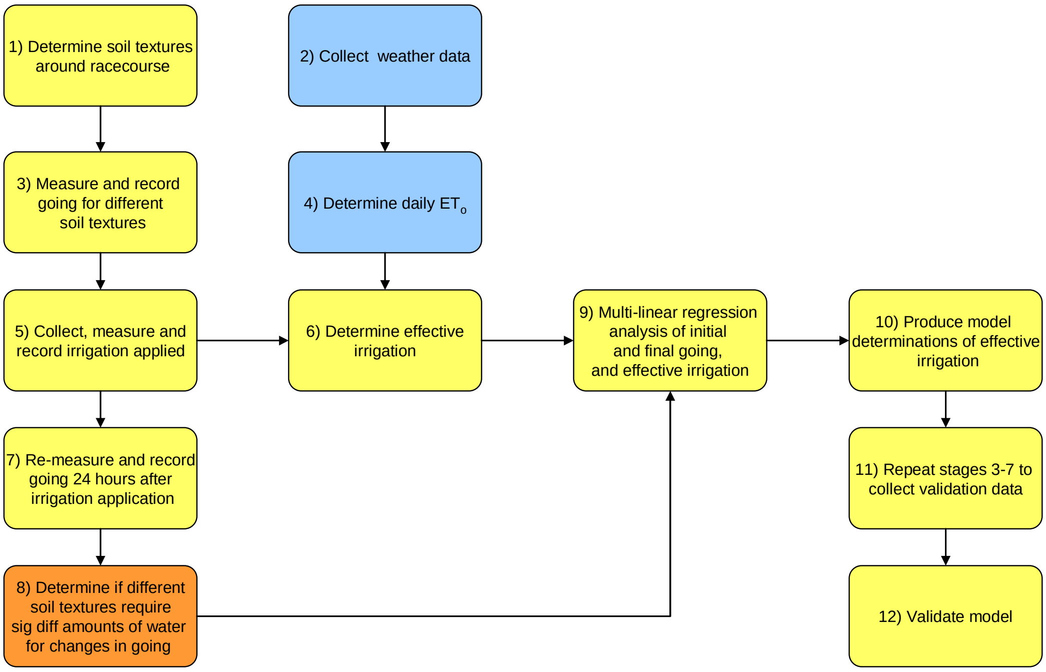


Figure 7.1: Flow diagram of processes to produce the irrigation determination model

7.1. Methodology.

Going values and water applications were measured and recorded at Leicester Racecourse to enable the determination of the change in going produced for a known amount of water applied.

7.1.1. Determination of going.

All measurements of going were conducted on the flat course at Leicester Racecourse using the going-stick method, as described in Section 5.0. Going data to develop the model was measured and recorded for the soil types identified in Section 4.3.1. during the period 16th August to 30th September 2005. Going data to validate the model was measured and recorded at the same locations during the period 21st June to 7th July 2006.

The going was determined at five points across the width of the flat course, at two metre and five metre intervals from the inner running rail on the round and straight sections of the flat course respectively, prior to a planned irrigation event. A five metre measurement spacing was used on the straight section as it is wider than the round section. This was followed by measuring the amount of irrigation water that was applied. The re-measurement of going, to determine the change in going for a known amount of applied water, was carried out 24 hours after the irrigation event to allow the applied water to achieve a uniform distribution through the soil profile. A second irrigation event was then measured and recorded, followed by going measurements taken after another 24 hour period had elapsed.

7.1.2. Collection of irrigation data.

Irrigation water was collected, measured and recorded close to the locations where going was determined. Catch-cans (195 mm dia x 188 mm h) were placed across the width of the flat course to intercept and collect the irrigation water. The catch-cans were spaced at the same intervals as the going measurements on the round and straight sections of track. The round section was irrigated with a combination of pop-up sprinklers and portable rain-gun sprinklers (Plate 7.1). The straight section was irrigated with a 25 metre wide travelling boom that almost spanned the entire width of the straight section (Plate 7.2).

The determination of the amount of water applied (depth in mm) consisted of the following calculation:

$$\text{Depth of water (mm)} = \frac{\text{Volume of water in catch-can (ltr)}}{\text{Surface area of catch-can (m}^2\text{)}} \qquad (26)$$

Plate 7.1: Catch-cans intercepting and collecting irrigation water from pop-ups on the round section of the flat course at Leicester Racecourse.

Plate 7.2: Catch-cans intercepting and collecting irrigation water from a travelling boom irrigator on the straight section of the flat course at Leicester Racecourse.

7.1.3. Determination of effective irrigation.

Soil water is lost to the atmosphere through the process of evapotranspiration (*ET*) (Section 2.3.5). In order to determine how much of the applied water was effective (was not lost to *ET*), the deduction of daily ET_o on the day that irrigation took place, was required. Actual evapotranspiration (ET_a) was assumed to be equal to ET_o (Section 6.1.3) and was calculated using weather station data from Leicester Racecourse and the methodology described in Section 6.1.2.

Where planned irrigation events did not take place due to forecast rainfall, the rainfall measured by the rain gauges on the weather station was assumed to be consistent over the entire racecourse, and was incorporated into the determination of the effective irrigation. The 'effective irrigation' was calculated using the following equation,

$$\textit{Effective irrigation}\ (\text{mm}) = (\textit{rainfall} + \textit{irrigation}) - ET_o \qquad (27)$$

Where

ET_o = reference crop evapotranspiration (mm)

7.1.4. Statistical analysis.

7.1.4.1. Going dataset.

The maximum value in the going-stick index range is 15.0. It is possible that readings of 15.0 are actually values beyond the maximum range of the index, such as 16.0, 17.0 or 18.0. This could not be determined however; therefore going-stick values of 15.0 were omitted from the going dataset prior to statistical analysis. This process reduced the total number of readings available for analysis, but made the dataset more reliable when determining the change in going.

7.1.4.2. Soil type.

To determine whether the changes in going for a given amount of effective irrigation were significantly different between the different soil textures, an analysis of covariance was conducted, with the effective irrigation as the dependant variable, and the initial and final going as the explanatory variables. The analysis was carried out with Statistica statistical software (StatSoft, Inc, 2004).

7.1.4.3. Effective irrigation.

Multiple linear regression was conducted with Statistica (StatSoft, Inc, 2004) to determine whether a relationship existed between the initial going (going A), final going (going B) and effective irrigation. Multiple linear regression was necessary, as the three variables required three dimensional modelling to best illustrate their interactions.

7.2. Results.

7.2.1. Collection of data.

7.2.1.1. Going data.

The locations where going measurements were taken were not the same each day, but they were conducted ±1 m of the previous day's measurement. This is due to the destructive effect of the going-stick when determining going (see Plate 5.2 in Section 5.0). Carrying out measurements on the exact same location would have given false readings of going, as the disturbed ground would have a loose, more open structure, which would yield dramatically lower values of going.

7.2.1.2. Irrigation water.

The amount of irrigation water collected with the catch-cans was consistent across the width of the straight section of the flat course, where water was applied with a boom irrigation system. However there were inconsistencies across the width of the round section of the flat course, where the pop-ups and portable rain-gun sprinklers are located behind the inner running rail. The catch-cans closest to the inner running rail tended to collect less water, as did the catch-cans furthest from the running rail. This can be explained to some degree by worn nozzles that are not producing the correct distribution of droplet sizes needed to ensure a uniform application of water over the area the sprinklers cover.

In addition, with the pop-ups and portable rain-gun sprinklers positioned behind the inner running rail, the sprinkler's jet of water becomes diffused by the uprights of the running rail as the sprinklers rotate through their 180° cycle (Plate 7.3). The diffused jet appeared, visually, to have smaller droplet sizes which tended to drift in the direction of the prevailing wind. The catch-cans at the furthest point from the running rail were at a distance just within the maximum reach of the sprinkler jet, and were also more prone to the effects of drift.

Plate 7.3: Diffused spray pattern of a pop-up sprinkler caused by the upright of the running rail.

7.2.2. Raw data.

All the raw data (minus going values of 15) were tabulated and merged together so that comparisons of the data pertaining to each soil type could be made (Table 7.1).

Table 7.1
Example of tabulated data showing the change in going for a given amount of effective irrigation on a sandy loam soil at location 'B' on the flat course at Leicester Racecourse.

Location	*Going A*	*Going B*	*Change in going*	*Effective irrigation (mm)*
B1	12.2	10.4	-1.8	13
B2	13.9	12.2	-1.7	13
B3	14.1	11.3	-2.8	13
B4	12.7	9.5	-3.2	13
B5	12.4	9.1	-3.3	13

The tabulated data showed that when forecast rainfall and planned irrigation did not occur (inputs of water = 0 mm), the deduction of ET_o resulted in the effective irrigation having a net deficit (rainfall + irrigation $<ET_o$). The reverse occurred when ET_o was less than the water inputs (rainfall + irrigation $>ET_o$). Overall the value of going decreased where the effective irrigation had a net surplus, and increased when the effective irrigation had a net deficit, as expected. However, some values of going increased when there was a net surplus, and decreased when there was a net deficit (Figure 7.2). This degree of variation was not expected, and could be attributable to sampling error, as referred to in Section 7.2.1.1, the poor distribution of irrigation water (Section 7.2.1.2), or the natural variation of the soil type within a confined area.

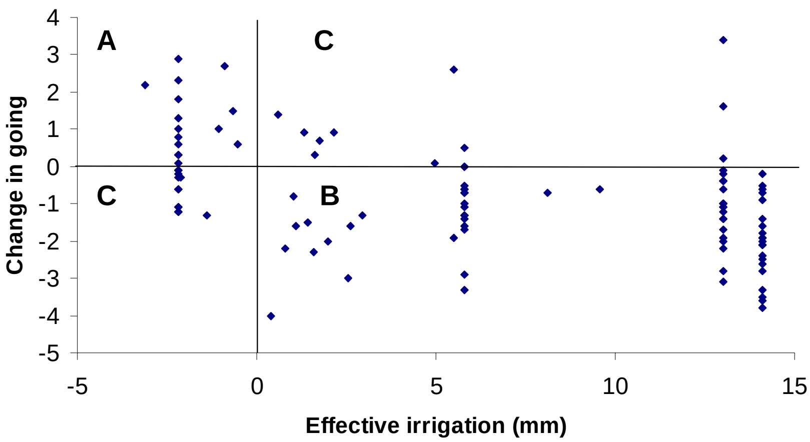


Figure 7.2: Changes in going for effective irrigation on a sandy clay loam where A) rainfall + irrigation $<ET_o$, B) rainfall + irrigation $>ET_o$, and C) random variation.

7.2.2.1. Accumulated effects of effective irrigation.

Irrigation applications typically resulted in a net surplus of irrigation applied, after the deduction of daily ET_o, although in some cases ET_o was greater than the amount of water applied. Usually the application of effective irrigation resulted in a reduction of going. Where irrigation and/or rainfall occurred on consecutive days, the change in going would continue, reflecting the accumulated water application (Figure 7.3).

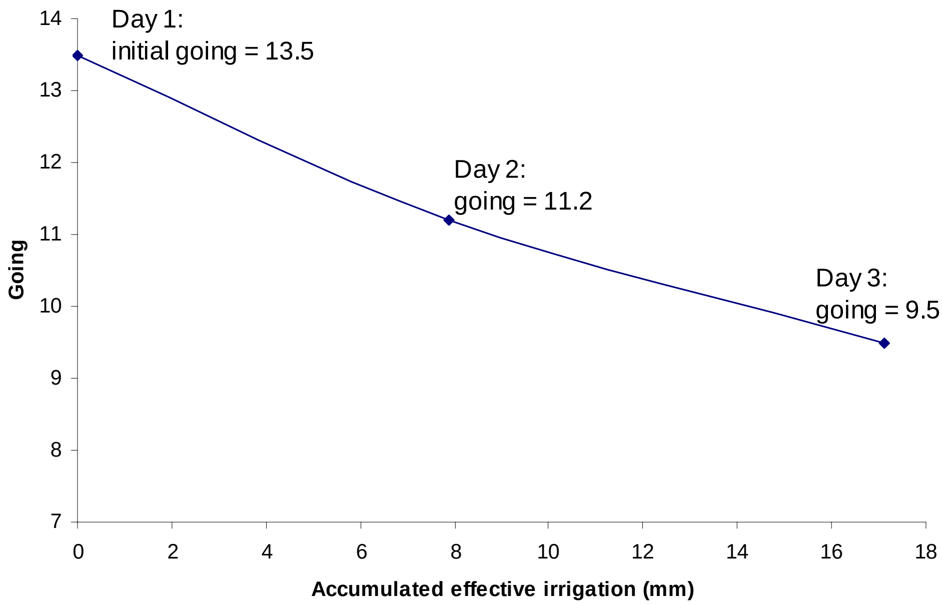


Figure 7.3: Example of the change in going in response to the accumulated effective irrigation over a three day period.

7.3. Analysis of Results.

7.3.1. Effect of soil type on changes in going for a given amount of effective irrigation.

Analysis of covariance showed that the mean initial and final going had a significant relationship (F pr <0.001 and 0.001 respectively) with effective irrigation. This was expected, as the value of going relates to soil strength, which requires inputs of water to change the soil from a hard state (initial going) to a plastic state (final going). Therefore the value of the initial and final going would dictate the amount of effective irrigation water required.

However, the analysis of covariance showed that soil type had no relationship (F pr 0.183) on the amount of effective irrigation needed to change going values, when allowing for the variation in the going before and after that irrigation. This is likely to do with the fact that although the soil types just fall within different textural classification, they are very similar (Figure 7.4). Although not significantly different, the results for the soil type do suggest that there may be the possibility of a trend for sandy loam soil to require more effective irrigation for a given change in going than a clay loam soil (Figure 7.5), and that sandy clay loam requires the least amount of effective irrigation for a given change in going, however there is not enough evidence to support a change in the model based on this observation.

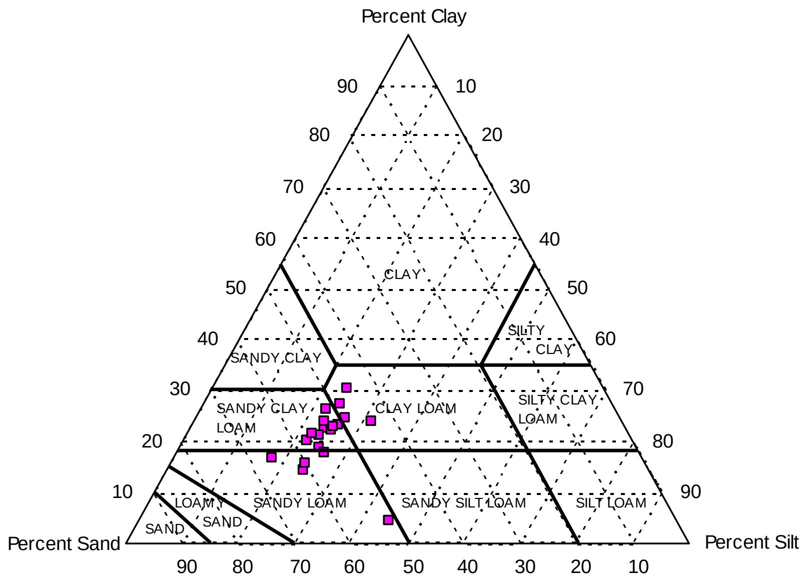


Figure 7.4: Soil textural triangle showing the variation between the soils found on the flat course at Leicester Racecourse.

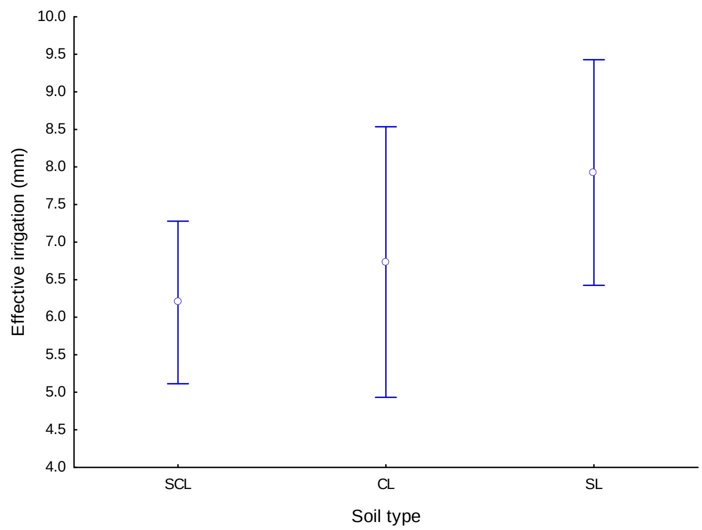


Figure 7.5: Means of effective irrigation for the different soil types with confidence interval at the 0.95 level (allowing for differences in going).

7.3.2. The development of a model to determine the amount of effective irrigation required to reduce going to a desired level.

The analysis of the interaction between soil type and effective irrigation suggested that there was no significant difference in the way different soil types change going class in response to irrigation. Therefore the data pertaining to each soil type was pooled to provide a larger dataset and enable the determination of the amount of effective irrigation required to change going from a known level to a desired level for all three soil types combined.

Multiple linear regression analysis indicated that a significant relationship existed (F pr <0.001) between the effective irrigation (dependant variable) and the initial and final going (explanatory variables). However, the coefficient of determination was low (r^2 = 0.25), which means that only 25% of the changes in going was explained by the applied effective irrigation. The equation to describe the regression of the effective irrigation is given as,

$$\textit{Effective irrigation} = B_1 + B_2 \text{ x } \textit{going A} - B_3 \text{ x } \textit{going B} \qquad (28)$$

Where

B_1	= intercept constant (18.34737)
B_2	= y-z plane constant (1.05839)
B_3	= x-z plane constant (2.20882)
Going A	= initial going
Going B	= final going

This equation provides a model to determine the amount of effective irrigation required to change a known level of going to a desired level of going, and is shown diagrammatically in Figure 7.6. However, the model requires the addition of an estimate of ET_o for the day that irrigation is to take place, as the model provides a value of effective irrigation; the amount of water required after any losses through ET_o. Estimates of daily ET_o for a given month can be ascertained from either published data for a specific area, or from local meteorological data providers.

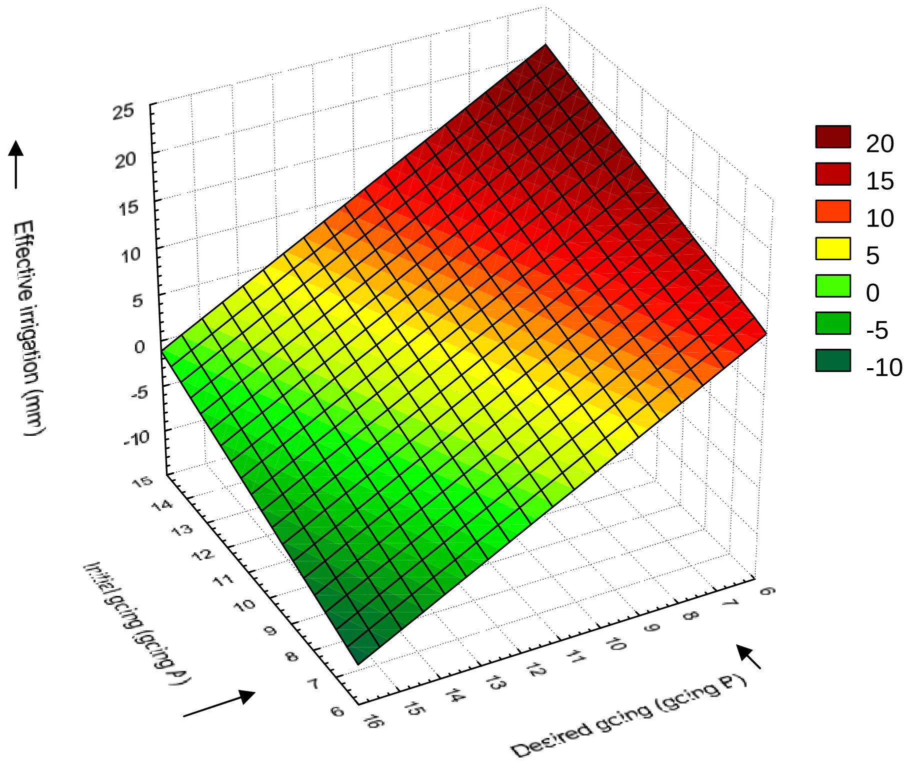


Figure 7.6: Three dimensional representation of the multiple regression model to determine the effective irrigation required to change going from a measured level to a desired level on sandy loam, sandy clay loam and clay loam soil types (Note: this figure is an illustration only, it is not intended to be used as a method to determine effective irrigation).

7.3.2.1. Determination of the confidence interval for the effective irrigation.

The confidence interval (C.I.) of the determination of effective irrigation was calculated to determine the minimum and maximum amounts of water required to attain a desired going-stick index. The equation to calculate the C.I. was a simplified version of Sokal and Rohlf (1995), and is shown in equation (29).

$$\text{C.I.} = \text{predicted } Z \pm t_{n-3} \times SE \qquad (29)$$

Where:

Z = predicted value at point (x, y)

t_{n-3} = student t value at n-3 degrees of freedom

SE = standard error of predicted Z value at point (x, y)

$$SE = s_z \sqrt{\left(\frac{1}{n} + c_{11}x^2 + c_{22}y^2 + c_{12}xy \right)} \quad (30)$$

Where:

Sz = standard deviation of Z values

n = number of observations in sample

x = initial going

y = desired going

c_{11} = Gaussian multiplier

c_{22} = Gaussian multiplier

c_{12} = Gaussian multiplier

Where: $$c_{11} = \frac{\sum x^2}{\left[\sum x^2 \sum y^2 - \left(\sum xy\right)^2\right]} \quad (31)$$

$$c_{22} = \frac{\sum y^2}{\left[\sum x^2 \sum y^2 - \left(\sum xy\right)^2\right]} \quad (32)$$

$$c_{12} = \frac{-\sum xy}{\left[\sum x^2 \sum y^2 - \left(\sum xy\right)^2\right]} \quad (33)$$

Examples of the predicted (determined effective irrigation) and observed (actual effective irrigation) rates are presented in Table 7.2. The predicted values are given with their associated confidence limits at the 95% level.

Table 7.2
Examples of actual effective irrigation and determined effective irrigation for each soil type (with confidence limits at the 95% level).

Soil type	*Initial going*	*Final going*	*Change in going*	*Actual effective irrigation (mm)*	*Determined effective irrigation (mm)*
Sandy loam	11.5	7	-4.5	13	15.06 ± 2.10
Sandy clay loam	12.7	12	-0.7	5.8	5.28 ± 1.05
Clay loam	12.8	11.8	-1	5.8	5.83 ± 1.04

7.3.3. Trends within the model.

Where the determination of irrigation requirement to maintain a set level of going is required, the equation for the model, described in Section 7.3.2, shows that less water is needed to retain harder going levels, for example 11.5, but more water is required to retain softer levels of going, for example 4.0. (Table 7.3). This can be explained by the fact that harder levels of going, and therefore greater soil strength, are achieved when the soil strength is increased due to a high matric potential in the soil, brought about by a drier soil water status, therefore only small inputs of water are required to maintain these drier conditions when *ET* is high compared to a wetter soil drying out in the same conditions.

Table 7.3
Examples of water requirements to preserve high and low levels of going.

Initial going (A)	*Final going (B)*	*Model equation*	*Determined effective irrigation (mm)*
11.5	11.5	$B_1 + B_2 \times going\ A - B_3 \times going\ B$	5.12
4.0	4.0	$B_1 + B_2 \times going\ A - B_3 \times going\ B$	13.75

Soils approaching the liquid end of the soil plasticity range contain a greater amount of water than the same soil in a plastic state. Greater amounts of water are required to retain a softer going level when the soil is approaching a liquid state (see Section 5.2.3) probably because some drainage is occurring. Alternatively the higher water inputs required could be because the water held in wetter soils is readily available, and therefore easier for the grass plant to access, resulting in the soil drying more quickly through *ET*. In a drier soil the grass plant has to work harder to obtain water, therefore the response to *ET* is slower, resulting in less water lost to the atmosphere.

7.4. Validation of the Model.

The validation of the water requirement model was carried out with an independent dataset of going and effective irrigation for the period 21st June to 7th July 2006. Some extreme outliers, due to the variations described in Section 7.2.2, were removed from the dataset. The edited dataset consisted of 233 observations. A determination of the amount of effective irrigation required for the changes in going in the dataset was carried out with the model detailed in Section 7.3.2.

Validation was carried out using linear regression analysis to determine whether a significant relationship exists between the predicted and observed effective irrigation values. Determinations of the sample correlation coefficient (r) and modelling efficiency (EF) were conducted using the methods described in Sections 6.4.1.2. and 6.4.1.3. to show the degree of association between the predicted and observed values, and whether or not the model to predict the amount of effective irrigation required was effective. Statistica statistical software (StatSoft, Inc, 2004) was used to conduct the linear regression and sample correlation coefficient analyses; a Microsoft Excel spreadsheet was used to calculate the modelling efficiency.

7.4.1. Linear regression analysis of the determination of effective irrigation model.

Linear regression analysis indicates that a significant relationship (F pr <0.001) existed between the predicted and measured effective irrigation rates (Figure 7.7). The coefficient of determination was low (r^2 = 0.26) indicating that 26% of the variation in the predicted effective irrigation can be explained by changes in the observed effective irrigation. The low value of r^2 was expected, as the coefficient of determination for the irrigation determination model – the interactions between the dependant and explanatory variables used to construct the model – was also low (r^2 = 0.25). It is unlikely that any predictions of effective irrigation would be significantly more accurate than the r^2 of the model.

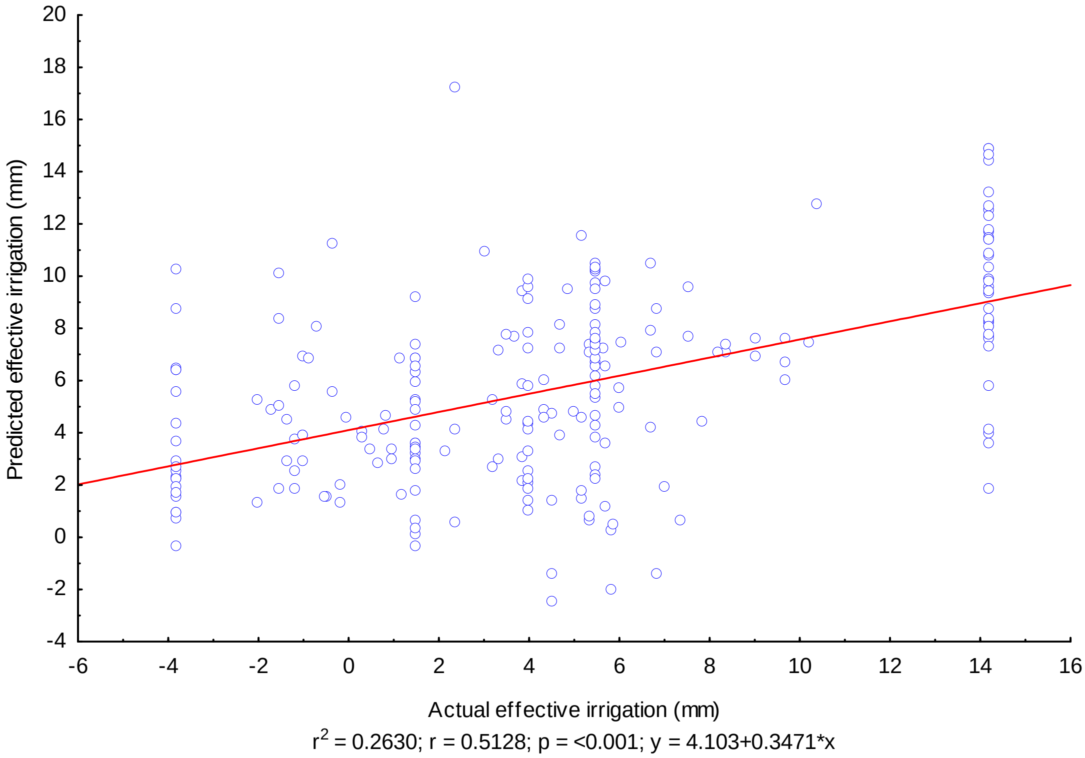


Figure 7.7: Linear regression analysis to show the relationship between the actual and predicted effective irrigation to reduce going to a desired level.

7.4.2. The sample correlation coefficient of the determination of effective irrigation model.

The sample correlation coefficient (r) was determined at the same time as the linear regression analysis, producing an r value of 0.51. This means that although the predicted values of effective irrigation do not have a perfect positive correlation with the observed values of effective irrigation, they show a reasonably good degree of association with the observed values. The significance of r was assessed using an F-test; r was significant (F pr <0.001).

7.4.3. Modelling efficiency of the determination of effective irrigation model.

The determination of effective irrigation requirements model achieved an *EF* value of 0.19, which means that the predicted values do not perfectly match the observed data. However the *EF* value (0.19) does indicate that a more accurate determination of the amount of effective irrigation required to reduce going to a desired level can be achieved with the model predictions, than would be using the mean of the observations.

7.5. Discussion of the Determination of Effective Irrigation Model.

7.5.1. Collection of data.

Going data was measured and recorded at the locations identified in Section 4.3.1. This provided a range of soil types from which the model could be derived. However the sampling was not carried out at the exact same location each time due to the physical disturbance of the soil caused by the going-stick. Secondary (final) sampling of going was conducted within approximately one metre of the initial measured going, thereby minimising as far as possible the effects of natural variation in soil properties on the going values recorded. Spatial variation in soil and turf properties is likely to occur on all racecourses, to some extent, therefore the final values of going measured in this way are deemed as representative and suitable for the development of the determination of effective irrigation model (DEFFIM).

The measurement of final going immediately after the application of water does not take account of any changes in soil strength that might occur over a long period as the water may not have distributed evenly through the soil profile. This was highlighted on one sampling day (24th October 2005) prior to a race meeting later that day. Overnight rainfall, in excess of 18 mm, had led to the Clark of the Course's decision to abandon the race meeting due to his description of the surface rating as "heavy going, soft in places". However, using the going-stick immediately after the rainfall indicated that the going was generally "good" going (8.0 of the going index on average). This is likely to be because a large amount of rainfall was still ponded at the surface and had not percolated through the depth of soil (100 mm) measured using the going-stick. This indicates that changes in strength for a given soil will be dependant on the infiltration rate and/or hydraulic conductivity of the soil as this controls the rate at which added water enters the soil and begins to change soil strength.

Based on this experience for Leicester Racecourse, it is likely that a second measurement of the going at least ten hours after rainfall or irrigation would have shown a change in the level of going in relation to applied water. The exact time for a change in going to occur will vary around the racecourse in response to changes in soil characteristics, but will be largely influenced by differences in infiltration rate. This also supports the idea of the 'time-lag' that seemed to influence MEGPREM (Section 6.3.4.3) and would suggest that a minimum waiting period is necessary before undertaking going measurements after a rainfall or irrigation event. The 24 hour period used between initial and final sampling of going in this study allowed any applied water to distribute evenly through the soil profile. Further research to determine the minimum period between a rainfall and/or irrigation event and the determination of going would be needed if the optimum pre-race irrigation period is to be determined for the racecourse.

All the data used to construct this model was collected from Leicester Racecourse. Although Leicester Racecourse has three distinct soil types – sandy loam, sandy clay loam and clay loam – the relationship between the amount of effective irrigation required to change the going value and the soil type was not significant. This can be attributed to the fact that the soil types encountered at Leicester Racecourse were at the boundaries between different soil texture classes, and therefore were not too dissimilar in respect to actual sand, silt and clay content. This allows, in this case, a single model that encompasses all three soil types to be used. Variation in soil types may be greater at other racecourses, potentially leading to the need to develop separate models to determine the effective irrigation required for the racecourses in question. Additionally the model assumes that the amount of irrigation required for a given soil, for example sandy loam, would be the same for sandy loam at another racecourse. This has not been established and will require further work to confirm whether or not this is the case.

The generation of the data to build the model requires the racecourse manager to have access to a going-stick to determine the initial and final going, catch-cans to measure the amount of irrigation water applied, and weather data to determine ET_o for the calculation of effective irrigation. When constructed, using the methods described in Section 7.3.2, the model can be easily used with a computer spreadsheet program.

7.5.2. Validation of the model.

DEFFIM was derived from multiple linear regression using the initial and final measured going as the explanatory variables and the effective irrigation as the dependent variable. The model can theoretically be used to determine the amount of water needed to be extracted to increase a measured level of going, although in practice this is very difficult to achieve. Therefore the model is primarily concerned with the amount of additional water required to lower the level of going.

Validation of the model suggests that predicted values of effective irrigation have a good degree of association (r = 0.51) with observed values and that the model was significant (F pr <0.001). The validation process also suggests that the model is more accurate (EF = 0.19) than just using the mean of the observations of effective irrigation. Therefore an objective determination of the amount of water required to change a measured level of going can be achieved. This is a significant improvement on the current, arguably subjective, methods being employed at racecourses to determine how much water to apply (see Section 3.3.3.1).

The resultant objective determinations are more defendable than subjective determinations where water suppliers and agencies question the amounts of water being used by racecourses in response to the Water Act 2003. Additionally total water consumption is likely to be reduced with the use of the model (see cost analysis in Chapter 9.0) as a direct result. The model can also aid the production of uniform surface conditions as it is driven by the initial going conditions and the desired going outcome, therefore a potential reduction in horse injuries may be achieved.

7.5.3. Potential improvement of the model.

There is scope to potentially improve the efficiency of the model, as the modelling process was limited by the amount and spread of the dataset, as the data collected did not encompass the whole range of the going-stick index i.e. 1.0 to 14.9. Some extreme variations in the data due to issues such as sampling error, natural variation of soil type, or poorly distributed irrigation water precluded the incorporation of some data points.

An increase in the size and range of the dataset used to develop the model should create a more efficient model.

The model, however, is principally concerned with the amount of water required to change a high (harder) level of going to a preferred lower (softer) level of going. It is unlikely that any racecourse manager would want to reduce the going to a level beyond that of good going (<8.0 of going-stick index) for flat racing, therefore the collection of data should concentrate on the range of going-stick index values from 8.0 to 14.9. Additional data could be measured, recorded and included in the model each racing season – when measurements of going are carried out as a general practise – to achieve a more complete dataset to refine the model. Additional measures of changes in going where irrigation has not taken place (deficit irrigation) would also improve the dataset.

The model determines the effective irrigation required and therefore requires the addition of an estimate of daily ET_o to take into account water losses through ET_o on the day when water applications are scheduled. Published values of average monthly ET_o are available for some areas, or alternatively they can be obtained from local weather data providers. The model can be used as a stand-alone tool, or in conjunction with MEGPREM (Chapter 6.0.) which models the determination of the initial going. A financial and environmental analysis is given in Chapter 9.0. which compares current irrigation practices with simulated determinations of water requirements using the combined values generated in MEGPREM and DEFFIM.

7.6. Conclusions.

A model that accurately determines the amount of water required to change initial going to a desired level of going would be a valuable tool to the Racecourse Manager. The model developed in this study achieves this aim, with the dual effect of meeting the demands of current environmental regulation – the Water Act 2003 – by enabling more precise amounts of water required to be calculated, and aids in the attainment of a uniform consistent racing surface. This may reduce the unnecessary use of water and the risk of potential injury to horses and their riders.

