Turf Irrigation and Nutrient Study —
Turf Manual

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Foreword

More than ever, managers of turf are required to provide facilities to a higher standard, under greater restrictions and with less funds. To add to this, soil conditions on the Swan Coastal Plain are somewhat unique and unfortunately not a lot of information is written to assist managers in Western Australia. The ever increasing awareness of our environment means that managers need to be well informed to ensure that these environmental issues are addressed.

The study expands our knowledge of the nutrient and water requirements of turf species on the Swan Coastal Plain. Based on detailed trials it aims to build on what information is currently available. This information has been directed to the turf practitioner/manager and intended to assist with the day-to-day challenge of turf preparation.

The project has served to highlight the importance of turf and its management in our society. It does not claim to provide all the answers, but is a starting point which will encourage further research and add to our existing knowledge. I believe this goal has been achieved as new projects are already in progress or are in the planning stages.

S.M. Morrison
Project Co-ordinator

TINS

Acknowledgements

This study could not have been undertaken without the efforts of a number of individuals and the generous contributions from both public and private organizations.

In particular, special mention must be given to two organizations:

- **The Royal Australian Institute of Parks and Recreation - W.A. Region,** for co-ordinating the project; and
- **The Horticultural Research and Development Corporation,** for the dollar for dollar contribution.

The Project Committee consisting of Sam Morrison, Philip Gale, Nina King, Dennis Cluning have ensured the project's completion and on budget. Thanks must also go to Professor John Considine, Professor Graham Aylmore and David Deeley who have provided expert reviews of the project.

Woodward-Clyde headed the consulting team and co-ordinated the research to ensure the completed document fulfilled the project's purpose, which was to provide turf managers with a useful manual with practical applications. Ken Johnston, the principal author, researched and wrote the articles (other than those where other and/or joint authorship is acknowledged) and David Johnston provided the technical editing.

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TINS

Contents

Setting the scene

Introduction
Environmental issues
Soils of the Swan Coastal Plain
Couch
Kikuyu

Turf nutrition

Soil chemistry
The nitrogen cycle
The need for nitrogen
Phosphorus management for established sites
The need for potassium by established turf
Turf establishment
The lesser major elements
Micronutrients
Nutrient deficiency symptoms

Irrigation

Soil and water
The water budget
Factors affecting water management
Irrigation management for turf grass
Irrigation application efficiency
Irrigation scheduling

Further information

pH and alkaline soils
The management of acidic soils
The soil PRI
Fertilizer spreaders—calibration
Sampling techniques
Organic sources of nitrogen
Dry patch

TINS experiments

Phosphorus—determining the amount required
Potassium—determining the amount required
Foliar applications of Fe and Mn
Nutrient investigations
Water use of couch grass
Survey sites—comparisons
Soil moisture sensors for sandy soils

Technical terms and conversion tables

Technical terms used in turf culture
Conversion factors and conventions

TINS

Introduction

K.J. Johnston and D.A.W. Johnston

For many centuries, humans have used turf grass to enhance their quality of life by using these grasses to beautify their gardens and parks. However, it is only in the latter part of the 20th Century that particular attention has been directed towards achieving a better understanding of the many facets of turf grass management. Two key inputs into such management that have received some attention overseas, but which need to be investigated further under the unique conditions which prevail throughout the Swan Coastal Plain in Western Australia, are those of turf grass nutrition and irrigation. The turf grass industry recognizes a need for better nutrient and irrigation management practices. It also understands that the adoption of such better practices will benefit the environment.

In 1989, a group of concerned people from local government councils and State government departments, initiated investigations into turf nutrient and irrigation management. They recognized the need for the local authorities, who together control over 5,500 hectares of public irrigated turf in the Perth Metropolitan Area, to match inputs of nutrients and irrigation with the requirements of turf grass. Thus, in 1990, the first stage of the " *Turf, irrigation and nutrient study*" (TINS) was initiated. This comprised an initial survey of the various situations in which turf was grown in the Perth Metropolitan Area and identified several aspects of turf management where improvements could be achieved.

