

A Study of the Evaluation of Variability in the Turf Environment

by

David Walter McKechnie

A review submitted to the Department of Crop Science,
University of Sydney in partial fulfilment of the requirements for the award of the
GRADUATE DIPLOMA OF AGRICULTURAL SCIENCE
(TURF MANAGEMENT)

Department of Crop Science
University of Sydney
April 1997

Declaration of Originality

The text of this thesis contains no material which has been accepted as part of the requirements for any other diploma or degree in any University, or any other material previously published or written unless due reference to the material has been made or the material has become assimilated into the general body of knowledge within the discipline.

David McKechnie

Acknowledgments

My father always said “it is better to learn from other peoples mistakes than to make your own”. This is true also in the scientific world (where due reference is given of course). Unfortunately the modern world is moving forward to fast to appreciate the knowledge and skill of not just the scientific profession, but also the tradesmen who know how to observe.

Major acknowledgments are due to:

Professor Martin, for the freedom to read.

Associate Professor A. J. Koppi, for the teaching of pedology.

David from the Crop Science workshop.

Frank Cridland TAFE teacher, for keeping the basics in sight.

Others who have helped or supported include;), Craig Briscoe (Fellow student), Mick Battam (fellow student), Malcom Harris (Northbridge GC), John Baker (Lane Cove CC Rtd), Christina (girlfriend) and Shelley Olsson (friend) for the marvellous editing.

Final acknowledgment must be given to all those researchers who have imparted their experiences and results in reference material. Without them, data would be unavailable to advance scientific knowledge and practical applications. Most answers are lurking waiting to be discovered.

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INTRODUCTION

There is much discussion in trade and scientific journals on the need to start planning for integrated management in agricultural and horticultural systems. In the Turf industry the requirement to maintain high quality playing surfaces under the ever intensifying usage pressures has lead to an increased dependency on applications of pesticides, fertilisers and water (Balogh et al 1992:7).

To implement management strategies for turf and lawn areas, an understanding of soil - plant relations, water management, and cultural practices needs to be further investigated, with the aim of furnishing uncomplicated information for the use of turf manager.

Towards this end improved soil and plant sampling methods and devices need to be designed, calibrated and tested for :-

- ◇ ease of collection;
- ◇ on site methods of quick testing;
- ◇ quick turn around for laboratory analysis;
- ◇ multipurpose use so that more information can be gathered without destroying playing surface quality; and
- ◇ relevance to local turf management practices.

Soil or plant samples are normally taken to give guidance on fertiliser requirements. These can take over a week or more in turn around time. Other samples are taken to isolate potential diseases in the plant, whilst in the turf research community, samples are used for the understanding of hydraulic conductivity, permeability, compaction and soil layering effects. Unfortunately the methods developed for these purposes are not readily used on turf surfaces due to:-

- ◇ their destructiveness
- ◇ the excessive time to take and process samples
- ◇ the lack of specialised equipment, or
- ◇ personnel not having the technical background.

Although numerous isolated tests are currently applied to the turf industry, the complexity of the situation demands a carefully integrated approach for the characteristics of each turf environment / situation. To make progress towards the goal of integrated management systems or best management practices some basic issues now need to be addressed and will be explored in the following pages.

A. Turf Maintenance

Turf managers use a number of techniques to provide quality playing surfaces. These tend to follow the growth pattern of the grass material used, broadly classified into the cool season grasses (C-3) and the warm season grasses (C-4). These techniques include mowing, fertilisation, dethatching, aeration, irrigation, pest control and disease control. All of these are practical turf maintenance techniques.

Generally these techniques are put into practice reactively rather than proactively due to the limited methods used to measure changes in the turf ecosystem by turf managers.

B. The Turf Ecosystem

To manage a turf ecosystem more effectively, knowledge of the environmental factors affecting certain management techniques (eg the spraying pesticides) need to be better understood. Zobel (1992) divided the idea of an ecosystem into two groups:-

- a) the biotic or thallosphere (the gaseous envelope surrounding the earth including micro/macro-organisms, insects, plants etc) and,
- b) the abiotic or rhizosphere (below surface including micro/macro-organisms, insects, plant roots, chemicals).

The biotic factors commonly known include the effects of wind, air temperature, precipitation and humidity, whilst the abiotic factors are not often seen (soil; pedology, chemistry, physics, plant growth, micro-organisms, etc). Zobel (1992) further divided the abiotic factors (Rhizosphere) further into temporally static and variable characteristics (Table 1).

Temporary Static Characteristics.	Temporary Variable Characteristics.
Compaction / Bulk Density	Temperature
Aggregate Size	Water
Pore Size & Distribution	Nitrogenous Compounds (NO ₃ / NH ₄)
Pan Layers	Other Chemicals
Geochemistry	Minerals (or nutrients)
Non-labile Organic Matter	Labile Organic Matter
	Carbon Dioxide
	Oxygen
	Other Gasses

Table 1. Static and Variable Characteristics within the Atmosphere of Earth (After Zobel 1992).

Understanding the affect of static and variable characteristics in the environment is important to design sampling methods that aid management techniques or strategies.

In this review special attention will be given to some of the scientific basics such as the soil, water, plant and nutrient interactions which influence practicable management techniques.

II. SAMPLING

Introduction

There are many tests for nutrient status; some very accurate procedures are suitable for the laboratory only, whilst others are adapted to on site testing (quick test) to give an indication of nutrient or physical levels. Whether these accurate or rapid type methods are a problem or benefit to practical management has yet to be fully established in Australia.

An understanding of the differences between 'quick tests' or laboratory tests, relationships between the terms used for nutrient availability, soil characteristics or minerals need to be established so that the variations given by different procedures can be related to each other for better interpretation of results.

A quick test could be described as 'a quick, accurate, and inexpensive analytical procedure' (Hartz 1994) that can be used in the field, while laboratory tests involve many replications of the same method to present accurate information that may or may not be influenced from contamination of the sample. (eg Rogers and Carter 1987)

To choose the correct method to sample and test a population (eg soil, plant material, insects or animal matter), not only the knowledge about the static and variable characteristics of the population, but also information on how the population was formed or developed is needed. For example to collect soil samples this could include information on spatial variation in both the chemical and physical properties or measurements.

Soil Variability

Soils are varied in their composition, due to their parent material, landforms, mineral / chemical structure, weathering, vegetation and the hydraulic sequence (Brewer and Walker 1969, Crocker 1959, Glentworth and Dion 1949, Nikiforoff 1949, Walker et al 1968).

The variation in chemical / physical composition is not just over large areas, but is also very marked on small areas to such an extent that small scale variability is a major issue in devising effective soil sampling methods (Cline 1944).

To help overcome the variation (spatial variability) of a soil profile, a number of samples in an area need to be taken, not only from different parts of the field, but also to different depths depending on subsurface formation or degradation of the profile due to the effects of nature, chemicals, water or compaction (Beckett and Webster 1971).

Also variation can be reduced by the use of mathematical calculations or statistics. These statistical methods can be used to find the correct number of samples to be collected from the area or volume of soil (Beckett and Webster 1971; Rayment and Higginson 1992a.). They reduce the effects of variation over the sampling area by using the minimum acceptable degrees of freedom (statistical) needed for the result of each type of test undertaken (eg P testing).

Other sources of variability in soil samples, besides natural causes, are the method in which the sample is collected, stored and prepared. For example, in taking samples for the determination of bulk density, the introduction of variation occurs from the selection of tools used to more importantly the way the operators use each tool (Beckett and Webster 1971).

The problems of sampling are compounded by differences of sampling depth, changes in PSA moisture content, season of the year and cultural activities. These factors may have a large bearing on some final soil test results whether they are of a static or variable characteristic. (eg Bulk Density, Gravimetric Moisture and nutrient availability)(Beckett and Webster 1971).

The soil by its nature is a highly variable body and when we sample the soil solum for laboratory testing we add to the variability by the method of sampling followed. An understanding of these variables need to be understood for high analytical work, but not necessarily for routine management practices.

Principles of Soil Sampling

In sampling, the soil should not be considered as an area but as a volume, with the individual samples considered as members of an infinitely larger population (Cline 1944). The reason behind this is that the soil volume exhibits three dimensional variations due to changes of slope, horizon development (eg black layer, dry patch, layering, soil formation, etc), subsurface differences (eg PSA) and so on. In turn, all of these affect chemical equilibrium, mineral decomposition and formation, colouring, water movement and biological activity (Brewer and Walker 1969, Crocker 1959, Nikiforoff 1949, Walker et al 1968).

Soil samples are normally collected by a greenkeeper or company representatives using a hollow tube or sampling tool. These samples are then sent to the laboratory for analysis. Guidelines on sampling methods are given by various companies providing analytical services (Appendix 1). They generally state that sample should be taken from an area of the same soil type and management practices. The recommended number of cores to be taken from an area such as a bowling green vary between 3 to 30 depending on the sampling tool used, the minimum sample weight required (usually set at about 300

grams of soil) and a maximum sampling depth.(around 7.5cm to more often 10cm),(Chemturf Pty. Ltd., Turforce, and Turfgrass Technology (Appendix 1)).

Sampling Methods

Turner and Waddington (1978) undertook a study to determine the differences for sampling, testing and fertilizer recommendations amongst soil testing laboratories within the USA. Of importance was the difference in the results of recommendations given for fertilisers / liming which was interpreted as 'probably [due to] the lack of data specifically relating soil testing to turfgrass areas'.

A number of local companies were approached to determine their recommended sampling procedure for soils and leaf analysis , and compared against Turners and Waddington (1978) tables. This is not a complete list of companies providing such services but does show similarities for collection methods.

This data required to calibrate analytical methods to field plot responses is rarely available for Australian agricultural and horticultural areas, but surprisingly enough did not receive mention in two recent reviews on soil testing and plant analysis within Australia (Handson and Shelly 1993, Peverill 1993).

Company	Sampling Depth (cm)	Soil Samples		Extractant Phosphorous	Potassium
		Maintenance	Established		
Australia					
Incitec	7.5			Colwell	Colwell
Turfgrass Technology	7.5				
Chemspray	10		USA Harris Lab		
Turforce	10			Bray No 1	
Pivot	10				
US *					
	Sampling Depth (cm)				
	Maintenance	Established			
Penn State	7.6	15.3		Bray P1	
Michigan State	5.1	5.1		Bray P1	
Sewerage Comm.	5.1+Thatch	15.3 to 20.3		Hellige-Truog	Hellige-Truog
V.P.I.	5.1 to 7.6	10.2 to 15.3		Double-Acid	Double-Acid
Maryland	7.6	15.3		"	"
Rhode Island	10.2	15.3		"	"
Rutgers	15.3 to 17.8	15.3 to 17.8		"	"

Table 2. Soil sampling depth and extractants used.