The continued process of data collection during subsequent racing seasons will increase the dataset from which the model is derived and should enable the refinement and improvement of the model, though this has not been tested. The creation of additional models, using the methodology described in this chapter, that take into account different soil types found at other racecourses or larger variation between soil types need to be established. This would ensure that all soil types on UK racecourses are addressed with regards to determining the amount of effective irrigation required to change a measured level of going to a desired level. Additionally, further work to establish whether the amount of water to change going for a given soil type on one racecourse would be the same for other racecourses with the same soil type needs to be conducted.

8.0. STUDY INTO THE EFFECTS THAT REGULAR WATERING HAS ON SOIL STRUCTURE.

Racecourses that maintain the surface rating at or very close to a level conducive to racing between race meetings often require frequent inputs of water through the summer months to replace water lost by *ET*. This potentially leads to excessive water use and, on racecourses that have soils that will shrink and swell, the soil maintaining a swollen state all year round. Minimizing water use between race meetings potentially has a dual effect. Firstly it may lead to wet/dry cycles, as described in Section 2.2.3.1. – dependent on the duration between race meetings. Wet/dry cycles will result in the soil undergoing shrink-swell events, which have been shown to improve soil structure (Pillai and McGarry, 1999), although the degree of shrinkage and swelling will vary depending on the clay content of the soil. Secondly, reducing water consumption will comply with the requirements of the Water Act 2003.

A study into the effects that shrink-swell cycles have on soil structure was conducted. The aim of the study was to determine whether soil structure is affected when the soils natural shrink and swell cycles are restricted by the application of irrigation water. This work relates to Objective Two to show the potential benefits that controlled water applications may have.

The study consisted of a randomised complete block design based on two soil textural treatments; Sandy loam and Clay loam, and two irrigation treatments; fully irrigated and partially-irrigated. The study was carried out over a 12 month period to maximise the likelihood that most seasonal weather conditions were experienced. A summary of the experimental parameters is given in Table 8.1.

Table 8.1
Summary of experimental parameters.

Treatment	***Description***
FI	Fully irrigated
PI	Partially irrigated
Soil textural classification	Sandy loam Clay loam
Turf composition	25 % ‘Aberimp’ Perennial ryegrass 20% ‘Raisa’ Chewings fescue 35% ‘Barcrown’ Slender creeping red fescue 20% ‘Limousine’ Smooth stalked meadow grass
Experimental design	Complete randomized block
Number of replicates	Six per soil textural classification, comprising of three FI, and three PI
Lysimeter dimensions	1 x 1 x 0.45 m
Location	Cranfield University at Silsoe campus
Construction date	27th November 2004
Growing-in period	130 days
Start date of experiment	25th May 2005
End date	18th October 2005

8.1. Materials.

8.1.1. Rootzone.

Two soils with different textural classifications were used, sandy loam (plots A-F) and clay loam (plots G-L). These are representative of common soil textures found on the majority of racecourses, based on the results of the questionnaire survey (Section 3.3.1). The clay loam was supplied by Boughton Loam Limited and sold as their “Club Cricket” clay loam. The sandy loam was sourced from the “Sand Pits” field at the Silsoe campus.

Particle size distribution analysis (PSD) using the Pipette Method (Bascomb, 1982) was carried out to establish the particle size distribution of the two soils. Three replicates per soil type were analysed for their sand, silt and clay content. The results of the PSD are given in Table 8.2.

Table 8.2
Particle size distribution analysis of trial plot soils.

Plots	*Total Sand (%)*	*Silt (%)*	*Clay (%)*	*Soil Textural Classification*
A – F	72.31	15.52	12.16	Sandy loam
G – L	37.77	30.68	31.56	Clay loam

8.1.2. Turfgrass coverage.

To ensure rapid establishment of grass cover, and a uniform root depth at the start of the experiment, 12 m^2 of Rowlawn 'Medallion' turf (Rowlawn, 2004) was used instead of seed on all plots. Medallion turf was chosen because it is a commercially available turf with a Perennial ryegrass and Smooth stalked meadow grass content, similar to a typical grass sward on a racecourse (see Section 3.3.2. for grass species present on UK racecourses). The composition of grass species in the turf is described in Table 8.1.

8.1.3. Detection cable.

A four metre length of 2.5 mm^2 single core cable was installed around the perimeter of each plot, outside the non-porous membrane, at a depth of approximately 75 mm. This enabled detection of each trial plot with a metal detector, in the event that the plots became indistinguishable from the surrounding grass land. The wire was installed on the 8th December 2004.

8.2. Preparation of the Trial Plots.

The trial plots on the Silsoe campus were originally constructed for Jones (2003) and are situated in an open, grassed area that is representative of the climate and 'in-field' conditions found in the East Midlands of the UK. The plots consist of twelve 1 m^2 holes, 0.45 m deep, that have been lined with a non-porous membrane to prevent lateral movement of soil moisture and the inter-mixing of the surrounding soil with the plot soil. Drainage for each plot consists of a separate perforated pipe overlaid by 150 mm of gravel. The drainage water was discharged into a ditch on the South side of the plots through separate solid pipes.

The plots were prepared by removing the rootzone previously placed in the holes (Jones, 2003) with the exception of a 10 mm layer (Plate 8.1) to act as a blinding layer over the gravel to prevent the migration of the trial rootzone into the drainage system (Figure 8.1).


A


B

Plate 8.1: Shrink-swell trial plots (A) with blinding layer overlying drainage (B).

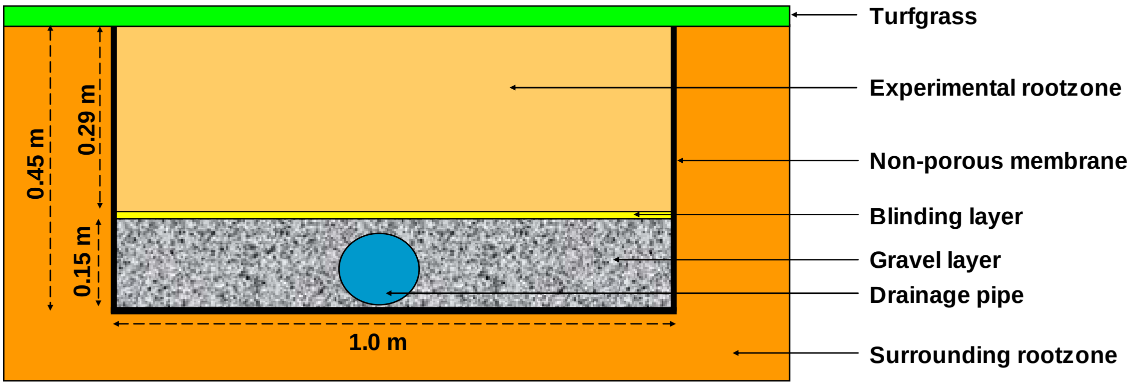


Figure 8.1: Profile of trial plot construction.

The clay loam rootzone to be used in this experiment had little evident soil structure as it had been air dried and passed through a 3 mm sieve. To prevent settlement at a later date the clay loam was consolidated in 75 mm layers by heeling-in the soil in two directions, at 90° to one another. Each layer was raked to create an interface between layers that would not impede drainage and root growth. The clay loam was installed on the 25th and 26th October 2004.

The sandy loam soil was moist and consolidated more readily than the clay loam. The layers were heeled-in and raked to create an interface layer as per the clay loam. Some stones and plant fibre was found in the sandy loam, and these components were removed to minimise any influence that they may have on the results of the trial. The sandy loam was installed one month after the clay loam, on the 26th and 27th November, due to poor weather conditions that inhibited the removal of the sandy loam from the Sand Pits field. Installation of the sandy loam at the same time as the clay loam would have been preferable, as there was the potential for some change to the clay loam structure during the intervening period.

The rootzone on which the turf was grown was washed off with a pressure washer prior to turf laying to reduce the thickness of the turf sod (in accordance with Beard, 1992), and to eliminate the possibility of an interface between the turf rootzone and the plot rootzone, which could interfere with rooting and water movement. The turf was laid on the 15th December 2004 and firmed to ensure good root to soil contact (Plate 8.2).

Plate 8.2: Trial plots with newly laid turf.

8.3. Maintenance.

8.3.1. Mowing.

All plots and the surrounding turfgrass area were mown once a week with a pedestrian rotary mower set at a maximum cut height of 50 mm. Clippings were not collected, in line with racecourse management practices (Plates 8.3 and 8.4). Undesirable plant species (weeds) were removed by hand as and when necessary.

Plate 8.3: Rotary mowing of trial area.

8.3.2. Wear.

The trial plots did not receive specific applied wear treatments, the only applied wear loading that the plots were subjected to was foot fall through the routine maintenance operations, such as weekly mowing.

Plate 8.4: Mowed trial area, study plots are marked using red marker paint.

8.3.3. Irrigation treatments.

Irrigation water had a dual purpose, a) to ensure the survival of the grass plant, and b) to ensure differences in wetting and drying cycles between the plots occurred. Two different irrigation application rates served as the treatments, 'Fully Irrigated,' where the soil was maintained at or close to a zero soil water deficit (SWD), and 'Partially Irrigated,' where the rootzone was allowed to dry to a 30 mm SWD, and then recharged through irrigation back to a zero SWD. The fully irrigated treatment was used to replicate the situation on racecourses which are watered throughout the summer to maintain race conditions, in some cases even when racing is not scheduled. The partially irrigated treatment was carried out to compare the potential effects that an alternative irrigation strategy could have on a racecourse soil structure. A complete randomized block configuration was used as the experimental design (Figure 8.2).

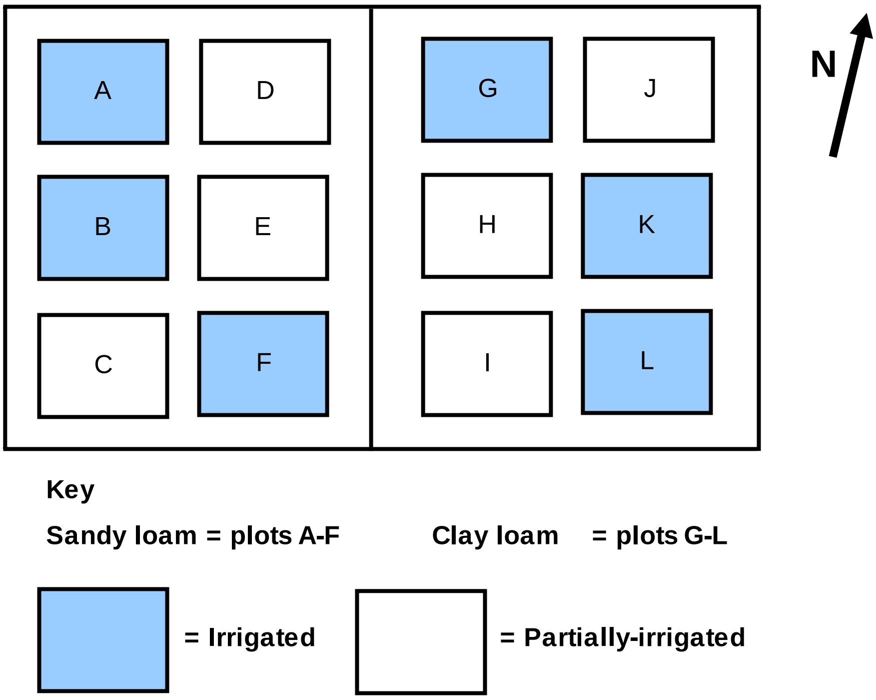


Figure 8.2: Randomized complete block design layout of the shrink-swell trial plots.

8.3.3.1. Initiation of irrigation process.

Before the experiment could begin, all plots had to be brought to field capacity to ensure that they began the trial with a zero SWD. This was achieved by saturating the plots and then covering them with plastic sheeting for a period of 48 hours, to prevent moisture loss through evapotranspiration (Plate 8.5). The plots were allowed to drain for 48 hours, at the end of which the plots

Plate 8.5: Irrigated plots covered during 48 hour field capacity phase.

were deemed to be at field capacity in accordance with SSSA (1997) which defines field capacity as '*the content of water, on a mass or volume basis, remaining in the soil 2 or 3 days after having been wetted with water after free drainage is negligible*'. Soil volumetric moisture content was measured with a theta probe (Charlesworth, 2000) at six hour intervals during the 48 hour period to ensure that drainage had nearly ceased (as evidenced by a gradual decline in the rate of drying) and to determine the soil volumetric moisture content at field capacity (see Appendix 7.1 for the six hour interval measurements).

8.3.3.2. Determination of soil water deficit.

Determination of the SWD was carried out with the Irrigation Management Services (IMS) irrigation scheduling program (Hess 1996b), which estimates daily changes in soil water storage from information on the soil and crop in synchrony with weather data for the site. The weather data was collected from the Silsoe campus weather station, located 100 m from the trial plots, at weekly intervals.

Additional inputs required by the IMS program were the average monthly reference crop evapotranspiration (ET_o) for the site, which was taken from Hess (1996c) for the period 1962-1996 at the Silsoe campus, and optionally a determination of daily ET_o from an external source, which was recommended by Hess (pers. comm.). This was used because the IMS program calculates an empirically generated estimate of ET_o using the '*Penman (1963) combination equation as modified by Thom and Oliver (1977) for rural lowland areas*' (Hess, 1996a). An empirically generated estimate of daily ET_o using the Penman-Montieth Method, as described in Section 6.1.2. was chosen. The Automatic Weather Station Evapotranspiration (AWSET) computer software program (Cranfield University, 2002) as described in Section 6.3.2.4. was used to generate the Penman-Montieth Method ET_o values.

8.3.3.3. Irrigation application.

The application of irrigation at the beginning of the trial was determined subjectively by the appearance of the sward and the prevailing weather patterns. This was due to the unavailability of the data from the weather station located at the trial site because the weather station data logger was not functioning. Irrigation practices in line with the calculated SWD within the IMS program began in late July 2005 when the collection of data from the weather station was possible.

All irrigation applications were carried out with a nine litre capacity watering can via a coarse rose outlet. Irrigation amounts applied were multiples of the nine litre watering can capacity (e.g. 9, 18, 27 and 36 litres). As each trial plot occupies an area of 1 m^2, the application of one litre of water equates to 1 mm depth of water over the area of the plot, therefore for every litre of water applied, the corresponding depth of water is determined. All weather data and irrigation events are given in Appendix 7.2.

8.4. Data Collection.

8.4.1. Surface hardness.

To describe the surface conditions that relate to running and falling, the term ‘hardness’ is often used (Chivers *et al*. 2005). The standard method to measure the surface hardness of natural turfgrass playing surfaces in the USA is the American Society for Testing and Materials ASTM F1702 method (McNitt, 2005). The ASTM F1702 comprises of a Clegg Impact Hammer (CIH) (Clegg, 1976) which measures impact attenuation using an accelerometer fitted to a 2.5 kg weight within the CIH.

Plate 8.6: 0.5 kg Clegg impact hammer.

However, only a 0.5 kg CIH (Plate 8.6) was available to carry out the determination of surface hardness. Each plot was measured with the 0.5 kg CIH at three randomly selected points at weekly intervals. Randomizing of the selected points was achieved by dropping three golf balls from a height of one metre onto each plot. The measurements were carried out immediately after mowing had taken place to ensure that all plots had a uniform height of cut to prevent any influences that differing heights of turfgrass canopy may have on the outcome of the surface hardness measurements.

The CIH was dropped three times at each point to minimize any cushioning effects the grass canopy would have on the hammer. The impact resistance of the third drop only was measured and recorded, after the methods of Aldous *et al*. (2005) and Chivers *et al*. (2005). This methodology differs slightly from the methods described by European Standard EN 14954:2005 (BSI, 2005), which states that five drops should take place on natural turf, with the fifth drop measured and recorded.

8.4.2. Soil volumetric moisture content.

Soil volumetric moisture content was measured at weekly intervals with a Theta Probe at the same time and location as the surface hardness measurements, to enable a determination of the interaction between surface hardness and the soil volumetric moisture content to be made. The recording of measurements began on the 22nd June 2005 and the final measurements were carried out on the 22nd September 2005 (i.e. 11 measurement events in total).

8.5. Destructive Analysis.

8.5.1. Hydraulic conductivity (K_{sat}).

Hydraulic conductivity (K) is described by Berryman (1974) as '*the rate of flow through unit cross section caused by hydraulic potential or head gradient*'. Under saturated flow K is considered constant if there is no change in the physical condition of the soil and water, within a space or over a period of time, as the water flows through the soil. Soil management can increase or reduce the value of K. Saturated hydraulic conductivity (K_{sat}) was measured and recorded as it gives an indication of the state of the soil structure in both soil types following the irrigation treatments.

Three cylindrical cells measuring 130 mm x 100 mm were inserted into each plot, to a depth of 150 mm, to enable the removal of undisturbed soil samples. The cells were then gradually submerged in a bucket of water to saturate the soil samples and prevent pockets of air being trapped in the soil, which might affect the rate of hydraulic conductivity (K_{sat}). The soil was maintained in a saturated condition for 48 hours.

K_{sat} was determined using the falling head method (Berryman, 1974), which determines an average K_{sat} value from different pressure heads of water. Manometers with a range of diameter sizes (2, 6, 12 and 21 mm) were used because the flow characteristics through the two different soils were such that this was necessary in order to obtain repeatable measurements.

8.5.2. Soil penetrative resistance (SPR).

To determine whether a full or partial irrigation treatment produces stronger soils, a Findlay Irving Soil Penetrometer, fitted with a 12 mm diameter cone, was used to measure soil resistance to vertical penetration. This enabled a determination of the relative strengths, at different depths, of the fully and partially irrigated soils to be made. Mulqueen *et al*. (1977) list the limitations of penetrometers as a tool for assessing the relative strengths of homogenous soils, but conclude that as the penetrometer gives quick and easy results, it is a useful tool for comparing the relative strengths of soils under similar conditions of moisture content and structural state.

Penetrometer measurements were taken at 35 mm intervals to a depth of 0.3 m. Five replicates per plot were measured at the beginning and end of the study to ascertain whether or not any significant differences in soil penetrative resistance (SPR) within and between irrigation treatments had occurred over time. The measurements were carried out on undisturbed parts of the plots.

8.5.3. Bulk density.

Dry bulk density (ρ_b) is directly related to total soil porosity as it expresses the relationship between a volume of soil and its mass and is therefore a good indicator of soil compaction or loosening (Hernanz *et al.*, 2000). The undisturbed soil samples used for the K_{sat} analysis were also used to determine the ρ_b for each plot for the corresponding irrigation treatments. After the K_{sat} testing the samples were oven dried at a temperature of 105°C for a 48 hour period in accordance with the methodology described in BSI (1990a). The ρ_b was then determined by dividing the weight of the dried sample (Mg) by the volume of the K_{sat} cell (m^3), as shown in Equation (34).

$$\rho_b = \frac{\text{Weight of dried sample (Mg)}}{\text{Volume of sample (m}^3\text{)}} \qquad (34)$$

The total pore volume for each soil and respective irrigation treatment was calculated using Equation (35), using the values of dry bulk density calculated in Equation (34).

$$\begin{aligned}\text{Total pore volume} &= 1 - (\rho_b \,/\, \text{particle density}) \\ &= 1 - (\rho_b \,/\, 2.65) \qquad (35)\end{aligned}$$

In addition to the determination of the soil pore volume, the linear shrinkage of the soil was also determined to characterise the potential extent of any shrink swell movements that might occur in the two soils during the experiment. The linear shrinkage test was carried out in accordance with BSI (1990b).

8.6. Statistical Analysis.

The multi sample analysis technique 'Analysis of Variance (ANOVA) with Replication,' was used to analyse the data from the experiment, and was carried out with Genstat (2005) statistical tool computer software. Anova was chosen as it allows simultaneous analysis of the effect of more than one factor on population means (Zar, 1996) which negates the need to perform a one-way ANOVA for each factor. ANOVA will also test for interaction amongst the factors. The 'Least Significant Difference,' (LSD) test (Clarke and Kempson, 1997) was carried out to ascertain the values of differences between sample means that achieve significance.

8.7. Results.

8.7.1. Bulk density.

Soil texture had a significant effect on ρ_b (F pr <0.001), as did the irrigation treatment (F pr <0.001). The interaction between the soil textural classification and irrigation treatment was also significant (F pr 0.011).

The mean ρ_b for the interaction between the soil texture and the two irrigation treatments were significantly different for both soils. The clay loam had a mean ρ_b of 1.30 Mg m^3 for the fully irrigated plots, and a mean ρ_b of 1.18 Mg m^3 on the partially irrigated plots (Figure 8.3). The sandy loam plots had a mean ρ_b of 1.53 Mg m^3 and 1.48 Mg m^3 on the fully irrigated and partially irrigated plots respectively. The interaction between the ρ_b and the K_{sat} was investigated, but no strong relationships were found. Full ρ_b analysis is given in Appendix 7.3.

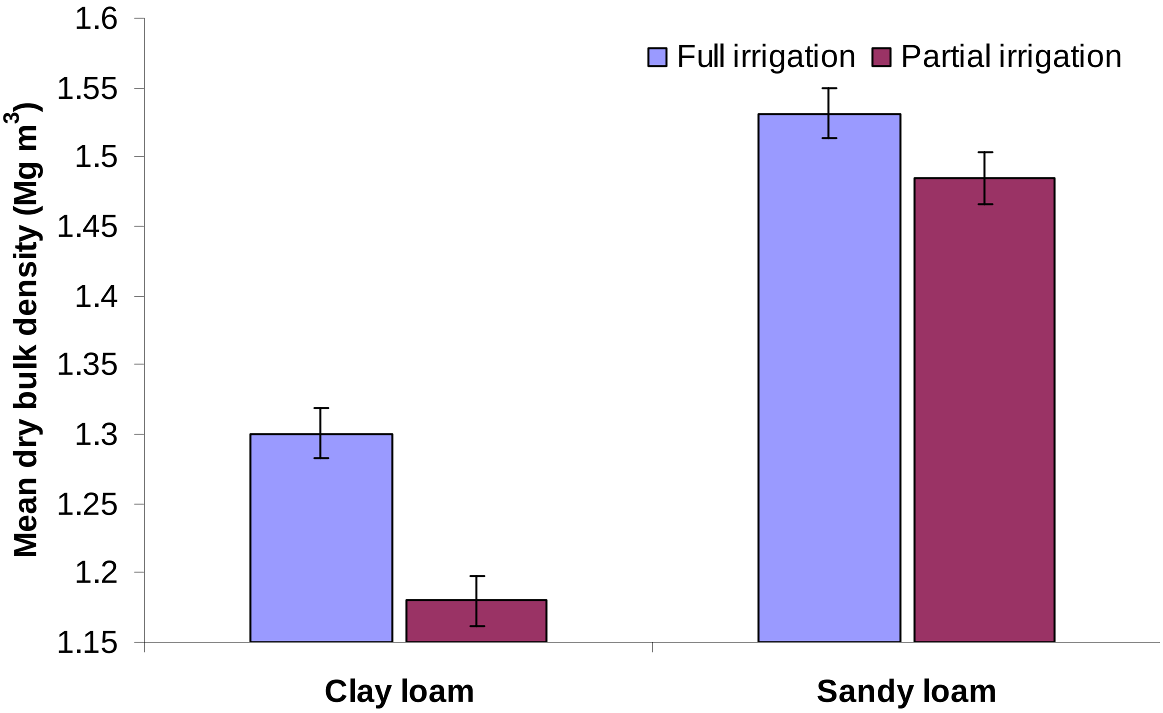


Figure 8.3: ρ_b means for soil textures at different levels of treatment with least significant difference of means at the 95% level.

The total pore volume for the soil texture and irrigation treatment, calculated from the ρ_b, was significant (F pr <0.001). The interaction between the soil types and irrigation treatments was also significant (F pr 0.011). The partially irrigated treatments had greater pore volumes than their respective fully irrigated soils. The partially irrigated clay loam had a total pore volume of 55%, compared to the fully irrigated clay loam which had a total pore volume of 51%. The partially irrigated sandy loam had 44% total pore volume, whilst the fully irrigated sandy loam had a total pore volume of 42% (Figure 8.4). The linear shrinkage of the clay loam was 12.86%, whereas the sandy loam had a linear shrinkage rate of 6.42% (see Appendix 7.4 for full analysis).

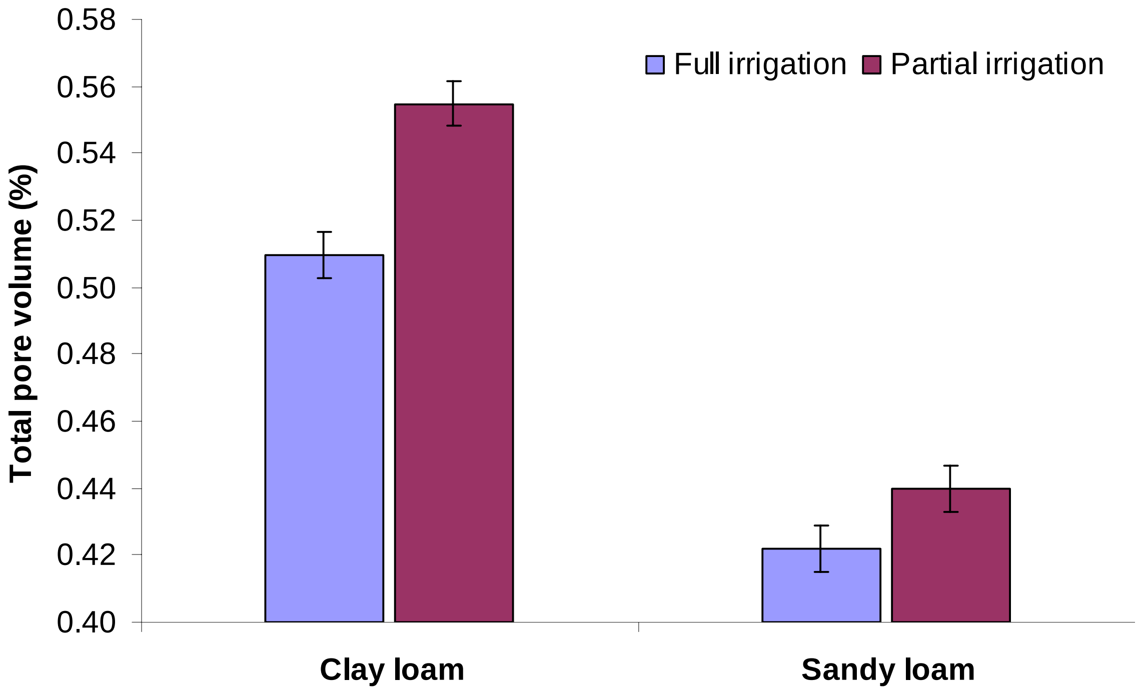


Figure 8.4: Total pore volume means for soil textures at different levels of treatment with least significant difference of means at the 95% level.

8.7.2. Hydraulic conductivity.

The two soil types had significantly different K_{sat} rates (F pr <0.001), as did the irrigation treatments (F pr <0.001). The interaction between soil type and the irrigation treatments was also significant (F pr <0.001), (Table 8.3). The mean K_{sat} for the interaction between soil types and the two irrigation treatments was significantly different for the clay loam plots, with mean K_{sat} values of 0.37 m d^{-1} for the fully irrigated plots, and 21.34 m d^{-1} for the partially irrigated plots. There was no significant difference in the mean K_{sat} value for the interaction between the sandy loam and the irrigation treatments (Figure 8.5). Full details of the analysis are given in Appendix 7.5.

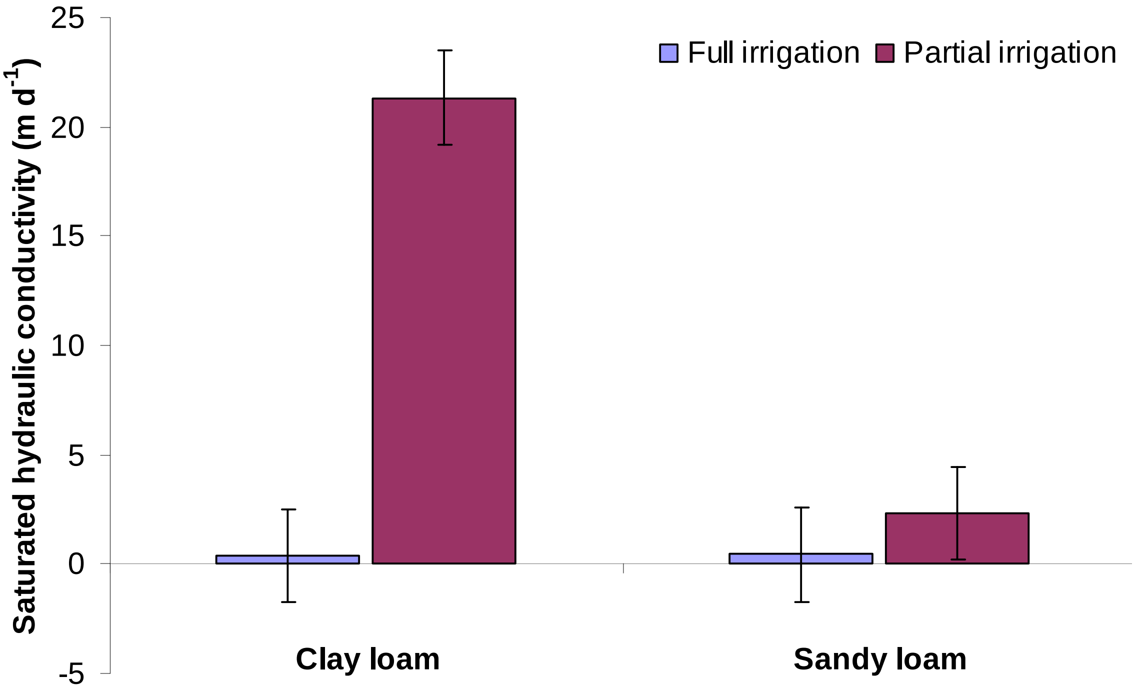


Figure 8.5: K_{sat} means for soil textures at different levels of treatment with least significant difference of means at the 95% level.

Table 8.3
Table of means for measured parameters at the end of the trial, with least significant difference of means at the 95% level.

	Sandy Loam		***Clay Loam***		
	Full irrigation	**Partial irrigation**	**Full irrigation**	**Partial irrigation**	**LSD** (95% level)
Dry bulk density (Mg m^3)	1.53	1.48	1.30	1.18	0.036
Pore volume (%)	42	44	51	55	0.013
$\mathbf{K_{sat}}$ (m d^{-1})	0.44	2.30	0.37	21.34	4.26

8.7.3. Soil penetrative resistance (SPR).

With the exception of the soil type, all factors – irrigation treatment, date and depth – had a significant effect on the SPR, with F pr values of <0.001, 0.002 and <0.001 respectively. All interactions between the factors, except the interaction between the soil type and irrigation treatment, and the interaction between the soil type, date and irrigation treatment, had a significant effect on the SPR (F pr <0.001). Full analysis is presented in Appendix 7.5.

Significant changes in the SPR occurred over time on the sandy loam plots, with greatest SPR occurring at the end of the study for both irrigation treatments (Figures 8.6 and 8.8). The clay loam plots however had lower SPR at the end of the study with the fully irrigated treatment (Figure 8.7), whereas changes in the partially irrigated treatment plots occurred in stages, whereby the final readings of SPR were greater than the initial readings to a depth of 140 mm, at a depth of 175 mm the SPR was the same for the initial and final readings, and at 210-315 mm the initial readings had greater SPR (Figure 8.9).

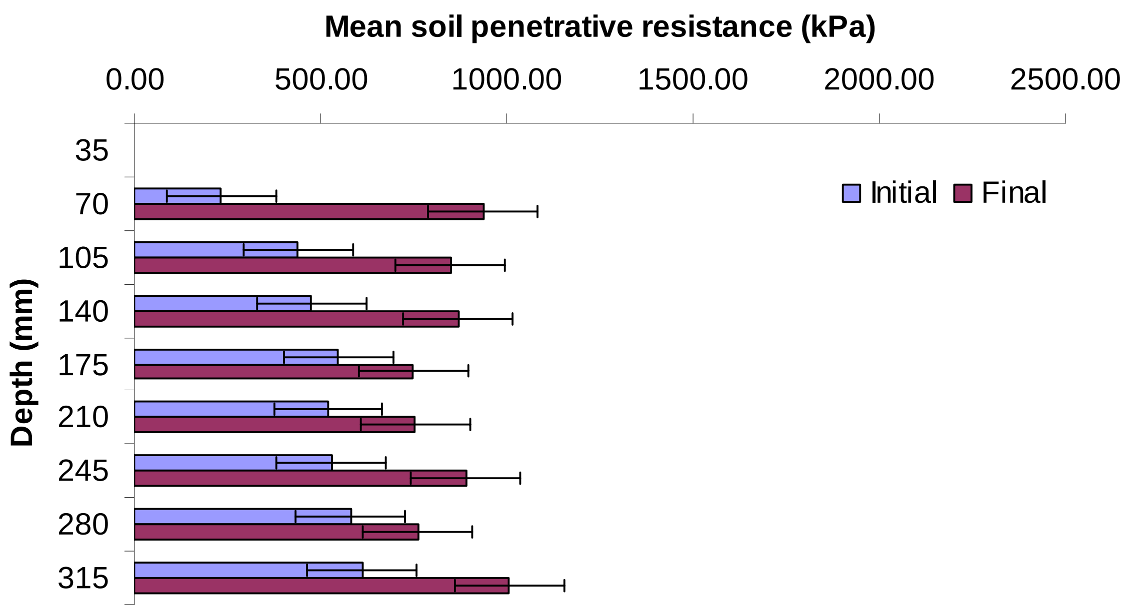


Figure 8.6: Initial and final soil penetrative resistance for fully irrigated sandy loam plots (A-F) with confidence limits at the 95% level.

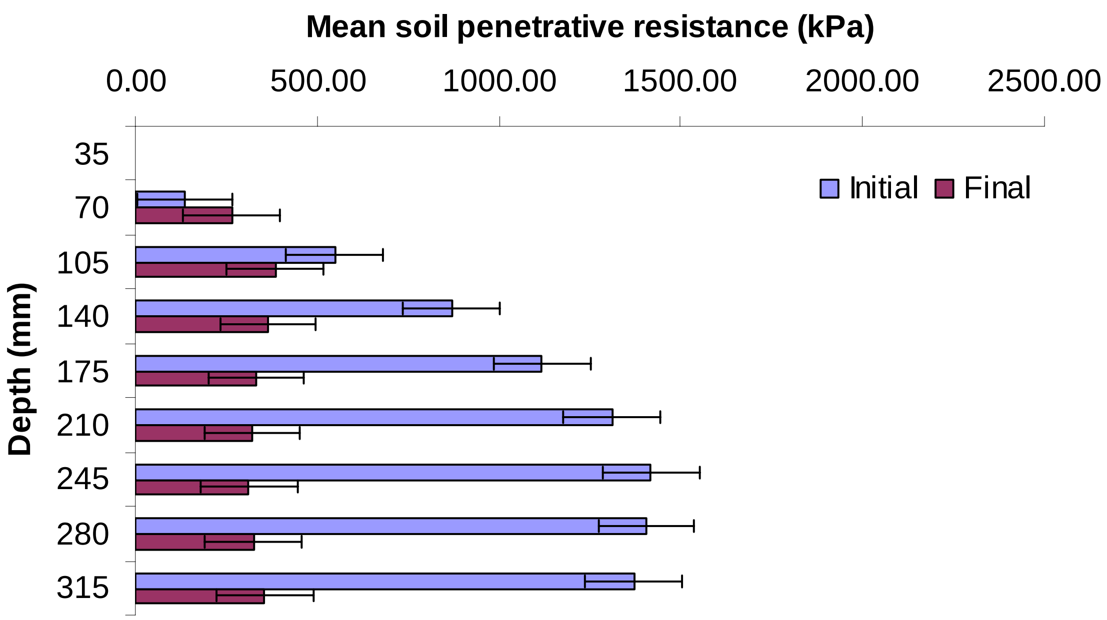


Figure 8.7: Initial and final soil penetrative resistance for fully irrigated clay loam plots (G-L) with confidence limits at the 95% level.