The second stage of the TINS project commenced in 1993. This stage received financial support from local government authorities; Western Australian government agencies and private enterprise. Because of the involvement of many members belonging to the Royal Australian Institute of Parks and Recreation (RAIPR) in the project, the Institute was seen as the appropriate body to co-ordinate the work. In addition, the RAIPR had a history of involvement in major projects of this nature which was an important consideration. AGC Woodward - Clyde was appointed as the principal consultant to undertake this stage of the study in conjunction with Sports Turf Technology. The TINS project was successful in attracting additional dollar for dollar funding from the Horticultural Research and Development Corporation (HRDC).

The main goal of this second stage of the project was to produce a manual on *'Turf management'*. This is that publication and it is intended that it be used by managers of irrigated turf in all turf areas, more especially those located on the Swan Coastal Plain. The topics reviewed discuss management strategies that minimize the risk of nutrient leaching and improve the efficiency of water use, while, at the same time, maintaining the desired level of turf quality. The subject matter in the topics contain relevant information obtained from world literature as available as of the mid 1990s. Also included are the research findings from work done as part of the TINS stage 2 project. In time, some of this material may be updated and reviewed. An important additional document is an extensive literature review prepared from a search of applicable literature. This review, which is separate from this manual, is thought to be the only document of its type.

The topics prepared for the manual, focus specifically on the best nutrient and irrigation management practices for the kikuyu and couch grasses as grown on the sandy soils of the Swan Coastal Plain. The handbook is designed so that readers may consult the 'Contents' page to select the appropriate topic and sections about which they seek information. Many of the topics contain inter-related subject matter which will lead turf managers to consult other relevant documents.

Setting the scene

TINS

Environmental issues

K.J. Johnston

Many environmental issues face managers of turf grass. Well managed turf grass systems confer considerable benefits to the environment. In addition to the recreational and aesthetic value of turf grass in the urban environment, the positive effects of well managed turf include dust control; absorption of atmospheric pollutants; wind and water erosion control; reduced water usage and pollution; noise abatement, the effect of cooling; enhancement of real estate values and the provision of wildlife habitats. However, in contrast to these many benefits, some turf grass management practices may have the potential to increase harmful environmental impacts. The two main environmental issues which turf managers face are:

- The loss of phosphorus and nitrogen via leaching into the surface and ground water bodies.
- The excessive use of water resources during the dry Western Australian summer in the greater Perth area.

Best Management Practice (BMP), which optimises the inputs of nutrients and water while minimising the risk to the environment, is the main approach used to solve environmental problems.

Fertilizers and environmental impacts

The maintenance of turf grass at all levels of quality usually requires the application of fertilizer. Nitrogen, phosphorus and potassium are the most widely applied nutrients for all turf grass areas, while nitrogen and phosphorus are the two nutrients which have the potential to contribute most to adverse environmental impacts.

The harmful effects of excess nitrogen include changes in productivity of natural and managed ecosystems; the potential eutrophication of surface waters; the contamination of ground water with nitrates and the partial depletion of stratospheric ozone by nitrous oxides. Birth defects; cancer; nervous system impairment and methemoglobinemia are the harmful human health disorders which may by caused by the presence of excess nitrates in drinking water.

The inorganic forms of phosphorus are not toxic to human health. The environmental problems associated with the excess application of phosphorus are concerned with the control of undesirable phosphorus nutrient levels in surface waters and their eutrophication. The eutrophication of surface and ground water bodies on the Swan Coastal Plain has been a major environmental issue in Western Australia since the early 1970s and has prompted much research into this problem. The nutrients which enter the water bodies originate from a variety of sources including fertilizers used on farms; specific agricultural locations such as piggeries, dairies and market gardens; and urban sources such as sewage, fertilized turf grass and recreation areas, and urban road run-off.

The Peel-Harvey system

In 1970, the Peel-Harvey estuary, south of the Perth Metropolitan Area, became seriously eutrophic. The condition of the estuary deteriorated progressively until, by 1978 onwards, the surface of the water was coated with blue-green algae in spring and early summer. Under normal conditions, phosphorus was the limiting nutrient for algal growth in the estuary. The development of extensive agriculture and the use of superphosphate, coupled with a small number of intensive agricultural industries, provided the main source of phosphorus. Some 90 per cent of the phosphorus entering the estuary was via the drainage from the catchment of the coastal plain.