*US From Turner and Waddington (1978)

Pererill (1993) reiterate some common requirements which must be met for reliable routine analysis; for soils

- a) Standardisation of sampling depth for particular crops
- b) Standardisation of sampling methods to obtain a representative sample

- c) Techniques for preventing the mixing of soil samples with different soil types or fertiliser histories including banded fertiliser applications for plants
- a) Selection of specific plant parts similar in physiological age
- b) Decontamination of sample to remove adhering soil, fertilisers, pesticides, etc.

Clearly a comprehensive listing of all the desirable requirements would make a very large list.

The use of 'quick' tests has also been bandied around popular turf literature, generally with a negative appraisal. However, these methods have the benefit of providing less expensive indicators of nutrient problems and are often tests which could be carried out by greenkeepers and others after brief training courses. There is a real need to assess which of these 'quick tests' are reliable and to encourage their use as appropriate.

As can be seen, the variability problem does not just exist within the natural environment, but is also a prominent feature of the methods used to assess it.

Soil and Plant Analysis

There are a several recent reviews on the subjects of soil and plant analysis (Brown 1993, Farina 1994, Rayment 1993, Robinson 1993, and Starr et al 1995). They all state common problems related to sampling procedures, which include;

- a) Number of Samples required
- b) Sampling Tool used
- c) Time of Sampling
- d) Influence of Sub soil properties
- e) Sample Contamination (Especially for Leaf Analysis (McCrimmon 1994)), and
- f) The reason why the sample was taken.

Whilst these problems occur at the time of soil / tissue sampling, other major problems arise in the interpretation of the raw data in numerous cases because of the lack of proper input-response calibration curves.

The same plants species grown under different climatic, rainfall / irrigation and soil types will produce different results for a given parameter when using the same analytical method. When the factor of

different methods is added the situation becomes even more confused. Some examples of the complex information provided to practitioners is given in the example below.

<i>Agrostis capillaris (tenuis)</i> Brown Top Bent			
Reference	pH	Soil Nutrients	Soil Moisture
Beard 1973 (Pg 71)	5.5 - 6.5	fertile (Low Nitrogen)	Moist
Davies and Howard 1994	5 - 5.5	Bsat* 20-45% (Low)	Not Noted
Grime et al 1988	3 - 8 (4-6)	Midly Acidic	Dryland
→			
			Moist

• Total Base Saturation Preferred

Table 3. Preferred Growing Conditions for *Agrostis capillaris (tenuis)*

Eg <i>Agrostis stolonifera var palustris</i> Creeping Bent Grass			
Reference	pH	Soil Nutrients	Soil Moisture
Beard 1973 (Pg 71)	5.5 - 6.5	fertile	Moist
Grime et al 1988	5.5 - >8	Not Noted	Wet

Table 4. Preferred Growing Conditions for *Agrostis stolonifera var palustris*)

As shown above for pH ranges and soil moisture recommended for two common turf species (Tables 3 and 4) there appears to be conflicting recommendations. Thus the preferred pH is one small example of the variation found within the literature, but as will detailed later pH compounds effects for nutrients and other soil properties and therefore should not be regarded as a ‘simple’ or single action factor.

I have also noted the recent discussion in the literature about soil testing for P. These discussions revolve around:

- a) the ability of P testing methods to discriminate between plant-available P and
- b) the relationship between available P and crop response.

While some success has been achieved with plant / soil data done with one method on a particular soil type (eg mineral) there seems no simple way of relating this information to data taken with a different method on another soil type (eg Organic). Added to this limited data on the turf plant nutrient

requirements or response curves (all done outside Australia as far as I am aware) and the problems are greatly compounded.

II. SOILS

Soil Formation

Soils have been shown to reflect the influences such as climate and topography upon their formation. Jenny (1941) in his Eminent book “Factors of Soil Formation” clarified these influences into climate, topography, parent material, time, and biotic effects. His progression of ideas and examples have tested by various pedological authors (Crocker 1959; Crocker and Major 1955; Dickson and Crocker 1953a, b; Nikiforooff 1949; Walker et al.1985) and are the basis of some soil science today.

In general terms, soils are formed from the interactions of climate (particularly rain fall, temperature and excess water (Nikiforooff 1949)) topography (Walker et al.1985) and at latter stages plant material (Crocker 1959; Crocker and Major 1955; Dickson and Crocker 1953a, b). These interactions have an influence upon the rate of mineral weathering therefore nutrient availability to plants (Jackson and Sherman 1953). These influences are presented in the diagram 1 on the following page.

From observation of the following diagram it can be seen that with increasing rainfall that salts ($CaCO_3 + MgCO_3$ and $CaSO_4$) and small clay particles are moved deeper (leached) within the profile. Such a scheme is also influenced by temperature which directly affects the rates of chemical reactions and indirectly by determining the predominant types of vegetation (eg See Brady 1990 pg 49).

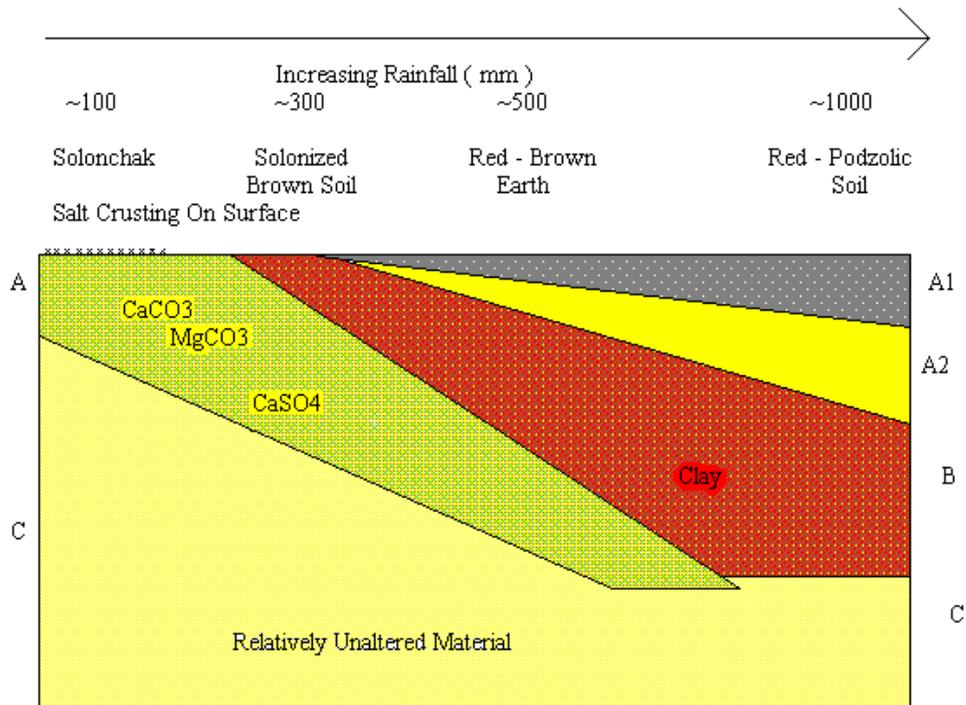


Diagram 1. The effect of increasing rainfall on a soil sequence in NSW (From Koppi 1990).

The concept of increased water movement leaching nutrients, salts and clay particles is also of relevance to practicable turf management, not just as an indication for plant growth in a certain temperature zone. Another factor alluded to is the cycling of organic matter, but this will be further expanded upon later.

Soil Chemical Properties

Chemical characteristics in the soil have a dynamic relationship between the nutritional and non nutritional elements. The influence of the biotic factors upon these chemical reactions in relation to their availability to the plant cannot be dismissed.

This dynamic and confusing relationship within the soil between biotic factors and chemical (mineral or nutritional) interactions can lead to misinterpretation of analytical results. An understanding of the basics effecting soil minerals/biotic interactions is needed so that the variability of this mineral occurring in different soils is appreciated. These include measuring soil pH, CEC, OC, Eh, and EC.

Soil pH

Soil pH is the negative logarithm of the activity (concentration) of ionised H ($-\log (H^+)$ where $(H^+) = \gamma [H^+]$ Where γ is the activity coefficient of H^+ and $[H^+]$ is the concentration of the H ion in solution measured in moles per litre (Russell 1988) in the soil solution (Brady 1990 and McLean 1982) and is measured on a scale of 1 to 14. It is also known as the soil Acidity (H^+) or Alkalinity (OH^-) of the soil, or in older books 'soil reaction'.

There are a number of factors that influence the pH at different levels. These include temperature, a pH of 7 (neutral) at 23 °C of pure water will give a pH of 6 at 100 °C (acid) or a pH of 7.5 at 0 °C (basic); several ions like Al or Fe attract and neutralise OH^- ions in the soil thus increasing the acidity of the soil at low pH (4.5 - 5.5) (McLean 1982); pH dependent charge sites on soil colloids (Chung & Zasoski 1994); soil solution ratio; CO_2 , (McLean 1982), competition between Cations and Anions through chemical reactions, type of organic matter, and the condition of the soil.

The effect of pH in the soil affects not only the availability of minerals in the soil for plant use but also some soil physical attributes such as clay dispersion (Chorom et al 1994), due to change in net particle charge caused by the change in pH.

As can be seen, pH is not only a measurement of an element but is also a biotic factor influencing not just chemical reaction but also soil physical characteristics.

Methods for Measuring pH

A number of methods are available to measure the pH of the soil and some of them are summarised below.

Method Code *	Variation	Soil	Type	Variation / Used To	Reference #
Raupach and Tucker	Nil	Base	Field	Field	1
pH of 1:2 Soil / Water	Nil	----		Lab	
pH of 1:5 Soil / Water	4A1	0.5-0.6 +	AD	Lab (pH_w)	2
1:5 soil 0.01M Ca Cl Dir,4B1	0- 0.5-		AD	Lab Soluble Salts / Variable Surface Charge	(pH_{Ca}) 3
1:5 soil 0.01M Ca Cl	4B2	0-0.5-	AD	Lab	Follows 4A1 4
1:5 soil /1M KCl Dir,	4C1	ΔpH^{**}	AD	Lab	Different Extract 4
1:5 soil /1M KCl	4C2	ΔpH	AD	Lab	Follows 4A1 4
pH of Na F soln	4D1		AD	Lab	Active Al 4
pH of H ₂ O ₂	4E1		Field	Lab	Acid Sulphate Soil 4
ΔpH	4F1		Calculation		Dominate Electrical Charge 4

Notes

* Code from Rayment and Higginson 1992

1 / Raulpach and Tucker 1959, 2 / Rayment and Higginson 1992 Also See Baker et al 1983, and Ahern et al 1995. 3 / Rayment and Higginson 1992 Also Conyers and Davey 1988, and Ahern et al 1995. 4 / Rayment and Higginson 1992.