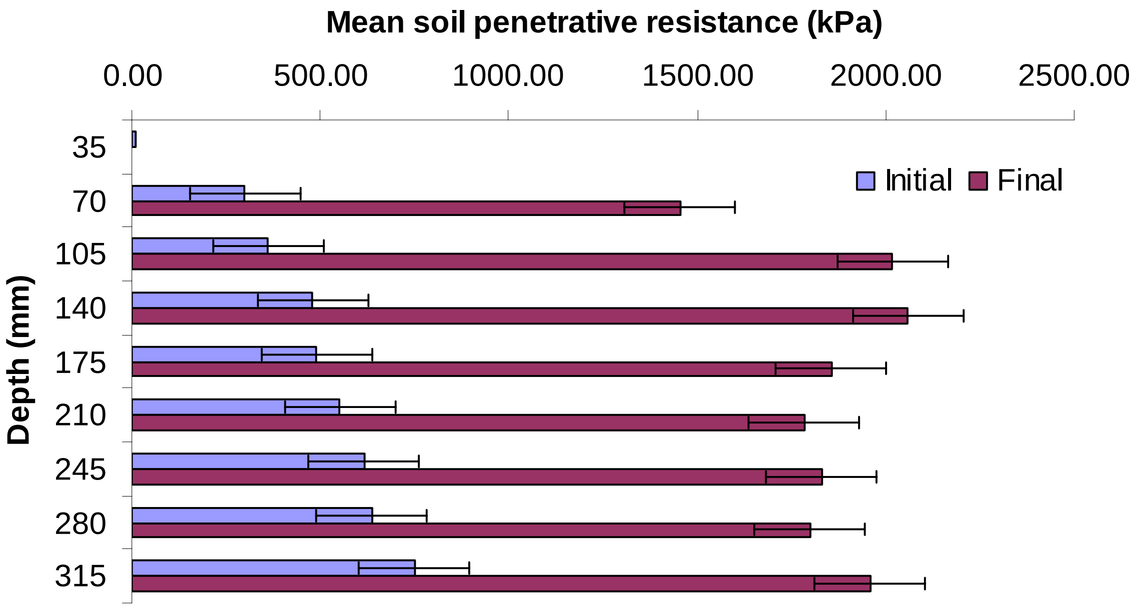


Figure 8.8: Initial and final soil penetrative resistance for partially irrigated sandy loam plots (A-F) with confidence limits at the 95% level.

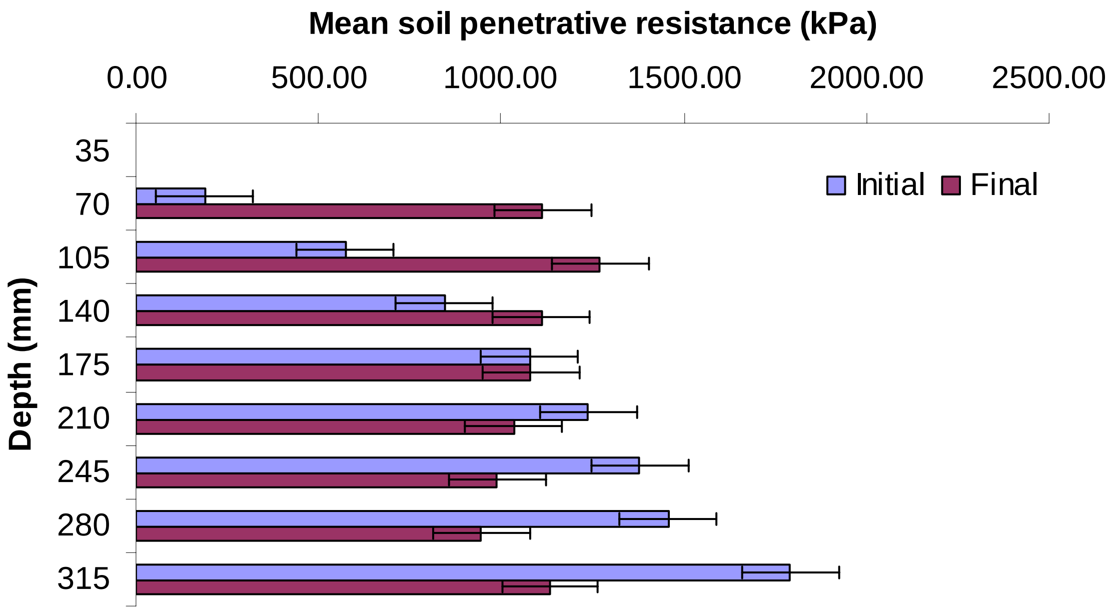


Figure 8.9: Initial and final soil penetrative resistance for partially irrigated clay loam plots (G-L) with confidence limits at the 95% level.

The differences recorded in the clay loam plots are likely to be due to different water contents at the time of testing. The initial tests were conducted when the clay loam was relatively dry, soon after construction. The final tests were carried out after a number of rainfall/irrigation events had occurred. To enable more accurate comparisons the water content should have been the same for the initial and final tests (Halvorson *et al*., 2003). The water content was not determined at the time SPR measurements were carried out; if this work is repeated this should be done. It is also likely that there was some disparity between the initial and final water content during the testing of the sandy loam plots too, but this was not verified.

Changes in water content with depth could account for the changes in SPR with depth in the partially irrigated clay loam plots, due to the potential of a suspended water table to occur as a consequence of the construction method, whereby the finer textured rootzone was laid over a coarser drainage layer. Additionally, interfaces from the layering and consolidation of the rootzone during the construction could have impeded water movement creating different water contents throughout the profile, resulting in different soil strength characteristics and therefore different SPR values.

8.7.4. Surface hardness.

Soil type and the interaction between the soil type and irrigation treatment did not produce significantly different results in respect to the hardness of the surface of the trial plots. However, the irrigation treatments were significantly different in respect to surface hardness (F pr <0.001), as was the date on which the measurements were taken (F pr <0.001), and the interaction between soil types and date (F pr 0.002). The interaction between the date the measurements were taken, and the irrigation treatment also had a significant effect (F pr <0.001) on the surface hardness. A significant effect was also found between the soil types, date, and the irrigation treatment interaction (F pr 0.041). Appendix 7.5 details the full analysis of the surface hardness.

8.7.5. Soil volumetric moisture content.

Soil type did not have a significant effect on the soil volumetric moisture content (θ_v), although the irrigation treatment did significantly effect the θ_v (F pr <0.001). The interaction between soil types and the irrigation treatment was also significant (F pr 0.003) (see Appendix 7.5). A significant effect on θ_v was also found with date (F pr <0.001), and the date and irrigation treatment interaction (F pr <0.001).

8.7.6. Interaction between the soil volumetric moisture content and surface hardness.

8.7.6.1. Clay loam interactions.

Regression analysis showed that a relationship existed between the θ_v and surface hardness on the clay loam plots. However the calculated regression coefficient accounted for only 43.6% (r^2 0.43) of the variance associated with the interaction between the θ_v and the surface hardness. This shows that although a relationship exists between the two measurements, it is not a strong relationship (Figure 8.10).

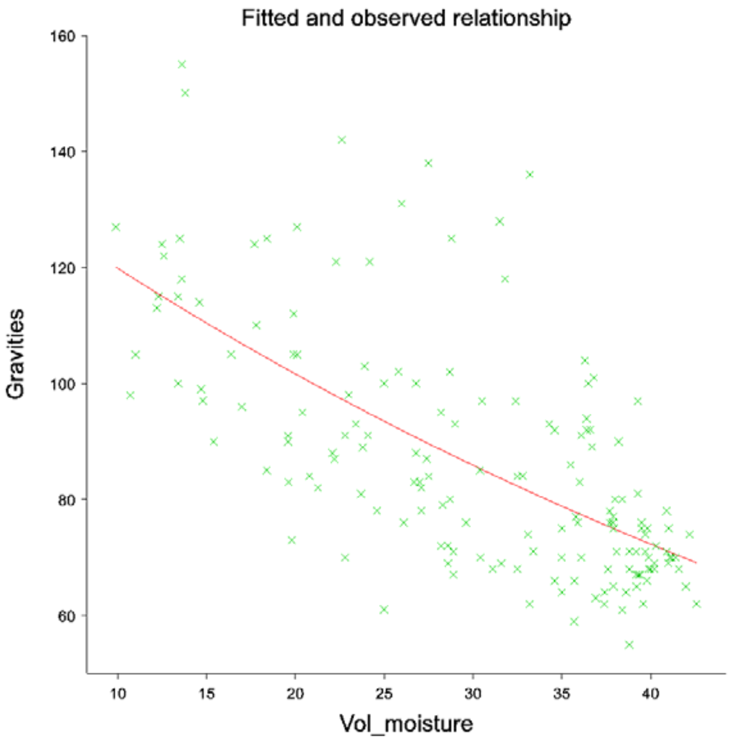


Figure 8.10: Interaction between the soil volumetric moisture content and surface hardness of a turfgrass sward grown on a clay loam soil.

8.7.6.2. Sandy loam interactions.

Regression analysis showed that a stronger relationship existed between the θ_v and surface hardness on the sandy loam plots. However the calculated regression coefficient accounted for only 53.0% (r^2 0.53) of the variance associated with the interaction between the θ_v and the surface hardness, this is still not a strong relationship (Figure 8.11).

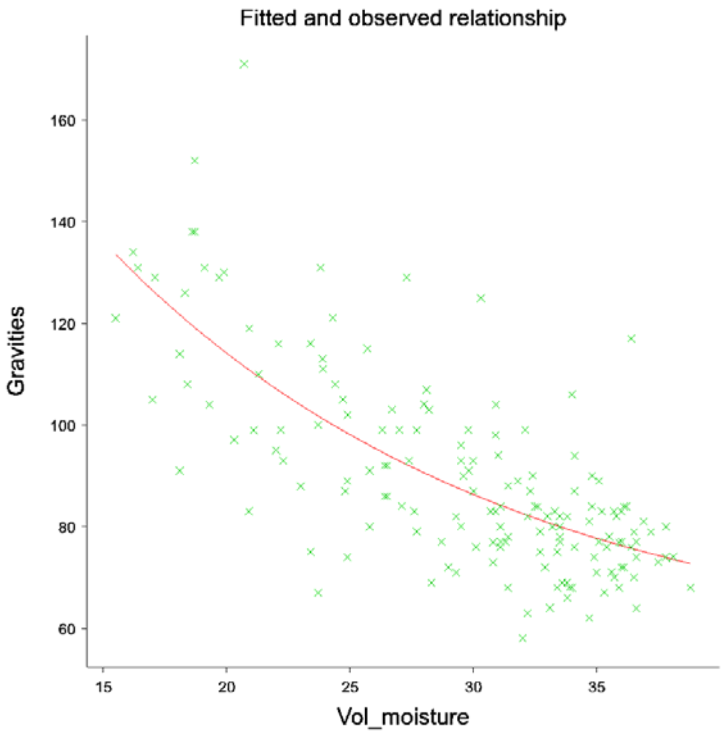


Figure 8.11: Interaction between the soil volumetric moisture content and surface hardness of a turfgrass sward grown on a sandy loam soil.

8.8. Discussion of Results.

8.8.1. Irrigation regimes.

The two irrigation treatments were designed to ensure that wetting and drying cycles occurred in one treatment but not in the other. The full irrigation regime maintained the plots at or close to a theoretical field capacity, and the partial irrigation regime allowed the soil to dry to a SWD of 30 mm before recharging the soil back to field capacity. These two treatments allowed any changes that occurred to the soil structure as a result of wetting and drying to become apparent. However the two regimes chosen have their own inherent disadvantages.

Maintaining the soil at field capacity can lead to over watering if a rainfall event occurs immediately after a scheduled irrigation event. Over watering can result in a lack of oxygen for turfgrass survival and can affect the soil strength and therefore the going conditions which can in turn affect the health of the competing horse. Additionally the potential for nutrient leaching, disease incidence and water logging, which can result in the abandonment of racing, can increase. More importantly, water can be wasted either through drainage and/or surface run-off. This has cost implications, both environmentally and in terms of direct water costs and labour/equipment costs. Excessive use of water can also lead to limitations on the availability of water for future use, through abstraction restrictions, if water is not being used effectively in accordance with the Water Act 2003.

Allowing the soil to dry to a critical SWD can lead to water stress, resulting in the turfgrass wilting and becoming stressed and more susceptible to disease. In addition the ability of the turfgrass to recover from wear is reduced. Surface characteristics can alter, with the surface becoming too hard, affecting the safety of the surface. The hardness of a surface is critical to a horse's health in a racing environment. Very few sports require a surface that is excessively hard, the exceptions being Tennis and Cricket, which require certain repeatable ball bounce characteristics.

The mobility of nutrients in the soil can also be reduced with a high SWD, resulting in poor nutrient uptake by the turfgrass leading to weak growth and changes in the appearance of the surface through inconsistent colour/verdure which can potentially unsettle a racing horse. In addition, the critical SWD will vary through the year with rooting depth; as roots grow deeper the readily available water is increased. Therefore the optimal irrigation schedule is constantly variable for the interval of application, and the amount of irrigation. This highlights the need for accurate measurement of the soil-water content so that efficient water management can be achieved.

This study indicates that over one growing season, keeping the soil at field capacity required a depth of 100 mm more water than the partially irrigated treatments (Appendix 7.2). This equates to an additional 6,760.5 m^3 of irrigation water over an average sized flat course (average racecourse dimensions based on questionnaire survey results given in Appendix 2.5). Therefore a substantial reduction in water consumption could potentially be made if the soil is not maintained at field capacity for prolonged periods.

8.8.2. Dry bulk density.

Upon removing soil samples from the fully irrigated sandy loam plots, the formation of black layer (Adams and Gibb, 1994; Fry and Huang, 2004) was noticeable at a depth of 250 mm. Black layer is a metal sulphide precipitate that forms in anaerobic conditions due to anaerobic bacteria (sulphur reducing bacteria) that feed on organic matter and release hydrogen sulphide (H_2S), which gives the soil a distinctive blackened layer. Black layer is indicative of poor drainage and/or saturated conditions. Although the presence of black layer was not expected, it was not surprising as the fully irrigated plots were maintained at a theoretical field capacity, coupled with a construction method that is likely to have created a suspended water table, similar to that found in a United States Golf Association (USGA) specification golf putting green (USGA, 2006). Some formation of black layer was also evident on the fully irrigated clay loam plots.

The mean ρ_b for the partially irrigated plots (1.18 Mg m^3 and 1.48 Mg m^3 for the clay loam and sandy loam respectively) was less than the mean ρ_b on the fully irrigated plots (1.30 Mg m^3 and 1.53 Mg m^3 for the clay loam and sandy loam respectively). This is partly due to the increased pore volume in the partially irrigated plots, generated by the formation of structure through shrink-swell cycles, and heave of the soil when swollen or frozen. The partially irrigated plots (both sandy loam and clay loam) had significantly different mean pore volumes than the fully irrigated plots. The partially irrigated clay loam plots had a mean pore volume of 55%, compared to a mean pore volume of 50% on the fully irrigated clay loam plots. The sandy loam had mean pore volumes of 44% and 42% for the partially irrigated and fully irrigated treatments respectively.

In addition to having a naturally greater porosity due to the interlayer pores in the clay particles, it is likely that the partially irrigated clay loam also had a greater mean volume of pores than the sandy loam because it had a greater propensity to shrink and swell on wetting and drying. This is confirmed by the results of the linear shrinkage test where the clay loam had double the linear shrinkage rate compared with the sandy loam (12.86% and 6.42% respectively). The greater volume of pores in the partially irrigated plots (both soil textures) is most likely due to heave, as no soil was removed from the plots during the experiment.

The change in soil volume is due to heave in the soil as a result of soil swelling during wetting cycles, which in effect, changes its structure. When dry, clay is a non-plastic solid. As the clay is wetted the smaller capillary pores fill and microscopic expansion of the soil occurs, but is not noticeable. When the capillary pores are full the soil volume (bulk) increases with water uptake. Clay becomes plastic when the distance between particle surfaces reaches approximately 2 nm (Marshall and Holmes, 1979). Macroscopic swelling occurs when the electrostatic attraction between the negatively charged layers of a clay (anions) and the positively charged atoms (cations) of water is less than the hydration energy of the cation. Further increases in the space between adjoining soil particles occurs when the active sites adsorb more water molecules. Swelling (and root growth) can cause soil movement that closes up soil pores, altering the volume and distribution of pore spaces. Swelling of this magnitude would have been less on the sandy loam plots because of the lower clay content in them.

Upon drying, air enters large pores and cracks as the bulk volume decreases in naturally structured soils, as opposed to a remoulded clay, and is termed ‘Structural’ shrinkage. A second phase of shrinkage, termed ‘Normal’ shrinkage occurs, whereby the decrease in volume is equal to the volume of water lost. Therefore the soil remains relatively wet as drying continues, dependent on how much air entered the soil during the structural shrinkage phase. A final phase, ‘Residual’ shrinkage, occurs as a result of air entry, which slows down the rate of decrease in soil volume in comparison to the rate of water loss.

The potential for the transitions for structural to residual shrinkage to occur are greater in soils with low clay contents (Stirk, 1954 cited in Marshall and Holmes 1979). However, a rigid framework that prevents the shrinkage process in drying soils is provided by the sand and silt content of the soil, which if great enough can prevent macroscopic shrinkage completely. This could explain why the sandy loam plots did not achieve the same mean volume of pores as the clay loam plots. The shrinkage process was likely to have been restricted in the sandy loam plots due to their greater sand content (72%) than the clay loam plots (38%).

As the soil dries the effects of hysterisis (described in Section 2.2.4.2) further alter the pore size and distribution, which through repeated shrink-swell cycles contributed to the heave in both soil types. ρ_b is an important component of soil strength. Increased density usually confers a stronger soil. These results are important as they suggest that different ρ_b values, as a result of shrink-swell cycles, can be arrived at with different irrigation regimes. Therefore the ρ_b on a racecourse that has soil prone to shrinkage and swelling as it dries and wets could theoretically be manipulated through water management.

8.8.3. Saturated hydraulic conductivity.

Methods to measure saturated hydraulic conductivity, such as the falling head permeameter method, are prone to scale effects due to the size of the receptacle that retains the soil sample. Fissures that run across the sample are blocked by the wall of the receptacle, potentially reducing preferential flow, and therefore influencing the measured rate of K_{sat}. However, since determining relative differences between the treatments is the key objective then, regardless of the method used the actual rates of K_{sat} are not critical; rather it is the differences between treatments that are of interest. Therefore as long as the methods used were consistent, then the results obtained are comparable.

The trial results showed that significant differences existed between soil types and irrigation treatments, although these differences are largely due to the high K_{sat} rate for the partially irrigated clay loam (21.33 m d^{-1}). The differences between both treatments on the sandy loam plots and the fully irrigated clay loam plots were not significant. The higher rate of K_{sat} on the partially irrigated clay loam and sandy loam plots is probably due to the effects of shrink-swell cycles on soil structure, which created new fissures that increased the rate of water flow through the soil profile.

In addition, the partially irrigated plots appeared to have a greater concentration of worms present in the soil. The fully irrigated plots were devoid of worms, as the water content of the soil was likely to be too high for worm survival. In contrast, the surrounding soil was extremely dry, and was unlikely to be an ideal environment for worms. However, the water content in the partially irrigated plots would have fluctuated from high to low due to the irrigation regime. This may have resulted in a soil water content that was more favourable to worm survival, which would account for the presence of worms in the partially irrigated plots. As a consequence, the worms had created some channels (large continuous pores) in the soil profile, causing preferential flow to occur.

It is likely that an accumulated effect of a greater pore volume and more worm channels caused the higher K_{sat} rates, rather than just the partial irrigation treatment alone. However, the partially irrigated treatment shows that with the right soil moisture conditions, worm populations can be encouraged, and that beneficial changes to the soil structure and potentially better drainage can be achieved. It could be argued that if worms were attracted to the partially irrigated plots, the differences between the fully and partially irrigated sandy loam plots could have been expected to be greater. It is possible however that a sandy loam environment is less favourable to worms than that provided by a clay loam, as worm populations generally rise with increasing clay content (Lee, 1985; Lavelle, 2001). The disadvantages usually associated with worms on sports turf i.e. surface interference from casts, are not an issue on a racing surface, as the canopy of the turf is taller, and is not affected by casting.

8.8.4. Soil penetrative resistance.

Although soil texture did not have a significant effect on SPR, the sandy loam and clay loam soils had differing results. The sandy loam soil had a greater SPR at the end of the trial for both the fully irrigated and partially irrigated treatments, with the partially irrigated treatments having significantly different SPR at every depth recorded The fully irrigated plots were significantly different to a depth of 175 mm, but not beyond that depth. This is due in part to consolidation of the soil over time from maintenance induced wear resulting in a greater degree of inter-packing between soil particles, which would account for the fully irrigated plots having greater SPR at the end of the trial. The smaller differences with depth in the fully irrigated plots are likely to be due to the water content increasing with depth, weakening the bonds between soil particles as the water content increases.

Variability in water contents most likely explains all the differences shown although it is not possible to relate these results to differences in irrigation regime. Ideally the plots should have had standardized water contents at the beginning and end of the trial to minimize any influence differences in water content may have at the time of measuring (Håkansson and Lipiec, 2000; Halvorson *et al*., 2003).

8.8.5. Surface hardness.

Surface hardness was significantly affected by the irrigation treatments, as expected. The fully irrigated plots were maintained in a more plastic state than the partially irrigated plots, and therefore had lower impact energies as the soil was able to deform and absorb the energy of the impacting hammer. The partially irrigated plots also achieved a plastic state when they had been recharged to field capacity, but upon drying out the soil reverted to a lower plastic / brittle state and thus a greater impact energy was recorded as the soil was unable to deform and absorb energy to the same degree as the wetter soil.

The date the measurements for the partially irrigated plots were taken was significant, as the measurements would have coincided with different stages in the irrigation treatments. This could have resulted in some measurements being taken when the soil was drier, and therefore stronger and harder. Date was not, however, significant with the fully irrigated plots, as they were kept at field capacity, minimising differences in soil strength due to the differences in soil water content.

Deformation of the soil in the fully irrigated plots – relative to the partially irrigated plots – may have led to greater consolidation from foot-fall during maintenance operations and could account (to some extent) for the higher bulk densities found in the fully irrigated plots. This is supported by the results of the racecourse survey (section 4.3.2), whereby the chase courses had a greater ρ_b than the flat courses, due in part to the time of year (winter) that the chase season covers. In winter, the soil is more likely to be wetter and more prone to mechanical damage under load.

Turf cover and vigour appeared to be comparable between the different treatments. Dry biomass was not assessed, therefore it is not known if significant differences in turf cover and quality occurred between the treatments or whether the differences in hardness measured were directly related to the health and amount of the turfgrass.

8.8.6. Soil volumetric moisture content.

The irrigation treatment had a significant effect on the soil volumetric moisture content (θ_v). The fully irrigated treatments maintained a relatively constant θ_v, whereas the partially irrigated treatment had a varying θ_v in direct response to the wetting and drying phases. All plots had uniform grass cover, and therefore would have achieved similar ET_o rates, with the exception of the partially irrigated plots at the extreme end of the drying phase, as soil water would not have been so readily available. The date the measurements were taken was significant because they coincided with the application of irrigation in some weeks, and not in other weeks, as with the surface hardness measurements.

8.8.7. Interaction of hardness and soil volumetric moisture content.

All data for the partially and fully irrigated treatments were combined for each soil type to provide a larger dataset and greater range of θ_v and surface hardness values. The interaction between surface hardness and θ_v was not as strong as expected for both soil types. The regression coefficient for these interactions was 0.43 and 0.53 for the clay loam and sandy loam respectively. It is unlikely that the differences in the relationship between surface hardness and θ_v for the two soil types is due to the turfgrass, as turf vigour and cover appeared (visually) comparable between all plots and the turf was mown prior to every measuring occasion to ensure that all plots had a uniform height of cut.

The results for the clay loam soil could be due to the partially irrigated θ_v varying from one extreme to another, in line with the shrink and swell cycles. Changes in soil strength, brought about by changes in cohesion, would be partly dependent on whether the soil was in a drying or wetting phase, due to the effects of hysterisis. The rate at which the soil re-wetted may have had an affect on the soil strength properties of the soil, and could account for some of the variation in the data. The same effect may account for the variance in the sandy loam results, but to a lesser degree.

8.9. Conclusions.

These results provide evidence that the irrigation regime has a direct influence on the formation of soil structure. Irrigation regimes that maintain susceptible soils at or close to field capacity remain in a swollen state and are unable to generate structure through shrink-swell cycles. Soils that are allowed to repeatedly dry out to a pre-determined SWD, and are then recharged to field capacity through irrigation, are able to develop soil structure through the formation of aggregates and peds, and the creation of fissures that increase the volume of pores, creating more transmission pores which improve the drainage characteristics of the soil.

The amount of shrinkage and swelling the soil achieves is dependent on the soil texture, but this study suggests that both the clay loam soil and the sandy loam soil had improved soil physical properties (ρ_b, K_{sat} and pore volume) as a direct result of a partial irrigation regime. The partial irrigation regime also reduces total water consumption, resulting in both financial savings and in meeting the demands of environmental regulation and the potential retention of abstraction licenses.

A partial irrigation regime is in stark contrast to current irrigation practices on racecourses in general. Racecourse managers tend to maintain a high soil-water content through the racing season to ensure a level of going that is not excessively hard. This makes a surface rating of good-to-firm more easily achieved with minimal inputs of water prior to a race meeting. This method may not be as detrimental to the soil structure as maintaining field capacity has been shown to be, but nevertheless it reduces the likelihood of shrink-swell cycles occurring. Assuming ceteris paribus, a partial irrigation regime will improve the soil structure and reduce total water consumption on a racecourse, without affecting the quality of the turfgrass sward. This does, however, increase the risk that surfaces might not wet-up in time for a race and could increase the possibility of harder ground for summer racing. This risk must be weighed against the high probability of the current practice producing soils with poor structure leading to drainage problems in the winter.

9.0. CONTROLLED WATER APPLICATIONS: AN APPRAISAL OF THE POTENTIAL ECONOMIC AND ENVIRONMENTAL SAVINGS.

Increasing environmental legislation has led to stricter rules with regards to water use (Weatherhead, 2004). The Water Act 2003, as described in Section 2.4.1, requires users of water to use water more effectively and, where possible, to reduce water consumption. Racecourses use a large amount of water as part of their management regime to control the surface rating of the racecourse in the summer months.

The financial cost of excessive water use on racecourses is apparent in potentially high water bills for users of mains water, such as Newcastle Racecourse, and in the possible loss of an abstraction license for racecourses that abstract water from a reservoir, lake or stream, (e.g. Leicester Racecourse). The loss of an abstraction license may put a racecourse out of business (unless it switches to the more expensive mains water), as it would be unlikely to achieve the level of going required for licensed racing without water applications during the summer months.

In general the three main methods used on racecourses to determine water requirements – visual analysis, the weather forecast and hard going (Section 3.3.3.1) – are subjective. Employing more accurate objective determinations offers the potential for optimizing water management and costs.

MEGPREM and DEFFIM, discussed previously, are potential tools available to racecourse managers that may allow more accurate determination of water requirements. Such models can aid racecourse managers in their decision making process in respect to water application strategies. By comparing the modelled results of an irrigation regime, directed by the use of DEFFIM, against actual irrigation values for Newcastle Racecourse, this chapter assesses whether or not savings, both environmental and economic, can be achieved using controlled water application strategies. This work relates to Objectives One and Two.

9.1. Methodology.

The flat course at Newcastle Racecourse has three main soil types (sandy loam, sandy clay loam and clay loam). For the purpose of this cost analysis only the parts of the track with sandy clay loam (SCL) textured soils were used for comparisons as this is the predominant soil textural type and is present on all sections of the racecourse. To simulate an alternative irrigation regime to the actual one carried out during 2004 to 2005, a determination of what the Rzone def and mean going might have been had no irrigation been applied was necessary.

9.1.1. Determination of the daily rootzone deficit.

A determination of the daily Rzone def, without any irrigation inputs, on Newcastle Racecourses's flat course for the period April 2004 to December 2005 was carried out with the WaSim SWB model, as described in Section 6.3.1. The weather data entered into the WaSim program for the same period was collected from the weather station located at Newcastle Racecourse. All race day dates during the 2004 and 2005 flat racing seasons are listed in Appendix 8.1.

9.1.2. Determination of mean going for a known soil texture.

To determine irrigation needs using DEFFIM, knowledge of the initial going is required. Mean going values for non-irrigated soils at Newcastle Racecourse do not exist. Therefore, in the absence of real going values, MEGPREM, in spite of its relatively poor results (Section 6.4), was used to indicate the likely mean going on the non-irrigated SCL parts of the course. The determination of the daily Rzone def without any irrigation inputs (Section 9.1.1 above) was used as the Rzone def input parameter in MEGPREM.

The daily mean going was determined for the period 18th June 2004 to December 2005 (see Section 6.3.4.1). There were only eight races prior to the 18th June during the 2004 flat season: four held in May and June, the others in March and April. It is unlikely that the races held in March and April required supplemental irrigation due to the prevailing weather conditions at that time of year.

9.1.3. Determination of effective irrigation requirements.

An estimate of the mean amount of effective irrigation required to reduce undesirable harder levels of going to desired, softer, levels on race days during the 2004 and 2005 flat racing seasons was calculated using DEFFIM (Chapter 7.0). The model was developed using the values of going on the soil types found at Leicester Racecourse. The soil types found at Leicester have a broadly similar textural classification to those found at Newcastle. The percentages of sand, silt and clay for the soil types at each racecourse closely match one another (Figure 9.1); therefore the use of this model for Newcastle Racecourse is deemed acceptable for the purpose of this exercise.

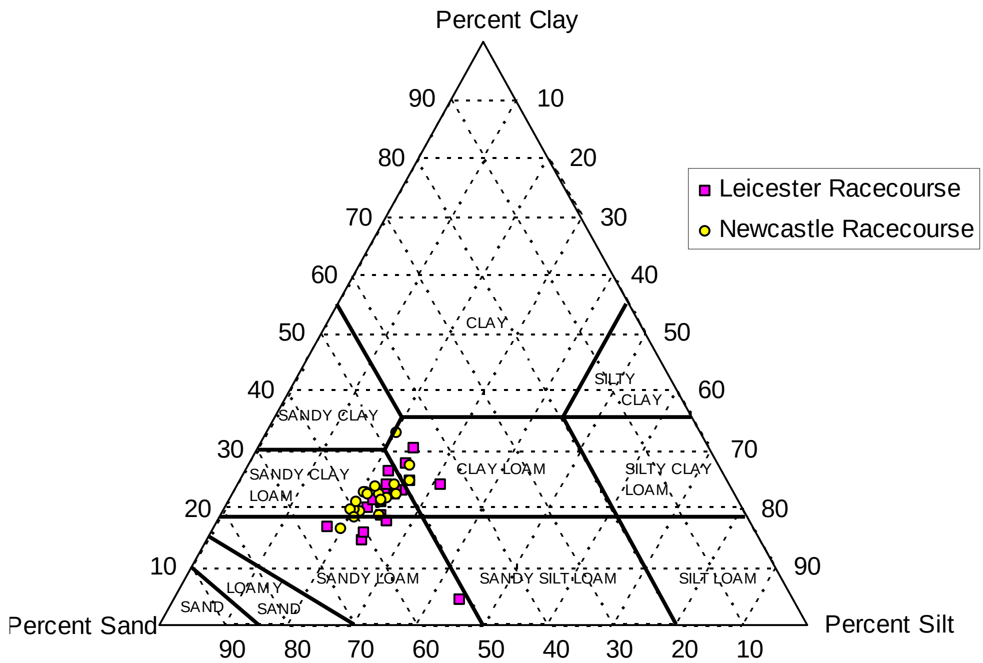


Figure 9.1: Soil textural triangle showing the percentages of sand, silt and clay for the soils found at Leicester Racecourse and Newcastle Racecourse.

The predicted daily mean going (Section 9.1.2) was used for the value of the initial going (Going A) input parameter. The desired level of going on a flat course is good-to-firm (Section 1.0). After discussions with the Clerk of the Course at Newcastle Racecourse (Armstrong, pers. comm.) the desired level of going (Going B in the determination model) was set as 8.3 on the going-stick index of going, as the Clerk has found that values ranging between 8.0 and 8.5 are representative of the surface conditions that are deemed good-to-firm at Newcastle Racecourse.

9.1.4. Total irrigation required.

DEFFIM requires the addition of water to allow for losses through ET_o. Daily ET_o values for the period April 2004 to December 2005 were known, therefore the daily ET_o values were added, where appropriate, to the determination of effective irrigation requirements. Any rainfall that occurred on the same day as the determined irrigation was deducted from the value of effective irrigation, as it is an input of water that has already occurred. All calculations were carried out on a Microsoft Excel spreadsheet. The equation to determine the total amount of water required to change the going from a high level to a value of 8.3 was:

$$\text{Total irrigation required} = -\,(\textit{rainfall} - ET_o) + \textit{effective irrigation} \qquad (36)$$

9.1.5. Volume of water applied.

The total area of each section of the flat course at Newcastle Racecourse was determined from the values of length and width given by Newcastle Racecourse in the questionnaire survey (Section 3.2):

$$\text{Chute section} = 600\text{m x } 22\text{m} = 13{,}200\text{m}^2 \qquad (37)$$

$$\text{Straight section} = 1{,}200\text{m x } 22\text{m} = 26{,}400\text{m}^2 \qquad (38)$$

$$\text{Round section} = 2{,}400\text{m x } 22\text{m} = 52{,}800\text{m}^2 \qquad (39)$$

The total volume of water applied to each section was calculated from the depth of water applied to each section and the determination of the surface area of each section (Equations 37, 38 and 39). In practise, the method of water application would dictate whether or not the whole width of the racecourse had a uniform application of water. Straight sections of a racecourse that are irrigated with a boom application system are more likely to have a uniform distribution of applied water than bends or sections of a racecourse that are irrigated from one side of the racecourse only (see Section 7.2.1.2). The calculated volumes given assume that the entire width of the flat course was irrigated.

9.1.6. Cost comparison of actual and simulated water applications.

The total depth and volume of water actually applied during the period 18th June 2004 to December 2005 was compared with the corresponding values for the simulated irrigation. A nominal value of £0.80 per cubic metre of mains supply water was used to enable the cost comparison to be conducted.