The problems experienced in the Peel-Harvey estuary and the increased incidence of algal blooms in the upper reaches of the Swan and Canning rivers beginning in about 1990, raised community concern for the health of the Swan-Canning estuary. Studies have shown that the cultivated turf areas and domestic gardens of Perth do contribute to nutrient enrichment of groundwater and waterbodies; which can lead to eutrophication of the river systems. It was this problem of eutrophication which caused representatives of local government and some State government departments to meet and to ultimately initiate the 'Turf Irrigation and Nutrient Study' (TINS). The major goal of this study is the development and implementation of best management practices for the culture of turf.

Water conservation

In addition to the issues of water quality, public concern focussed on matters of water allocation. It was almost a tradition that turf managers used water on turf areas as if it were an inexhaustible resource. This attitude slowly began to change in the early 1990s. Unfortunately, the lack of research data as to turf grass water requirements and the water scheduling techniques required for sandy soils hindered such change. The most important research priority for many years will be the development of water conservation techniques for turf grass management and the implementation of these research findings by turf managers.

On the Swan Coastal Plain, specific information is required on water management guidelines for optimum water conservation. Such information will be essential to develop consistent BMPs for the irrigation management of turf grass areas. The aim of the TINS project is to bring together much of the available information gathered from world literature and combine this with data obtained from local experiments. The topic, 'Irrigation scheduling' deals with some of this information.

Summary

- **The two major environmental issues which face the turf grass industry are the loss of phosphorus and nitrogen by leaching and the excessive use of water resources.**
- **The information presented in this manual will assist industry to develop best management practices (BMPs) that will reduce the impact of management on the environment.**

Further reading

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TINS

Soils of the Swan Coastal Plain

D.A.W. Johnston

Location

The Swan Coastal Plain in the south-west corner of Western Australia, extends from about Jurien Bay in the north to Busselton in the south. It lies on the west side of the Darling Scarp, the Whicher Range and the Blackwood Plateau in latitudes roughly 30.3°S to about 33.6°S, and between longitudes 115°E and 116°E. Being on the south-west coast of the continent in such latitudes, it has a Mediterranean climate characterized by wet winters and long dry summers. To the immediate east of the plain lie the margins of the Great Plateau and the Great Plateau itself which covers much of the South-West Land Division of Western Australia. To the west lies the Indian Ocean.

The Swan Coastal Plain is a narrow strip of land some 15 to 30 km wide. It occupies a special position in the history and development of Western Australia. It takes its name from the Swan River on whose banks the Swan River Settlement was established in 1829. The river itself only flows during the main winter months and is tidal almost to the foothills of the Scarp. The western section, where the city of Perth has been built, is a drowned river valley creating panoramic vistas with large areas of sheltered water. The only other rivers of note which seasonally flow through the Plain are the Moore, Canning; the Serpentine, Murray, Harvey system; Collie; Preston and Capel.

Origin

The Swan Coastal Plain is formed almost entirely of depositional material either from fluviatile, (water deposited) or aeolian, (wind deposited) activity. The oldest soils lie in the east while the Quindalup dunes near the coast at Bold Park are about 6500 years old. The geological deposits of the Plain began to form when India drifted north-west and the west coast was formed some 65 to 136 million years ago. Erosion from the now plateau continued and deposited material to form the present Perth Basin. Finally the coastal sediments emerged, possible by uplift, less than 2 million years ago. Further sediments were deposited by wind and water. The present strongly seasonal winter rainfall climate may have started about 700,000 years ago and this has resulted in the unique vegetation of the Plain.

With a few exceptions, most of the soils of the Swan Coastal Plain are relatively infertile, low in necessary plant nutrients and with little organic matter. The aeolian deposits are sandy and very low in clay.

The soil pattern

Because of the manner of their formation, the geomorphic elements which are a feature of the Swan Coastal Plain are roughly parallel to the coast. There are some three major soil patterns with the Ridge Hill Shelf in the east, the Pinjarra Plain and the Coastal Dunes in the west. The soil formations are:

The Ridge Hill Shelf

Some 2 to 3 km wide at the foot of the Darling Scarp dominated by coarse ferruginous gravel which may constitute up to 50 per cent of the soil by weight. The soils are high in sand. The series is much dissected by streams. These soils are very old, of poor water holding capacity and low in exchangeable cations and plant nutrients.

The Pinjarra Plain

Comprises a series of coalescing alluvial fans deposited by the streams and rivers from the Scarp. It is divided into several soil systems:

1) The Coolup System

The most extensive and oldest of the series, composed of medium textured alluvium often with grit and coarse sand in the eastern sections of the series. The main soil type is the Coolup sand. The soils are strongly leached with lateritic characteristics. They are low in exchangeable cations.