Chart 1. Comparison of pH measurement

As is shown above a number of methods can be used to measure the pH of the soil, depending on what information is required to assess the profile. This can be divided into:-

1. pH indication (methods), Raupach, 4A1, 4B1, and 4B2.
2. Estimation of ΔpH (Current electrical Soil Charge), 4F1,
3. Indication of active Aluminium, 4D1 and
4. Indication of Acid Sulphate soils, 4E1.

The conversion factor between different methods, particularly CaCl (pH_{Ca}) and water (pH_w), is needed to relate information gained on similar or different soils taken over different time periods. Ahern et al (1995) modelled the variation over 7894 samples taken in Queensland Australia, with the conclusion that variation between pH_{Ca} and pH_w is smaller in the acid range of the pH scale

particularly in highly weathered soils (Acid eg kransozem) compared to Calcaric soils (eg solodised solonetz and solodic soils).

The variability in the nature of soils is shown here and needs to be expanded upon to give better guide lines to the practical manager. Due to the technical nature of this information it is beyond the scope of this review.

Redox Relationships (*pe* or *Eh*)

Redox relationships or redox potential is the Oxidation (the process where a substance gives up electrons or a reaction with oxygen, $O(g)$ (where $g=$ gas)) and reduction (where the substance takes up an electron or the loss of oxygen, $CO_2(g)$)(Jacob 1970, Baas Becking et al 1960) of a chemical reaction. These reactions are standard in all chemical reactions, particularly in soils. Unfortunately few scientists and understandably few turf managers make full use of this knowledge (Lindsay 1979).

Redox potential can be expressed as the negative log of electron activity and can be measured by the difference in millivolts between a platinum and standard hydrogen electrode (*Eh* or *pe*). This electrical activity comes from the reactions of the protons (+ ions) and electrons (- ions) within the soil at various concentrations. It is this measurement in electrons that makes the *Eh* compatible to pH measurements and can consequently be plotted against each other (Baas Becking et al 1960). Baas Becking et al (1960) have commented on the four types of chemical reactions that occur for neutralisation to take place;

- ◇ 1) Electrons or protons are not involved
- ◇ 2) Protons only involved
- ◇ 3) Electrons only involved
- ◇ 4) Protons and Electrons involved

Baas Becking et al (1960) using pH and *Eh* data on an empirical approach graphed this data for different types of water (Sea, River, Ground, Mine, Lakes and Rain), soils, peats, sediments (Ocean, river, and tidal) and organisms (algae etc). Their interpretation of the results indicate at a high pH, a low *Eh* generally occurs and at low pH, a high *Eh* values are obtained.

These *Eh* vs pH graphs also give stability fields for various compounds in reaction (Baas Becking et al 1960). Some of these naturally occurring non-metallic transformations are presented in table 5.

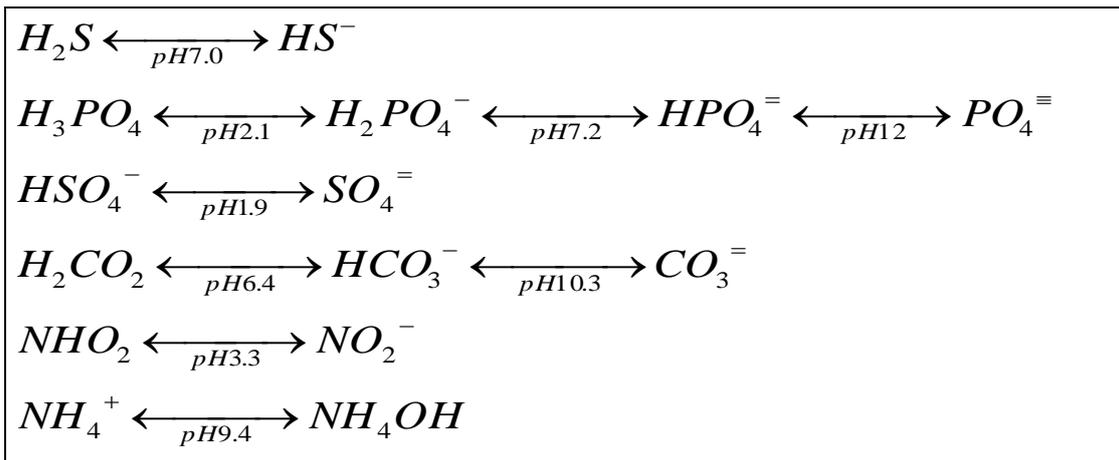


Table 5. Reactions from Stability diagrams (Baas Becking et al 1960)

As can be seen from the above reaction equations, pH performs a distinct role in the dynamics of compound formation, whilst the effects of redox (pe), O(g) and / or CO₂(g) are not identifiable within these equations.

Redox reactions in the soil are an important consideration in fertiliser application as the formulation of a nutrient applied into a system with an unfavourable pe/pH scale will change that formula to a compound ;1) available to the plant

- 2) unavailable to the plant
- 3) a leachable compound
- 4) a compound tied up in the soil matrix
- 5) a combinations of the above.

Electrical Conductivity (EC)

EC is the measurement of soluble salts in the soil (Anions and Cations) and consist not only of Na, Mg, Ca, Cl, SO₄, HCO₃ (Cations, Positive Ions), but also K, NH₄, NO₃ (Anions, negative Ions) (Rayment and Higginson 1992 pp15-16.). These salts are known as salinity in natural waters (Rhoades et al 1992). They have been measured both in deciSiemens per metre (dS/m), or in older papers as millimoles per litre (mmolc/l), milli Siemens per centimetre and micro Siemens per centimetre. (1 dS/m = 10 mmolc/l = 700 mg/l @ 25°C Rhoades et al 1992).

EC is important in giving an indication of the quantity of soluble salts (nutrients) or salinity of the soil. Unfortunately the concentration of salts in the soil solution will vary depending on the volumetric moisture content of the soil. (ie less moisture in the soil volume means a higher EC concentration).

Another influence on the EC is the difference of the ionic concentrations (charges +/-) of the various 'salts'. EC can therefore be used to work out the Osmotic component of the total water potential, Total Dissolved Salts (TDS), and total cations/anions by the use of one of the following formula (Bresler, et al 1982);

<p>Osmotic potential</p> $-0.36 * EC_e (\text{mmho/cm}) \approx \psi^{\circ} (\text{Osmotic potential}) \text{ bar}$ <p>Range 3-30mmhos</p>
<p>Total Cations or Anions from EC</p> $\text{Total Cations or Anions (mEq/l)} \approx 10 * EC (\text{mmho/cm})$
<p>Total Dissolved Salts (mg/l) from EC</p> $\text{TDS (mg/l)} \approx 0.64 * 10^3 * EC (\text{mmho/cm})$

Table 6. Formula for EC to Osmotic pressure, Total Cations and TDS. From Bresler, et al 1982

The osmotic potential (or salt content) can affect all properties in the soil and soil water phase from total available water to the solubility of compounds (eg pesticides)(Madhun and Freed 1990 pg 432).

Methods of Measuring EC

There are two popular methods for measuring EC; these are a 1:5 soil/ water extract ($EC_{1:5}$)(3A1 Rayment and Higginson 1992) and a EC/Saturated Extract (EC_e) (14B1 Rayment and Higginson 1992). As noted previously, the volume of water will affect the concentration of salts, therefore the final interpretation.

Slavich and Petterson (1993) concluded that EC_e can be estimated from $EC_{1:5}$ with an assumed estimate of the saturated water content. They go on to say that the estimate of EC_e be reported along with the estimate of the soil saturated water content, particularly in sandy soils.

Measurement of the Electrical Conductivity of soil or water concentrations will give indications of cation/anion range levels as well as the level of salts. Regular monitoring of EC levels can be of benefit to turf managers.

Organic Matter

Organic Matter is an important component of the soil volume consisting of living and decaying plant and animal remains (hence all of the elements that are contained in these remains). It affects the soils physical and chemical properties from nutrient and chemical retention/release (pH), soil binding / dispersion, water holding capacity, through to water infiltration and water repellency.

With Organic Matter (OM) playing such a diverse role in the soil volume, the information on its contributions to ecological environment (soil, plant and aerobic), from a micro to macro form is dispersed over various scientific subjects and time periods. Authors who have prepared papers various papers on organic matter have proposed varying views relating to each subject (Christensen 1992).

Some of the roles of Organic matter include; its chemical procedure of break down (Oades 1989), the affects on soil structure (Tisdall and Oades 1982), bulk density (Free et al 1947 as reported by Vomocil 1957) and clay-organic interactions (Mortland 1970), these all have interaction upon the measurable properties of each role (Tisdall and Oades 1982).

Organic matter enters the soil through the surface (Leaf litter etc) and subsurface (Roots). This is broken down to humus, humic substances, and then into either the humin fraction (HF), humic acid fraction (HAF), or fulvic fraction (FF) (Oades 1989). Each of these fractions represents a number of different organic molecules that seem to have similar characteristics .

Tisdall and Oades (1982) have shown the effect organic matter has on soil aggregation. These binding agents have been classed by Tisdall and Oades (1982) into three different but not dissimilar types of classes ;

- a) Transient. eg polysaccharides.
- a) Temporary. fungal hyphae and roots.
- b) Persistent. aromatic compounds (contains benzene ring) associated with metal cations and polymers.

On the other hand, Mortland (1970) covers bonding mechanism in the soil profile, which include;

Cationic	Anionic
Ion-dipole and coordination	Hydrogen bonding
Van der Waals Forces	Pi Bonding
Entropy Effects	Covalent Bonding

Humic Fraction	Humic Acid Fraction		Fulvic Acid Fraction
CEC (cmol kg) and Acidity Increasing			
100?	300	500	1000
Carbon Content (g Kg) decreasing			
550	620	560	430
Oxygen Content (g Kg) increasing			
340	290	360	510
Nitrogen (g Kg) decreasing Content			
46	55	41	7
Hydrogen Content (g Kg) variable			
55	29	67	50

Table 7. Chemical Fractions of the Soil Organic Matter (From Oades 1989)

Danneberger and Hudson (1994), working with Localised Dry Spot syndrome (LDS), showed connections between the increase in OM and the occurrence of LDS. They produced the following table indicating the relative organic fraction and the amounts found in wettable and nonwettable soils.