9.2. Results.

9.2.1. Total rainfall.

Irrigation applications are usually carried out to supplement rainfall (Section 2.3.5.5). The total rainfall depth at Newcastle Racecourse for 2004 was 778 mm whereas in 2005 the total rainfall depth was 790 mm. The amounts of rainfall for 2004 and 2005 were greater than the 30 year average rainfall of 640 mm for the Newcastle Racecourse area (Met Office, undated). Rainfall totals during the May to September period when supplemental irrigation is generally required, is more relevant, however. During that period, August 2004 and July 2005 had far greater monthly rainfall totals (180.6 and 97.8 mm respectively) than the corresponding 30 year averages of 69.75 and 55.8 mm for these months (highlighted in Table 9.1). The rainfall values are discussed in other sections of this chapter.

Table 9.1
Monthly Rainfall for 2004, 2005 and the 30 year average for Newcastle Racecourse.

Month	***2004 Rainfall*** *(mm)*	***2005 Rainfall*** *(mm)*	***30 Year Average rainfall*** *(mm)*
January	89.00[1]	46.00	55.49
February	10.00[1]	54.20	38.08
March	43.00[1]	52.00	50.84
April	63.80[2]	102.40	45.00
May	24.60	49.60	51.77
June	88.00	45.40	50.10
July	65.80	97.80	55.80
August	180.60	39.00	69.75
September	19.80	65.00	58.80
October	141.40	94.00	50.53
November	24.20	107.60	60.30
December	27.80	36.80	53.32
Total	**778.00**	**789.80**	**639.78**

[1]*rainfall data provided by Newcastle Racecourse*
[2]*weather data up to the 19th April provided by Newcastle Racecourse*

9.2.2. Depth of water applied.

Newcastle Racecourse applied supplemental irrigation during the 2004 and 2005 flat racing seasons. The total depth of water applied from the 18th June 2004 to December 2004, and January 2005 to December 2005, to the three sections of the flat course (identified in Section 6.3.2) are presented in Table 9.2. Knox *et al*. (2006b) state that a racecourse with soils classed as having medium available water capacity and located in Agroclimatic Zone Two, such as Newcastle Racecourse, should require a 'reasonable' or optimum irrigation need of 180 mm (depth of water) per year. The results in Table 9.2. would suggest that Newcastle Racecourse did not apply excessive amounts of water in 2004 – although the 2004 data is for six months only – but was possibly over reliant on irrigation during 2005 on the chute (188 mm) and straight (225 mm) sections of the flat course.

The actual irrigation applied by Newcastle Racecourse included irrigation events between race meetings, possibly to maintain a set soil moisture status or to aid the germination of seed in repaired divots. The addition of supplemental irrigation in between race days was not included in the simulated irrigation regime as the focus was on achieving optimum going on race days, not between race days. The simulated irrigation applications to achieve a desired level of going of 8.3 on a race day resulted in fewer irrigation events. As a result, less water was applied with the simulated water applications in 2004 and 2005. The simulated water applications reduced the total depth of water applied by 44 mm for the chute and straight sections, and by 24 mm on the round section in 2004 (Table 9.2). The differences between the actual and simulated depths of water for 2005 were 97, 134 and 57 mm for the chute, straight and round sections respectively.

Table 9.2
Total depth of actual and simulated supplemental water applied to the flat course at Newcastle Racecourse for the 2004 and 2005 flat racing seasons, with the number of irrigation events given in brackets.

	Total depth of water applied and section of the flat course			
Year	**Chute** (mm)	**Straight** (mm)	**Round** (mm)	**Simulated** (all sections mm)
2004*	60 (7)	60 (7)	40 (4)	16 (2)
2005	188 (21)	225 (26)	148 (17)	91 (7)

** excluding irrigation events prior to the 18th June 2004*

9.2.3. Volume of water applied.

The actual area of each section that is occupied by SCL is not known. Therefore the volume of water that would have been applied had each entire section consisted solely of SCL is presented in Table 9.3. Use of the simulated values imply that in 2004 the actual water applications could be reduced, hypothetically, by 73% (581 m^3) for the chute and straight (1162 m^3) sections, and 60% (1267 m^3) for the round section of the flat course at Newcastle Racecourse (Table 9.3). The simulated water application values for 2005 were also lower than the actual applications of water, with reductions of 52% (1280 m^3) for the chute section, 60% (3538 m^3) for the straight section, and 39% (3010 m^3) for the round section. A potential benefit associated with the lower volumes of the simulated water applications is that shrink-swell cycles (Chapter 8.0) could occur, leading to improved soil structure and drainage in soils with noticeable shrink and swell characteristics.

Table 9.3
Comparison of the total volume of actual and simulated water applied to each section of the flat course at Newcastle Racecourse in 2004 and 2005.

Year and Section	***Actual volume of water applied*** *(m^3)*	***Simulated volume of water applied*** *(m^3)*	***Difference between actual and simulated*** *(m^3)*
2004*			
Chute	792	211	581
Straight	1584	422	1162
Round	2112	845	1267
Total	**4488**	**1478**	**3010**
2005			
Chute	2481	1201	1280
Straight	5940	2402	3538
Round	7814	4804	3010
Total	**16235**	**8407**	**7828**

** excluding irrigation events prior to the 18th June 2004*

9.2.4. Economic analysis of actual and simulated supplemental irrigation.

Based on the volumes of water in Table 9.3. and a unit price of £0.80 per cubic metre of mains supply water, the total cost of actual water applications in 2004 was £3590.40 (Table 9.4). The round section was the most expensive section to irrigate due to its area. The total cost of simulated water applications was £1,182.40 in 2004, which resulted in a notional saving of £2,408.00.

The total cost of actual water applications in 2005 was £12,988.00. The cost of simulated water applications in 2005 was £6,725.60, resulting in a theoretical net saving of £6,262.40. The total cost savings for mains supply water at Newcastle Racecourse for the 2004 and 2005 flat racing seasons, had the values for the simulated water applications been used, would have been £8,670.40.

Table 9.4
Comparison of costs associated to actual and simulated water applications on all sections of the flat course at Newcastle Racecourse for the 2004 and 2005 flat racing seasons.

Year and Section	***Actual Cost (£)***	***Simulated Cost (£)***	***Difference in Cost*** *(actual-simulated)(£)*
2004			
Chute	633.60	168.80	464.80
Straight	1267.20	337.60	929.60
Round	1689.60	676.00	1013.60
Total	**3590.40**	**1182.40**	**2408.00**
2005			
Chute	1984.80	960.80	1024.00
Straight	4752.00	1921.60	2830.40
Round	6251.20	3843.20	2408.00
Total	**12988.00**	**6725.60**	**6262.40**

9.2.5. Comparison of actual and simulated supplemental water applications.

Each irrigation event had a knock-on effect to the Rzone def as expected, whereby it would influence the Rzone def value for the following seven days or so, although where prolonged periods without supplemental irrigation occurred, the Rzone def returned to the level it would have been had no irrigation taken place (Figure 9.2). As the value of the Rzone def changed immediately after a scheduled irrigation event, the prediction of the mean going would also change, resulting a change in effective irrigation requirements.

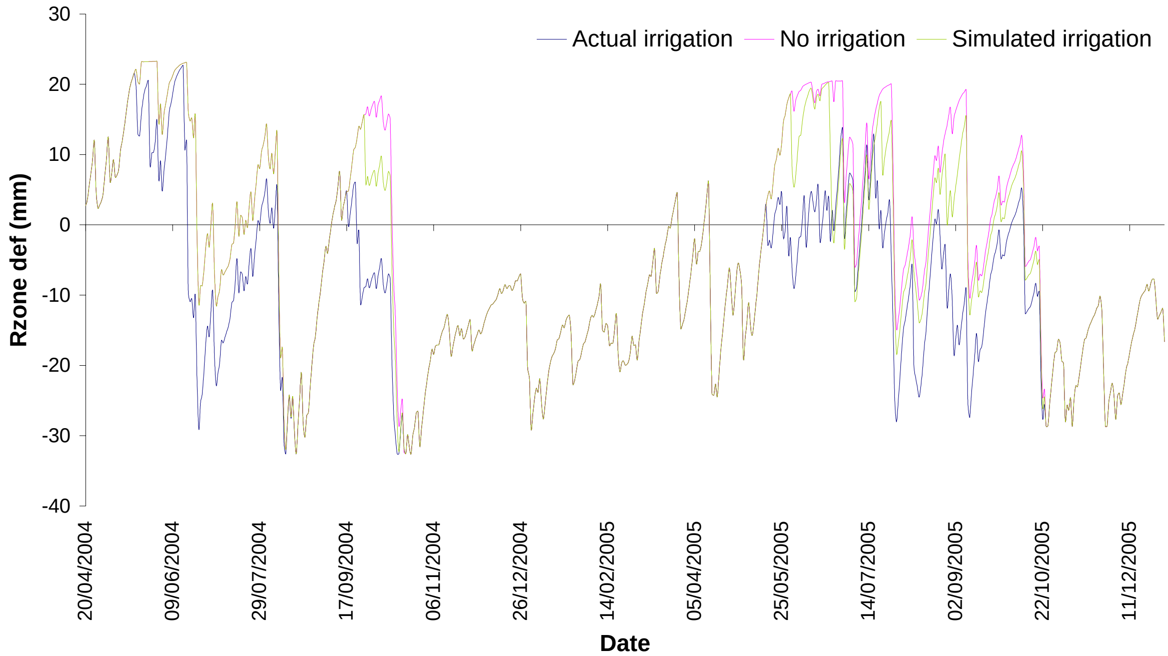


Figure 9.2: Rzone def for actual irrigation, without irrigation and with simulated irrigation for sandy clay loam soil on the round section of the flat course at Newcastle Racecourse.

The simulated depth of water applied was always greater than the maximum amount of water that Newcastle Racecourse can currently apply in a 24 hour period (6 mm) to the whole course, which is the recommended minimum capability that a racecourse should have (HRA, 2005). The use of an irrigation regime, such as the simulated regime, may require racecourses to re-evaluate the capacity of their irrigation systems.

Overall the actual going values for 2004-2005 were, in general, lower than the ideal 8.0 – 8.5 range. Simulated going for the entire period often had values of going greater than the desired 8.3 (Table 9.5). This is due to the simulated model not having any irrigation inputs between racedays to encourage shrink-swell cycles and minimize water use. The predicted values of going on race days for the simulated irrigation schedule were, however, at or closer to the optimum value of 8.3 than the actual mean going (Table 9.6). All values of actual going for each section of the flat course and corresponding predicted going are given in Appendix 8.2. The days that simulated irrigation took place, the amount of water that was applied using Equation (36) and the change to going are presented in Table 9.7.

Table 9.5
The number of going readings for the actual and simulated irrigation regimes that were greater or less than the optimum value of 8.3 (including non-race days)

	Section of racecourse			
Difference from 8.3	***Chute***	***Straight***	***Round***	***Simulated***
-5	5	1	0	0
-4	7	7	4	0
-3	6	2	4	1
-2	9	7	10	1
-1	11	8	9	9
0	23	22	20	15
1	22	31	29	31
2	3	8	8	20
More	1	1	3	10

Table 9.6
The number of going readings for the actual and simulated irrigation regimes that were greater or less than the optimum value of 8.3 on racedays only

	Section of racecourse			
Difference from 8.3	***Chute***	***Straight***	***Round***	***Simulated***
-2	5	2	4	0
-1	3	4	2	4
0	7	7	5	5
1	1	3	4	7
2	0	0	1	0

Table 9.7
Simulated supplemental irrigation applications to sandy clay loam soil on the flat course at Newcastle Racecourse for the 2004 and 2005 flat racing seasons.

Date	**Initial predicted going**	**Rainfall** (mm)	**ET_o** (mm)	**Determined Effective Irrigation** (mm)	**Total Irrigation Applied** (mm)	**Final predicted Going**	**Actual Going**		
							C	**S**	**R**
03/08/04	9.4	6.2	1.7	9.97	5	8.9	6.2	6.4	7.5
28/09/04	10.0	1.0	1.2	10.60	11.0	8.9	8.9	9.1	9.6
18/05/05	8.9	0.8	1.5	9.44	10.0	7.9	(8.5)	(9.2)	(9.2)
31/05/05	10.0	0.0	2.6	10.63	13.0	8.8	8.2	7.9	8.3
22/06/05	10.4	0.0	3.7	11.07	15.0	9.3	(8.7)	(8.5)	(8.7)
23/06/05	9.7	0.0	4.4	10.33	15.0	8.2	7.8	8.5	8.7
22/07/05	10.2	0.0	2.8	10.84	14.0	9.0	8.3	8.3	8.5
25/08/05	9.1	0.0	2.3	9.59	12.0	7.9	(7.9)	(8.0)	(8.5)
04/09/05	9.2	0.0	2.0	9.76	12	8.0	(7.6)	(8.4)	(8.4)

Data in brackets = only data available within 24 hours of the date given.

9.3. Discussion.

9.3.1. Rainfall.

The total rainfall for 2005 (790 mm) was comparable to 2004 (778 mm incorporating rainfall measurements provided by Newcastle Racecourse for the period of 2004 prior to the installation of the weather station). In some cases actual irrigation took place prior to a rainfall event, as estimations of future precipitation can only be indicated by weather forecasts, the accuracy of which can be questioned. As Newcastle Racecourse irrigated without knowledge of future rainfall, this could account for the lower than expected values of actual mean going produced.

The simulated irrigation had full knowledge of rainfall events on a given day (future rainfall events were not considered), and this could account, to a small extent, for the lower number of water applications, particularly in 2005. However, the level of going, not the prevailing weather conditions, was the influencing factor as to whether irrigation should take place in the simulations, although clearly the level of going is influenced by the weather conditions, particularly the rate of ET_o and rainfall.

9.3.2. Actual water applications.

The differences in the depths of actual water applied in each section of the flat course relate to the irrigation regime discussed in Section 6.3.2. The difference in total amounts of water between the different sections could be attributed to the localised environmental conditions of each section, or rainfall prior to a planned irrigation event on a given section, making irrigation unnecessary. Additionally, the irrigation regime is influenced by the distance of the races to be held. For example, the full length of the chute is not always used, and therefore does not require supplemental irrigation.

There were fewer irrigation events in 2004 and therefore lower total depths of water were applied to each section than in 2005. This is due to the 2004 dataset beginning on the 18th June – due to the time required for the SWB to reach equilibrium – therefore any irrigation events prior to the 18th June were discounted. There were five irrigation events totalling 55, 55 and 43 mm of applied water on the chute, straight and round sections respectively prior to the 18th June 2004. The greater inputs of supplemental irrigation in 2005 can be explained by the fact that there were 50% more race days in 2005 (18 race days) than in 2004 (12 race days). The additional irrigation inputs were probably applied to maintain the going at a level conducive for racing regardless of whether racing was programmed in the immediate future.

The irrigation applied in 2004 was less than the 180 mm threshold recommended by Knox *et al*. (2006b), even when the irrigation applications prior to the 18th June are taken into account. However the lower levels of mean going recorded (Section 9.2.5) would suggest that greater amounts of water than necessary were applied during 2004. This is reinforced by the fact that the total rainfall for 2004 (778 mm) was far greater than the 30 year average (640 mm). This reasoning would also account for the lower than expected mean going values in 2005, as the total rainfall that year was 789 mm and the total irrigation water applied was greater than 180 mm on the chute and straight sections of the flat course.

The applications of water also included non-race days (mainly during 2005). The applications probably had a range of purposes such as enabling turfgrass survival, to offset ET_o, to aid germination of grass seed and to prevent the soil drying out too much (as referred to in Section 8.8.3), so that very hard conditions never occurred on the racecourse. Water applications for these purposes were not quantified in the irrigation data supplied by Newcastle Racecourse.

9.3.3. Simulated water applications.

Simulated water applications were carried out twice in 2004. This is due in part to the fact that irrigation determinations were not conducted for race meetings prior to the 18th June 2004. There were fewer race days in 2004 than 2005; therefore the likelihood of the need for supplemental irrigation was reduced. There were more simulated irrigation events and greater volumes of water applied in 2005, but the amounts were much lower than the corresponding actual water applications for the same period.

The fewer water application events and lower total volumes of water applied with the simulated applied irrigation can be explained partly by the fact that water applications between race meetings were not considered. The primary aim of this chapter was to compare actual costs and water use to maintain target going on the racecourse against modelled costs and water use to maintain the target going. Clearly additional watering would be required to maintain turf quality and to aid renovation works and this is a valid criticism of the approach used in this chapter. It is likely, however, that water applications to meet the demands of ET_o, and to maintain turf quality and encourage seed germination would not have made an appreciable difference to the volume of water applied in the simulation during the period tested (2004-2005) due to the higher than average rainfall. It is likely that during periods of drought additional water would be required for the reasons given earlier.

However the simulated irrigation applied a large amount of water at each irrigation event, as shown in Table 9.7. If the soil has a low infiltration rate surface ponding and/or run-off could potentially occur, which could lead to some of the applied water missing its target area and therefore not influencing the surface rating as intended. If the volumes of water calculated from the modelling simulation were actually applied, it is likely that this would increase the number and severity of shrink-swell cycles occurring in the soil (dependent on the shrinkage rate of the soil). Shrink-swell cycles brought about by reduced water applications were shown to improve the structural characteristics and drainage properties of soil (Section 8.7). Improved structure and drainage could result in fewer race meetings held in the winter months being cancelled due to water logging. This could protect Racecourse revenue streams.

Although it should be noted that if the soil has dried between irrigation events to the point where a significant amount of shrinkage has occurred, it is possible that large transmission pores (cracks) could form. This could potentially result in applied water bypassing the upper soil profile and the expected changes in going not occurring.

9.3.4. Observations of going.

The actual mean going (observed going) was lower than the predicted mean going (prior to simulated irrigation) as expected, as the actual going was influenced by all irrigation and rainfall events. The predicted going was based on a Rzone def that had not received any irrigation inputs, so that a determination of the ideal amount of water to influence the predicted going to a desired level could be achieved. The simulated supplemental irrigation requirements were determined and carried out when the going was greater than 8.3 on the going-stick index prior to a race. As a result, the predicted mean going for the simulated water applications was often greater than 8.3 on non-race days than many actual mean going determinations, as there was no simulated irrigation applied between racedays.

The actual mean going tended to be softer on many race days (<8.3). It is possible that this is due to water applications coinciding with rainfall that was not forecast, or to the fact that 2004 and 2005 had greater rainfall than the 30-year average which resulted in the lower values of actual mean going. The predicted mean going after the modelled irrigation had taken place did not always achieve the desired 8.3 value but was often closer to 8.3 than the actual mean going recorded on the track on a raceday. This is because the simulated irrigation used the mean of the determined effective irrigation values as the amount of effective irrigation required. Using the upper or lower value of the confidence interval in the determination of effective irrigation required (Section

7.3.2.1) may have yielded better results. This highlights the errors in the determination of effective irrigation that can occur for certain irrigation events, and such errors associated with an irrigation event will accumulate as the year progresses', assuming that more than one error occurs.

9.4. Conclusions.

The theoretical comparison of actual and simulated water applications (Section 9.2.4) showed that large reductions in water consumption – 33010 m^3 in 2004, 7828 m^3 in 2005 – may be possible with the use of MEGPREM and DEFFIM though consideration of extra water needed to maintain turf quality must be made. These reductions in total water consumption would help racecourses to fulfil the requirement of the Water Act 2003. These findings suggest that controlled water applications based on the use of models to manage the surface rating (going), could significantly reduce the total annual water consumption on a racecourse.

The (theoretical) potential financial savings to racecourses that use mains supply water using this example are estimated as 67% (£2,408.00) in 2004 and 48% (£6,262.00) in 2005. For the reasons discussed previously, this is likely to be an overestimate of the actual savings that might be made, but this does suggest that there is scope for racecourses to save money by more carefully targeting their irrigation.

Racecourses that abstract water for irrigation purposes would be able to show that they are using the abstracted water more effectively, contributing to a defensible argument for future retention of their abstraction licence. It must be stressed, however, that the findings of this chapter are hypothetical and are merely an example as to how the models might be used.

10.0. SUMMARY FINDINGS.

A detailed discussion of the work carried out, the results of that work and the conclusions drawn from it are given in each chapter. This chapter summarises the key findings and relates these conclusions to the aims and objectives of the research. The contribution to knowledge that the research provides and the direction of future work are also considered.

10.1. Key Findings.

1) The empirical model to predict the mean going 'MEGPREM' (Objective One, Chapter Six) provided useful information for the direction of the research, but was found to be a poor predictor of going. The results of the validation analysis, however, suggest that MEGPREM, with additional research, has the potential to successfully predict going values for known soil types, providing Racecourse Managers with a positive useful tool.

2) The empirical model based on effective irrigation 'DEFFIM' (Objective Two, Chapter Seven) was found to be a useful model and could be a potential tool to assist Racecourse Managers in achieving effective and efficient water application strategies so that uniform going along the length of a racecourse can be achieved.

3) The shrink-swell study (Chapter Eight) provided evidence that the formation of soil structure can be influenced by irrigation. The adoption by racecourses, between race meetings, of the partial irrigation regime used in the study could potentially achieve improvements in their soil physical properties (ρ_b, pore volume, K_{sat}).

4) The hypothetical cost analysis (Chapter Nine) found that a simulated irrigation regime, directed by the MEGPREM and DEFFIM models, used significantly less water than the actual irrigation practices carried out at Newcastle Racecourse during the period 2004 to 2005. This provides theoretical evidence that the DEFFIM model could reduce water consumption in accordance with the requirements of the Water Act 2003.

10.2. Contribution to Knowledge.

This research has produced two new empirical models (MEGPREM and DEFFIM) designed to assist racecourse managers to better manage the going on racecourses. The MEGPREM model takes into account factors that influence soil strength, i.e. soil type, soil-water content and depth of rooting. Additionally, through the use of the going-stick, actual soil strength properties of penetration and shear resistance are incorporated. This reflects the interactions of the constituent components of soil strength, which in turn influences the degree of surface hardness and therefore the level of going. This has not been done before since other methods to determine going, for example the penetrometer method, tend to concentrate on only one or two parameters.

The DEFFIM model provides values for the amount of effective irrigation required to change soil strength such that a desired level of going is achieved. This is new and has been shown to be a successful method. DEFFIM has the potential to provide Racecourse Managers with a robust tool to aid their decision making processes with regards to the use of water to manage going. The potential savings in water consumption and cost, shown in the theoretical cost analysis, reinforce the potential of the MEGPREM and DEFFIM models to aid racecourse managers in the production of safe racing surfaces whilst meeting the demands of environmental regulation. This research should be made readily accessible to the horseracing industry so that Racecourse Managers can take advantage of the findings.

10.3. Recommendations for Future Work.

1) Re-evaluate MEGPREM with measurements of going taken consistently at the same locations to confirm whether or not the model is more accurate than the initial validation tests would suggest.

2) Develop MEGPREM models for other racecourses using the methodologies described in Chapter Six to determine conclusively whether or not the methodology is transferable to other racecourses.

3) Collect further data to refine DEFFIM

4) Determine whether the amounts of effective irrigation for a given soil type, generated by DEFFIM, would be the same for an identical soil on another racecourse.

5) Expand the shrink-swell study to include other soil types that are found on racecourses to determine if they will benefit from wetting and drying cycles.

6) Determine the maximum soil-water deficit at which the soils found on UK racecourses will cause shrinkage without creating large transmission pores that provide bypass flow of applied water.

7) Establish typical water infiltration rates for the different soil types found in a UK racecourse environment so that a determination can be made of the maximum rate of water application before surface ponding and/or run-off occurs.

8) Disseminate the findings of this research to the horseracing industry so that it is accessible to Racecourse Managers in an easy to read and understand format.

11.0. REFERENCES

Adams, W.A. and Jones, R.L. (1979) 'The Effects of Particle Size Composition and Root Binding on the Resistance to Shear of Sportsturf Surfaces', *Rasen Turf Gazon*, **2**, 48-53.

Adams, W.A., Tanavud, C. and Springsguth, C.T. (1985) 'Factors Influencing the Stability of Sportsturf Rootzones' in F. Lemaire (ed.) *5th International Turfgrass Research Conference*, Institut National de la Recherche Agronomique, Avignon: France, 391-399.

Adams, W.A. and Gibbs, R.J. (1994) *Natural Turf for Sport and Amenity: Science and Practice*. Wallingford: CAB International.

Aldous, D.E. and Wilson, J.R. (1999) 'Turfgrass Growth and Physiology', in D.E. Aldous (ed.), *International Turf Management Handbook*. London: CRC Press, 49-63.

Aldous, D.E. and Chivers, I.H. (2002) *Sports Turf and Amenity Grasses*. Collingwood, Australia: Landlinks Press.

Aldous, D.E. and Chivers, I.H. and Kerr, R (2005) 'Player Perceptions of Australian Football League Grass Surfaces', *International Turfgrass Society Research Journal*, **10**, 318-326.

Allen, R.G., Jensen, M.E., Wright, J.L. and Burman, R.D. (1989) 'Operational Estimates of Reference Evapotranspiration', *Agronomy Journal*, **81**, 650-662.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper ; 56. Rome: Food and Agriculture Organization of the United Nations.

Armstrong, J. (pers. comm.) Clerk of the Course, Newcastle Racecourse.

Aronson, L.J., Gold, A.J., Hull, R.J. and Cisar, J.L. (1987) 'Evapotranspiration of Cool-Season Turfgrasses in the Humid Northeast', *Agronomy Journal*, **79** (5), 901-905.

Avery, B.W. (1980) *Soil Classification for England and Wales* [Higher Categories]. Soil Survey Technical Monograph No.14. Harpenden: Soil Survey.

Bailey, C.J., Reid, S.W.J., Hodgson, D.R., Suann, C.J. and Rose, R.J. (1997) 'Risk Factors Associated with Musculoskeletal Injuries in Australian Thoroughbred Racehorses', *Preventive Veterinary Medicine*, **32**, 47-55.

Baker, S.W. (1995) 'The Effect of Rootzone Composition and Grass Type on the Performance of Turf for Horse Racing in Malaysia', *Journal of the Sports Turf Research Institute*, **71**, 42-51.

Baker, S.W., Cook, A. and Binns, D.J. (1999) 'The Effects of Aeration Treatments and Soil Moisture Content on the Quality of Turf for Horse Racing', *Journal of Turfgrass Science*, **75**, 100-109.

Bascomb, C.L. (1982) 'Physical and Chemical Analyses of <2mm Samples', in B.W. Avery and C.L. Bascomb (eds.) Soil Survey Laboratory Methods. Soil Survey Technical Monograph No.6, 14-41.

Bathe, A.P. (1994) '245 Fractures in Thoroughbred Racehorses: Results of a 2-year Prospective Study in Newmarket', in *Proceedings of the American Association of Equine Practitioners*, **40**, 175-176.

Beard, J.B. (1973) *Turfgrass: Science and Culture*. New Jersey: Prentice Hall.

Beard, J.B. (1992) 'Controlled Environment Research Methods for Turfs', *Turfgrass Agronomy Monograph*, **32**, 615-651.

Bengough, A.G. and Mullins, C.E. (1990) 'Mechanical Impedance to Root Growth: A Review of Experimental Techniques and Root Growth Responses', *Journal of Soil Science*, **41**, 341-358.

Berryman, C. (1974) *Infiltration Rates and Hydraulic Conductivity*. ADAS Field Drainage Experimental Unit Technical Bulletin No.74/4.

Böhm, W. (1979). *Methods of Studying Root Systems*. New York: Springer-Verlag.

Bonfield, T. (pers. comm.) Former Manager for TurfTrax Racing Data.

Borg, H. and Grimes, D.W. (1986) 'Depth Development of Roots with Time: An Empirical Description', *Transactions of the American Society of Agricultural Engineers*, **29** (1), 194-197.

Brady, N.C. and Weil, R.R. (2002) *The Nature and Properties of Soils* (13th edition). New Jersey: Prentice Hall.

Brown, P. and Kopec, D. (2000) *Turf Irrigation Management Series Two: Converting Reference Evapotranspiration into Water Use*. Tucson: University of Arizona.

Brown, P.W., Mancino, C.F., Young, H.M., Thompson, T.L., Wierenga, P.J. and Kopec, D.M. (2001) 'Penman Monteith Crop Coefficients for Use with Desert Turf Systems', *Crop Science*, **41** (4), 1197-1206.

BSI. (1990a) *British Standards Methods of Test for Soils for Civil Engineering Purposes: Part 2. Classification Tests*. BS 1377: Part 2: 1990. London: British Standards Institution.

BSI. (1990b) *British Standards Methods of Test for Soils for Civil Engineering Purposes: Part 1. General Requirements and Sample Preparation*. BS 1377: Part 1: 1990. London: British Standards Institution.

BSI. (1991) *Grounds Maintenance – Part 3: Recommendations for Maintenance of Amenity and Functional Turf (other than sports turf)*. BS7370-3: 1991. London: British Standards Institution.

BSI. (2005) *Surfaces for Sports Areas — Determination of Hardness of Natural Turf and Unbound Mineral Surfaces for Outdoor Sports Areas*. BS EN 14954:2005. London: British Standards Institution.

Bullock, P., Newman, A.C. and Thomasson, A.J. (1985) 'Porosity Aspects of the Regeneration of Soil Structure after Compaction', *Soil and Tillage Research*, **5**, 325-341.

Burgess, P. (pers. comm.) Lecturer in Crop Ecology and Management, Cranfield Univeristy at Silsoe.

Burges Salmon. (2003) *Racecourse Guidance Document: Water Supplies*. Unpublished Report. London: Burges Salmon.

Calder, I.R., Harding, R.J. and Rosier, P.T.W. (1983) 'An Objective Assessment of Soil-Moisture Deficit Models', *Journal of Hydrology*, **60**, 329-355.

Campbell, N. (2003) 'Does Trade Liberalization Make the Porter Hypothesis Less Relevant?', *International Journal of Business and Economics*, **2** (2), 129-140.

Canillas, E.C. and Salokhe, V.M. (2002) 'A Decision Support System for Compaction Assessment in Agricultural Soils', *Soil and Tillage Research*, **65** (2), 221-230.

Carrow, R.N. (1995) 'Drought Resistance Aspects of Turfgrasses in the Southeast: Evapotranspiration and Crop Coefficients', *Crop Science*, **35** (6), 1685-1690.

Catrice, H. (1993) 'Turf for Horse Racing: Conflicting Requirements of the Turf Grass Plant and the Horse', in R.N. Carrow, N.E. Christians and R.C. Shearman (eds.), *International Turfgrass Society Research Journal*. Kansas: Intertec Publishing Corp, 517-521.

Charlesworth, P. (2000) *Irrigation Insights No.1: Soil Water Monitoring*. Canberra: Land and Water Australia.

Chivers, I.H. (pers. comm.) Personal communication.

Chivers, I.H. (1999) 'Prescription Surface Development: Racetrack Management', in D.E. Aldous (ed.), *International Turf Management Handbook*. London: CRC Press, 299-310.

Chivers, I.H. and Aldous, D.E. (2003) 'Performance Monitoring of Grassed Playing Surfaces for Australian Rules Football', *Journal of Turfgrass and Sports Surface Science*, **79**, 73-79.

Chivers, I.H., Aldous, D.E. and Orchard, J.W. (2005) 'The Relationship of Australian Football Grass Surfaces to Anterior Cruciate Ligament Injury', *International Turfgrass Society Research Journal*, **10**, 327-332.

Cisar, J. (1994) 'Management of Parks with Respect to Environmental Concerns in the United States', in R.J. Gibb and M.P. Wrigley (eds.), *Proceedings of the 5th New Zealand Sports Turf Convention*, New Zealand: Massey University, 9-12 May 1994. Palmerston North, NZ: New Zealand Turf Culture Institute Inc, 147-150.

Clanton, C., Kobluk, C., Robinson, R.A. and Gordon, B. (1991) 'Monitoring Surface Conditions of a Thoroughbred Racetrack', *Journal of the American Veterinary Medical Association*, **198** (4), 613-620.

Clarke, G.M. and Kempson, R.E. (1997) Introduction to the Design and Analysis of Experiments. New York: John Wiley and Sons.

Clegg, B.E. (1976) ‘An Impact Testing Device for in situ Base Course Evaluation’, *Australian Road Research Bureau Proc*, **8**, 1-6

Clothier, B. (2001) ‘Assessment of Soil Moisture Content and the Management of Irrigation’, in G. Paterson (ed.) *Proceedings of the Inaugural New Zealand Sports Turf Conference and Trade Show*, 2nd-5th July 2001, Rotorua Convention Centre: New Zealand.

Connellan, G.J. (1999) ‘Turfgrass Irrigation’, in D.E. Aldous (ed.), *International Turf Management Handbook*. London: CRC Press, 119-138.

Cranfield University. (undated) Unpublished soils data. Soils Laboratory. Silsoe: Cranfield University at Silsoe.

Cranfield University. (2002) *AWSET: Potential Evapotranspiration Program for Automatic Weather Stations*. Version 3.0 (19). Silsoe: Cranfield University at Silsoe.

Davidson, E. J. and Ross, M.W. (2003) ‘Clinical Recognition of Stress-Related Bone Injury in Racehorses’, *Clinical Techniques in Equine Practise*, **2** (4), 296-311.

Devitt, D.A., Morris, R.L. and Bowman, D.C. (1992) ‘Evapotranspiration, Crop Coefficients, and Leaching Fractions of Irrigated Desert Turfgrass Systems’, *Agronomy Journal*, **84** (4), 717-723.

Dexter, A.R. (1988) ‘Advances in Characterization of Soil Structure’, *Soil and Tillage Research*, **11**, 199-238.

Doorenbos, J. (1976) *Agro-Meteorological Field Stations*. Rome: Food and Agriculture Organization of the United Nations.

Doorenbos, J. and Pruitt, W.O. (1977) *Guidelines for Predicting Crop Water Requirements*. FAO Irrigation and Drainage Paper; 24. Rome: Food and Agriculture Organization of the United Nations.

Draper, N.R. and Smith, H. (1998) *Applied Regression Analysis* (3rd edition). New York: Wiley-Interscience.

Dresser and Stranks (pers. comm.) Dresser, M. Research Officer and Stranks, S. Technician, Natural Resources Department, Cranfield University at Silsoe.

Ellis, D.R. (1994) 'Some Observations on Condylar Fractures of the Third Metacarpus and Third Metatarsus in Young Thoroughbreds', *Equine Veterinary Journal*, **26** (3), 178-183.

Emmons, R. (2000) *Turfgrass Science and Management* (3rd edition). New Jersey: Delmar Thomson Learning.

Environment Agency. (2005) *The Water Act 2003* [www document]. <http://www.environment-agency.gov.uk/subjects/waterres/564321/828248/?version=1&lang=_e> (accessed 4th April 2005).

Ervin, E.H. and Koski, A.J. (1998) 'Drought Avoidance Aspects and Crop Coefficients of Kentucky Bluegrass and Tall Fescue Turfs in the Semiarid West', *Crop Science*, **38** (3), 788-795.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Case, J.T., Ardans, A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J. and Woods, L.W. (1996) 'Fatal Musculoskeletal Injuries Incurred during Racing and Training in Thoroughbreds', *Journal of the American Veterinary Medical Association*, **208** (1), 92-96.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Jack, R.A., Case, J.T., Ardans, A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J. and Woods, L.W. (1998) 'Relationship between Race Start Characteristics and Risk of Catastrophic Injury in Thoroughbreds: 78 Cases (1992)', *Journal of the American Veterinary Medical Association*, **212** (4), 544-549.