2) The Wellesley System

A distinctive fine textured alluvium with a self mulching surface and a strong, coarse blocky structure below. The soils have a high clay content with a very low pH at the surface of 4.8 rising with depth to about 7.1. Gypsum crystals occur at a depth of about 1 metre. The exchangeable cations are dominated by magnesium and sodium.

3) The Boyanup Series

The Boyanup loam is a bright yellow earthy soil which is easily mapped. Most common in the Harvey area. Often associated with gilgai micro-relief which may be caused by the swelling of the underlying Wellesley material coming to the surface. Relatively high in organic carbon and exchangeable calcium is the main cation.

4) The Blythwood System

These soils have generally red duplex profiles distributed along present streams. These soils are similar to the Swan series in the Swan Valley mapped in 1955, the River series 2 soils at Capel and the Marybrook series at Busselton. Exchangeable cations are low with magnesium replacing calcium at depth. The content of fine sand is high.

5) The Belhus System

These are coarse textured soils, limited in extent, and are best developed in the Swan Valley where they form terraces adjacent to the river. They are red earthy sands, massive and porous. They are favoured for viticulture.

6) The Dardanup System

These soils are present as broad outwash fans covering older systems and occur extensively at Waroona, Harvey and Dardanup. They are brown earths in which the profiles show no clear differentiation. These soils are high in silt and have high levels of phosphorus, potassium and exchangeable cations.

7) The Pyrton System

Similar to the Dardanup series and occurs as low river terraces. It has dark brown loamy material in the upper horizons, but at depth changes to an unrelated layer of fine sand.

8) The Vasse System

The youngest of the eight series, these are estuarine alluvia often only 1 to 2 metres above sea level. The soils are variable and include layers of clay, shells, marine algae and coarse calcareous sand. Seen at the Wonnerup Inlet near Capel.

The Coastal Dunes

These landscapes on the western edge of the Swan Coastal Plain are divided into four main systems, the Bassendean; Spearwood; Quindalup and Yoongarillup which is developed on marine limestone deposits.

1) The Bassendean Dune System

This extensive system is best developed north of Perth being more than 20 km wide in some places. It narrows to the south and declines rapidly south of Bunbury and is almost absent in the Busselton area. Consists of low hills and intervening swampy areas. To the north, the Bassendean system disappears abruptly at about Jurien Bay. The sand grains are well rounded and sorted indicating that the sand came ashore after transport and sorting by water and was further sorted by wind. On the ridges and well drained sites, iron podsols have developed and the water table is at least 10 metres deep. In low lying areas the water table may be within 2 metres of the surface. The Bassendean dune system is divided into numerous sub series such as Gavin sand; Joel sandy loam; Jandakot sand and Muchea sand. The Jandakot sand is notoriously non wetting because the sand grains are coated with hydrophobic organic compounds.

2) The Spearwood Dune System

These dune systems consist of a core of Tamala limestone with a hard capping of calcite overlain with a variable depth of sand. There is some conjecture as to how these dunes were formed. One theory is that the material originated as calcareous beach sand blown inland to form high dunes which were then leached over a long time to leave a decalcified mantle of siliceous sand in which a soil profile developed. Another theory is that the yellow sands are a relict aeolian desert sediment derived from the weathered granites far to the east. This would mean that the then arid zone would have extended some 800 km to the west during a previous drier climate.

The system has been variously divided into two main soil association with the Cottesloe association in the west and the Karrakatta association to the east. The Cottesloe soils have been described as the brownish sands of the undulating coastal limestones with the Karrakatta soils as the yellowish sands of the undulating hills. The important Spearwood sand is confined mainly to the Spearwood area and at Wanneroo north of Perth. There is evidence that many of the westward parts of the coastal dunes have suffered recent sorting, with the Quindalup dunes being formed only 6500 years ago. The brown Spearwood sands are much favoured by horticulturists. The soils are shallow, often associated with limestone outcrops and are slightly higher in clay than the Karrakatta soils. They have a large calcium exchange component and the soils have a neutral pH. Groundwater is found at shallow depth.