Organic Fraction	Non-wettable Soil (LDS)	Wettable Soil
Humic Acids	> quantities	< quantities
Fulvic Acids	> quantities different with methanol extraction	< quantities spectra same
Lipids	> quantities C16 fatty acid present	< quantities No C16 fatty acid present

Table 8. Comparison between wettable and non wettable soil and their OM Content From Danneberger and Hudson (1994)

They continue by discussing Hudson's unpublished data on the polarity effect on the sorption characteristics of carbazole and fenarimol in wettable and non wettable soils, where carbazole, the least polarised compound displayed increased sorptivity on non wettable soils. This was related to the organic carbon isotherm.

In all these different processes the organic matter is made up of the basic building blocks of carbon, hydrogen, oxygen, nitrogen, phosphorous, and sulphur. Research has shown that there are distinct ratios between carbon:organic nitrogen (C:N ratio) and carbon:organic sulphur (C:S ratio) as the amount of organic matter accumulates over time, while the carbon:organic phosphorous (C:P ratio) is less distinct (Russell's 1988 pg 568). These principles will vary in poorly drained and/or highly acid (pH < 5) soils.

Comparable Organic Fractions	Nil	Humin Fraction	Temporary
	Humic Acids	Humic Acid	Transient
	Fulvic Acids	Fulvic Acid Fraction	Persistent
	Lipids	Nil	Nil
Author	Danneberger and Hudson 1994	From Oades 1989	From Tisdall and Oades 1982

Table 9. Comparison of different Organic fraction described by various Authors.

The use of very sandy soil in man made turf profile (eg USGA specification) produces soil profiles with low CEC and low water holding capacity, leading to a high likelihood of nutrient leaching with incorrect irrigation practices. This has lead to amendments such as; fired clay, vermiculite, perlite, zeolite, and organic material added to turf profiles to increase CEC and moisture holding characteristics (Beard 1973, Huanag and Petrovic 1995). With the increased use of organic based products for the amelioration of existing soils and the incorporation into soils used for new construction, it is becoming urgently necessary that we improve our knowledge of the management, movement and type of organic compounds in the turf/soil environment.

Of importance is the effect of organic matter on soil bulk density and water infiltration. Free et al (1947 as reported by Vomocil 1957) show that an increase in organic matter decreased the soils bulk density.

	Honeoye Silt Loam		Sassafras Silt Loam	
%OM	4.10%	2.80%	4.40%	2.60%
g/cm ³	1.47	1.6	1.48	1.69

Table 10. OM vs Bulk density From Free et al 1947

By bringing together information on the break down of OM through different fractions (Oades 1989), the effect of OM on soil aggregation (Tisdall and Oades 1982), then comparing these organic fractions to the amount of wettable/nonwettable soil (Danneberger and Hudson 1994), and taking into account the various effects of bonding mechanism (Mortland 1970) similarities can be found. This can be pursued to improved knowledge on organic matter turnover in the turf environment, and better use of its attributes (nutrient/water holding capacity, soil aggregation), and it potential problem (influence on non wettable soils, black layer formation (Adams and Smith 1994), bulk density (Free et al 1947 As reported by Vomocil 1957)) and nutrient contamination (Prof Martin per comms), leading to the identification of appropriate organic amendments.

Modelling Turnover of Organic Matter

The turn over, or breakdown of organic matter through the different chemical forms is not just related to management (cultivation practices, pesticide application, and fertilisation), soil chemical reactions and consumption by organisms, but also to temperature and rainfall (Climatic Zones).

This can be demonstrated by the formation of peaty type soils in cold moist areas (eg Ireland), whilst tropical zones tend to have highly leached soils with little if any organic matter at depth (eg Tate and Churchman 1978, Russell's 188 pg 593). This has implications far reaching on the management of OM throughout the various climate zone found within Australia.

Jenny (1941 as quoted by Russell's 1988) exhibited this association by the formula;

$$N = ce^{-kT} \quad (\text{Equation 1.})$$

where N is total Nitrogen, c and k are constants and T is the mean annual temperature. This formula held for well drained cultivated soils from the mid west of the USA.

Reim Vis (1980) with his work in the Netherlands looked at the accumulation of organic matter in top 5 cm of the profile over 35 sports fields. By using the equation

$$\frac{Ym - Y}{Ym - Yo} = e^{-k_2 t} \quad (\text{Equation 2.})$$

where Y = OM content, Yo = initial OM content, Ym = OM at equilibrium, k_2 = coefficient of decomposition, and t = time in years, he was able to work out that the rate of accumulation of organic matter will equal the rate of decomposition when organic matter equal about 9% of the soil volume.

To model the turnover of OM effectively work done by Oades (1989), Tisdale and Oades (1982) and Mortland (1970) need to be merged together. This has been done by a simple two stage model widely used in the study of OM, (Russell's 1988 pg 604), where OM is divided into matter that is undecomposed (plant and animal remains (nahrhumus)) is placed in one compartment (P) and the remaining OM (dauerhumus) is placed in another (Q). (Where nahr = nourish and dauer = endure (Attiwill and Leeper 1990).

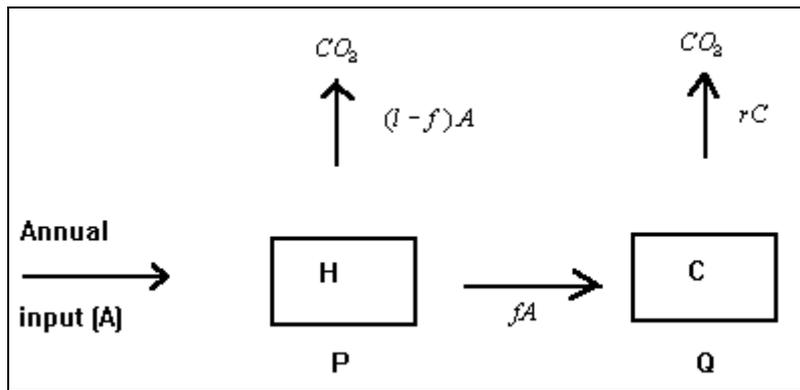


Diagram 2. Two compartment Model for the Turn Over of OM (Russell's 1988 pg 604)

This is based on the assumptions that there are two phases in the break down of organic matter, measured by the amount of organic carbon where ;

- a) Compartment P - undecomposed plant and animal remains
- b) Compartment Q - decomposed or remaining material including the microbial biomass.
- c) Compartment Q contains more decomposed material than Compartment P containing undecomposed
- d) All parts of Q are decomposed at the same rate
- e) The annual input of all animal and plant carbon of which (f) the isohumic fraction enters compartment Q each year (approx 0.7)

This can be written as;

$$dC / dt = fA - kc \quad (\text{Equation 3})$$

where k is the fraction of compartment Q decomposed per year and t is time in years. The solution to this equation is;

$$C = (fA / k) + (C_o - fA / k)e^{-kt} \quad (\text{Equation 4.})$$

where C_o is the initial carbon content of compartment Q and there fore the soil.

When the carbon content comes into equilibrium;

$$dC / dt = fA - kC$$

(Equation 5 and 6.)

$$fA / k = C_e$$

(C_e)this written as;

$$dC / dt = fA - kC \text{ and } fA / k = C_e \quad (\text{Equation 7.})$$

Except for the work done by Reim Vis (1980) there has been little further research work done on the turn over of organic matter in turf surfaces, either man made sand profiles (eg USGA) or insitu soils maintained as playing surfaces. By comparing fertiliser inputs with plant growth and organic matter break down equations the management of mat/thatch layers by cultural methods (scarifying, coring etc) could be reduced.

Other work at Rothemstead by Warren and Johnston (1964 as quoted by Russell's 1988 pg 597) compared the effect of acidity (pH) to the amount of carbon in the soil over 'depth' on a grassland system by the addition of ammonium sulphate or lime in comparison to a control. This showed that a mat layer formed on unlimed plots receiving acidifying fertiliser, whilst unfertilised and limed plots did not produce mats. The pH was also more alkaline at depth in the limed soils.

This work coincides with information given by Russell's (1988 pg 565) where the amount (or percentage) of organic matter in the soil is often reduced in relation to the depth of the profile with the exception of podzols type soils (Russell's 1988 pg 566) and the possibly of modified sand based turf profiles (McKechnie personal observation).

Attwill and Leeper (1990) in their book on Australian Forest soils also note that the break down of organic matter involves a two stage process. They approached this subject using the German terms of *Nahrhumas*, ((NH) *nahr* = Nourish) and *Dauerhumas*, ((DH) *dauer* = endure) where NH is more readily broken down by micro-organisms, while DH is resistant to breakdown and may exist for centuries.

The principle of relating the Organic fraction to 'out of date terms' (NH and DH) is to show the difference between the ;

- 1) Chemically reactive fraction (nutritional),
- and
- 2) The chemically stable fraction (physical).

The exact composition of each fraction (DH / NH) is hard to define, but may not be necessary if the type of fraction (Chemical or physical) can be identified within the profile. eg C/N ratio.

The understanding of the role of organic matter in turf areas is limited. The information required to manage not just the organic nutrients, (eg Nitrogen and Phosphorous) but also accumulation, decomposition, organic mater relationships to water holding capacity, drainage, dry patch and black layer has not been acquired. Awareness of the accumulation and decomposition process for organic matter will aid in better management practices (Jenkinson and Rayner 1977, Riem Vis 1980).

Methods of Measurement of Organic Matter

As noted previously the OM material is varied, and the methods to determine the whole OM content or part of the OM will determine which test to use. Most laboratories will use the Organic Carbon to Organic matter conversion ratio in determining the whole of OM.

This organic carbon to OM conversion factor varies between 1.724 and 2 in the scientific literature however this may lead to inconsistencies where cold and/or wet profiles exist.

Some other methods used are;

- Loss on ignition of the soil	Reim Vis (1971)	OM
- Walkley & Black	Rayment and Higginson (1992)	OC
- Heanes Wet Oxidation	Rayment and Higginson (1992)	OC

(It also recommended to see Nelson and Sommers 1982. pp 539 - 577.

In Page et al Agronomy No 9 Part 2.)

Notes: Reim Vis (1980) determined OM content as the loss on ignition at 600°C,
after initially removing the water content in oven at 105 °C,
then sieving the soil through a 2 mm sieve to remove plant material.