Field, T.R.O. and Murphy, J.W. (1990) 'Racetrack Performance', in P. Evans (ed.) *Proceedings of the 4th New Zealand Sports Turf Convention*, 13th-16th August 1990, Massey University, Palmerston North, New Zealand, 143-143.

Field, T.R.O., Murphy, J.W. and Lovejoy, P.J. (1993) 'Penetrometric Assessment of the Playability of Course Turf', in R.N. Carrow, N.E. Christians and R.C. Shearman (eds.) *International Turfgrass Society Research Journal*, **7**, 512-516.

Field, T.R.O. (1994) 'Horse Racing Tracks', in Adams, W.A. and Gibbs, R.J. (1994) *Natural Turf for Sport and Amenity: Science and Practice*. Wallingford: CAB International, 329-353.

Fleming, M.C. and Nellis, J.G. (2000) *Principles of Applied Statistics* (2nd edition). London: Thomson learning.

Frohwein, T. and Hansjürgens, B. (2005) 'Chemical Regulation and the Porter Hypothesis: A Critical Review of the New European Chemicals Regulation', *Journal of Business Chemistry*, **2** (1), 19-36.

Fry, J., Wiest, S., Qian, Y. and Upham, W. (1997) 'Evaluation of Empirical Models for Estimating Turfgrass Water Use', *International Turfgrass Society Research Journal*, **8**, 1268-1273.

Fry, J. and Huang, B. (2004) *Applied Turfgrass Science and Physiology*. New Jersey: John Wiley and Sons.

Genstat. (2005) *GenStat Release 8.1* (PC/Windows XP) 8th edition, Lawes Agricultural Trust (Rothamsted Experimental Station).

Greeneem. (undated) *Greeneem Coir* [www document]. <http://www.greeneem.com/neemcoir.htm> (accessed 1st April 2005).

Hague, P. (1993) *Questionnaire Design*. London: Kogan Page.

Håkansson, I. and Lipiec, J. (2000) 'A Review of the Usefulness of Relative Bulk Density Values in Studies of Soil Structure and Compaction', *Soil and Tillage*, **53** (2), 71-85.

Halvorson, J.J., Gatto, L.W. and McCool, D.K. (2003) 'Overwinter Changes to Near-Surface Bulk Density, Penetration Resistance and Infiltration Rates in Compacted Soil', *Journal of Terramechanics*, **40**, 1-24.

Harrington, K. (1994) 'Control of Weed Grasses in Racetracks', in R.J. Gibb and M.P. Wrigley (eds.), *Proceedings of the 5th New Zealand Sports Turf Convention*, New Zealand: Massey University, 9-12 May 1994. Palmerston North, NZ: New Zealand Turf Culture Institute Inc, 178-179.

Henley, W.E., Rogers, K., Harkins, L. and Wood, J.L.N. (2006) 'A Comparison of Survival Models for Assessing Risk of Racehorse Fatality', *Preventive Veterinary Medicine*, **74**, 3-20.

Hernanz, J.L., Peixoto, H., Cerisola, C. and Sánchez-Giroń,V. (2000) 'An Empirical Model to Predict Soil Bulk Density Profiles in Field Conditions using Penetration Resistance, Moisture Content and Soil Depth', *Journal of Terramechanics*, **37** (4), 167-184.

Hess, T. (pers. comm.) Senior Lecturer in Agricultural Water Management, Institute of Water and the Environment, Cranfield University at Silsoe.

Hess, T. (1994) *Silsoe College Irrigation Scheduling Programme*. Silsoe: Silsoe College.

Hess, T. (1996a) *BALANCE – Soil Water Balance*. Silsoe: Silsoe College.

Hess, T. (1996b) "A Microcomputer Scheduling Program for Supplementary Irrigation", *Computers and Electronics in Agriculture*, **15** (3), 233-243.

Hess, T. (1996c) "Evapotranspiration Estimates for Water Balance Scheduling in the UK", *Irrigation News*, **25**, 31-36.

Hess, T., Leeds-Harrison, P. and Counsell, C. (2000) *WaSim Technical Manual*. Oxfordshire: H.R. Wallingford.

Hess, T. (2002) *Potential Evapotranspiration Program for Automatic Weather Stations*. Silsoe: Cranfield University at Silsoe.

Hill, T., Carmichael, D., Maylin, G. and Krook, L. (1986) 'Track Condition and Racing Injuries in Thoroughbred Horses', *The Cornell Veterinarian*, **76** (4), 361-379.

HMSO. (2003) *Water Act 2003: Chapter 37* [www document]. <http://www.legislation.hmso.gov.uk/acts/acts2003/20030037.htm> (accessed 4th April 2005).

HR Wallingford and Cranfield University. (2002) *WaSim – A Training Package for Irrigation, Drainage and Salinity*. Version 1.8.15. www.cranfield.ac.uk/iwe/wasim/

HRA. (2005) *The Horseracing Regulatory Authority General Instructions*. London: Horseracing Regulatory Authority.

Hubbard, J.C.E. (1984) *Grasses: A Guide to their Structure, Identification, Uses and Distribution in the British Isles* (3rd edition). London: Penguin.

Hughes, K. (1998) 'A Trainers Eye View', *New Zealand Turf Management Journal*, **12** (1), 11.

Hussein, J. and Adey, M.A. (1995) 'Changes of Structure and Tilth Mellowing in a Vertisol due to Wet/Dry Cycles in the Liquid and Vapour Phases', *European Journal of Soil Science*, **46**, 357-368.

Jiang, H., Fry, J.D. and Wiest, S.C. (1998) 'Variability in Turfgrass Water Requirements on a Golf Course', *HortScience*, **33** (4), 689-691.

Jensen, M.E., Burman, R.D. and Allen, R.G. (1990) *Evapotranspiration and Irrigation Water Requirements*. ASCE Manuals and Reports on Engineering Practice No.70. New York: American Society of Civil Engineers.

Jones, P. (2003) *An Investigation to Determine Whether the Incorporation of Zeolite into Sand Based Rootzone Construction Materials Benefits Grass Quality Growth and Nutrient Retention Without Adversely Affecting Drainage*. Unpublished MSc Thesis. Silsoe: Cranfield University at Silsoe.

Kirkham, M.B. (2005) *Principles of Soil and Plant Water Relations*. London: Elsevier Academic Press.

Klein, M. and Rothfels, J. (1999) *Can Environmental Regulation of X-Inefficient Firms Create a "Double Dividend"?* [www document]. <http://www.iwh-halle.de/d/publik/disc/103.pdf> (accessed 30th March 2005).

Knox, J.W., Weatherhead, E.K., and Ioris, A.A..R. (2006a) 'Allocation and Control of Water for Irrigated Agriculture in Scotland', *Water International*, *Journal of the International Water Resources Association* (in press)

Knox, J.W., Weatherhead, E.W. and J.A. Rodriguez-Diaz (2006b). *Exploration of the Reasonable Needs for New Licences Brought About by the Water Act 2003 (Trickle irrigation)*. Final Science Report (SC040008/SR) Environment Agency.

Lavelle, P. (2001) Soil Ecology. AA Dordrecht Kluwer Academic Publishers.

Laxon, L. (1998) 'What Trainers and Jockeys Expect of Race Track Surfaces', in *Proceedings of the 6th New Zealand Sports Turf Convention*, New Zealand: Rotorua Convention Centre, 28-31 July 1998. Palmerston North, NZ: New Zealand Sports Turf Institute, 128-129.

Lee, K.E. (1985) Earthworms: Their Ecology and Relationships with Soils and Land Use. Sydney: Academic Press.

Loague, K. and Green, R.E. (1991) 'Statistical and Graphical Methods for Evaluating Solute Transport Models: Overview and Application', *Journal of Contaminant Hydrology*, **7**, 51-73.

Lodge, R. and Shanks, S. (1999) *All-Weather Surfaces for Horses*. London: J.A. Allen.

Lodge, T.A. and Baker, S.W. (1992) 'Soil Moisture Content and Evapotranspiration Rates of Three Types of Golf Green Construction in Response to Different Rates of Irrigation', *The Journal of the Sports Turf Research Institute*, **68**, 104-113.

Magni, S., Ruga, L., Gaetani, M, Volterrani, M. and Miele, S. (2005) 'Effect of Drainage and Soil Amendment on the Quality of Horse Racecourse Turf under Simulated Use', *International Turfgrass Society Research Journal*, **10**, 466-471.

Marshall, T.J. and Holmes, J.W. (1979) *Soil Physics*. Cambridge: Cambridge University Press.

McNitt, A.S. (2005) 'Synthetic Turf in the USA – Trends and Issues', *International Turfgrass Society Research Journal*, **10**, 27-33.

Meron, M., Tsipris, J. and Charitt, D. (2003) 'Remote Mapping of Crop Water Status to Assess Spatial Variability of Crop Stress', in J. Stafford and A. Werner (eds.) *Precision Agriculture: Proceedings of the 4th European Conference on Precision Agriculture*, Berlin, 15-18 June 2003. The Netherlands: Wageningen Academic, 405-410.

Met Office. (undated) *Met Office Gridded Datasets* [www document]. <http://www.met-office.gov.uk/research/hadleycentre/obsdata/ukcip/index.html> (accessed 14th August 2003).

Miller, R.L., Action, C., Fullerton, D.A. and Maltby, J. (2002) *SPSS for Social Scientists*. Basingstoke: Palgrave MacMillan.

Mintel (2005) *Dog and Horse Racing – UK – September 2005*. [www document]. <http://reports.mintel.com/sinatra/reports/search_results/show&&type=RCItem&page=0&noaccess_page=0/display/id=125557> (accessed 14th May 2006).

Mitchell, J.K. and Soga, K. (2005) *Fundamentals of Soil Behaviour* (3rd edition). New Jersey: John Wiley and Sons.

Mitra, S. (2000) 'Salts Influence the Health of Turf', *Golf Course Management*, **68** (7), 64-67.

Mohr, R.D. (2002) 'Technical Change, External Economies, and the Porter Hypothesis', *Journal of Environmental Economics and Management*, **43**, 158-168.

Mulqueen, J., Stafford, J.V. and Tanner, D.W. (1977) 'Evaluation of Penetrometers for Measuring Soil Strength', *Journal of Terramechanics*, **14** (3), 137-151.

Multimap. (undated) *Multimap.com* [www document]. <http://www.multimap.com> (accessed 22nd November 2002).

Murphy, J. and Field, T. (1994) 'Racetrack Research', in R.J. Gibb and M.P. Wrigley (eds.), *Proceedings of the 5th New Zealand Sports Turf Convention*, New Zealand: Massey University, 9-12 May 1994. Palmerston North, NZ: New Zealand Turf Culture Institute Inc, 183-185.

Murphy, J.W., Field, T.R.O. and Thomas, V.J. (1996) 'Racetrack Traction Assessment by Penetrometer Part II: Application of the Model', *Journal of Turfgrass Management*, **1** (4), 51-62.

National Soil Resources Institute. (2002) *A Guide to Better Soil Structure*, Silsoe: Cranfield University at Silsoe

Netreg. (2005) *Sector Guidelines* [www document]. <http://www.environment-agency.gov.uk/netregs/sectors/?lang=_e&region=> (accessed 31st March 2005).

Neylon, J. and Stubbs, A. (1999) 'Turf Racing Surfaces: Determining the Best Evaluation Method', *Turf Craft International*. **65**, 63-66.

Oikawa, M., Inada, S., Fujisawa, A., Yamakawa, H. and Asano, M. (2000) 'The Use of a Racetrack Hardness Measurement System', *Equine Practice*, **22** (4), 26-29.

Oikawa, M. and Kusunose, R. (2005) 'Fractures Sustained by Racehorses in Japan during Flat Racing with Special Reference to Track Condition and Racing Time', *The Veterinary Journal*, **170**, 369-374.

Parkin, M., Powell, M. and Mathews, K. (1997) *Economics* (3rd edition). Harlow: Addison-Wesley.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2006) 'Catastrophic Fracture of the Lateral Condyle of the Third Metacarpus/Metatarsus in UK Racehorses – Fracture Descriptions and Pre-existing Pathology', *The Veterinary Journal*, **171**, 157-165.

Perry, C., Pocknee, S. and Hansen, O. (2003) 'A Variable Rate Pivot Irrigation Control System', in J. Stafford and A. Werner (eds.) *Precision Agriculture: Proceedings of the 4th European Conference on Precision Agriculture*, Berlin, 15-18 June 2003. The Netherlands: Wageningen Academic, 539-544.

Perris, J. (1999) 'Is the Going Getting Better?', *International Turfgrass Bulletin*, **205**, 23-25.

Pierrang, M. and Catrice, H. (1989) 'Turf for Horse Racing: Thatch Maintenance', in H. Takatoh (ed.) *Proceedings of the 6th International Turfgrass Research Conference*, Tokyo, 31st July – 5th August 1989. Tokyo: Japanese Society of Turfgrass Science, 247-248.

Pillai, U.P. and McGarry, D. (1999) 'Structure Repair of a Compacted Vertisol with Wet-Dry Cycles and Crops', *Soil Science Society of America Journal*, **63** (1), 201-210.

Pinchbeck, G.L., Clegg, P.D., Proudman, C.J., Morgan, K.L., Wood, J.L.N. and French, N.P. (2002) 'Risk Factors and Sources of Variation in Horse Falls in Steeplechase Racing in the UK', *Preventative Veterinary Medicine*, **55**, 179-192.

Pinchbeck, G.L., Clegg, P.D., Proudman, C.J., Stirk, K.L., Morgan, K.L. and French, N.P. (2004) 'Horse Injuries and Racing Practices in National Hunt Racehorses in the UK: The Results of a Prospective Cohort Study', *The Veterinary Journal*, **167**, 45-52.

Porter, M.E. (1991) 'America's Green Strategy', *Scientific American*, **264** (4), 168.

Porter, M.E. and Van der Linde, C. (1995) 'Toward a New Conception of the Environment –Competitiveness Relationship', *Journal of Economic Perspectives*, **9** (4), 97-118.

Pratt, G.W. (1984) 'Racing Surfaces – A Survey of Mechanical Behaviour', *Proceedings of the 30th Annual Convention of the American Association of Equine Practitioners*. 321-331.

Qian, Y.L., Fry, J.D., Wiest, S.C. and Upham, W.S. (1996) 'Estimating Turfgrass Evapotranspiration Using Atmometers and the Penman-Monteith Model', *Crop Science*, **36**, 699-704.

Richie, W.E., Green, R.L. and Gibeault, V.A. (1997) 'Using ET_o (Reference Evapotranspiration) for Turfgrass Irrigation Efficiency', *California Turfgrass Culture*, **47** (3 and 4), 9-15.

Riggs, C.M. (2002) 'Fractures – A preventable Hazard of Racing Thoroughbreds?', *The Veterinary Journal*, **163**, 19-29.

Rowell, D.L. (1994) *Soil Science: Methods and Applications*. Harlow: Longman.

Rowlawn. (2004) *Products* [www document]. <http://www.rowlawn.co.uk/productDetail.asp?productID=1> (accessed 16th December 2004).

Scott, H.D. (2000) *Soil Physics: Agricultural and Environmental Applications*. Ames: Iowa State University Press.

Shildrick, J.P. (1985) 'Thatch: A Review with Special Reference to the UK Golf Courses', *The Journal of the Sports Turf Research Institute*, **61**, 8-25.

Singh, P. (undated) *Data Needs for Soil Water Balance Simulation* [www document]. <http://www.icrisat.org/gt-aes/oneds/DataNeeds.htm> (accessed 16th June 2006).

Smith, P.D. and Thomasson, A.F. (1982) 'Density and Water-Release Characteristics', in B.W. Avery and C.L. Bascomb (eds.) *Soil Survey laboratory Methods.* Technical Monograph No.6, 42-56.

Smith, J., Smith, P. and Addiscott, T. (1996) 'Quantitative Methods to Evaluate and Compare Soil Organic Matter (SOM) Models', in D.S. Powlson, P. Smith and J.U. Smith (eds.) *Evaluation of Soil Organic Matter Models*, Nato ASI Series, **138**, 181-199.

Snyder, V.A. and Miller, R.D. (1985) 'Tensile Strength of Unsaturated Soils', *Soil Science Society of America Journal*, **49** (1), 58-65.

Sokal, R.R. and Rohlf, F.J. (1995) *Biometry: The Principles and Practices of Statistics in Biological Research*. New York: W.H. Freeman.

Spoor, G. and Godwin, R.J. (1979) 'Soil Deformation and Shear Strength Characteristics of some Clay Soils at Different Moisture Contents', *Journal of Soil Science*, **30**, 483-498.

SPSS (2001) *SPSS for Windows*, Release 11.0.0.

SSSA. (1997) *Glossary of Soil Science Terms 1996*. Wisconsin, USA: Soil Science Society of America.

StatSoft, Inc. (2004). *STATISTICA* (data analysis software system), version 7. www.statsoft.com.

Stewart, B.A. and Nielson, D.R. (1990) *Irrigation of Agricultural Crops*. Agronomy no.30. Wisconsin, USA: American Society of Agronomy.

Stover, S.M. (2003) 'The Epidemiology of Thoroughbred Racehorse Injuries', *Clinical Techniques in Equine Practice*, **2** (4), 312-322.

Taylor, H.M., Huch, M.G. and Klepper, B. (1972) 'Root Development in Relation to Soil Physical Conditions', in D. Hillel (ed.) *Optimizing the Soil Physical Environment Toward Greater Crop Yield*, London: Academic Press, 57-77.

Terzaghi, K., Peck, R.B. and Mesri, G. (1996) *Soil Mechanics in Engineering Practice* (3rd edition). New York: Wiley-Interscience.

TurfTrax. (2004) *The TurfTrax GoingStick: Operations Manual April 2004*. Oakley, Bedfordshire: TurfTrax Group Limited.

Turgeon, A.J. (2002) *Turfgrass Management* (6th edition). New Jersey: Prentice Hall.

USGA. (2006) *USGA Recommendations for a Method of Putting Green Construction* [www document]. <http://www.usga.org/turf/course_construction/green_articles/putting_green_guidelines.html> (accessed 20th October 2006).

Venu, S. (2002) *Environmental Regulation and Industrial Competitiveness: The Porter Hypothesis* [www document]. <http://www.blonnet.com/2002/04/19/stories/2002041900310900.htm> (accessed 30th March 2005).

Verheyen, K., Wood, J.L.N. and Lakhani, K.H. (2001) 'An Epidemiological Study to Determine Risk Factors for Fractures in British Racehorses in Training: A Preliminary Report', in R.B. Williams, E. Houghton and J.F. Wade (eds.), *Proceedings of the 13th International Conference of Racing Analysts and Veterinarians*, Cambridge: UK, 2000. Newmarket: R and W Publications, 274-277.

Waldron, L.J. and Dakessian, S. (1982) 'Effect of Grass, Legume and Tree Roots on Soil Shearing Resistance', *Soil Science Society of America Journal*, **46**, 894-899.

Water UK. (2006) *Water Resources: Should the UK have a National Water Grid?* [www document]. <http://www.water.org.uk/home/policy/reports/resources-briefings/national-grid> (accessed 17th July 2006).

Weatherhead, E. K., Knox**,** J.W., Twite, C.L., and Morris, J. (2002). *Optimum Use of Water for Industry and Agriculture* (Part B. Agriculture). Environment Agency R&D Technical Report. Cranfield University at Silsoe

Weatherhead, K. (2004) 'Changes to Irrigation Water Abstraction Management in England and Wales', *UK Irrigation*, **32**, 2-5.

Westbrook-Dominick, A. (1992) 'Thoroughbred's Tough Turf: Speed, Class and Beauty at Saratoga Springs', *Turf North*, **5** (10), 16-21.

Whalley, W.R., Leeds-Harrison, P.B., Clark, L.J. and Gowing, D.J.G. (2005) 'Use of Effective Stress to Predict the Penetrometer Resistance of Unsaturated Agricultural Soils', *Soil and Tillage Research*, **84** (1), 18-27.

Williams, R.B., Harkin, L.S., Hammond, C.J. and Wood, J.L.N. (2001a) 'Racehorse Injuries, Clinical Problems and Fatalities Recorded on British Racecourses from Flat Racing and National Hunt Racing During 1996, 1997 and 1998', *Equine Veterinary Journal*, **33** (5), 478-486.

Williams, R.B., Harkin, L.S., Hammond, C.J. and Wood, J.L.N. (2001b) 'Predominance of Tendon Injuries on British Racecourses (Flat Racing and National Hunt Racing)', in R.B. Williams, E. Houghton and J.F. Wade (eds.), *Proceedings of the 13th International Conference of Racing Analysts and Veterinarians*, Cambridge: UK, 2000. Newmarket: R and W Publications, 274-277.

Winter, P. (1998) ‘Racing into the Future to Keep the Going Good’, *International Turgrass Bulletin*, **200**, 13-16.

Wood, J.L.N., Harkins, L.S. and Rogers, K. (2001) ‘A Retrospective Study of Factors Associated with Racehorse Fatality on British Racecourses from 1990-1999’, in R.B. Williams, E. Houghton and J.F. Wade (eds.), *Proceedings of the 13th International Conference of Racing Analysts and Veterinarians*, Cambridge: UK, 2000. Newmarket: R and W Publications, 274-277.

Wrigley, M., Rawson, J. and Bridgman, J. (1994) ‘Total Management Considerations for Racing Surfaces’, in R.J. Gibb and M.P. Wrigley (eds.), *Proceedings of the 5th New Zealand Sports Turf Convention*, New Zealand: Massey University, 9-12 May 1994. Palmerston North, NZ: New Zealand Turf Culture Institute Inc, 180-182.

Zar, J.H. (1996) Biostatistical Analysis (3rd edition). London: Prentice-Hall International.

Zebarth, B.J. and Sheard, R.W. (1985) ‘Impact and Shear Resistance of Turf Grass Racing Surfaces for Thoroughbreds’, *American Journal of Veterinary Research*, **46** (4), 778-784.

APPENDIX ONE

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Appendix 1.1: EMI Soil Mapping for Sports Surfaces.

Traditional soil analysis methods usually require soil samples to be removed from the playing surface, which can affect the performance characteristics of the surface (e.g. ball roll on a golf putting green). The samples are then sent to specialist laboratories for analysis. This can be expensive and time consuming, and may not give an accurate account of the soil characteristics within the soil profile.

However, developments in remote sensing for precision farming has led to more efficient, economic and effective management practices, and has driven advancements in soil mapping techniques, including non-intrusive rapid scanning sensors that can measure soil apparent electrical conductivity (ECa) by electromagnetic induction (EMI). Research by Frogbrook *et al.* (2003) and Gale (2003) showed that EMI soil scanning can quickly identify general soil characteristics, and highlight areas that require further study using traditional soil analysis techniques. Gale (2003) also showed the potential of EMI scanning on sports surfaces.

How an EMI scanner works

There are two types of EMI scanner; the Veris® 3100, and the EM38. The Veris®3100 uses a pair of coulter-electrodes that inject electrical current into the soil. This method disturbs the surface, and therefore is not used on sports surfaces. The EM38 however provides non invasive methods of measuring ECa to a depth range of 1.5m in the vertical dipole mode and 0.75m in the horizontal dipole mode. The mode of operation of the EM38 is shown in Figure 1 overleaf. A magnetic field (that varies in strength with depth in the soil) is induced from a transmitting coil. The relative strength of the magnetic field is illustrated by the relative diameter of the circles in the figure. At 38mm below the soil surface the magnetic field is strongest and has an effective sensing depth of about 1500mm.

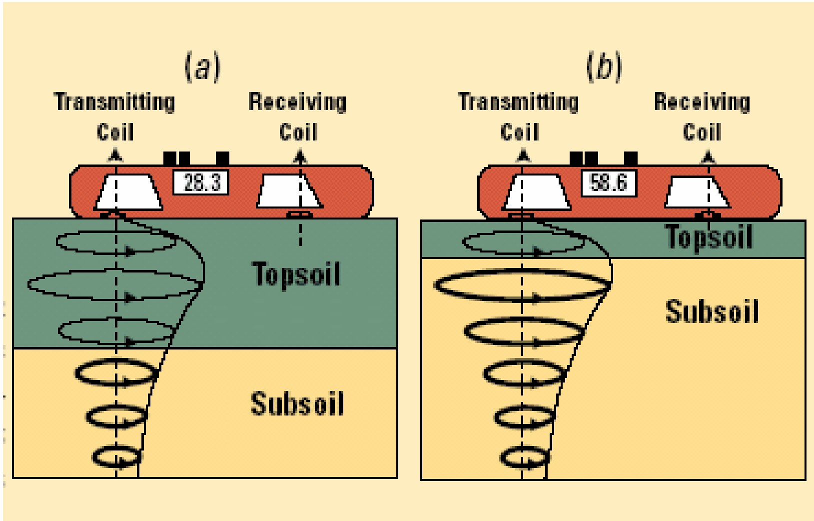

Figure 1: Principle mode of operation of EM38 (Davies *et al*., 1997)

A receiving coil reads primary and secondary "induced" currents in the soil. It is the relationship between these primary and secondary currents that measures soil conductivity. In the figure, the thicker circles illustrate soils that are better conductors of electrical current. Clay soils have a higher electrical conductivity than coarser textured soils, so when a clay horizon is nearer the surface (b in Figure 1) the EM sensor reading is higher. Deeper top soils having a clay horizon further below the soil surface (a in Figure 1) are less conductive to electrical current and have lower EM readings (Davies *et al*., 1997). The standard units of measuring bulk soil conductivity (EC_a) are millisiemens per metre (mSm^{-1}). Siemens are the inverse of Ohms and are the measurement of conductance.

(Taken from Gale, 2003)

Conducting an EMI scan

A site survey to plot and reference topographic levels, orientation and known landmarks of the area is carried out using Global Positioning System (GPS) surveying technology simultaneously to the EMI scan. The EMI scanner can record and position soil measurements at speeds between 10-15 km/h, when towed behind an appropriate vehicle, if ground weather conditions are suitable.

To pin point the exact locations of EMI readings in relation to longitude and latitude reference points located by the GPS satellites, differential GPS (DGPS) and radio transmitters and receivers are positioned at a ground base station and on the vehicle towing the EMI scanner. Data is logged at five points per second into a data logger during the scanning process. The data is then transferred to a computer to configure it into GIS files. Included in the data are a topographic plan of the area scanned – taken from the GPS component of the scan – and vertical and horizontal dipole results.

Maps produced from EMI data

Gale (2003) described two methods for transforming ECa data into images of the data. The first method – to explore the data set and see if the resultant ECa map showed any similar ECa variations – involved a clustering technique, using GIS Arcmap, to transform the ECa data into six classifications (Figure 2). The second method involved using 20 classifications for the original ECa data, which are then interpolated to produce contoured images (Figure 3).

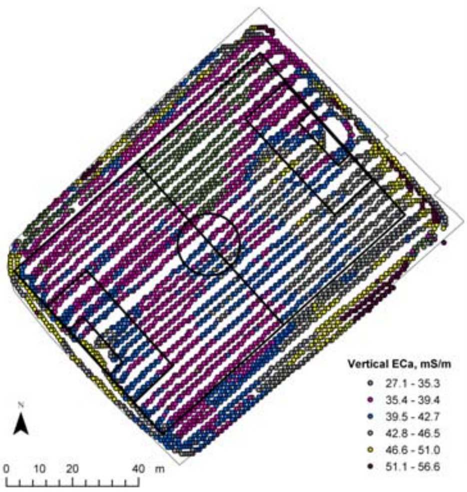

Figure 2: Clustered vertical ECa (mS/m) soil map (Gale, 2003)

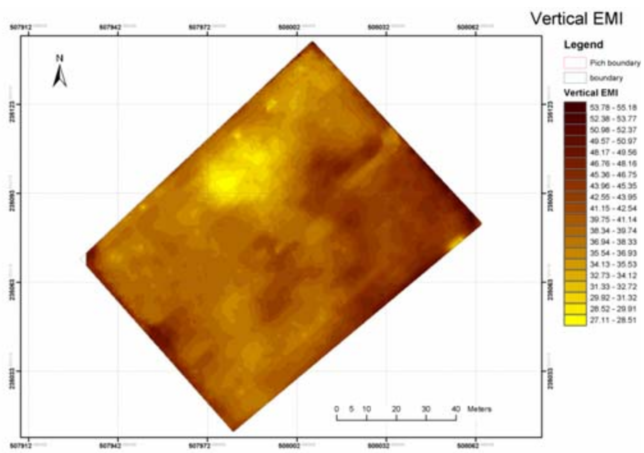

Figure 3: Verticle 20 classification contoured Eca (mS/m) soil map (Gale, 2003)

Using the map as a surface maintenance tool

The EMI soil maps in Figure 2 and Figure 3 show two layers of a sports surface GIS map (a football pitch in this case). Their importance to the manager of the facility extends from the ability of the soil to conduct an electrical current. Sand has a low conductivity (indicated by the lighter areas in Figure 3), silt has a medium conductivity, and clay has a high conductivity (indicated by the darker areas in Figure 3). The maps show the manager that an area of the pitch has a high sand content, which will influence drainage and potentially leaching of nutrients in that area, enabling the manager to adjust maintenance practices accordingly for that area.

Further analysis of the ECa data (such as analysis of variance) can also indicate any areas that may have compaction or differences in moisture content. Although Frogbrook *et al.* (2003) and Gale (2003) conclude that an EMI ECa map is not a substitute for soil sampling, but is a good method to identify areas for in-depth analysis. However an EMI ECa map does form a useful layer in a GIS database, enabling the manager quick access to site specific information that can be cross-referenced and, where necessary, analyzed with other information (layers) within the GIS database.

Conclusions

The adoption of Electromagnetic Induction (EMI) soil mapping technology is beginning to become widely accepted. Such acceptance may see the introduction of other developing technologies, such as yield mapping which is already present in the agriculture industry.

References

Davis, J.G., Kitchen, N.R., Sudduth, K.A. and Drummond, S. (1997) 'Using Electromagnetic Induction to Characterize Soils', *Better Crops and Plant Foods* No. 4, Published by the Potash and Phosphate Institute.

Frogbrook, Z.L., Oliver, M.A. and Derricourt, K.E. (2003) 'Exploring the Spatial Relations between Soil Properties and Electro-Magnetic Induction (EMI) and the Implications for Management', in J. Stafford and A. Werner (eds.) *Precision Agriculture: Proceedings of the 4th European Conference on Precision Agriculture*, Berlin, 15-18 June 2003. The Netherlands: Wageningen Academic, 217-222..

Gale, L.W. (2003) *A Preliminary Investigation into the Relationship between Electromagnetic Induction Data and Soil Chemical and Physical Properties of a Low Maintenance Natural Turf Football Pitch*. Unpublished MSc thesis. Silsoe: Cranfield University at Silsoe.

Appendix 1.2: Implementation of the Water Act 2003.

Subject	Implementation target date
Water resources management / abstraction licensing	• Licensing changes by 1 April 2005. • Drought plans become statutory in 2005. • Water Resources plans become statutory in 2007/08.
Water Services Regulatory Authority	• 1 April 2006.
Consumer Council for Water	• 1 Oct 2005 as the start date for functions of the CCW
Better Regulation provisions not dependent on Authority and CCW implementation	• 1 April 2004 - specialist members of the Competition Commission; • 1 Oct 2004 - Determination references under Section 12 WIA, including allocation of Competition Commission costs; forward work programmes and annual reports. • 1 April 2005 - Regulator's new statutory duties; social and environmental guidance; standards of performance; financial penalties; SI making powers for provision of information to the Council; reasons for regulator's decisions; co-operation between regulators; revised enforcement procedures*; links between Director's pay and standards of performance * this provision has now been commenced on 1 October 2004.
Competition	• Application process for new water supply licences in place by summer 2005. • Regime will start in autumn 2005. • Other measures later, for example collective licence modification process. • Power to modify the threshold will be in place by the time the regulators' review of competition is completed (not before 2008).
DWI powers	• 1 April 2004.
Fluoridation	• SI's on indemnity and consultation to be introduced in November 2004.
Water Resale	• Ofwat have the discretion to produce the Water Resale order.
Flood defence	• 1 April 2004.
Reservoirs	• EA to become enforcement authority on 1 October 2004. • SofS to issue directions for flood plans no earlier than 1 April 2005.
Water Conservation	• 1 April 2004.
Fire hydrants	• 1 April 2004.
Coal Mine Water Pollution	• 1 April 2004.
Contaminated land	• Section 86 will form part of a package to include extension of regime to embrace radioactivity. Anticipated 2005.
Transfer of discharge consents	• January 2005.
Trade effluent consents	• Spring 2005.
Self lay and requisitioning	• 28 May 2004.

Source: DEFRA

Appendix 1.3: Examples of Product and Process Offsets.

Example of a Product Offset

In 1990 the firm Raytheon found itself required, by the Montreal Protocol and the U.S. Clean Air Act, to eliminate ozone-depleting chlorofluorocarbons (CFCs) used for cleaning printed electronic circuit boards after the soldering process. Scientists at Raytheon initially thought that complete elimination of CFCs would be impossible. However, they eventually adopted a new semiaqueous, terpene-based cleaning agent that could be reused. The new method proved to result in an increase in average product quality, which had occasionally been compromised by the old CFC based cleaning agent, as well as lower operating costs. It would not have been adopted in the absence of environmental regulation mandating the phase-out of CFCs.

Example of a Process Offset

At Ciba-Geigy's dyestuff plant in New Jersey, the need to meet new environmental standards caused the firm to re-examine its wastewater streams. Two changes in its production process – replacing iron with a different chemical conversion agent that did not result in the formation of solid iron sludge and process changes that eliminated the release of potentially toxic product into the wastewater stream – not only boosted yield by 40% but also eliminated wastes, resulting in annual cost savings of $740,000.

Taken from Porter and van der Linde (1995)

APPENDIX TWO

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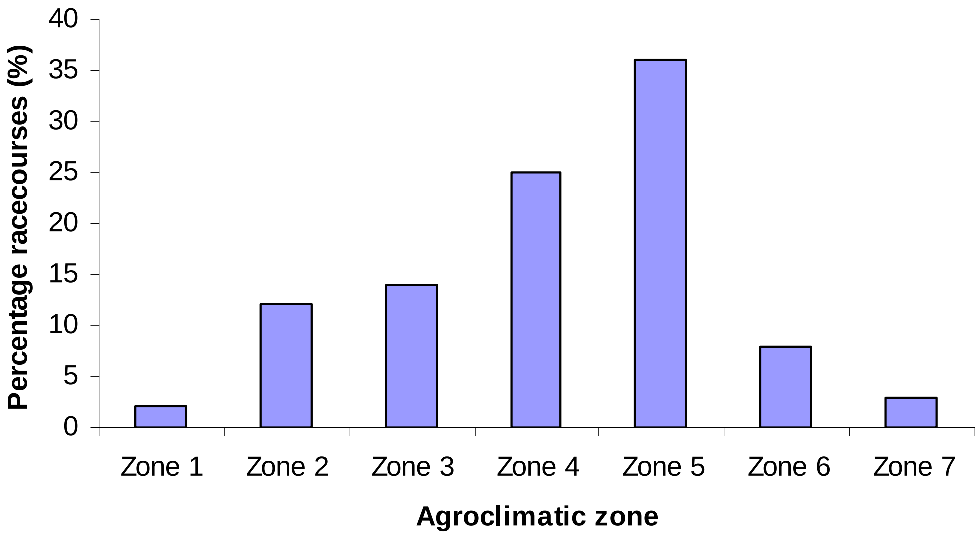
Appendix 2.1: Agroclimatic Zones.