3) The Quindalup Dune System

This name now applies to the entire system of coastal calcareous dunes. The name was first applied to the beach dune ridges of the Geographe Bay shoreline. It now includes the extensive parabolic dunes extending from Bunbury to Dongarra. Both the beach ridges and dunes originated as sediment on the ocean floor, washed onto the beach and blown inland. Some four phases of formation have been identified and this is shown by the depth of the organic staining, with about 50 cm staining in the oldest to virtually nil in the youngest.

Shoreline formation at Rockingham has been shown to have been continuous to the present day.

The soils of the northern and southern part of the Swan Coastal Plain differ in many respects. From about Ludlow to Busselton, the soils have an east-west orientation and are adjacent to the Blackwood Plateau, whereas the northern part of the Plain is west of the Darling Plateau. The sand in the south is derived from weathered sandstones and the whole area is poorly drained. The Spearwood dune system is lacking in the south, but its place has been taken by the series of low limestone ridges.

4) The Yoongarillup System

The low limestone ridges of this system are most common near Busselton. There is a narrow fringe of calcareous beach ridges and Busselton sand is typical of the soils developed on the sandy alluvium. Most nutrients are in the surface organic matter. The main soil associations of the Yoongarillup system include Busselton sand and Wonnerup sand which is a shallow sandy soil over marine limestone. Some sections of this association extend north to Mandurah. There are other soil types associated with swampy areas and major streams in the Busselton area.

Land use

Land use within the Swan Coastal Plain is much influenced by urban needs and the continuing growth of cities and towns on the plain. Agricultural use is closely related to soil type, with the brown alluviums of the Dardanup series being the most favoured for irrigation. These soils have a high natural fertility and maintain good structure under cultivation. The Boyanup soils at Harvey are also widely used for irrigation. Lime has been used on the sandy surfaced soils and peaty swamps to counter soil acidity, especially where the pH was <4.2.

Within the dune systems, agricultural land use is closely related to soil type. The Bassendean Dune System poses severe limitations for agriculture, but responds to irrigation. Because the system has almost no external drainage it provides a valuable water resource. In the 1930s, the groundwater level at Herdsman Lake varied seasonally by as much as 2 metres. This range can be expected to increase with pumping for the metropolitan water supply.

The Spearwood Dune System likewise responds to irrigation and fertilization. However, these soils are attractive for urban development and will one day be taken out of cultivation.

The Quindalup Dune System is largely used for recreational pursuits. However, the younger associations in this series near the coast are unstable if disturbed.

In the southern parts of the Swan Coastal Plain near Busselton, much of the alluvial plains were and are poorly drained. Before the advent of artificial drainage they were waterlogged for much of the year. Many soils in this area are complex, but the most favoured are the red earths associated with some of the major streams. These soils are free-draining and respond to heavy dressings of a complete fertilizer plus sulphur.