Nitrogen

Nitrogen unlike other nutrients is not procured from the soil minerals, but originates from the atmosphere. Its compounds bind to organic matter rather than the soil exchange sites (Cation/Anion). In Turf profiles sources of nitrogen are principally from fertiliser applications, but some also still come from the atmosphere, irrigation, and biological fixation (Petrovic 1990).

An understanding of the Nitrogen cycle in the soil is important to optimise its use by the turf and minimise the loss through the various phases of the nitrogen cycle or the application of fertiliser (Hassink 1995a, b). These phases include different soil types, pH affects, water logging, organic matter turn over, organic matter build up and other chemical/biological reactions within the soil.

The amount of nitrogen is closely related to organic carbon, otherwise known as the C/N ratio. This ratio in soils is normally around 10-14:1, but can increase in acid soils

Measurement of nitrogen in the soil volume is difficult because nitrogen does not readily bind to exchange sites in the soil. This could be further investigated in other reviews.

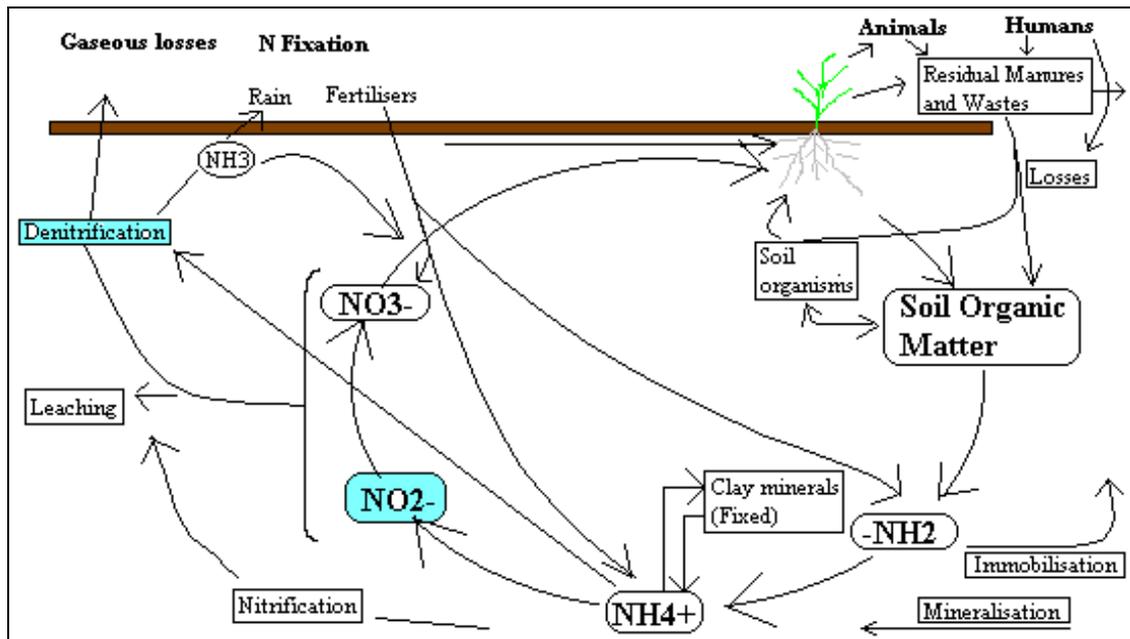


Diagram 3. Part of the N Cycle. From Brady 1990

III Soil Particle Size

As will be shown later soil pore size influences the soil matrix potential and therefore the soil moisture content, but the pores or gaps in the soil are themselves influenced by the soil particle size and the amount of compaction (soil bulk density).

Soil particle size in practice reflects not only upon the size of the individual soil grains, but also the conglomerations of soil particles from crumbs up to the macro-structures known as peds. These come in various shapes and sizes and are formed from soil particle bonding; either chemically, organically or through compaction. A good example of the different soil peds are black cracking clays (2:1 layer silicates) that swell up when moisture is added (the influence of single soil particles) and shrink as they dry producing large deep cracks within the soil (the formation of soil peds).

The voids left between soil peds and between single grains are known as pore spaces. It is these voids between soil particle that allow the soil to:

retain moisture

retain air pockets

allow excess moisture to move through the profile

From using a soil sample to calculate bulk density and assuming the density of the solids is 2.65, the volume of each fraction (ie, air, solids, and moisture) or the pore space relation in the sample at the time of sampling can be calculated by using the following formula.

$$\% \text{ Vol. of soil solids (Sv)} = \frac{\text{Vol. of soil in sampler}}{\text{Vol of sampler}} \times 100$$

$$\% \text{ Vol. of Water in Soil Core (Wv)} = \frac{\text{Vol. of water in sampler}}{\text{Vol of sampler}} \times 100$$

$$\% \text{ Vol. of Air in soil core (Av)} = \frac{\text{Sample Vol.} - (\text{Solid Vol.} + \text{Water Vol.})}{\text{Vol of sampler}} \times 100$$

Adapted from Koppi 1994 pp53.

		Camden	Camden	Boree	Boree
Volume of Soil Solids	%	52.49	49.04	50.63	45.07
Volume of Soil Air	%	21.92	28.19	37.89	46.62
Volume of Soil Water	%	25.60	22.77	11.48	8.31
Total	%	100.00	100.00	100.00	100.00

Table 11. Percentage of Solids, Air and Moisture in a Soil Sample.

With regular sampling (every 3 , 6 , or 12 months) this would inform managers of the soils physical characteristics, leading to reliable information when renovation practices should proceed (eg coring, topdressing etc) due to the changes recorded within the profile. As stated the increase in the percentage of total solids from a sample is a clear indication of compaction taking place.

The particle size and bulk density characteristics of soil are important to turf managers when s/he;

-is ordering soil or,

-maintaining soil profiles,

so that an engineering approach can be taken for the soil description. For example the USGA soil profile has been designed for reduced compaction and a high water infiltration rate after heavy rainfall, but these benefits will only be achieved and maintained if specifications are closely followed, particularly in relation to particle size distribution.

Specialised profiles such as the USGA have many benefits, but also some problems. Included within these problems are soils that are used generally have low CEC and water holding ability. To help correct this, various people recommend the addition of organic matter (OM) in some form. As the OM breaks down it is incorporated within the soil matrix and influences the water holding capacity, CEC, soil structure and the hydraulic conductivity.

Clearly then, the USGA profile is not permanently stable, leading to the need for a method to regularly monitor soil properties to identify potential problems before they develop to the point of interfering with profile behaviour.

- D_{gw} : capillary rise from ground water (perched water)
entering the root zone
- D_p : precipitation
- D_{et} : Evapotranspiration
- D_{pr} : precipitation that occurs as surface runoff
- D_{tw} : tail water (surface) runoff resulting from overland flow
- D_{dp} : deep percolation
- D_{pl} : precipitation intercepted by the plant (crop)
- $D_{\Delta s}$: change in soil moisture storage in the root zone(as a
positive for increasing soil moisture)

other terms not included in this formula but are relevant (from Walker and Skogerboe 1987) are;

- D_e : evaporation from soil surface or ponded water
- D_{pz} : precipitation that infiltrates into the soil
- D_t : transpiration from the plants
- D_{tw} : tailwater (surface) runoff resulting from overland flow
from irrigation (rain) supply
- D_z : infiltrated water resulting from overland flow of the
irrigation water supply
- D_{pn} : net precipitation, or the depth of precipitation that is
made available to the plant system
- D_d : drainage requirement for maintaining a salt balance in
the root zone

Note: All values expressed in depth equivalent mm of water

As seen in the preceding formulae there are a number of perspective's in understanding moisture balance within systems ranging from simple (Beard 1985) to more complex (Walker and Skogerboe 1987). These equations are useful for monitoring or evaluating irrigation systems, although more knowledge is required by a practical manager to use these tools.

Moisture and chemical reactions

Moisture influences any number of reactions within the soil environment. These include the pediological and chemical properties of turf and soil management, in as much the different ratios of moisture to air (*pe*) influence the chemical properties of the soil. This leads to a need for more understanding of the moisture characteristics, movement, soil - moisture - plant relationships, to help improve our knowledge of irrigation practices on plant growth with the aim of improving water use and plant growth under irrigated and non irrigated areas.

Not all of this work has been done nor would it be applicable to some managers, it is therefore in practicable terms only the relevant material will be covered.

Soil Water

The physical properties of a soil are governed by the interaction between the solid part (minerals, organic, and living tissue), air filled voids, and moisture. The solids are arranged like various sized balls or fragments within a container with moisture clinging to the surface of these balls and air filling the voids.

Although the moisture content of a natural soil can range from waterlogged to air dry, these particular points have special names, viz saturation, field capacity or permanent wilting point. These are defined as follows:-

- saturation (SAT) an excess of moisture in the soil leading to drainage to lower levels and/or runoff from the surface
- field capacity (FC) is the maximum amount of moisture that the soil can hold with out drainage occurring
- permanent wilting point (PWP) is that point where the plant will not recover from wilting after water is added to the soil.

The difference between PWP and FC is known as the available soil water (AW). In most literature this is considered as the available moisture content of the soil for plant growth.

$$AW = FC - PWP$$

Reid et al (1984) point to the need for 'simple, practical concepts of soil-plant water behaviour', and explain the notion of 'available' and 'extractable' water (EW). In continuation of these thoughts Reid et al (1984) follows the thoughts of Ritchie (1981a, b. as quoted by Reid et al 1984) by using the term of drained upper limit (DUL) and lower limit (LL) in substitution of FC and PWP (respectively).

$$EW = DUL - LL$$

These terms make allowances for variations ranging from lower soil fluxes, laboratory calibration, and the varying definition of FC and PWP used by different authorities (Reid et al 1987).

This extractable water (EW or moisture content) in the soil is absorbed by the plants close to the surface (Diagram 4 soil layer A). As we move down the profile the amount of energy required to remove the moisture from the soil increases. By requiring more energy to remove moisture the plant has a preference to remove moisture nearest the surface before removing moisture from deeper areas. The “tension” which develops in the water system is known as water potential and reflects the energy required to secure the water from the soil.

The air portion of the soil also needs to be taken into account for plant growth.