The agroclimatic zones are based on the potential soil moisture deficit (PSMD) a zone will have at the end of a year. The level of PSMD in each zone is measured in mm, and given below as:

Zone 1	0 – 75mm	**Zone 2**	76 – 100mm	**Zone 3**	101 – 125mm
Zone 4	126 – 150mm	**Zone 5**	151 – 175mm	**Zone 6**	176 – 200mm
Zone 7	>200mm				

The percentage of racecourses in England, Scotland and Wales in each agroclimatic zone is shown in the diagram below,



Appendix 2.2: Racecourses in England, Scotland and Wales Grouped by Agroclimatic Zone.

Zone	***Racecourse***		
1	Ayr		
2	Carlisle	Cartmel	Hamilton Park
	Haydock Park	Hexham	Kelso
	Newcastle		
3	Aintree	Catterick	Chepstow
	Ludlow	Musselburgh	Sedgefield
	Uttoxeter	Wolverhampton	
4	Bangor-on-Dee	Bath	Beverley
	Goodwood	Newbury	Nottingham
	Perth	Plumpton	Pontefract
	Redcar	Ripon	Thirsk
	Warwick	Wetherby	Wincanton
5	Ascot	Brighton	Cheltenham
	Chester	Doncaster	Epsom Downs
	Exeter	Fakenham	Folkestone
	Fontwell Park	Hereford	Leicester
	Lingfield Park	Market Rasen	Newton Abbot
	Salisbury	Southwell	Stratford on Avon
	Taunton	Towcester	York
6	Newmarket	Sandown Park	Windsor
	Worcester	Yarmouth	
7	Huntingdon	Kempton Park	

The rainfall for racecourses in the same agroclimatic zone differs due to their spatial variation. Therefore mean rainfall values cannot be calculated. The graphs in Appendix 2.3 (overleaf) show the difference in rainfall (for 2001) for three racecourses that are in the same zone (zone 5). The long term average (LTA) rainfall for the area each racecourse is located in is also given. Note Ascot rainfall is greater than the LTA, Lingfield Park is almost equal to the LTA, and Doncaster had a lower rainfall in 2001 than the LTA.

Appendix 2.3: Comparison of the Annual Rainfall for 2001 with the Long Term Average Rainfall.

Only racecourses that gave 12 months rainfall data in the questionnaire survey (Chapter Three) are given.

Racecourse	***Annual rainfall for 2001*** *(mm)*	***30 Year average rainfall*** *(mm)*	***Difference to the 30 year average*** *(mm)*
Ascot	958.00	693.50	+ 264.50
Bangor-on-Dee	724.00	755.55	- 31.55
Beverley	790.00	719.05	+ 70.95
Cartmel	1258.00	1219.10	+ 38.90
Catterick	647.00	813.95	- 166.95
Chester	562.00	693.50	- 131.50
Doncaster	540.00	646.05	- 106.05
Epsom Downs	1102.00	722.70	+ 379.30
Folkestone	921.00	719.05	+ 201.95
Fontwell Park	969.00	821.25	+ 147.75
Goodwood	1063.00	821.25	+ 241.75
Hamilton Park	783.00	1292.10	- 509.10
Haydock Park	1031.00	861.40	+ 169.60
Hereford	819.00	886.95	- 67.95
Hexham	750.00	876.00	- 126.00
Kempton Park	782.00	624.15	+ 157.85
Lingfield Park	787.00	824.90	- 37.90
Ludlow	767.00	784.75	- 17.75
Musselburgh	723.00	795.70	- 72.70
Newbury	747.00	733.65	+ 13.35
Newcastle	754.00	638.75	+ 115.25
Newton Abbot	996.00	1073.10	- 77.10
Nottingham	782.00	602.25	+ 179.75
Perth	794.00	832.20	- 38.20
Plumpton	1144.00	890.60	+ 253.40
Pontefract	695.00	657.00	+ 38.00
Redcar	571.00	737.30	- 166.30
Ripon	609.00	817.60	- 208.60
Salisbury	1079.00	886.95	+ 192.05
Sandown Park	828.00	624.15	+ 203.85
Thirsk	604.00	627.80	- 23.80
Wetherby	669.00	722.70	- 53.70
Windsor	798.00	671.60	+ 126.40
York	554.00	605.90	- 51.90

Appendix 2.4: Survey Questionnaire.

Name of race course:...

Section A: Race course details

(If accurate details are not known, please give your best estimate)

1. Do you ever irrigate the race course? | 1 | YES/NO | (delete one)

IF YOUR ANSWER IS NO, PLEASE GO STRAIGHT TO SECTION C

		Flat	Hurdle	Steeplechase
2. Total length of race course(s) (m)	2			
3. Average width of race course(s) (m)	3			
4. Total area of irrigated land? (m^2)	4			

5. Grass sward composition as a percentage (please ensure entries total to 100%)

5	Bent		6	Fescue	
7	Rye		8	Timothy	
9	Annual meadow grass		10	Rough stalked meadow grass	
11	Smooth stalked meadow grass		12	Other (please specify in space below)	

Grass species	(%)	Grass species	(%)

6. Please identify the predominant soil type present with a 'P', and tick any other soil types that are present too

13	Sand		14	Sandy loam	
15	Sandy clay loam		16	Sandy clay	
17	Clay loam		18	Clay	
19	Silty clay		20	Silty clay loam	
21	Silt loam		22	Sandy silt loam	

7. How do you decide on your irrigation requirements? (please tick)

23	Evapotranspiration rate (ET)		24	Penetrometer readings	
25	Weather forecast		26	Visual assessment	
27	Timed interval e.g. every third day		28	Moisture meter	
29	Hard "going"		30	Other (please specify)	

8. What source(s) of water do you use for irrigation, and is it metered?

Enter the amount from each source as a percentage of the total water used (please ensure entries total to 100%)

		Metered	% of total
31	Surface water, including ponds, lakes, gravel or clay workings, rivers, streams or other water courses	YES/NO	
32	Ground water, including wells, bore holes and springs rising on the holding	YES/NO	
33	Public mains supply	YES/NO	
34	Rainwater collected on site	YES/NO	
35	Re-use of water from other purposes	YES/NO	
36	Other (please specify below)	YES/NO	
		TOTAL	100 %

9. Most / least water consumption in any year
(please state amount in m^3)

		m^3	Year
37	Most		
38	Least		

10. Irrigation system

39	Age of irrigation system (years)	
40	Pump type	
41	Pressure of system (bar)	
42	Flow rate of system (l/min)	
43	Metered before the pump	YES/NO
44	Metered after the pump	YES/NO
45	Metered before and after the pump	YES/NO

11. Are there restrictions to the water license(s) for irrigation water?

46	YES/NO

(delete one)

If yes, please specify:

12. Is there a fixed amount of water available for irrigation?

47	YES/NO

(delete one)

If yes, please state amount in m^3

Section B: Irrigation use in 2001

13. Did you irrigate the race course in 2001? | 48 | YES/NO | (delete one)

IF YOUR ANSWER IS NO, PLEASE GO STRAIGHT TO SECTION C

		Flat	Hurdle	Steeplechase
14. Total amount of irrigation water used in 2001? (m^3)	49			
15. Total area of irrigated land in 2001? (m^2)	50			

16. What method(s) of irrigation did you use for irrigation in 2001?
Enter the area irrigated by each method as a percentage of the total area (please ensure entries total to 100%)

		Percentage of total
51	Static or hand-moved sprinklers, tow lines	
52	Hose reels with rain guns	
53	Hose reels with booms	
54	Hose and hand held spray gun	
55	Pop-up sprinklers	
56	Other (please specify)	
	TOTAL	100%

17. What was the total monthly rainfall and amount of irrigation applied in 2001? (please state rainfall in mm, and irrigation applied in m^3)

		Rainfall (mm)	Irrigation (m^3)			Rainfall (mm)	Irrigation (m^3)
57	Jan			58	Feb		
59	Mar			60	Apr		
61	May			62	Jun		
63	Jul			64	Aug		
65	Sept			66	Oct		
67	Nov			68	Dec		

Section C: Race days

18. Number of race days in 2001?

69	Flat season	
70	Jump season	

19. Number of cancelled race days between 1991-2001 due to

		Flat	Jump
72	Frozen ground		
73	Water logging		
74	Other		

If 'other' please give details:

Appendix 2.5: Descriptive Statistics of the Questionnaire.

The questionnaire survey was completed and returned by racecourses in England, Scotland, and Wales. The full results of the questionnaire survey (raw data and analysis) are given in the accompanying CD-Rom at the back of this thesis.

Number of responses to the questionnaire survey

	No. of questionnaires	*Percent (%)*
Returned questionnaires	49	83
Missing questionnaires	10	17
Total	59	100

Mean Length of racecourses (m)

	N	*Minimum*	*Maximum*	*Mean*	*S.E.*
Flat course	28	1650	4180	2882.93	118.05
Hurdle course	31	1609	3219	2459.94	73.41
Steeplechase course	31	1609	3219	2474.55	79.76

Mean Width of racecourses (m)

	N	*Minimum*	*Maximum*	*Mean*	*S.E.*
Flat course	29	16	40	23.45	1.01
Hurdle course	31	10	40	21.48	1.52
Steeplechase course	31	11	40	19.68	1.30

APPENDIX THREE

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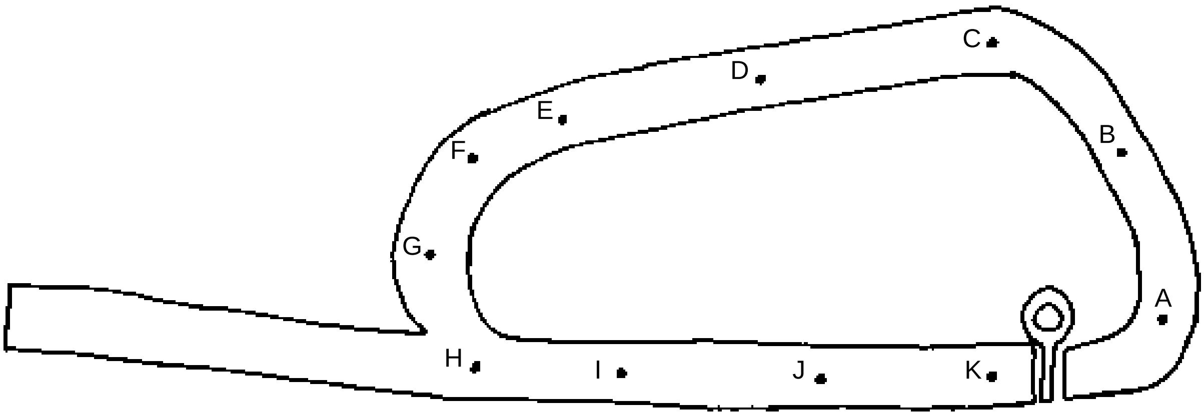
Appendix 3.1: Audit of Eight Racecourses.

The locations where samples were collected / measured on the eight racecourses are given in the following sections. A summary of the soil type and bulk density values are also given. Detailed analysis of the soil type, bulk density and soil penetrative resistance are given in the accompanying CD-Rom.

Appendix 3.1.1: Catterick Racecourse

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the flat and hurdle tracks. The soil textural classification and bulk density are given in the following table.

Soil textural classification for Catterick Racecourse

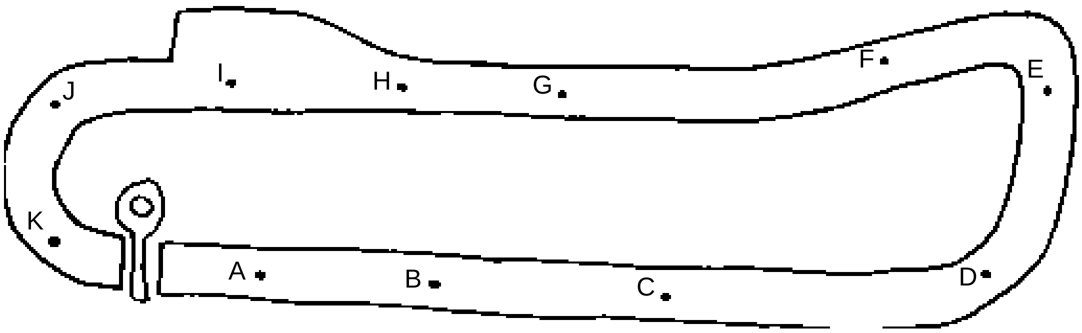


Location	Textural Class	Bulk Density (g/cm^3)	Location	Textural Class	Bulk Density (g/cm^3)
A – Flat	Sandy loam	0.78	**A – Hurdle**	Sandy loam	0.87
B – Flat	Sandy loam	0.90	**B – Hurdle**	Sandy loam	0.85
C – Flat	Sandy loam	0.84	**C – Hurdle**	Sandy clay loam	0.93
D – Flat	Sandy loam	0.79	**D – Hurdle**	Sandy loam	1.00
E – Flat	Sandy loam	0.88	**E – Hurdle**	Sandy loam	1.00
F – Flat	Sandy loam	0.79	**F – Hurdle**	Sandy loam	1.11
G – Flat	Sandy loam	0.72	**G – Hurdle**	Sandy loam	1.17
H – Flat	Sandy loam	0.82	**H – Hurdle**	Sandy loam	1.02
I – Flat	Sandy loam	0.97	**I – Hurdle**	Sandy loam	1.03
J – Flat	Sandy loam	0.80	**J – Hurdle**	Sandy loam	0.98
K – Flat	Sandy loam	0.87	**K – Hurdle**	Sandy loam	1.07

Appendix 3.1.2: Leicester Racecourse.

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the flat and jump tracks. The soil textural classifications and bulk density are given in the following table.

Soil textural classification for Leicester Racecourse

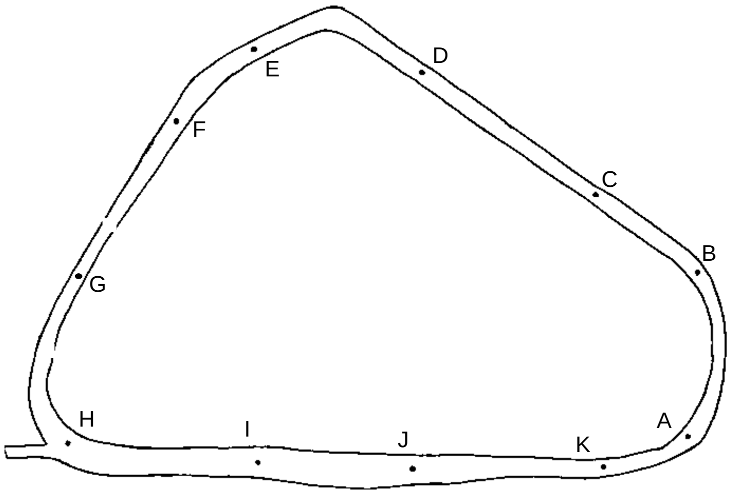


Location	Textural Class	Bulk Density (g/cm^3)	Location	Textural Class	Bulk Density (g/cm^3)
A – Flat	Sandy clay loam	0.67	**A – Jump**	Sandy loam	0.89
B – Flat	Sandy clay loam / Sandy loam	0.78	**B – Jump**	Sandy loam	0.94
C – Flat	Clay loam	0.68	**C – Jump**	Clay loam	0.82
D – Flat	Sandy clay loam	0.67	**D – Jump**	Sandy clay loam	0.97
E – Flat	Sandy clay loam	0.80	**E – Jump**	Clay loam	0.77
F – Flat	Clay loam	0.65	**F – Jump**	Clay loam	0.72
G – Flat	Sandy clay loam	0.63	**G – Jump**	Sandy clay loam	0.78
H – Flat	Sandy loam	0.74	**H – Jump**	Sandy loam	0.94
I – Flat	Clay	0.56	**I – Jump**	Clay loam	0.81
J – Flat	Clay loam	0.79	**J – Jump**	Sandy loam	1.11
K – Flat	Sandy clay loam	0.71	**K – Jump**	Sandy clay loam	0.94

Appendix 3.1.3: Lingfield Park Racecourse.

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the flat and jump tracks. The soil textural classifications and bulk density are given in the following table.

Soil textural classification for Lingfield Park Racecourse

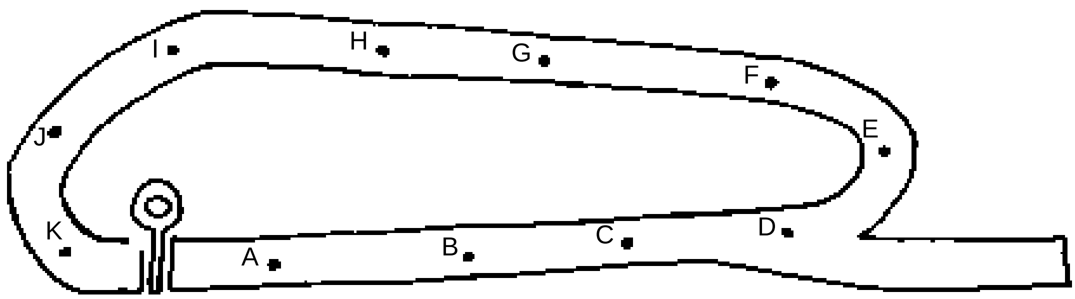


Location	Textural Class	Bulk Density (g/cm^3)	Location	Textural Class	Bulk Density (g/cm^3)
A – Flat	Sandy Silt Loam	1.17	**A – Jump**	Silty Clay Loam	0.84
B – Flat	Sandy Silt Loam	1.02	**B – Jump**	Clay Loam/Sandy Silt Loam	0.99
C – Flat	Sandy Silt Loam	1.34	**C – Jump**	Sandy Silt Loam	0.86
D – Flat	Sandy Silt Loam	1.14	**D – Jump**	Sandy Silt Loam	1.10
E – Flat	Sandy Silt Loam	0.72	**E – Jump**	Sandy Silt Loam	0.73
F – Flat	Sandy Silt Loam	0.76	**F – Jump**	Silt Loam	0.94
G – Flat	Sandy Silt Loam	0.58	**G – Jump**	Sandy Silt Loam	0.70
H – Flat	Sandy Silt Loam	1.16	**H – Jump**	Sandy Silt Loam	0.73
I – Flat	Sandy Silt Loam	0.92	**I – Jump**	Sandy Silt Loam	0.71
J – Flat	Sandy Silt Loam	0.69	**J – Jump**	Silty Clay Loam	0.82
K – Flat	Sandy Silt Loam	0.85	**K – Jump**	Sandy Silt Loam	0.70

Appendix 3.1.4: Musselburgh Racecourse.

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the flat and jump tracks. The soil textural classifications and bulk density are given in the following table.

Soil textural classification for Musselburgh Racecourse

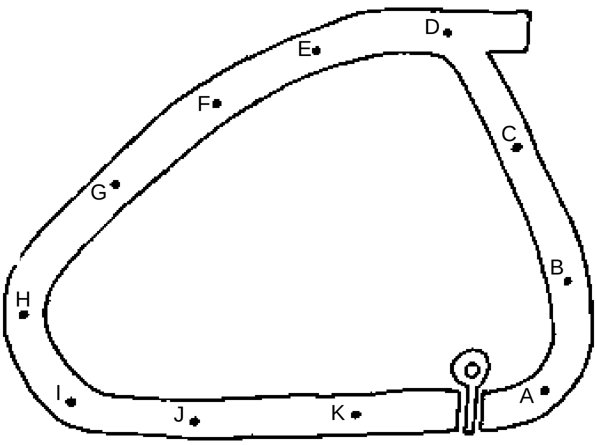


Location	**Textural Class**	**Bulk Density** (g/cm^3)	**Location**	**Textural Class**	**Bulk Density** (g/cm^3)
A – Flat	Loamy sand	0.92	**A – Jump**	Sand / loamy sand	1.13
B – Flat	Sandy loam / loamy sand	0.92	**B – Jump**	Sand	1.16
C – Flat	Sandy loam	0.88	**C – Jump**	Sand	0.88
D – Flat	Loamy sand	0.73	**D – Jump**	Sand	1.08
E – Flat	Loamy sand	0.90	**E – Jump**	Sand	1.23
F – Flat	Loamy sand	1.13	**F – Jump**	Sandy loam	1.12
G – Flat	Loamy sand	0.99	**G – Jump**	Sandy loam	1.13
H – Flat	Sandy loam	0.77	**H – Jump**	Sandy loam	1.16
I – Flat	Loamy sand	0.92	**I – Jump**	Loamy sand	0.91
J – Flat	Loamy sand	0.83	**J – Jump**	Loamy sand	0.96
K – Flat	Loamy sand	1.06	**K – Jump**	Loamy sand	1.06

Appendix 3.1.5: Newcastle Racecourse.

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the flat and jump tracks. The soil textural classifications and bulk density are given in the following table.

Soil textural classification for Newcastle Racecourse

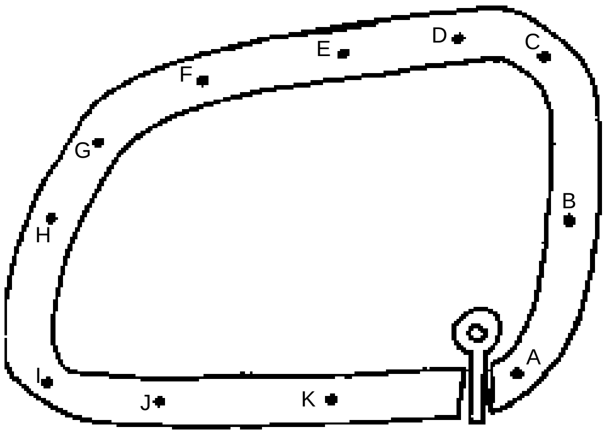


Location	Textural Class	Bulk Density (g/cm^3)	Location	Textural Class	Bulk Density (g/cm^3)
A – Flat	Sandy clay loam	0.64	**A – Jump**	Sandy clay loam	0.74
B – Flat	Sandy clay loam	0.60	**B – Jump**	Sandy clay loam	0.66
C – Flat	Sandy loam	0.66	**C – Jump**	Sandy clay loam	0.61
D – Flat	Sandy clay loam	0.69	**D – Jump**	Sandy clay loam	0.75
E – Flat	Sandy clay loam	0.62	**E – Jump**	Sandy clay loam	0.75
F – Flat	Sandy clay loam	0.62	**F – Jump**	Sandy clay loam	0.62
G – Flat	Sandy clay loam	0.58	**G – Jump**	Sandy clay loam	0.69
H – Flat	Sandy clay loam	0.58	**H – Jump**	Sandy clay loam	0.78
I – Flat	Sandy clay loam	0.66	**I – Jump**	Clay loam	0.65
J – Flat	Sandy clay loam	0.60	**J – Jump**	Clay loam	0.76
K – Flat	Sandy clay loam	0.60	**K – Jump**	Sandy loam	0.76

Appendix 3.1.6: Newton Abbot Racecourse.

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the hurdle and jump tracks. The soil textural classifications and bulk density are given in the following table.

Soil textural classification for Newton Abbot Racecourse

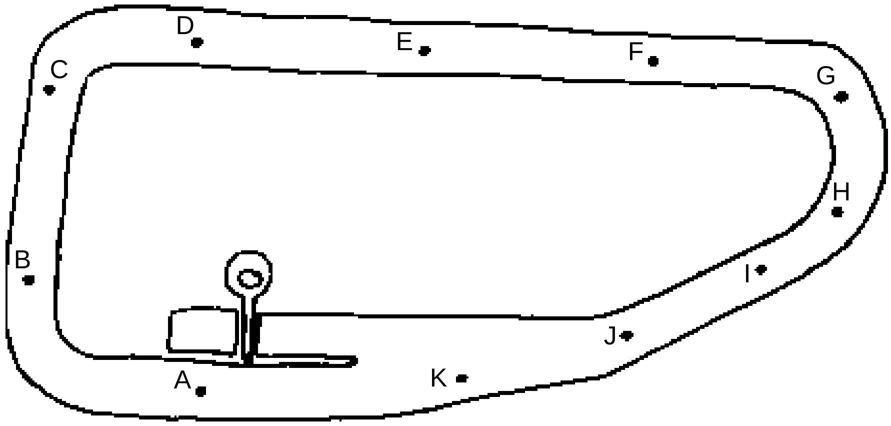


Location	Textural Class	Bulk Density (g/cm^3)	Location	Textural Class	Bulk Density (g/cm^3)
A – Hurdle	Sandy silt loam	0.66	**A – Jump**	Sandy loam	0.60
B – Hurdle	Clay loam	0.59	**B – Jump**	Clay loam	0.65
C – Hurdle	Clay loam / Sandy silt loam	0.71	**C – Jump**	Clay loam	0.57
D – Hurdle	Clay loam	0.63	**D – Jump**	Sandy loam	0.84
E – Hurdle	Sandy loam	0.72	**E – Jump**	Sandy clay loam	0.50
F – Hurdle	Sandy loam	0.45	**F – Jump**	Sandy loam	0.60
G – Hurdle	Clay loam	0.60	**G – Jump**	Sandy loam	0.72
H – Hurdle	Clay loam	0.52	**H – Jump**	Clay loam	0.53
I – Hurdle	Sandy loam	0.63	**I – Jump**	Clay loam	0.55
J – Hurdle	Sandy loam	0.69	**J – Jump**	Clay loam	0.49
K – Hurdle	Sandy loam	0.67	**K – Jump**	Clay loam	0.52

Appendix 3.1.7: Sandown Park Racecourse.

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the flat and jump tracks. The soil textural classifications and bulk density are given in the following table.

Soil textural classification for Sandown Park Racecourse

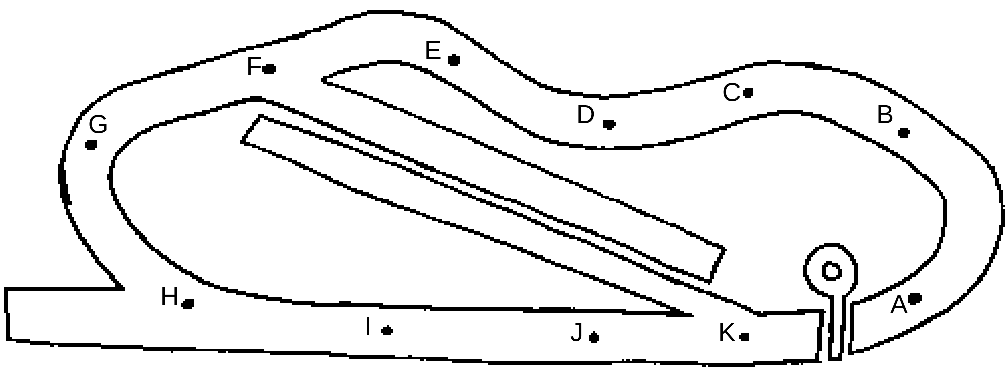


Location	Textural Class	Bulk Density (g/cm^3)	Location	Textural Class	Bulk Density (g/cm^3)
A – Flat	Loamy sand	0.84	**A – Jump**	Loamy sand	0.94
B – Flat	Loamy sand	0.81	**B – Jump**	Sandy loam	0.97
C – Flat	Loamy sand / Sandy loam	0.72	**C – Jump**	Loamy sand	0.90
D – Flat	Sandy loam	0.74	**D – Jump**	Sandy loam	1.08
E – Flat	Loamy sand / Sandy loam	0.67	**E – Jump**	Loamy sand	0.91
F – Flat	Sandy loam	0.79	**F – Jump**	Sandy loam	0.91
G – Flat	Loamy sand	0.83	**G – Jump**	Sandy loam	1.02
H – Flat	Sandy loam	0.66	**H – Jump**	Sandy loam	0.90
I – Flat	Loamy sand	0.88	**I – Jump**	Sandy loam / Loamy sand	0.94
J – Flat	Loamy sand	0.71	**J – Jump**	Loamy sand	1.04
K – Flat	Loamy sand	0.71	**K – Jump**	Loamy sand	0.92

Appendix 3.1.8: Uttoxeter Racecourse.

The locations of the sampling and on-site measurements that were carried out are shown on the map (below), and were taken from the corresponding locations on the hurdle and jump tracks. The soil textural classifications and bulk density are given in the following table.

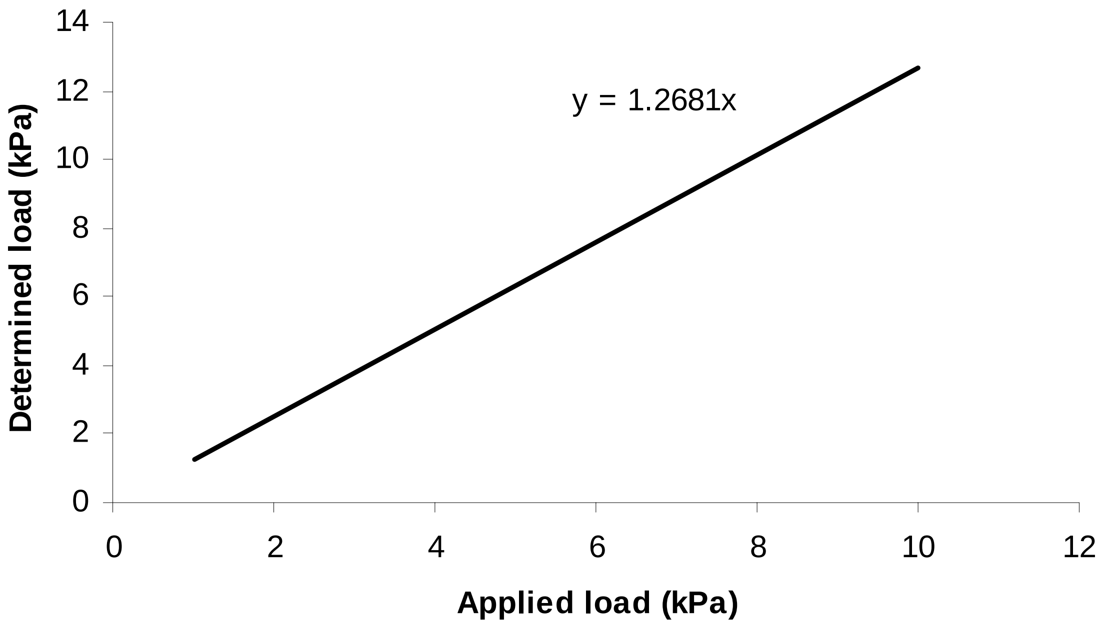
Soil textural classification for Uttoxeter Racecourse



Location	**Textural Class**	**Bulk Density** (g/cm^3)	**Location**	**Textural Class**	**Bulk Density** (g/cm^3)
A – Hurdle	Sandy loam	0.73	**A – Jump**	Clay loam	0.77
B – Hurdle	Sandy clay loam / Sandy loam	0.83	**B – Jump**	Clay loam	0.75
C – Hurdle	Sandy clay loam	0.74	**C – Jump**	Sandy clay loam / Clay loam	0.68
D – Hurdle	Sandy silt loam / Clay loam	0.74	**D – Jump**	Sandy loam	0.65
E – Hurdle	Sandy loam	0.82	**E – Jump**	Sandy loam	0.79
F – Hurdle	Sandy loam	0.75	**F – Jump**	Sandy clay loam / Clay loam	0.68
G – Hurdle	Sandy loam	0.97	**G – Jump**	Sandy loam	0.69
H – Hurdle	Sandy loam / Sandy clay loam	0.77	**H – Jump**	Clay loam	0.71
I – Hurdle	Clay loam	0.84	**I – Jump**	Clay loam	0.57
J – Hurdle	Sandy loam	0.82	**J – Jump**	Clay loam	0.68
K – Hurdle	Sandy clay loam	0.74	**K – Jump**	Sandy clay loam / Clay loam	0.60

Appendix 3.2: Calibration of the Penetrometer.

The penetrometer was calibrated by applying known loads to the penetrometer and recording the determination of the load give by the penetrometer. Linear regression analysis was conducted (shown in the graph below) to show the correlation between the two sets of values. The description of the correlation (Y = 1.2681 x X) was used to convert the readings given by the penetrometer to a calibrated real value.



Appendix 3.3: Larger Bulk Density Samples taken at Leicester Racecourse.

Clay loam samples

SAMPLE	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Tin number	1078	47	16	1073	1089	10	30
Wt of wet soil +tin (g)							
Wt of dry soil +tin (g)	1978	2000.85	2102.75	1965.8	1899.25	2084.55	2194.25
Wt of tin (g)	973.74	937.58	1034.72	1018.92	1015.92	978.08	1029.92
Sample volume cm^3	1021.15	1021.15	1021.15	1021.15	1021.15	1021.15	1021.15
Wt of water (g)							
Wt of dry sample (g)	1004.26	1063.27	1068.03	946.88	883.33	1106.47	1164.33
Moisture content %	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Dry Bulk Density g/cm^3	**0.98**	**1.04**	**1.05**	**0.93**	**0.87**	**1.08**	**1.14**

Mean bulk density = 1.08 Mg m^3

Sandy loam samples

SAMPLE	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Tin number	36	1001	1097	1041	1024	1100	1010	74
Wt of wet soil +tin (g)	2577.95	2548.4	2456.95	2667.45	2515.3	2580.25	2592.15	2481.3
Wt of dry soil +tin (g)	2093.95	2023.1	1948.55	2185.7	2031	2109.6	2132.45	2006.4
Wt of tin (g)	1017.3	1028.18	973.3	1033.38	968.88	975.76	1018.94	938.34
Sample volume cm^3	1021.15	1021.15	1021.15	1021.15	1021.15	1021.15	1021.15	1021.15
Wt of water (g)	484	525.3	508.4	481.75	484.3	470.65	459.7	474.9
Wt of dry sample (g)	1076.65	994.92	975.25	1152.32	1062.12	1133.84	1113.51	1068.06
Moisture content %	44.95%	52.80%	52.13%	41.81%	45.60%	41.51%	41.28%	44.46%
Dry Bulk Density g/cm^3	**1.05**	**0.97**	**0.96**	**1.13**	**1.04**	**1.11**	**1.09**	**1.046**

Mean bulk density = 1.08 Mg m^3

Samples highlighted in yellow are possibly divot mix and therefore were excluded from the determination of the mean bulk density for each soil type.

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Appendix 4.1: The Going-Stick Operators Manual.

This appendix provides an abridged version of the going-stick operator's manual. The full manual can be found on the accompanying CD-Rom at the back of this thesis.

Introduction to the TurfTrax GoingStick

The TurfTrax GoingStick has been designed to assess the going conditions on a UK racecourse using a numerical scale of 1 – 15. The stick measures penetration - the force taken to push the tip of the stick fully into the ground, and shear - the force taken to pull the handle of the stick back to an angle of 45° away from the ground.

Once three readings of penetration and shear are taken, these readings are then averaged to give a numerical value and a going statement derived from this value, using the TurfTrax Going Scale. To give a true assessment of going around the course, a zoned Going grid is created based on an EMI scan (see section 2 & Appendix 1). Furthermore, at least 50% of the total number of grids on each course should be tested to produce a valid going assessment. For example if you are testing a National Hunt course with 80 grids, 40 on the Hurdle and on 40 the Chase, at least 20 grids on each course should be tested.

The GoingStick is then connected to a PC via a serial port once all readings have been taken. This offers the ability for information to be transmitted without manual intervention providing purity of audit trail. Bespoke software then converts this data to a flat file to which outputs via Excel as a .CSV file (see Appendix 2). This information is then sent to TRD via email, fax or verbally by telephone. TurfTrax Racing Data (TRD) then manually updates the going map image for each course before uploading this to our website at www.turftrax.co.uk. This information is retained separately in either hard copy or digital format by TRD.

The Going Map is then constructed by taking the average GoingStick reading for each, zone and ascribing this to a set colour for this index. The average reading for all sections of a course is known as the TurfTrax Index and is given as a single figure to one decimal point that translates to the traditional bands.

Key used on Going Map

13+	Hard
12	Firm
10	Good to Firm
8	Good
6	Good to Soft
4	Soft
2	Heavy

Going Index Guide

13.0 –15.0 = Hard

11.0 – 12.9 = Firm

9.0 – 10.9 = Good to Firm

7.0 – 8.9 = Good

5.0 –6.9 = Good to Soft

3.0 –4.9 = Soft

1.0 –2.9 = Heavy

Using the Going-Stick

Selecting a Grid Point

Once the stick has been turned on, previous data has been cleared and the correct calibration type has been selected, you are ready to start taking readings on the course. The following screen should be shown 'Waypoint = 1+/- Flat'. (If a going description and value is being shown at this point, the stick has not been cleared of data.) The waypoint number refers to the reference point on the TurfTrax going grid. Either find the nearest number on the running rail or check the grid map to find your starting location. If you are positioned in Grid 1 click the next button, if you are starting in another grid press the + button until the correct Grid number is showing, then click the next button.

Taking a Reading

The screen should be showing the words 'Push into Ground'. At this point ensure the stick is as vertical as possible push the tip of the stick firmly into the ground in one gradual movement, until the whole of the tip is in the ground and turf stop is in contact with the ground. The footrest can be used as an aid if the ground is quite firm and dry, but ensure that the stick is kept vertical when the footrest is used and that your foot pushes the stick downwards not at an angle in to the ground. At this point momentarily release the pressure on the stick handle, if you continue to push once the turf stop has hit the ground the tip sensor will still be reading pressure on the tip.

The stick will now display the words 'Pull Stick Back'. At this point pull the handle of the stick gradually back towards the ground until the handle is at an angle of approximately 45° away from the surface. Now remove the tip from the ground. The screen will again show

'Push into Ground'. Repeat the process above two more times, pushing the stick into the ground and pulling back. The stick needs to take a total of 3 penetration and 3 shear readings to give an average going for the grid/area that is being tested.

Once 3 readings have been taken the stick will give a Going Value and statement for the area that has just been tested, the screen should show something like 'Waypoint=1 8.7 Flat'. It may be useful to refer to the TurfTrax Going Scale at this point, the stick is saying that the ground in the example is Good but is on the Good to Firm side or quicker side of Good. The going scale is on the handle of the stick for reference as well as being printed in section 2 of the manual.

Variable Readings
If the ground that has been tested is particularly variable or an anomaly has been measured by the stick, such as a stone or verti-drain hole, the stick will display the words 'Waypoint=1 Too variable Flat'. At this point the operator can make a decision to either re-take the readings within that grid or move on to the next grid. To re-take the reading press the next button, use the +/- button to scroll down to the last waypoint number, and click the next button again. If you chose not re-take the reading, when the results are downloaded it will be indicated that this area of the course produced a variable reading.

Moving On
Once you have taken a going measurement in your first grid area and it is displaying on the screen, move onto the next grid area. Press the next button, the Waypoint number will increment up by one. If this is the grid you require click next to take readings, or use the +/- button to scroll to the correct grid.

Finishing Off
Once you have taken readings from all relevant areas of the course, you are ready to download them onto a Computer. If it is going to be a while before you download the readings you can turn the stick off without any data being lost. If the stick runs out of charge while you are walking the course the stick will also save any data you have already collected.

Appendix 4.2: Calibration of the Going-Stick.

Known weights were applied to the going-stick when it was switched to its going measuring mode and when it was switched to its engineering mode. Values for penetration and shear for the known weights were recorded. The known weights were converted to an applied load in MPa. The recorded values of penetration and shear were then correlated to the applied loading using linear regression. The description of the regression provided the correction factor to convert the going-stick values into MPa.

To covert values of going, determined by the going-stick, to MPa:

Divide penetration value by 3.299 (based on results of Figure 1).

Divide shear value by 10.505 (based on results of Figure 1).

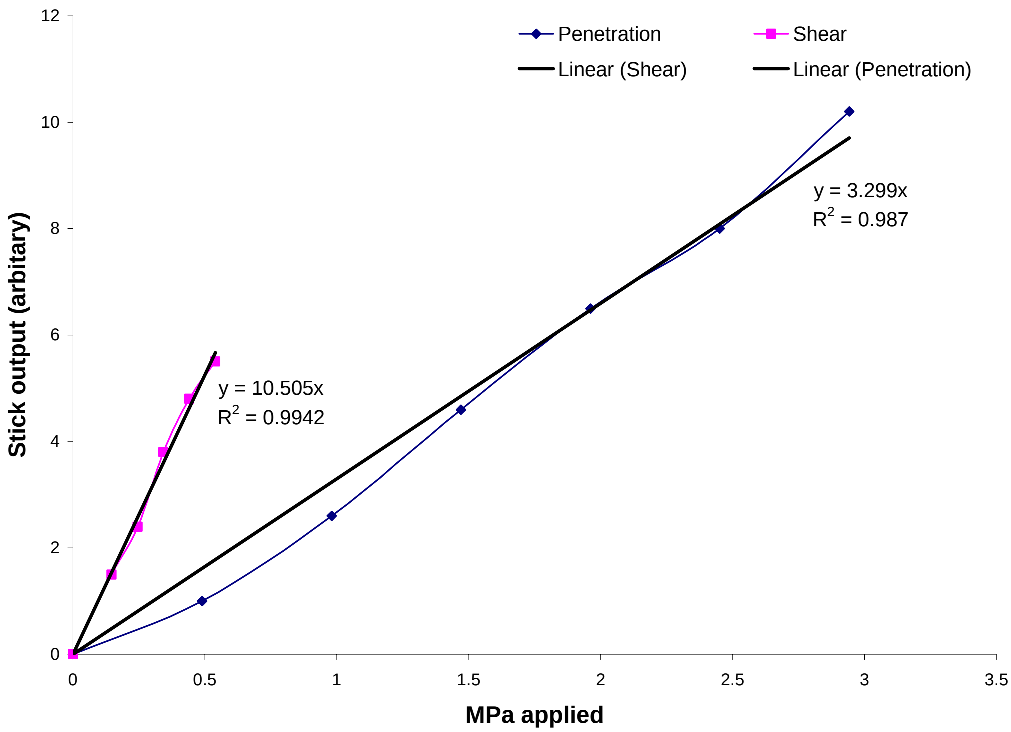

Figure 1: Going mode calibration

To convert engineering mode values, determined by the going-stick, to MPa:

Divide penetration value by 47.834 (based on results of Figure 2).

Divide shear value by 73.234 (based on results of Figure 2).

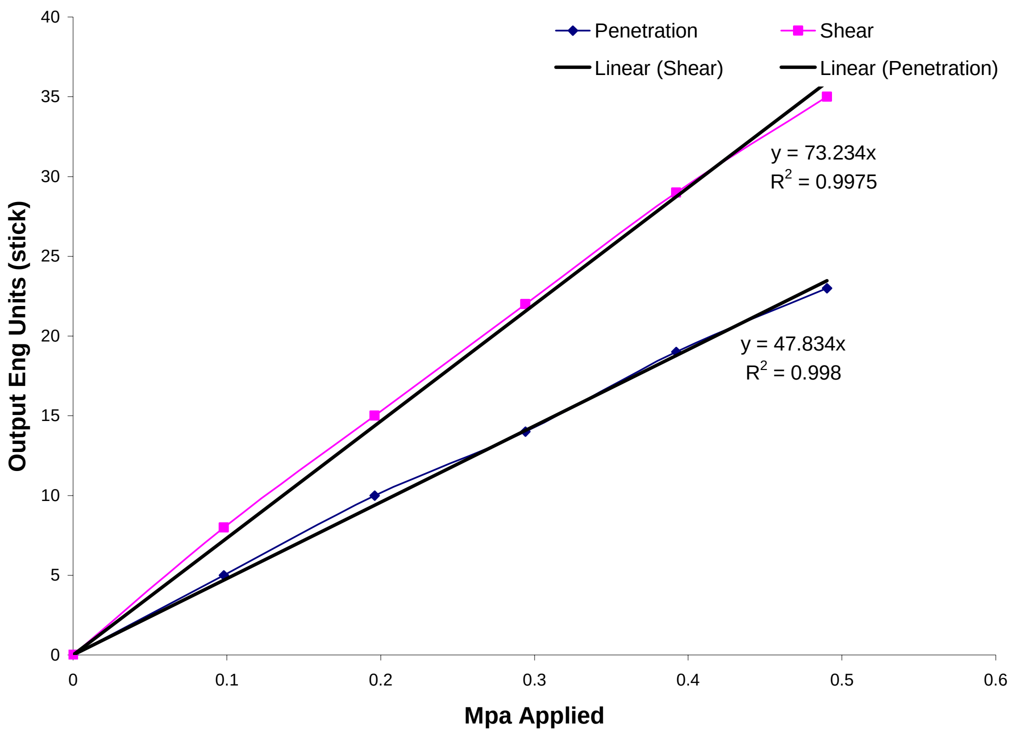

Figure 2: Engineering units' mode calibration

Calibration figures provided by Dresser, M. and Stranks, S. Cranfield University at Silsoe.

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Appendix 5.1: The Penman-Montieth Equation

Net radiation

If net radiation is not measured it is estimated from;

$R_{ns} = (1\text{-}\alpha)R_s$

$$f = \left(a_c \frac{b_s}{as + b_s}\right)\frac{n}{N} + \left(b_c + \frac{a_s}{a_s + b_s} a_c\right)$$

$\varepsilon' = a_1 + b_1\sqrt{ed}$

$$R_{nl} = -f\varepsilon'\sigma\left(\frac{Tk_{\max}{}^4 + Tk_{\min}{}^4}{2}\right)$$

$R_n = R_{ns} + R_{nl}$

Evapotranspiration

$$T = \left(\frac{T_{\max} + T_{\min}}{2}\right)$$

$\lambda = 2.501\text{-}0.002361T$

$$ea = \frac{ea_{T_{\max}} + ea_{T_{\min}}}{2}$$

$$\Delta = \frac{4098ea}{(T + 237.3)^2}$$

$$ra = \frac{1n\left(\frac{Zw - d}{Zom}\right)x1n\left(\frac{Zs - d}{Zoh}\right)}{k^2 U_z}$$

$$\gamma = \frac{cpP}{\varepsilon\lambda} \times 10^{-3}$$

$$\gamma^* = \gamma\left(1 + \frac{rc}{ra}\right)$$

$$T_{kv} = T_k\left(1 - 0.378\frac{ed}{P}\right)^{-1}$$

$$P = \frac{P}{T_{kv}\frac{R}{1000}}$$

$$ETaero = \frac{86.4}{\lambda}\frac{1}{\Delta + \gamma^*}\frac{\rho cp}{ra}(ea - ed)$$

$$ETrad = \frac{\Delta}{\Delta + \gamma^*}\frac{(R_n - G)}{\lambda}$$

$$ET_o = ETrad + ETaero$$

Symbol	***Description***	***Unit***	***Value***
λ	latent heat of vaporisation	MJ kg^{-1}	
Δ	slope of vapour pressure curve	kPa $°C^{-1}$	
γ	psychrometric constant	kPa $°C^{-1}$	
ρ	atmospheric density	kg m^{-3}	
α	albedo	-	0.23 for grass
k	von Karman constant	-	0.41
ε	ratio of molecular weight of water to dry air	-	0.622
σ	Stefan Boltzman constant	MJ m^{-2} K^{-4} d^{-1}	4.903 x 10^{-9} MJ m^{-2} K^{-4} d^{-1}
ε’	net emissivity	-	
γ*	modified psychrometric constant	kPa $°C^{-1}$	
a_c	empirical constant	-	1.35
a_1	empirical constant	-	0.34
a_s	Ångström constant	-	

Symbol	***Description***	***Unit***	***Value***
b_c	empirical constant	-	-0.35
b_1	empirical constant	-	-0.14
b_s	Ångström constant	-	
cp	specific heat of moist air	kJ kg °C^{-1}	1.013 kJ kg-1 °C^{-1}
d	zero plane displacement of wind profile	m	0.08m for grass
ea	mean saturation vapour pressure	kPa	
ed	actual vapour pressure	kPa	
ETaero	aerodynamic term	mm d^{-1}	
ET_o	reference crop evapotranspiration	mm d^{-1}	
ETrad	radiation term	mm d^{-1}	
f	cloudiness factor	-	
G	soil heat flux	MJ m^{-2} d^{-1}	
n	bright sunshine hours	H d^{-1}	
P	atmospheric pressure	kPa	
R	specific gas constant	J kg^{-1} K^{-1}	287 J kg^{-1} K^{-1}
ra	aerodynamic resistance	s m^{-1}	
rc	bulk surface resistance	s m^{-1}	70 s m^{-1} for reference grass
R_n	net radiation	MJ m^{-2} d^{-1}	
R_{n1}	net longwave radiation	MJ m^{-2} d^{-1}	
R_{ns}	net shortwave radiation	MJ m^{-2} d^{-1}	
R_s	incoming solar radiation	MJ m^{-2} d^{-1}	
T_i	mean air temperature for day i	°C	
T_k	mean air temperature	K	
T_{kv}	virtual temperature	K	
T_{max}	maximum air temperature	°C	
T_{min}	minimum air temperature	°C	
Uz	windspeed at height z	m s^{-1}	
Zoh	roughness parameter for heat and water vapour	m	0.0015m for grass
Zom	roughness parameter for momentum	m	0.01476m for grass
Zs	screen height	m	1.2m
Zw	height of wind-speed measurement	m	2m

Appendix 5.2: Developing the Methodology for a Simple Rainfall Balance to Predict the Mean Going on the Flat Course at Newcastle Racecourse

To aid the determination of irrigation requirements for turfgrass survival, and to influence the surface rating of a racecourse (going), an objective assessment of the prevailing climatic conditions, particularly rainfall, is necessary. This appendix describes how a simple rainfall balance was developed to show the effects of rainfall on the going of a racecourse, and how the rainfall balance was used to produce a model to predict the mean going on a racecourse. This work relates to Objective Three of the project, and forms part of the work to test Hypothesis Two.

Determination of water loss from the surface

Weather data was collected from a weather station located at Newcastle Racecourse. The raw data was processed using AWSET software (Cranfield University, 2002), to arrive at a daily summary of the weather, which included values for ET_o using the Penman-Montieth equation, as described in Section 6.1.2.

Simple rainfall balance development

Using the weather data and AWSET program, a basic rainfall balance was developed. The rainfall balance equation is,

$$RB = inputs - outputs$$

Where RB = rainfall balance (mm)
$inputs$ = rainfall (mm d^{-1})
$outputs$ = ET_o (mm d^{-1})

From the above calculation a basic daily and monthly water balance for Newcastle Racecourse is achieved. However this equation assumes that the initial soil-water status is field capacity and that there is no drainage (an additional output) or supplemental water applications (an additional input). The water balance also assumes that water lost through evapotranspiration is at the rate of ET_o, whereas the actual evapotranspiration for the turfgrass (ET_c) may be more or less.

Results of the simple rainfall balance

An example of a daily rainfall balance is given in Figure 1, and shows that all days for the month of May 2004 at Newcastle Racecourse, except the 4th, 7th, 20th and 21st had a negative rainfall balance i.e. outputs (ET_o) were greater than inputs (rainfall).

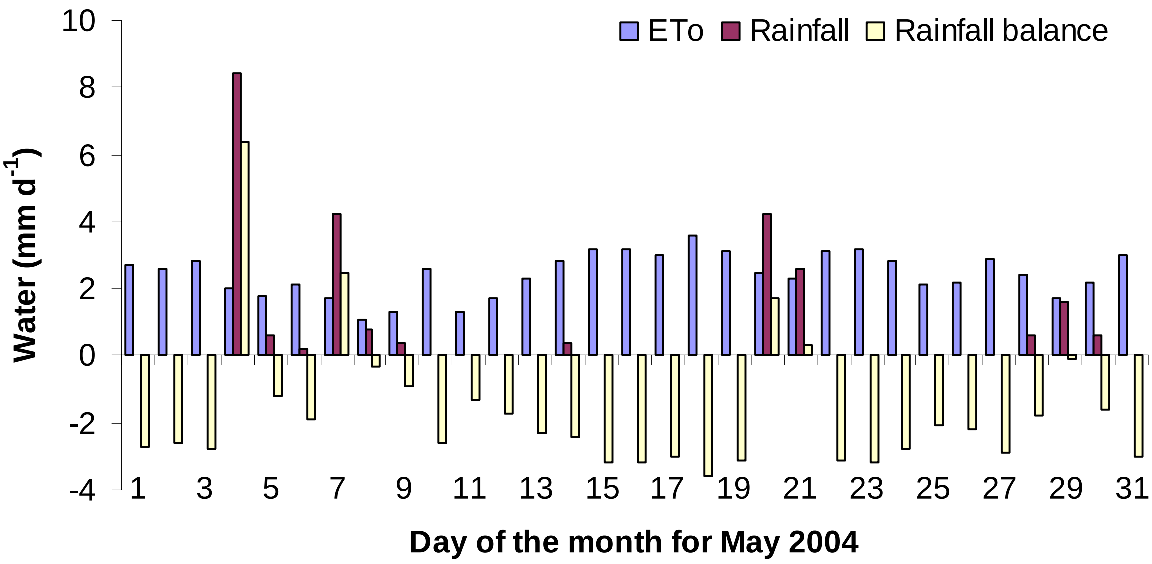


Figure 1: Daily rainfall balance for the month of May 2004 at Newcastle Racecourse

The monthly water balance dating from May 2004, which was the first complete month, to December 2004 is given in Figure 2. The monthly water balance shows that outputs (ET_o) were greater than inputs (rainfall) during the months of May, July and September. All other months were the reverse; inputs were greater than outputs.

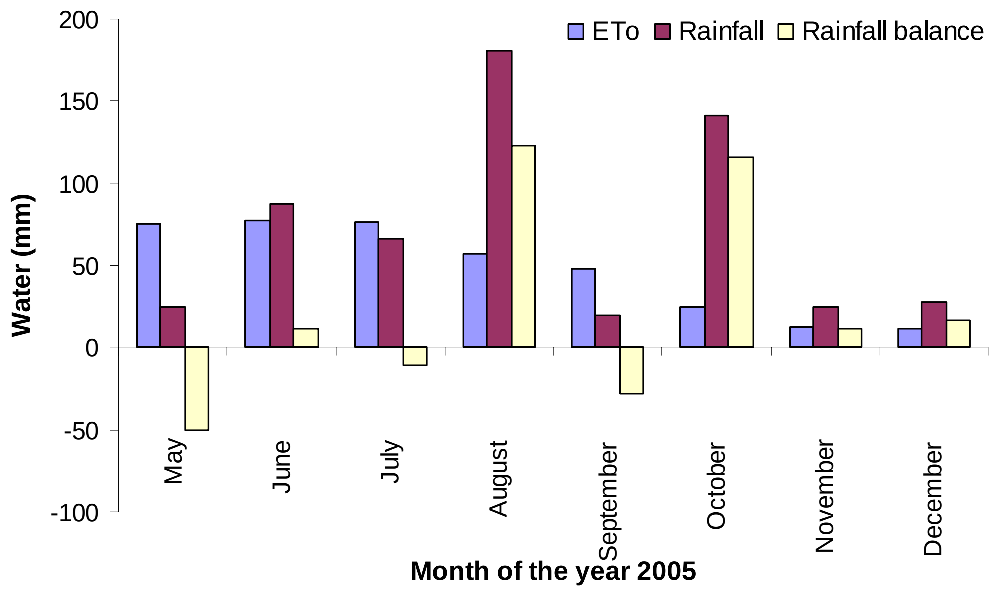


Figure 2: Monthly water balance from May-December 2004 at Newcastle Racecourse

The results of the simple rainfall balance will aid better determination of water requirements for grass plant survival, and may reduce the amount of water currently being applied by racecourses. An effective rainfall balance will also help the racecourses justify the need for supplemental irrigation water to the relevant water authorities.

Calibration and error

Going data

Going data, as measured with the Going-Stick for the 2004 and 2005 flat racing seasons at Newcastle Racecourse, was supplied by TurfTrax Ltd. The measurements of going for a given day are taken from 59 grid points on the flat course – referred to as waypoints on the going-stick – and 82 grid points on the jump course, which is the chase and hurdle course combined, hence the larger number of grid points.

The number of days per month that going for the whole course had been measured is varied due to the fact that the going is measured prior to and during a race meeting only. Therefore the number of race meetings throughout the year governs the availability of measurements of going for the whole course. The Clerk of the Course usually measures the going. Additionally, the type of course measured (flat or jump) is dictated by the racing season, as flat course measurements are not generally taken during the jump season, and vice versa.

Analysis of simple rainfall balance model to predict the mean going at Newcastle Racecourse

The values of going for all 59 waypoints on the flat course at Newcastle Racecourse were used to arrive at a mean value of going for a given day. The resultant meaned going was plotted against a rainfall balance for the corresponding month. The mean going responded to the pattern of the rainfall balance, where there was a water balance deficit – ET_o was greater than rainfall – the mean going was above eight on the 15 point index (firmer than good). Where the rainfall balance had a surplus – rainfall was greater than ET_o – the mean going would fall to below eight (Figure 3).

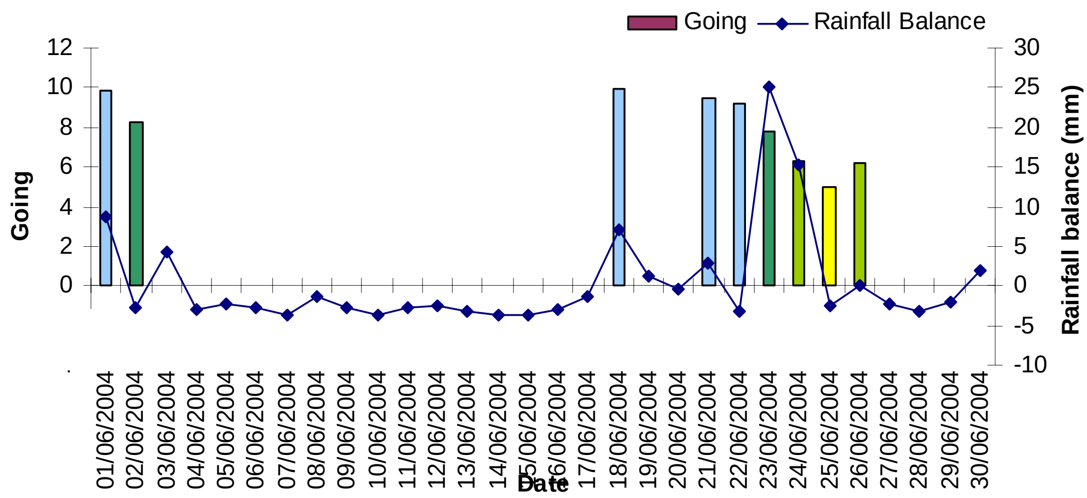


Figure 3: Water balance verses going for June 2004 at Newcastle Racecourse

These results suggest that by using a simple rainfall balance, the effects of water on going can be generally described. Where water inputs are greater than water outputs softer surface ratings are achieved. Where water outputs are greater than water inputs, firmer surface ratings of the racecourse occur. This work provides evidence to support the hypothesis (Hypothesis Four) that irrigation (an input of water) has a significant effect on the surface rating (going) of a racecourse as it influences soil strength by altering the soils matric potential and transforms the soil from a brittle state to a plastic state. Additional supporting evidence is provided by the validation of the going-stick with regards to the regression analysis between going and volumetric content (Section 5.2.3.), which showed that as volumetric soil moisture content decreased, the value of going would increase. However to quantify this, given that meaningful information relating to irrigation scheduling can be obtained, a more detailed and responsive model is required.

Analysis of the interaction between the rainfall balance and mean going

Non-linear regression analysis using a decaying exponential curve, with Genstat software (Genstat, 2001), was carried out to determine the interaction between accumulated rainfall balances for 1 to 45 days and mean going measurements for the period April 2004 to April 2005. Non-linear regression analysis was used because the change in going brought about by water applications at the lower end of the 15 point scale would become less as the soil approached its liquid limit. The regression analysis showed that the optimum number of days for the rainfall balance component of the model is 22 days (Figure 4). A summary of the regression analysis of the interaction between the accumulated rainfall balances for 1 to 45 days, and the average going at Newcastle Racecourse is given in the accompanying CD-Rom.

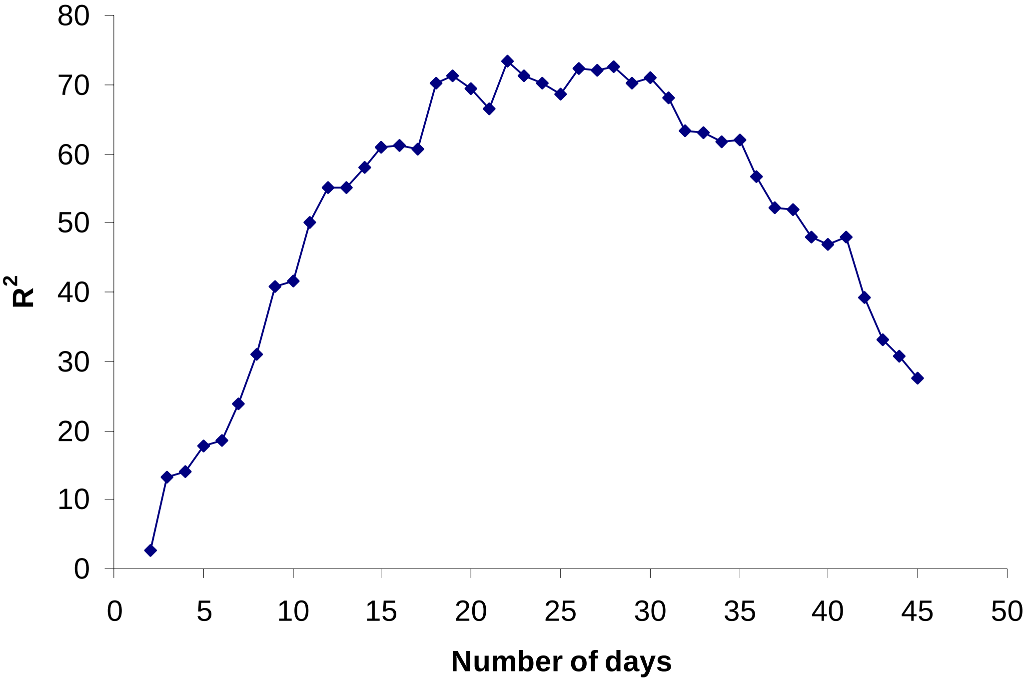


Figure 4: Number of accumulated day's rainfall balance verses R^2 values generated from regression analysis for each accumulated day

The percentage variance for the interaction between 22 days accumulated rainfall balance and the average going on the flat racecourse at Newcastle accounted for 73.4% (R^2 = 0.73) (Figure 5).

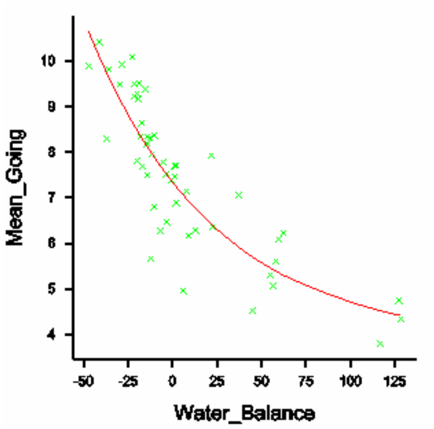


Figure 5: Non-linear regression analysis of the interaction between a 22 day rainfall balance and mean going at Newcastle racecourse

From the non-linear regression analysis of the 22 day accumulated rainfall balance, a predictive model for mean surface rating of the flat course at Newcastle racecourse has been achieved, although it can only be as accurate as the 73.4% correlation value for all the 22 day rainfall balance data. The predictive model uses the equation,

$$Y = A + (B \times R^X)$$

Where Y = Going
A = 3.843
B = 3.501
R = 0.98602
^{X} = accumulated rainfall balance

Assumptions with the rainfall balance model

The rainfall balance generated to build the predictive model is calculated by subtracting the accumulated reference crop evapotranspiration (ET_o) from the accumulated rainfall over a period of 22 days, weather conditions prior to the 22 day period are not included.

The model does not take into account additional inputs and outputs of water that may occur through irrigation and capillary rise (inputs), or drainage (output). Therefore the model assumes that irrigation, capillary rise and drainage do not occur.

Evapotranspiration is assumed to be at the rate of ET_o and that the turfgrass does not have either a higher or lower rate of evapotranspiration (ET_c). The model assumes that there is no significant change in the soil texture around the racecourse, and that rainfall does not exceed the infiltration rate of the soil.

The historical measurements of going data, as measured by the going-stick, used to build the model were taken from all the waypoints around the racecourse. The model assumes that the going measurements recorded are representative of the actual going for the entire racecourse on the day they were taken.

Validation of the simple rainfall balance model to predict going

Weather data from 1st May 2005 to the 24th August 2005 was used to validate the simple rainfall balance model. Going values, as measured with the Going-Stick, for 25 days during the same period were also determined to enable comparisons of the predicted mean going with the actual mean going. Linear regression analysis was conducted to show if a significant relationship existed between the predicted and actual mean going. A sample correlation coefficient test was carried out to determine whether the predicted mean going and actual mean going had a strong positive or negative correlation. Modelling efficiency was conducted to assess the accuracy of the predicted values. The methods to validate the rainfall balance (linear regression, sample correlation coefficient, F test and modelling efficiency) are described in Section 6.4.1.

Rainfall balance model

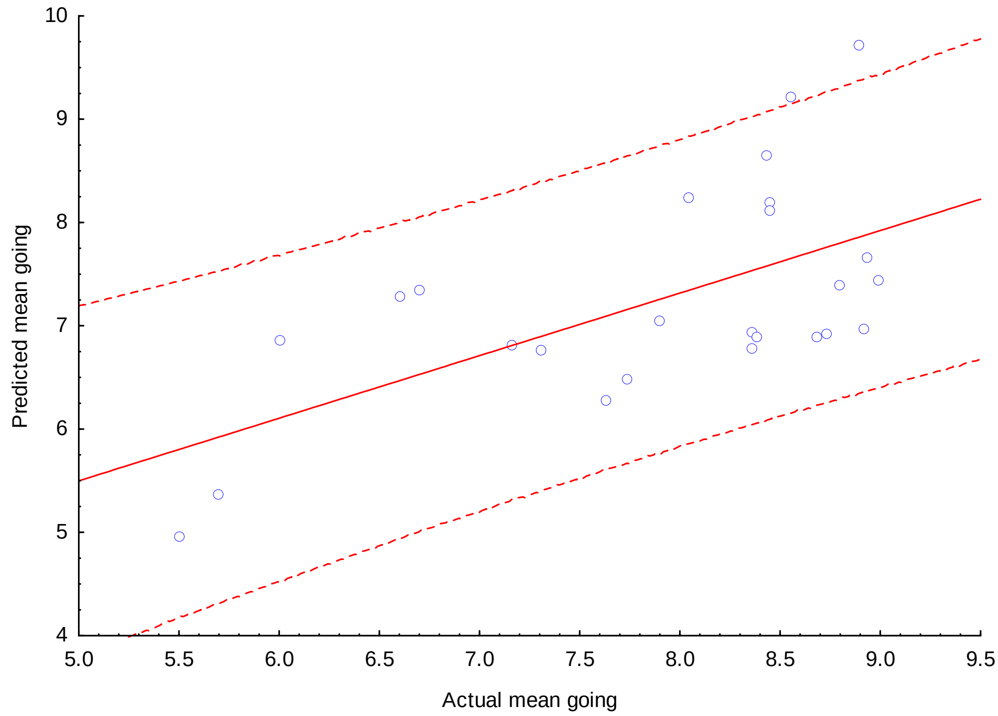
The results are based on the 22 day rainfall balance for 25 measured dates (Table 1) using the prediction equation $Y = A + (B \text{ x } R^X)$, as determined in Section 7.2.5.1. The results show that all the predicted mean going results are ≤1.95 points of the mean of the actual recorded going, based on the going-stick index of going. The index of going classifications for the going-stick has increments of two whole points for each going classification. Therefore the results of ≤1.95 points equates to within a going classification, or where the values are at the boundaries of a going classification, within half a going classification.

Table 1
Comparison of the initial results of the average going prediction model with the actual mean going values at Newcastle Racecourse

Date	22 Day rainfall balance (mm)	Predicted mean going	Actual mean going
01/05/2005	58.7	5.38	5.70
05/05/2005	80.9	4.96	5.50
09/05/2005	10.6	6.86	6.00
10/05/2005	1.2	7.29	6.60
11/05/2005	-0.1	7.35	6.70
17/05/2005	-1.9	7.44	8.99
18/05/2005	-6.2	7.66	8.93
13/06/2005	-36.7	9.71	8.89
13/07/2005	-0.9	7.39	8.80
15/07/2005	12.4	6.78	8.36
18/07/2005	8.1	6.96	8.92
19/07/2005	9.2	6.91	8.73
20/07/2005	9.8	6.89	8.68
21/07/2005	8.7	6.94	8.36
22/07/2005	-15.5	8.19	8.45
23/07/2005	-14.2	8.12	8.45
28/07/2005	-30.4	9.21	8.55
02/08/2005	11.8	6.80	7.16
03/08/2005	12.9	6.76	7.31
05/08/2005	6.3	7.04	7.90
08/08/2005	9.9	6.88	8.38
10/08/2005	20.2	6.47	7.74
11/08/2005	25.8	6.27	7.63
23/08/2005	-22.5	8.64	8.43
24/08/2005	-16.2	8.24	8.04

A significant relationship (F pr = 0.0012) exists between the predicted and actual mean going for the flat course at Newcastle Racecourse. Linear regression, to show if a correlation exists between the predicted and the actual going, resulted in a coefficient of determination of 37% (r^2 = 0.37) (Figure 6).

The value of the coefficient of determination is not as high as expected; revisions to the model would be necessary to improve this value. These revisions would initially include factoring in irrigation. Additional revisions may include adjusting ET_o to an estimate of ET_c, drainage and capillary rise. However, with such revisions, the rainfall balance would no longer be a simple model, and would start to evolve into a more complex model.