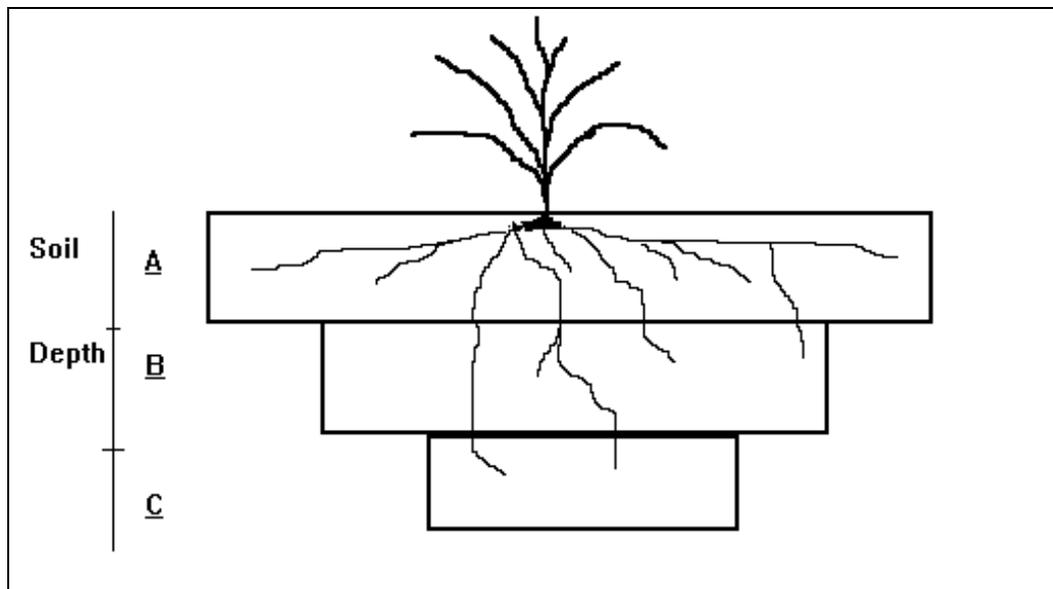


Diagram 4. Plant roots over soil depth.

Soil Water Measurement

Water deficiency or drought has been a limiting factor for plant growth throughout the ages. In order to improve our knowledge and prevent crop water stress injury, many methods in relating soil water to plant growth have been, and still are in development. Some of these are simple and others complicated which can lead to confusion or even rejection of their value amongst practitioners.

There are many methods of measuring soil water status. One way of classifying the most popular methods is to divide them up on the basis of whether they are based on;

- (i) water content
- (ii) water matrix potential
- (iii) water content / matrix potential

The amount of water in the soil can be described in two ways, either as moisture content (volumetrically or gravitationally) or as the water's potential energy (matrix potential, see table below). The type of answer required dictates the form of measurement used (Hanks 1992 Pg 40 - 57.).

Moisture is lost from the plant and soil through evapotranspiration (Et) and drainage (matrically). It is therefore important to know how both of these influence both the water managerial question, 'how much water do I need to apply to an area (or more correctly a soil volume) to provide a satisfactory level of soil moisture?'

All of these methods of describing the moisture status of the soil have their benefits as well as problems.

Soil Moisture Content (θ)

Soil moisture content is the amount of moisture contained in a known amount of soil. This can be expressed in either volume or weight terms.

EXPERIMENTAL 1. Gravimetric Soil Moisture

Two soils were collected and dried in an oven over night at 105°C (as per Rayment and Higginson (1992) test 2A1) and the difference in mass between the original soil and the oven dry soil gives us the moisture content of the soil as received. This can be written as;

$$\theta_g(\text{Gravimetric. Moisture}) = \frac{\text{Mass. } H_2O(\text{Loss})g}{\text{Mass. Oven. Dry. Soil. } g}$$

Moisture Content Desc	Measure	Camden Soil 1	Camden Soil 1	Boree Soil 2	Boree Soil 2
Mass Soil Core *	g	74.94	75.39	75.00	75.00
Mass Tin + Lid *	g	30.49	38.31	34.45	36.90
Mass Tin/Lid/Soil FC *	g	222.20	221.76	212.73	202.29
Mass Tin/Lid/Soil OD *	g	204.05	205.65	204.59	196.41
Mass OD Soil	g	98.62	91.95	95.14	84.51
Mass Water (Mass Loss)	g	18.15	16.11	8.14	5.88
<u>Moisture Content (Thea G)</u>	<u>$g \cdot g^{-1}$</u>	<u>0.18</u>	<u>0.18</u>	<u>0.09</u>	<u>0.07</u>

Table 12. Calculation for Gravimetric Soil Moisture

As can be seen above the mass (weight) of the soil cores are similar but the final moisture contents are different (Thea G). The Camden soil is a clay (Red Podzolic) soil and the soil from Boree is a very

sandy soil. This leads to a difference in the water holding capacity (the amount of water held in the soil as grams of water in each gram of soil).

Moisture Content (Thea G)	$g \cdot g^{-1}$	0.18	0.18	0.09	0.07
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Table 13. Moisture held (grams) per gram of soil

The water holding capacity is also related to the soil bulk density (compaction), soil particle size, and the soil total matrix potential of the soil. The combination of all these factors make soil interpretations seem complicated.

To simplify this data we can divide the bulk density (ϕ or ρ) by the moisture content. This will give us the available amount of moisture per volume of soil, in this case cubic centimetres of soil.

EXPERIMENTAL 2. Soil Bulk Density

Soil Bulk Density

		Camden	Camden	Boree	Boree
Diameter 1 of core *	cm	4.75	4.73	4.75	4.73
Diameter 2 of core *	cm	4.72	4.73	4.72	4.73
Length 1 of core *	cm	4.03	4.04	4.03	4.04
Length 2 of core *	cm	4.02	4.01	4.02	4.01
Mean Diameter of Core	cm	4.74	4.73	4.74	4.73
Mean Length of Core	cm	4.03	4.03	4.03	4.03
Vol of Core Sample	cm ³	70.90	70.75	70.90	70.75
Bulk Density	g cm	1.39	1.30	1.34	1.19

Calculations not rounded until here.

Table 14. Calculations of core samplers for soil bulk density

where;

$$\text{Bulk Density } (\phi \text{ or } \rho) = \frac{\text{the mass (or weight) of Oven Dry (OD) soil}}{\text{Volume of the core sampled}}$$

$$cm^2 / cm^2$$

Moisture Content		Camden	Camden	Boree	Boree
Moisture Content (Thea G)	$g \cdot g^{-1}$	0.18	0.18	0.09	0.07
Bulk Density	$g \cdot cm^{-3}$	1.39	1.30	1.34	1.19
Moisture/soil	cm^3 / cm^{-3}	0.13	0.13	0.06	0.06

Table 15. Moisture Ratio per gram or volume of soil

Provided any two of the three parameters in the above discussion are known, the third can be calculated in accordance with the formula :

$$\text{Gravimetric Moisture Content} * \frac{1}{\text{Bulk Density}} = \text{Vol Moist Content}$$

ie. $\theta_g * \frac{1}{\rho} = \theta_v$

Even if the gravimetric moisture (table 15) content is the same (Camden Soil), differences in soil bulk density can lead to changes in volumetric water content (Boree Sand), (tables 14 and 15). Although a ratio using both measurements may bring forth a common characteristic for comparative relationships over long term management or measurement (table 13).

Water Potential (ψ)

From the beginning of the study into soil science, workers have looked for one soil characteristic to measure or indicate the maximum amount of information about the status of the moisture in the soil. Many consider that the concept of Water Potential (ψ) is the closest concept capable to perform this role to date.

Water potential has been defined (Hanks 1992) “as the amount of work that a unit quantity of water in an equilibrium soil-water (or plant - water) system is capable of doing when it moves to a pool of water in the reference state at the same temperature”.

It is better understood when the components of water potential are explained.

In equation form,

$$\psi_W = \psi_M + \psi_S + \psi_P$$

where;

ψ_W is the water potential

ψ_M is the matrix potential

= vertical distance between a point in the soil and the water level of a manometer connected to this point .

ψ_S is the solute or osmotic potential

the effect of salts (including nutrients) on water energy

ψ_P is the pressure potential .

= the vertical distance from a point in question to the free water surface (water table elevation)

This leads to a total potential equation:

$$\psi_T = \psi_W + \psi_Z$$

where

ψ_T is the total potential

= the total amount of energy require to move water

ψ_W is the water potential ($\psi_W = \psi_M + \psi_S + \psi_P$)

ψ_Z is the gravitational potential

= the vertical distance from a reference point , the point in elevation

Water potential is measured in units of, atmospheres, kilopascals, meters of water and other SI or imperial units (See table 16.).

Each of these components of water potential affect the final value of water potential which leads to water movement within the soil, where the laws of nature always require that water will move from areas of high to areas of low water potential (Hanks 1992).

Another important consideration for the measurement of water potential is the Reference Point (RP) used (in elevation or depth) in relation to what is needed to be measured, (This means any point above the RP is positive potential, while below is negative). Soil moisture volume is directly proportional to the total potential although the actual amount will depend on soil particle size and bulk density.

EXAMPLE Water Potential

For a practical example we look at the water filtering through a golf green from an irrigation system. If we take our measurement (RP) from above the turf (1) all water below is negatively measured. When the RP is located within the thatch layer (2) water ponding on the surface is positive head and water below is negative. The last perspective is when the RP is in the drainage layer (3), all water above this is positive. This means we have to look at water from an infiltration point of view (1 and 2) and from a drainage perspective (3), where the measurements are the same but the reference point (RP) for the measurements changed. From this, some rationale for water flow problems can be worked out, but the details are beyond this review (See Hanks 1992 and Miyazaki 1994).

Suction			Matrix Potential	Equivalent as		
(m)	(bar)	(pF)		(J kg ⁻¹ or kPa)	cylindrical pore diameter	relative humidity (%)
0.01	0.001	0	-0.1	3 mm	100	
0.1	0.01	1	-1	300µm	100	
1	0.1	2	-10	30µm	99.99	
10	1	3	-100	3µm	99.93	0.08
100	10	4	-1,000	300nm	99.28	0.8
1,000	100	5	-10,000	30nm	93	8
10,000	1,000	6	-100,000		48.4	
100,000	10,000	7	-1,000,000		0.07	

• kPa is commonly used for potential , but is a unit of pressure.