$r^2 = 0.3707$; $r = 0.6088$; $p = 0.0012$; $y = 2.4704 + 0.6058*x$

Figure 6: Linear regression analysis to show the relationship between the predicted and actual measurements of mean going, with prediction intervals at the 90% level

The predictions of mean going for the flat course are more accurate where there is a deficit water balance. Predictions are not as accurate where a surplus water balance exists (Table 1). The regression analysis of the data to build the model showed that there was less variation in the data where there was a deficit water balance (going values greater than 8.0), and that there was greater variation in the data where there was a surplus water balance (Figure 5). The greater amount of variation in the surplus water balance data could account for the less accurate predictions of going, as the model at the lower end of the going index was built on a broader range of values of going, when compared to the more specific values of deficit water balance at the higher end of the going scale. This indicates that soil becomes more variable when approaching a liquid state.

The research project aim is to optimize going through water applications, and is primarily concerned with management issues relating to harder (drier) surface conditions. As a result, the predictive model predicts mean going values that are comparative with measured mean going where a deficit water balance exists; the values that the research project aims to address.

The lower mean values of going are not as crucial to the project. The model is more useful than the 73.4% for the coefficient of determination (r^2) value for the prediction model would suggest. Given the large number of assumptions associated with this model, the correlation between predicted and actual mean going (r^2 = 0.37) is acceptable.

The sample correlation coefficient of the rainfall balance model

The sample correlation coefficient (r) was 0.60. This indicates that the rainfall balance does not provide a perfect positive correlation with the observed values of going, but does show a good association with the observed values. The significance of r was assessed using an F-test; r was significant (F pr <0.001).

Modelling efficiency of the rainfall balance model

The *EF* value of the rainfall balance was -0.25, which means that the predicted values of mean going are less accurate for the prediction of mean going than using the mean of the observed going. However data presented in Table 1 suggests that the predictions of mean going are more accurate where there is a deficit rainfall balance. The *EF* includes all values used to validate the model, the larger errors associated with the values for a surplus rainfall balance may be the cause of the poor *EF* value.

Conclusion

The rainfall balance is a simple model that demonstrates the effects of water on going, but fails to accurately predict (statistically) the mean going on a racecourse. It does however indicate that the management of going via watering at Newcastle Racecourse should be considered over a 22 day period. Revisions to the model are likely to improve the accuracy of the rainfall balance, but it would no longer be a simple model. Therefore the development of a more precise model that distinguishes between the different soil types present, any differences in the management practices of sections of the racecourse, and incorporates irrigation and drainage, should be investigated to determine whether better predictions can be obtained.

Appendix 5.3: Parameters Measured by the Weather Station at Newcastle Racecourse

The table below shows the parameters that the weather station at Newcastle racecourse measures. The measurements are taken every half hour. A summary of all of the weather data for Newcastle racecourse can be found in the accompanying CD-Rom.

Label	AirSpeed	Rainfall	Rain2	SoilTemp	EnergyES	Wind Dir	Air Temp	Humidity	Grnd Temp	Gust
Units	m.s-1	mmRain	mmRain	deg C	kW.m-2	deg	deg C	%RH	degC	m/s
01/09/2005 00:00	0.06	0	0	16.62	0.0004	216	16.22	94.208	14.49	0.5
01/09/2005 00:30	0.06	0	0	16.49	0.0004	96	16.22	94.6176	13.69	0.5
01/09/2005 01:00	0.00	0	0	16.37	0.0004	144	15.87	94.6688	12.96	0.3
01/09/2005 01:30	0.04	0	0	16.24	0.0004	0	15.59	94.976	13.63	0.3
01/09/2005 02:00	0.00	0	0	16.13	0.0004	120	15.67	95.2832	12.86	0.0
01/09/2005 02:30	0.45	0	0	16.02	0.0005	192	15.74	95.8464	14.88	1.3
01/09/2005 03:00	0.30	0	0	15.97	0.0005	192	16.51	95.8464	15.77	1.1
01/09/2005 03:30	0.05	0	0	15.97	0.0005	240	16.44	95.5904	15.47	0.6
01/09/2005 04:00	0.44	0	0	15.96	0.0005	288	15.95	95.0784	14.49	1.3
01/09/2005 04:30	0.06	0	0	15.91	0.0005	120	15.78	94.8224	13.91	0.6
01/09/2005 05:00	0.08	0	0	15.84	0.0005	192	15.53	94.3616	13.43	0.8
01/09/2005 05:30	0.09	0	0	15.77	0.0029	120	15.09	93.8496	12.66	0.6
01/09/2005 06:00	0.00	0	0	15.67	0.0179	96	15.21	93.952	13.35	0.0
01/09/2005 06:30	0.17	0	0	15.61	0.0503	168	15.58	94.0544	14.8	0.8
01/09/2005 07:00	0.37	0	0	15.6	0.075	240	16.4	93.1328	15.92	1.5
01/09/2005 07:30	0.32	0	0	15.65	0.1349	264	17.13	91.2896	17	2.3
01/09/2005 08:00	0.64	0	0	15.77	0.1696	264	17.45	87.552	17.61	2.6
01/09/2005 08:30	1.68	0	0	15.92	0.1847	312	17.37	84.3776	17.52	4.1
01/09/2005 09:00	1.69	0	0	16.06	0.29	264	17.2	82.6368	17.85	4.0
01/09/2005 09:30	1.49	0	0	16.21	0.4025	144	17.38	81.0496	18.98	3.6
01/09/2005 10:00	1.96	0	0	16.46	0.3372	216	17.8	76.544	19.23	5.6
01/09/2005 10:30	2.29	0	0	16.73	0.4112	288	17.49	75.008	19.06	7.0
01/09/2005 11:00	1.52	0	0	16.94	0.4576	312	18.08	73.0112	20.44	6.0
01/09/2005 11:30	1.92	0	0	17.15	0.2941	216	17.89	69.0176	18.84	5.8
01/09/2005 12:00	2.17	0	0	17.29	0.5304	216	18.25	63.232	20.58	5.5
01/09/2005 12:30	2.10	0	0	17.48	0.4912	288	18.66	58.9824	20.57	5.1
01/09/2005 13:00	2.65	0	0	17.75	0.4073	288	18.4	58.8288	19.72	7.3
01/09/2005 13:30	2.41	0	0	17.91	0.4496	288	18.46	57.7024	20.11	5.5
01/09/2005 14:00	2.25	0	0	18.05	0.476	264	18.76	55.7568	20.55	5.3
01/09/2005 14:30	2.01	0	0	18.18	0.5	336	19.3	52.992	21.86	4.8
01/09/2005 15:00	2.08	0	0	18.37	0.4006	288	19	53.0944	20.72	6.8

Appendix 5.4: Conversion of the Going data to a Mean Value.

The going data from the waypoints for each soil type in each section of the racecourse was converted to a mean value for every day that going was determined. The table below shows an example of the waypoints for the sandy clay loam soil on the round section of the flat course at Newcastle Racecourse. The number of waypoints varies for each soil type within a given section. The conversion of all soil types and sections is given in the accompanying CD-Rom.

			Waypoints						
Date	**Rzone def (mm)**	**Mean going**	**7**	**17**	**21**	**24**	**27**	**32**	**35**
14/07/2004	-10.6922								
15/07/2004	-8.03767	7.7	8.4	9.1	6.7	8	7.1	6	8.2
16/07/2004	-4.8258								
17/07/2004	-9.66155	5.9	6.5	6.5	6.2	7	5.3	6	4.7
18/07/2004	-6.76154								
19/07/2004	-7.06154	7.5	7.9	7.6	6.9	8	6.9	7	8.4
20/07/2004	-9.39213								
21/07/2004	-7.39213	6.6	7.5	7	6.7	8	7.2	5	4.9
22/07/2004	-8.39213	7.8	7.9	8	6.5	8	8.9	8	8.3
23/07/2004	-5.39213	7.3	8.1	6.8	6.6	9	7.9	6	7.2
24/07/2004	-3.39213	7.7	7	10	7.1	7	6.8	8	8.7
25/07/2004	-7.33241								
26/07/2004	-4.63242	8.1	9.1		8.1	7	9.4	7	7.7
27/07/2004	-2.03241								
28/07/2004	0.567589								
29/07/2004	6.76E-02	8.2	8.3	8.7	6.7	7	8.9	8	9.8
30/07/2004	2.367592	8.1	8.8	8	8	8	8.6	7	8.9
31/07/2004	3.367592								
01/08/2004	4.667591								
02/08/2004	6.46759	8.4	8.9	8.5	7.1	9	8.2		9.3
03/08/2004	2.009048	8.1	8.8	10	8.8	8	6.4		6.6
04/08/2004	0.209049	7.5	6.5	9.7	6.6	9	6.9		6.4
05/08/2004	2.40905								
06/08/2004	-0.47377	6.5	7	6.5	5.8	6	7.5	7	6
07/08/2004	2.626228								

Appendix 5.5: Particle Size Distribution for Waypoint Samples Taken from York Racecourse.

The soil texture in each waypoint measured at York Racecourse was determined using Particle size distribution analysis as described in Section 4.2.1. The results for the sand, silt and clay fractions and their soil class are given in the tables below.

	Waypoints											
	3	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**
Coarse Sand %	3.12	0.004	1.96	5.45	3.78	4.13	4.13	72.90	7.49	7.57	5.33	1.83
Sand	23.17	0.32	18.32	25.26	27.21	22.97	24.85	6.59	18.35	26.28	39.34	21.90
Fine Sand %	44.30	99.36	40.51	37.92	35.50	47.27	37.66	11.88	5.53	51.97	36.32	61.07
Sand %	70.60	99.72	60.79	67.72	66.49	74.37	66.64	91.36	31.36	82.88	80.99	84.81
Clay %	7.36	0.05	6.03	26.65	7.24	3.54	4.37	1.66	62.85	16.96	16.74	11.76
Silt %	22.04	0.23	33.17	5.63	26.27	22.10	28.99	6.98	5.79	0.22	2.27	3.43
Textural Class	**Sandy Clay Loam**	**Sand**	**Sandy Clay**	**Sandy Clay Loam**	**Sandy Loam**	**Sandy Clay Loam**	**Sandy Clay Loam**	**Sand**	**Clay**	**Sandy Loam**	**Sandy Loam**	**Loamy Sand**

	Waypoints											
	39	**42**	**45**	**48**	**51**	**54**	**57**	**60**	**63**	**66**	**69**	**71**
Coarse Sand %	2.64	5.95	9.19	5.35	5.88	3.31	5.71	3.01	3.37	0.68	3.99	2.62
Sand	22.18	31.66	27.03	32.89	29.38	27.10	33.05	6.08	31.40	7.33	21.64	24.96
Fine Sand %	59.52	46.82	41.14	43.27	55.06	55.52	39.55	12.51	44.75	13.22	37.15	36.84
Sand %	84.34	84.43	77.35	81.52	79.32	85.93	78.31	21.61	79.53	21.23	62.78	64.42
Clay %	3.64	13.98	20.72	4.38	20.14	13.41	5.10	4.91	1.39	10.57	13.60	11.46
Silt %	12.03	1.58	1.93	14.10	0.54	0.66	16.59	73.49	19.09	68.20	23.62	24.11
Textural Class	**Loamy Sand**	**Loamy Sand**	**Sandy Clay Loam**	**Sandy Loam**	**Sandy Clay Loam**	**Loamy Sand**	**Sandy Loam**	**Sandy Silt Loam**	**Loamy Sand**	**Sandy Silt Loam**	**Sandy Clay Loam**	**Sandy Clay Loam**

Appendix 5.6: Water Applications at York Racecourse during 2006.

The total amount of water applied to the sandy clay loam and sandy loam waypoints is given in the following tables. The full irrigation data including the method of application can be found in the accompanying CD-Rom, as can the Rzone def, observed and predicted going for the four waypoints analysed (waypoints 13, 30, 51 and 57).

Total irrigation applied (mm) to the sandy clay loam waypoints.

Waypoint	3	12	18	21	45	51	69	71
03/06/2006		3	2	2	3.5	3.5	2	2
04/06/2006		3.5	2.5	2.5	3.5	3.5	2.5	2.5
05/06/2006		3.5	2.5	2.5	3.5	3.5	2.5	2.5
06/06/2006		3.5	7.5	7.5	6	6	2.5	2.5
07/06/2006		5.5	4	4	10.5	10.5	6	6
08/06/2006			5	5	5	5	3.5	3.5
09/06/2006			5	5			2	
10/06/2006							2	
12/06/2006		3	8	8	10	11	9	
13/06/2006					5	5	3	3
14/06/2006		1.25	1.25	1.25	2.5	2	2	2
15/06/2006			5	5	5	5		
17/06/2006		2.5	2.5	2.5			4	
18/06/2006		3	3	3			2	4
28/06/2006		3	3	3	4	4	3	3
02/07/2006		3.5	2.5	2.5	3	3	3	3
03/07/2006		3.5	7.5	7.5	8	8	3	3
04/07/2006		6		10	5	5	5	5
05/07/2006		6	10	10	5	5	5	5
06/07/2006			5	5	5	5		
07/07/2006			5	5	5	5	2	2
08/07/2006		5	5	5			1	1
09/07/2006					5	5	4	2
11/07/2006			5	5	5	5	4	2
12/07/2006							4	2
13/07/2006							5	
14/07/2006		1.5	1.5	1.5			2	
15/07/2006		1.5	1.5	1.5			2	
16/07/2006		5	4	4	6	6	4	4
17/07/2006		2.5	2	2	3	3	2	2
18/07/2006		2.5	2	2	13	13	2	2
19/07/2006		5	4	4	6	6	4	4
20/07/2006		9	13	13	2	2.5	3	3.5
21/07/2006	3	3	2	2	8.5	8	13	13.5
22/07/2006							4	4
28/07/2006		5	4	4			5	5
08/08/2006							2	2
09/08/2006							4	4
10/08/2006		3	2.5	2.5	3.5	3.5	2.5	2.5
11/08/2006		6	2.5	2.5	6	7	2.5	3
Total	**3.0**	**99.8**	**130.3**	**140.3**	**147.5**	**149.0**	**134.0**	**105.5**

Total irrigation applied (mm) to the sandy loam waypoints.

Waypoint	15	30	33	48	57
03/06/2006	2	3	3	3.5	3.5
04/06/2006	2.5	4	4	3.5	3.5
05/06/2006	2.5	4	4	3.5	3.5
06/06/2006	2.5	4	4	6	6
07/06/2006	4	8	8	10.5	10.5
08/06/2006		4.5	4.5	5	5
09/06/2006	5	2.5	2.5		
10/06/2006		2.5	2.5		
12/06/2006	8	13	8	10	11
13/06/2006		2	2	5	5
14/06/2006	1.25	1.25	1.25	2.5	2
15/06/2006	5	5		5	5
17/06/2006	2.5	2.5	2.5		
18/06/2006	3				
28/06/2006	3	3.5	3.5	4	4
02/07/2006	2.5	3	3	3	3
03/07/2006	7.5	8	3	8	8
04/07/2006		5	5	5	5
05/07/2006	10	10	5	5	5
06/07/2006	5	5		5	5
07/07/2006	5	5		5	5
08/07/2006	5	5			
09/07/2006		6	6	5	5
11/07/2006	5	6	6	5	5
12/07/2006		6	6		
13/07/2006		5	5		
14/07/2006	1.5	2	2		
15/07/2006	1.5	2	2		
16/07/2006	4	6	6	6	6
17/07/2006	2	3	3	3	3
18/07/2006	2	3	3	13	8
19/07/2006	4	6	6	6	6
20/07/2006	8	13.5	3.5	2	2.5
21/07/2006	7	3.5	3.5	8.5	7.5
22/07/2006		5	5		
28/07/2006	4	4	4		
10/08/2006	2.5	3	3	3.5	3.5
11/08/2006	2.5	6.5	6.5	6	7
Total	**120.3**	**181.3**	**136.3**	**147.5**	**143.5**

Appendix 5.7: Summary of Rooting Depth Values for the Flat Course at Newcastle racecourse.

The mean rooting depth for the flat course at Newcastle Racecourse for the year 2005 are given in the table below. The root depth increased each month and reached a peak value in June. The standard error of the samples (55 root depth measurements each month) increased as the root depth increased up to the month of April. The standard error reduced after April, but overall, considering the number of samples, the standard error is reasonably low.

Month	Mean depth (mm)	± S.E.
January	12.60	0.47
February	14.11	0.50
March	16.04	0.55
April	18.73	0.71
May	20.69	0.69
June	21.15	0.64
September	15.09	0.53

APPENDIX SIX

Contents of Appendix Six

The data for Appendix Six can be found on the accompanying CD-Rom. The data includes:

- A summary of the weather at Leicester Racecourses for the period April 2005 to July 2006.
- The initial and final going measured and recorded at Leicester Racecourse for the construction and validation of the DEFFIM model.
- The effective irrigation for the construction and validation of DEFFIM.
- The Results of the multiple linear regression analysis.
- The results of the validation of DEFFIM.

APPENDIX SEVEN

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Appendix 7.1: 48 Hour Field Capacity Phase of Shrink-Swell Trial Plots.

All plots in the shrink-swell trial were brought to field capacity. The plots were watered to the point of saturation, determined by a constant flow of drainage water from the drain outlets of each plot and the occurrence of surface ponding. The plots were then covered with plastic sheeting to prevent water loss by ET. The volumetric soil moisture content of the plots was measured with a Theta Probe at six hourly intervals over a 48 hour period. The values for each measurement are given in the table below. The rate of drainage became constant in the last 12 hours, the differences between readings was due to diurnal changes, whereby water lost by ET would condense on the plastic and return back to the soil in droplets overnight.

	% volumetric moisture content at time (hrs)								
Plot ID	**0**	**6**	**12**	**18**	**24**	**30**	**36**	**42**	**48**
A	44.97	38.17		39.20	38.60	37.73		38.50	39.67
B	44.10	39.60		38.73	38.53	38.20		37.77	37.43
C	44.40	39.59		38.89	38.40	37.70		37.41	37.91
D	45.01	40.21		39.04	38.57	38.54		38.06	37.76
E	44.25	39.64		40.18	39.27	38.69		37.59	38.28
F	44.10	38.13		37.60	37.87	38.60		36.40	38.13
G	47.33	37.63		38.10	39.83	36.17		38.50	40.43
H	47.56	38.22		39.21	39.65	38.44		37.98	38.60
I	47.95	39.08		39.76	40.19	39.61		40.53	39.99
J	46.57	37.45		37.88	38.42	38.04		39.69	39.59
K	48.43	39.70		42.60	39.50	39.17		40.40	40.33
L	45.93	36.60		38.43	39.00	38.57		38.67	39.13

Plots highlighted in yellow are the fully irrigated plots.

Appendix 7.2: Summary of Irrigation Applied to the Shrink-Swell Plots.

A summary of the irrigation applied to the shrink-swell trial plots is given in the table below. A summary of the weather at the trial site for the period the trial was held can be found on the accompanying CD-Rom.

Irrigation applications to the shrink-swell trial plots

	Sandy loam		**Clay loam**	
Date	**FI** (mm)	**PI** (mm)	**FI** (mm)	**PI** (mm)
03/06/05	27	0	27	0
07/06/05	18	18	18	18
10/06/05	9	0	9	0
14/06/05	27	27	27	27
18/06/05	18	9	18	9
20/06/05	36	36	36	36
10/07/05	18	0	18	0
15/07/05	27	18	27	18
17/07/05	18	0	18	0
19/07/05	0	36	0	36
01/08/05	18	0	18	0
08/08/05	9	0	9	0
10/08/05	9	0	9	0
15/08/05	9	0	9	0
30/08/05	9	0	9	0
12/09/05	0	27	0	27
20/09/05	18	0	18	0
Total	**270 mm**	**171 mm**	**270 mm**	**171 mm**

FI =*fully irrigated,* PI = *partially irrigated*

Appendix 7.3: Summary Bulk Density Values for the Shrink-Swell Trial Plots

Sandy loam + fully Irrigated					
Plot	**Bulk density** (g/cm^2)	**Plot mean**	**S.E.**	**Treatment mean**	**S.E.**
A1	1.517				
A2	1.549				
A3	1.534	1.533	0.009		
B1	1.514				
B2	1.553				
B3	1.488	1.518	0.019		
F1	1.554				
F2	1.528				
F3	1.546	1.543	0.008	1.531	0.007

Sandy loam + Partially Irrigated					
Plot	**Bulk density** (g/cm^2)	**Plot mean**	**S.E.**	**Treatment mean**	**S.E.**
C1	1.457				
C2	1.494				
C3	1.461	1.471	0.012		
D1	1.452				
D2	1.472				
D3	1.524	1.483	0.022		
E1	1.519				
E2	1.515				
E3	1.468	1.501	0.017	1.485	0.010

Clay loam + fully Irrigated					
Plot	**Bulk density** (g/cm^2)	**Plot mean**	**S.E.**	**Treatment mean**	**S.E.**
G1	1.298				
G2	1.292				
G3	1.315	1.302	0.007		
K1	1.316				
K2	1.315				
K3	1.298	1.309	0.006		
L1	1.304				
L2	1.279				
L3	1.285	1.289	0.008	1.300	0.005

Clay loam + Partially Irrigated					
Plot	**Bulk density (g/cm^2)**	**Plot mean**	**S.E.**	**Treatment mean**	**S.E.**
H1	1.144				
H2	1.168				
H3	1.147	1.153	0.008		
I1	1.195				
I2	1.156				
I3	1.162	1.171	0.012		
J1	1.260				
J2	1.195				
J3	1.189	1.215	0.023	1.180	0.012

Anova table for the dry bulk density (ρ_b) of the plots at the end of the shrink-swell study

```
Variate: Dry Bulk_Density

Source of variation d.f.    s.s.         m.s.         v.r.        F pr.

Soil_Texture.Plot stratum
Soil_Texture        1      0.6472202    0.6472202    579.47      <.001
Treatment           1      0.0630847    0.0630847    56.48       <.001
Soil_Texture.Treatment
                    1      0.0122840    0.0122840    11.00       0.011
Residual            8      0.0089353    0.0011169    2.01

Soil_Texture.Plot.Sample stratum
                    24     0.0133587    0.0005566

Total               35     0.7448830
```

Anova table for the total pore volume of the plots at the end of the shrink-swell study

```
Variate: Pore_volume

Source of variation d.f.    s.s.         m.s.         v.r.        F pr.

Soil_Texture.Plot stratum
Soil_Texture        1      0.09225394   0.09225394   578.51      <.001
Treatment           1      0.00896809   0.00896809   56.24       <.001
Soil_Texture.Treatment
                    1      0.00173611   0.00173611   10.89       0.011
Residual            8      0.00127575   0.00015947   2.00

Soil_Texture.Plot.Sample stratum
                    24     0.00191270   0.00007970

Total               35     0.10614659
```

Appendix 7.4: Linear Shrinkage of the Shrink-Swell Trial Soils.

SOIL AND WATER LABORATORY

NSRI

ANALYTICAL RESULTS REPORT

Name: Colin Mumford

Address: Cranfield University

Date of sample receipt: 14/09/05

Sample Identifier: 238/05/1 and 238/05/2

Date of completion of analysis:12/10/05

Analytical results:

Sandy Loam	**Plastic Limit**	**17.28%**
	Liquid Limit	**27.10%**
	Plasticity Index	**9.82%**

% Linear Shrinkage 6.42%

% of sample passing 425um was 84.47%

Clay Loam	**Plastic Limit**	**22.58%**
	Liquid Limit	**41.00%**
	Plasticity Index	**18.42%**

% Linear Shrinkage 12.86%

% of sample passing 425um was 98.24%

Technician name: Margaret Boon

Laboratory Manager's Signature: G. Lovelace Date: 13.10.2005

Mrs.Gabriela B. Lovelace MSc IEng MIAgrE

Appendix 7.5: Analysis of Variance Results for Parameters Measured During the Shrink-Swell Study.

ANOVA table for saturated hydraulic conductivity (K_{sat}) of the trial plots

Variate: Ksat_m_d_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_texture.Plot stratum					
Soil_texture	1	2426.804	2426.804	41.06	<.001
Treatment	1	3519.758	3519.758	59.55	<.001
Soil_texture.Treatment					
	1	2462.544	2462.544	41.66	<.001
Residual	32	1891.442	59.108	58.78	
Soil_texture.Plot.Sample stratum					
	72	72.402	1.006		
Total	107	10372.950			

ANOVA table for soil penetrative resistance (kPa) on the trial plots

Variate: Penetration_resistance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_texture.Plot stratum					
Soil_texture	1	567510.	567510.	2.14	0.181
Treatment	1	44346471.	44346471.	167.39	<.001
Soil_texture.Treatment					
	1	683056.	683056.	2.58	0.147
Residual	8	2119377.	264922.	0.38	
Soil_texture.Plot.Date stratum					
Date	1	13480519.	13480519.	19.55	0.002
Soil_texture.Date	1	73791308.	73791308.	107.02	<.001
Date.Treatment	1	37029327.	37029327.	53.70	<.001
Soil_texture.Date.Treatment					
	1	869600.	869600.	1.26	0.294
Residual	8	5515986.	689498.	3.70	
Soil_texture.Plot.Date.Samples stratum					
	96	17882908.	186280.	5.00	
Soil_texture.Plot.Date.Samples.*Units* stratum					
Depth	8	108257444.	13532181.	363.35	<.001
Soil_texture.Depth	8	5338488.	667311.	17.92	<.001
Date.Depth	8	22143774.	2767972.	74.32	<.001
Treatment.Depth	8	6240238.	780030.	20.94	<.001
Soil_texture.Date.Depth					
	8	18473614.	2309202.	62.00	<.001
Soil_texture.Treatment.Depth					
	8	1171630.	146454.	3.93	<.001
Date.Treatment.Depth					
	8	6241669.	780209.	20.95	<.001
Soil_texture.Date.Treatment.Depth					
	8	1069337.	133667.	3.59	<.001
Residual	896	33369478.	37243.		
Total	1079	398591731.			

ANOVA table for surface hardness

Variate: Gravities

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_texture.Plot stratum					
Soil_texture	1	702.2	702.2	1.07	0.331
Treatment	1	34575.3	34575.3	52.66	<.001
Soil_texture.Treatment					
	1	326.0	326.0	0.50	0.501
Residual	8	5252.3	656.5	6.49	
Soil_texture.Plot.Date stratum					
Date	8	36538.2	4567.3	45.15	<.001
Soil_texture.Date	8	2895.3	361.9	3.58	0.002
Date.Treatment	8	13703.6	1712.9	16.93	<.001
Soil_texture.Date.Treatment					
	8	1763.1	220.4	2.18	0.041
Residual	64	6474.5	101.2	0.72	
Soil_texture.Plot.Date.Sample stratum					
	216	30560.0	141.5		
Total	323	132790.8			

ANOVA table for the soil volumetric moisture content (θ_v)

Variate: Vol_moisture

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil_texture.Plot stratum					
Soil_texture	1	19.753	19.753	0.31	0.592
Treatment	1	10236.943	10236.943	161.64	<.001
Soil_texture.Treatment					
	1	1084.604	1084.604	17.13	0.003
Residual	8	506.656	63.332	9.79	
Soil_texture.Plot.Date stratum					
Date	8	4074.518	509.315	78.74	<.001
Soil_texture.Date	8	92.026	11.503	1.78	0.098
Date.Treatment	8	860.041	107.505	16.62	<.001
Soil_texture.Date.Treatment					
	8	31.484	3.935	0.61	0.767
Residual	64	413.973	6.468	0.93	
Soil_texture.Plot.Date.Sample stratum					
	216	1497.873	6.935		
Total	323	18817.872			

APPENDIX EIGHT

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Appendix 8.1: 2004 and 2005 Fixtures Lists for Newcastle Racecourse…………. 294

Appendix 8.2: Actual and Predicted Mean Going Values for Newcastle Racecourse During the 2004 and 2005 Flat Racing Seasons……….296

Appendix 8.1: 2004 and 2005 Fixtures Lists for Newcastle Racecourse

Newcastle Racecourse 2004 Fixtures List

Date	Name of Meeting	Flat/Jumps
Saturday 3rd January	Cantor Sport Dipper Day	Jumps
Wednesday 21st January		Jumps
Wednesday 4th February		Jumps
Saturday 21st February	Tote Eider	Jumps
Monday 1st March		Jumps
Saturday 13th March	Guinness St Patrick's Meeting	Jumps
Saturday 20th March		Jumps
Monday 29th March	First Flat meeting	Flat
Saturday 3rd April	Grand National Day	Flat
Tuesday 20th April		Flat
Monday 26th April	Evening meeting	Flat
Monday 3rd May	Northumbrian WaterAid Family Raceday	Flat
Wednesday 12th May	**PARKLANDS PRO-AM RACE NIGHT**	Flat
Thursday 20th May		Flat
Wednesday 2nd June		Flat
Thursday 24th June	Seaton Delaval Trophy	Flat
Friday 25th June	Northern Rock Gosforth Park Cup – evening meeting	Flat
Saturday 26th June	John Smith's Northumberland Plate	Flat
Saturday 24th July	Beeswing Ladies Day	Flat
Wednesday 4th August	NSPCC Charity Raceday	Flat
Friday 13th August		Flat
Friday 27th August	Evening meeting	Flat
Monday 30th August	Chisholm Bookmakers Blaydon Races	Flat
Monday 6th September		Flat
Wednesday 29th September	**THE RENAULT VANS RACEDAY**	Flat
Sunday 10th October	Sunday Funday	Flat
Wednesday 20th October		Flat
Friday 12th November	First National Hunt Meeting	Jumps
Saturday 27th November	Pertemps Fighting Fifth Hurdle	Jumps
Monday 6th December		Jumps
Saturday 18th December	Christmas Hurdle	Jumps

Newcastle Racecourse 2005 Fixture List

Date	Name of Meeting	Flat / Jumps
Monday 10th January		Jumps
Wednesday 19th January	The Rhodar.co.uk Asbestos Removal Raceday	Jumps
Wednesday 2nd February	The Woodford Group Raceday	Jumps
Tuesday 15th February	St Valentine's Raceday	Jumps
Saturday 26th February	Totesport Eider Meeting	Jumps
Tuesday 8th March	Haggerston Castle Holiday Village Raceday	Jumps
Saturday 19th March	Guinness St Patrick's Meeting	Jumps
Saturday 9th April	Bet365 Grand National Day	Flat
Tuesday 19th April	Renault Vans Raceday	Flat
Monday 2nd May	Unison Raceday	Flat
Wednesday 11th May (eve)	Evening Meeting	Flat
Thursday 19th May	The Henry Colbeck "Fish and Chips" Raceday	Flat
Wednesday 1st June	Prince's Trust Charity Raceday	Flat
Thursday 23rd June	TSG Seaton Delaval Trophy Day	Flat
Friday 24th June	Northern Rock Gosforth Park Cup – evening meeting	Flat
Saturday 25th June	John Smith's Northumberland Plate	Flat
Saturday 23rd July	Betfred Beeswing Ladies Day	Flat
Wednesday 3rd August	NSPCC Charity Raceday	Flat
Friday 12th August	Northumbrian WaterAid Charity Raceday	Flat
Friday 26th August	Evening Racing with the Cantor Index Group	Flat
Monday 29th August	Chisholm Bookmakers Blaydon Races	Flat
Monday 5th September		Flat
Wednesday 28th September		Flat
Sunday 9th October	The Royal British Legion Raceday	Flat
Wednesday 19th October	Parkinson's Disease Society Charity Raceday	Flat
Friday 11th November	The Lumsden & Carroll Construction Raceday	Jumps
Saturday 26th November	Pertemps Fighting Fifth Hurdle	Jumps
Monday 5th December		Jumps
Saturday 17th December	Betfred Christmas Hurdle	Jumps

Appendix 8.2: Actual and Predicted Mean Going Values for Newcastle Racecourse During the 2004 and 2005 Flat Racing Seasons

The actual mean going for sandy clay loam soil on the three different sections of Newcastle Racecourse on a raceday is provided in the table below. The predicted going for the simulated irrigation regime is also given. Mean going and predicted going values for all soil types on race and non-race days during the same period are given in the accompanying CD-Rom.

Going on racedays

Date	Chute	Straight	Round	Simulated
24/06/2004	7	6.8	5.8	8.3
25/06/2004	2.7	5.1	4.4	7.3
26/06/2004	5.7	6.9	5.5	7.5
24/07/2004	6.4	8.3	7.7	8.6
04/08/2004	6.2	6.4	7.5	8.9
13/08/2004	DNA	DNA	DNA	5.4
27/08/2004	DNA	DNA	DNA	5.7
30/08/2004	4.4	4.2	4.1	6.7
06/09/2004	7.7	7.9	7.8	8.1
29/09/2004	8.9	9.1	9.6	8.9
10/10/2004	7.7	8.1	7.9	8.8
20/10/2004	DNA	DNA	DNA	5.8
09/04/2005	DNA	DNA	DNA	8.0
19/04/2005	DNA	DNA	DNA	5.9
02/05/2005	DNA	DNA	DNA	7.7
11/05/2005	4.9	6.8	7	7.2
19/05/2005	DNA	DNA	DNA	7.9
01/06/2005	8.2	7.9	8.3	8.8
23/06/2005	DNA	DNA	DNA	9.3
24/06/2005	7.8	8.5	8.7	8.2
25/06/2005	DNA	DNA	DNA	7.9
23/07/2005	8.3	8.3	8.5	9.0
03/08/2005	6.6	8.1	6.7	7.1
12/08/2005	DNA	DNA	DNA	7.2
26/08/2005	DNA	DNA	DNA	7.8
29/08/2005	DNA	DNA	DNA	8.3
05/09/2005	7.6	8.4	8.4	8.0
28/09/2005	8.2	8.3	9.2	8.4
09/10/2005	DNA	DNA	DNA	8.7
19/10/2005	DNA	DNA	DNA	7.6

DNA = Data Not Available

ACCOMPANYING CD-ROM

A CD-Rom can be found at the back of this thesis. The CD-Rom contains additional information that was too expansive to be included in the appendices. The contents of the CD-Rom are given below.

Contents of the accompanying CD-Rom

1. Questionnaire survey: raw data (requires SPSS software).
2. Questionnaire survey: full analysis of results.
3. Bulk density raw data for the eight audited racecourses.
4. Soil penetrative resistance raw data for the eight audited racecourses.
5. Full analysis of results for the eight audited racecourses.
6. Going-Stick operators manual: full version.
7. Optimum number of days for rainfall balance model.
8. Newcastle Racecourse weather summary for 2004 to 2006.
9. Calculation of mean going.
10. Irrigation data for York Racecourse during 2006.
11. Rzone defs for the four waypoints analysed at York Racecourse.
12. Summary of weather data for Leicester Racecourse April 2005 to July 2006.
13. Initial and final going for the construction of DEFFIM.
14. DEFFIM effective irrigation data.
15. Initial and final going for the validation of DEFFIM.
16. DEFFIM validation effective irrigation data.
17. Raw data for DEFFIM (requires Statistica software).
18. Analysis of variance for the different soil types in the DEFFIM model construction (requires Statistica software).

19. Analysis of variance for the initial and final going in the DEFFIM model construction (requires Statistica software).

20. Sandy clay loam mean going and predicted mean going at Newcastle Racecourse.

21. Shrink-swell trial: summary of weather conditions.

22. An electronic copy of the thesis.