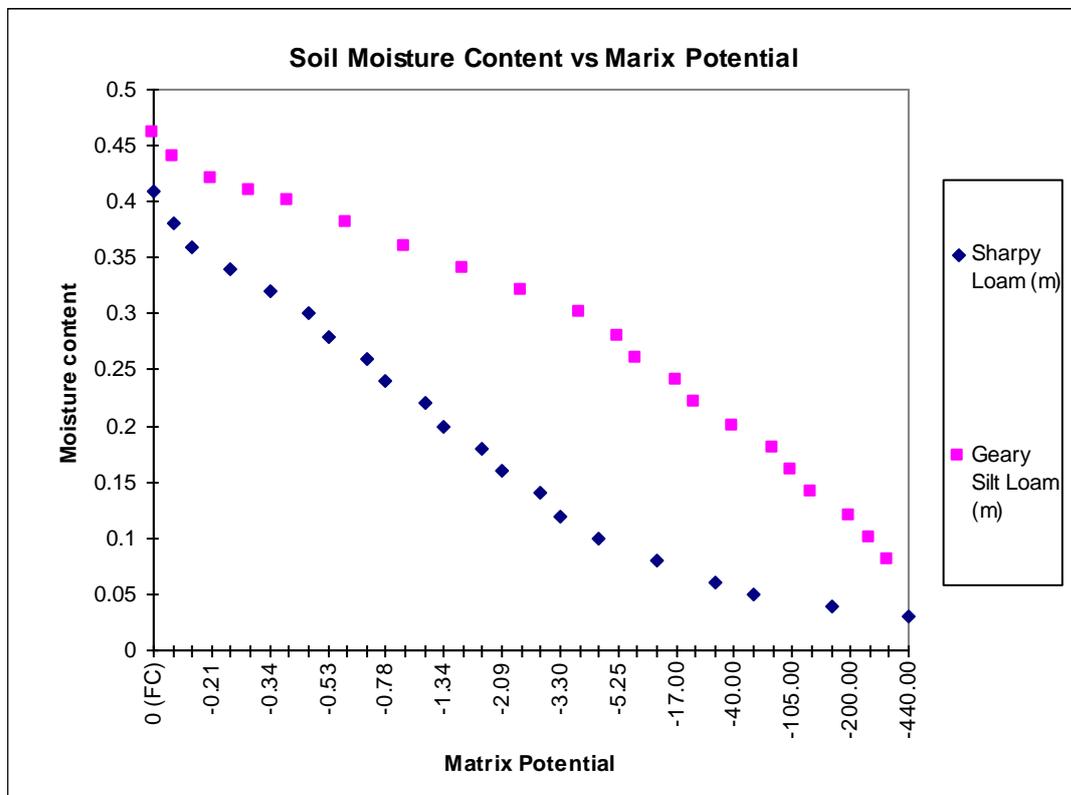
Table 16.Units of soil suction and its equivalents (From Hanks 1992 pp 25)

Moisture Content vs Matrix Potential

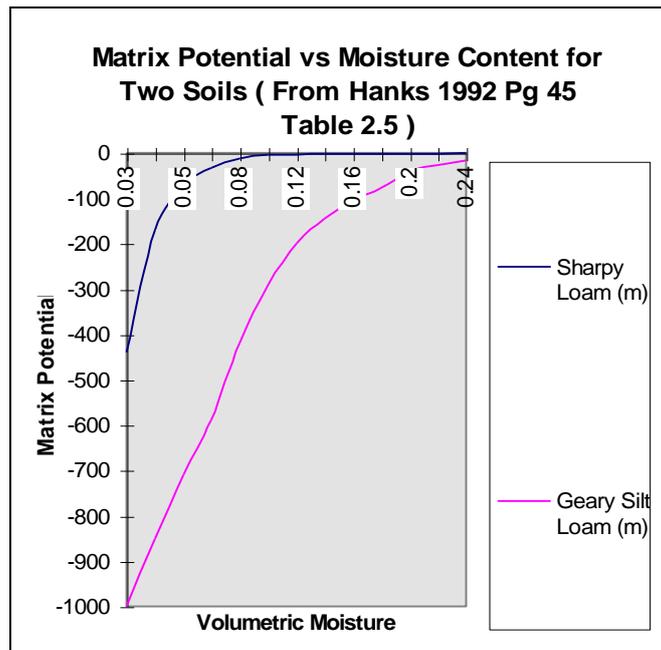
As stated earlier the plant available moisture (or water AW) in the soil is the difference between permanent wilting point (PWP) and field capacity (FC).

$$AW = FC - PWP$$

When drying a soil for the determination of moisture content the manual process of drying in an oven at 105°C always reduces the moisture to a level below the PWP. The end result is that the oven drying method of measuring moisture content always gives higher available moisture figure than the actual available water in the soil. Calibration of the soil (to get round this difficulty) requires the determination of the moisture characteristic (moisture curve) and the bulk density. A fuller study would also take into account the plant or crop factor, but this is usually ignored to simplify calculations.



Graph 1. Moisture Content vs Matrix Potential in Two Soils
(From Hanks 1992 Pg 45 , Table 2.5).



Graph 2. Matrix Potential vs Moisture Content for two Soils (From Hanks 1992 Pg 45 , Table 2.5).

It can be seen in graph 2 that the available water for each soil is quite different when the formula for field capacity is used;

$$FC - PWP = AW$$

Where FC = 0 kpa and PWP = -1500 kpa

Sarpy Loam 0.41-0.08 = AW 0.33 g/g

Geary Silt Loam 0.46-0.24 = AW 0.22 g/g

Comparing the above calculations with chart 1 we find that the Sarpy loam holds more moisture per gram of soil than the Geary Loam. It can also be said that the Geary Silt Loam would need to be irrigated 1.5 times more than the Sarpy loam to maintain a given crop in a state of active growth.

Other factors that influence the relationship between moisture content and matrix potential include hysteresis, capillary rise, water flow (saturated and unsaturated), water vapour, soil structure and evaporation rate (for details see Hanks 1992 and Miyazaki 1994)

There are other ways of measuring soil moisture besides the moisture content and the matrix potential (Suction). These are all related, but due to the complexities within the soil - water domain (particularly

the effects of 'salts' and temperature), they become hard to directly relate to each other except for moisture content and total soil water matrix potential.

Soil Water Measurement

Water deficiency or drought has been a limiting factor to agriculture and horticulture through the ages. In order to improve our knowledge and prevent crop water stress injury, many methods of relating soil water to plant growth have been and still are being developed. Some of these methods are simple whilst others are complicated, all of which can lead to confusion or lack of adoption amongst practitioners.

Methods for relating soil water to plant growth can be divided based on;

- ◇ visual assessment
- ◇ laboratory soil moisture measurement
- ◇ insitu direct soil moisture measurement
- ◇ climate data
- ◇ soil moisture and climate data .

All of these methods have their benefits as well as problems.

Visual Assessment

This is the most common estimation of soil water status, as it relies on the practitioner to observe when the grass land requires irrigation. One problem is that excessive water may be applied therefore the water is not used efficiently, the percentage of air is reduced (rising water tables / perching), and associated problems of diseases, weeds and pests (eg nematodes) are induced.

Insitu Direct soil moisture measurement

The direct measurement of soil moisture include methods such as feel (the use of the hand) and instrument based methods (soil moisture probes), including TDR, gypsum blocks, neutron probe, heat

probes, tensiometers. All of these require calibration with a standard method which is usually done in the laboratory.

Laboratory soil moisture measurement

Most soils sampled for testing usually end up in the laboratory for standard calibration (either in volumetric moisture or water potential). The standard method for soil water content - is the loss of weight after drying in an oven at 105 degrees Celsius overnight. Methods for determining the moisture characteristic or key points such as FC and PWP include the tension table, pressure membrane apparatus, Haine's apparatus, and the vacuum desiccator-filter paper method or the filter paper method.

Climate data

The use of climatic data to manage irrigation systems has appealed to many users due to the so called simplicity and availability of equations known as, The Penman Equation, Penman Modified and the Blaney-Criddle (1950 as quoted from Doorenbos and Pruitt 1992). Others methods using climatic data rely on the temperature differences under specified radiation conditions between the air at large and the crop surface, using data gathered from hand held devices or from satellite imagery.

These methods can be reliable but typically, some local adjustment or "fudge factor" needs to be taken into account. For example high rates of nitrogen are associated with increased water use (Viets 1962).

Using climate data on its own creates another problem in that soil and root depth factors are not taken into account, which can lead to wastage of water through runoff, evaporation, or more likely drainage if the predictions from the formulae are blindly followed.

Evapotranspiration ET From Weather Data

ET models have two components, evaporation (E)(from the soil surface) and transpiration (T) (From the soil through the plant parts)(Beard 1985).

This leads to a number of different method to calculate soil moisture loss. Doorenbos and Pruitt (1992) have given a number of examples. These are; The Blaney -Criddle method (monthly calculations),

$$(ET_o = c[p(0.46T + 8)]mm/day)^* (1),$$

Radiation method (daily / weekly / monthly etc calculations),

$$(ET_o = c(W : Rs)mm/day)^* (2),$$

Penman equation , or modified (daily calculations),

$$(ET_o = c[W.Rn + (1 - W).f(u)(ea - ed)]mm/day)^* (3),$$

and Pan Evaporation (Crop reference transpiration / daily),

$$(ET_o = Kp.Epan)^* (4).$$

* from Doorenbos and Pruitt 1992

where :

- ET_o reference crop ET in mm / day (Equation 1,2,3,4)
- c adjustment for humidity, wind, and sunshine hrs (Equation 1,2)
- T mean daily temp over the month / °C (Equation 1)
- p percentage annual daylight hrs (Equation 1)
- Rs Solar Radiation in mm / day (Equation 2)
- W Weighting factor for altitude and temperature (Equation 2)
- W temperature related (Equation 3)
- Rn Net radiation in mm/day (Equation 3)
- $f(u)$ wind - related (Equation 3)
- $(ea - ed)$ Sat Vapour pressure @ mean air temp and the actual vapour pressure (Equation 3)
- c adjustment factor for day / night weather conditions (Equation 3)
- $Epan$ Mean daily Evaporation value of period, mm/day (Equation 4)
- Kp Pan coefficient (Equation 4)

from Doorenbos and Pruitt 1992

Based on Van Bavel's (1966) literature there are many contradictory theories relating to the same topic. His three reasons why this may be so are;

1. Evaporation from the soil is confused with moisture depletion or even worse with water application. 'The irrelevancy of such comparisons needs no further comment'(Van Bavel 1966 also see Reid et al 1984).
2. Net radiation is usually estimated rather than measured.
3. The use of daily averages are not suited to [calculate] modelling due to variations of cloud cover, vapour pressure deficit, wind speed, and the effect of soil heat flow (He noted that measurement should be made in the boundary layer rather than temperature in a Stevenson screen at 1.5m and wind speed at 3m above the ground).

Method	Temp	Humidity	Wind	Sunshine	Radiation	Evaporation	Environ
Blaney-Criddle	#	0	0	0			0
Radiation	#	0	0	#	(#)		0
Penman	#	#	#	#	(#)		0
Pan Evaporation		0	0			#	#
# Measured							
0 Estimated Data			(#) If Available (Not Essential)				

Table 17. Measured and Estimated Parameters for Irrigation Formulae from Doorenbos and Pruitt 1992

Explanations for the above three points lead to further discussions on the differences between estimated or assessed values for different sites, and the purpose of the formulation of coefficients (fudge factors) for incorporation into an empirical formulae. Thus many formulae use coefficients to adjust pan or Class A pan evaporation rates to ET. Yet the pan, which is an open body of water has very different characteristics to the soil /plant evaporation interface.

Evidence for empirical formulae (eg Penman formulation) giving poor agreement to measured (lysimeters) evaporation in a well watered alfalfa-bromegrass cover on a 24 hour basis is provided by Tanner and Pelton (1960 as quoted by Van Bavel 1966).

Other authors (Beard et al 1992, Borrelli et al 1981, Feldhake et al 1983, Fernandez and Love 1993, Johns et al 1983, Kim and Beard 1988, Salaiz et al 1991, Throssell et al 1987, and Tovey et al 1969) have demonstrated significant variations of ET rate of turf grasses between C3 and C4 types, and in their response to for various climatic factors, leaf areas, soil types, and soil moisture contents within the USA. Unfortunately, for turfgrasses there seems to be no comparative study undertaken within Australia.

The effects of management practices such as fertiliser, construction methods, plant growth regulators, pesticides and mowing have also been investigated (Green et al 1990, King et al 1984, Krogman 1966, Lodge and Baker 1992, Willard et al 1990, Woledge and Pearse 1985). Again variation in the ET rates for turf areas and grasslands has been established within a uniform climatic zone.

Evapotranspiration ET From Weather Data II

Other ways of determining ET particularly for large areas such as field crops, have been developed from these base methods and in some cases they use similar data, or use data from satellites (Mack et al 1990).

In some cases this information can be taken from the 'broad' metrological data available from standard weather stations (Capehart and Carlson 1994, Swan and Volum 1986) and relate back to large land areas.

Although simply general guides, these types of calculations are useful for large areas where the expense of ground monitoring is prohibitive, or for establishing general water requirement figures for proposed new irrigation systems.

ET Summary

The use of ET figures derived from formulae for scheduling irrigation are a useful management tool, over periods ranging from one week to one month. However if used over short periods, over use or under use of water can often occur, leading to plant death or loss of water into the water table. This is of

particular concern for sandy profiles with narrow brackets of available water for plant growth compared with loam soils.

Many other authors have proposed, reviewed, and commented on ET formulas and their accuracy in many different types of situations (eg Swan and Volum 1986 and Capehart and Carlson 1994). Features that most such formulae have in common are:

- ◇ ET formulas are designed for set periods e.g. weekly, monthly, etc.
- ◇ ET is an estimate rather than a precise measurement of moisture lost from the plant-soil interface.
- ◇ Most ET formulas do not take into account the moisture flux (movement) within the profile.
- ◇ ET formulas generally made no allowance for cutting height, fertilizer use and numerous other factors discussed in the preceding paragraphs.

However as noted before, when no other information or equipment is available, the use of ET is a useful way of estimating moisture loss from the plant/soil system. ET data can also be productive in establishing water usage estimates for new or proposed irrigation projects.

Plant Water Relations

Water content in the plant component is always more than 80% and in some cases higher than 90% (Slayter 1967). More or less moisture will be held within the plant's various tissues (stems, leaves, roots, and fruits/seeds), but of all the moisture the plant transpires (uses) or holds, it is estimated that only about 1% is used for metabolic activities (Russell 1988) (e.g.) as a source of hydrogen in carbohydrates).

Research into plant water relations has been pursued by various people for centuries according to Russell (1988) with even Aristotle devoting some thought to the matter, although it is not till recent years that technology has been able to look at all the aspects of this relationship from macro to micro scale. The result is a large volume of information which is diverse and difficult to review.

In 1931 Penfound published the results of a detailed study of the effects of light and moisture *upon Helianthus annuus* and *Polygonum hydropiper*. This work from earlier this century gave information on root / shoot growth in dry - wet soils, in shade and sunlight, and was typical of the work conducted at this time when knowledge of the dynamic nature of soil - plant water relations was limited.

Twenty five years later Jamison (1956) reviewed some of the factors affecting available moisture supply for plant growth and his list, set out below, reflected the vast progress made over the last quarter of a century:-

Plant Factors

- a) plant conditions (nutrients present, stage of growth, degree of turgor)
- b) rooting habit (depth, spread, nutrient uptake, etc)
- c) plant resistance to drought

Soil Factors

- a) moisture tension relations
- b) soil solution osmotic pressure effects
- c) types of ions present
- d) soil moisture conductivity
- e) soil depth
- f) soil layering
- g) soil temperature and temperature gradients

Amongst others, Gardner (1960) followed on this earlier work with further discussions on soil / plant / atmosphere suction or pressure gradients. Of particular note are his comments "soil suction

measurements are much preferred over water content measurements when it is desired to relate soil moisture to plant response”.

Later, Taylor and Klepper (1978) proposed three factors controlling plant water potential decrease;

- a) energy input into the leaf (radiation) and the resultant loss of water
- b) water movement from internal evaporating surfaces through stomata to the air
- c) the supply of water from soil to the stomata

Their discussions concentrated mainly on the third point.

The work by Jamison (1956), Gardner (1960), Taylor and Klepper (1978) and recent authors have recently been summarised by Lösch (1992). The subject has been one of active interest as Lösch’s (1992) opening comment reflect “the total number of papers during the past 2 years exceeds 2000 titles published”.

Work done with other plants has relevance to turf grasses, but can only be used as a guide. As Baker and Van Bavel (1986) showed with their work on couchgrass (*Cynodon dactylon*) water does not only move from the roots to the stolons, but also back down to other roots in drier soils, thus establishing a link with numerous studies of trees which also display this phenomenon.

On the other hand, the fact that turf grasses are cut shorter than grazed pasture grasses can give them very different responses to water relation factors mainly due to surface texture effects (roughness).

Soil moisture is of great importance to the plant, but there is more information than space to review the movement and use of moisture in the plant, albeit, the atmosphere. Suffice to say the importance and usage terms in the soil water environment such as permeant wilting point and field capacity (or DUL and LL) must be acknowledged.

Interrelated Management Options

There is an abundance of different measurable properties in the soil, their interactions are diverse in the character and usually complicated. I have reviewed some that I believe are of paramount importance to Turf Management practices (pH, redox reactions, electrical conductivity, organic matter, soil water potential, soil water content, irrigation practices, solute potential and soil bulk density), although this list is incomplete.

These fundamental properties are related to soil formation processes which influence plant distribution and therefore turf management practices. This is well illustrated in the recent work presented by Hassink (1995a, b) who looked at the soil supplying power of N to grasslands under fertilised and unfertilised conditions to optimise nitrogen use efficiency (NUE).

By using his calculation:

$$\text{Optimum Fertiliser Application} = -81 - 0.8 * \text{NFNS} + 0.0375 * \text{Max Dry Matter Yield}$$

he was able to reduce the amount of nitrogen fertiliser from the recommended 400kg/ha per year by an average of 42kg/ha per year for grasslands on mineral soils(application rate range from 247kg to 750kg /ha per year). He also obtained some evidence that the maximum dry matter production of the grasslands was related to seasonal moisture conditions.

The management of turfed (grassland) areas can be a simple or hard task depending on the approach used by the manager (greenkeeper). One such method is the use of soil and leaf analysis to determine appropriate fertiliser requirements. Other options include the use of 'quick tests' to indicate approximate levels of chemical and physical parameters.

The use of nutrient analysis is also important for disease, insect and pollution control, as a healthy plant receiving a balanced nutrition is often more resistant to disease, less attractive to at least some insects

(Phelan et al 1996), while a carefully managed nutrient application program based on the results of such analyses leads to reduced and more timely applications with reduced leaching potential.

This then requires a knowledge of how conditions are assessed and recommendations formulated and explained to turf managers.

Variability Problem for a Turf Pest

Nematodes have received attention in popular literature recently, particularly in reference to the possible overuse of Nematicides and consequential induction of enhanced biodegradation within the soil (Beehag 1995).

Most sampling methods for nematodes follow those described by White and Dickens (1984). This is where the nematode population are extracted from standard soil samples. As shown the previous Table 2 (page 7) soil sampling depth recommendation vary with the organisation taking the sample, hence the nematode count in terms of mass or volume of soil will be strongly influenced by this except in these rare occasions where the nematodes are uniformly distributed throughout the top of the soil profile.

Brodie (1976) pointed out some of the influences of certain soil properties (root distribution , soil moisture, height of water table, temperature, rainfall, and depth of subsoil) on the vertical distribution of three nematode species. Davis et al (1994a, b.) expanded this further and undertook studies on golf greens in Northern Illinois (USA) and confirmed the variability of nematode populations in the golf greens. His suggestion was that it was better to relate nematode damage to root density rather than the amount of soil sampled.

Conclusion

Integrated management methods (or best management practices) within turf systems are still needed to aid the effective use of fertilisers, pesticides and water. The implications of the various properties of the soil-plant or soil-soil interactions with each other are not as well documented or as well known to managers as one would like (eg redox vs pH reactions).

To remedy this situation requires the summarising of a wide variety of information related to turf management and the development or modification of techniques to measure and implement more judicious management practices. This review set out to achieve this objective, but has only marginally opened the door on a small percentage of the relevant information available.

A summary of points in this broad review include:

- a) Management practices should be better related to local conditions or climatic zones and more attention must be paid to the transfer of information between areas of similar local conditions.
- b) Relationships between climatic conditions, soil formation processes and vegetation types should be investigated and related back to turf management practices.
- c) More education for managers on soil / plant sampling methods and handling must be implemented in order to reduce the amount of variation in samples submitted for analysis or investigation.
- d) Better understanding of organic matter and the role it plays within the soil, including breakdown, effects on nutrient availability, turf management problems (dry patch / black layer) and influence on pesticides.
- e) Analysing the role, measurement, management and effects of irrigation practices and methods.
- f) Further work on developing methods for sampling pest populations in turf profiles.

Would it be better to start with sampling methods that can be standardised for turf management practices and playing surfaces that deal with soils, plants and pest populations? As with all problematic solving we must weave our way through the intricate web of knowledge in order to achieve an understanding of our management practices, in this case directly relating to our turf management and its environment.

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