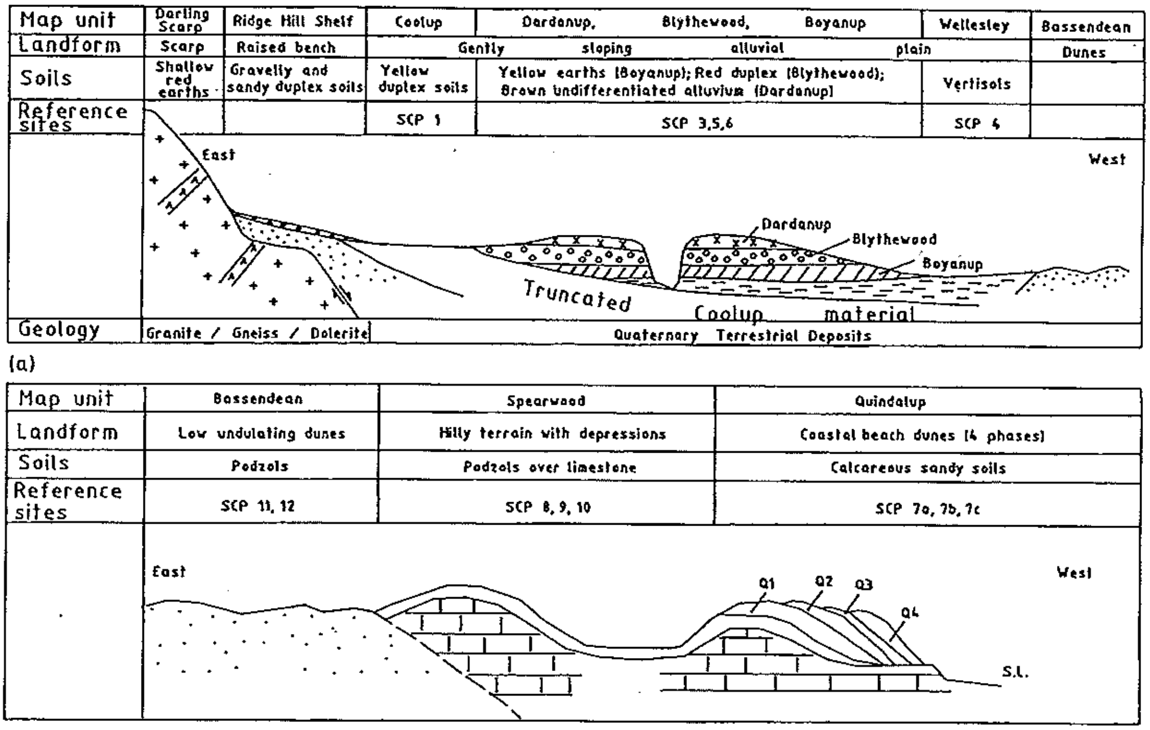

Figure 1. After Figure 13, McArthur W.M. (1991). Reference soils of south-western Australia. Swan Coastal Plain: Reference Sites in relation to (a) fluviatile deposits and (b) wind blown deposits - map units from McArthur and Bettenay (1960).

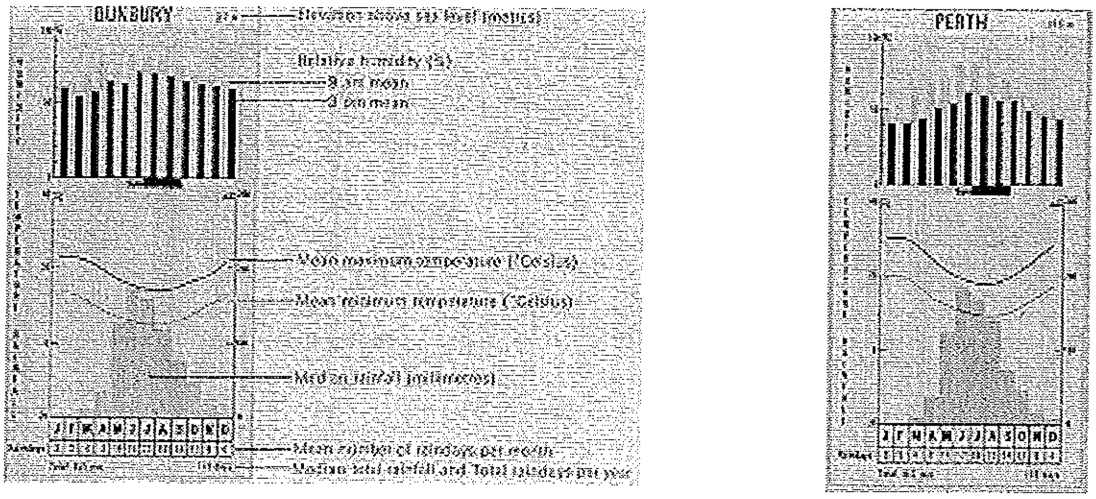

Figure 2: Climatic characteristics of Perth and Bunbury showing elevation above sea level; relative humidity; mean maximum temperature; mean minimum temperature; median rainfall; mean number of rain days per month; median total rainfall and total rain days per year.

Further reading

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TINS

Couch

K.J. JOHNSTON

Origin and distribution

Couch is found in more than 80 countries throughout the tropical and subtropical areas of the world. Common couch, *Cynodon dactylon,* naturalized in the south-west of Western Australia, was probably introduced from its place of origin, Africa, during the colonial period from 1829 to 1900.

The genus *Cynodon* comprises many species with *Cynodon dactylon* being the most widespread. Its extensive distribution is attributed to its tetraploid genetic make up which confers broad variability. The species is highly fertile and is propagated by seed, stolons and rhizomes. *Cynodon dactylon is* commonly called Bermuda grass in many areas of the world.

Cynodon transvaalensis is a diploid species that reproduces sexually, but rarely produces viable seed. Although it is used for lawns and other turf applications, its principal use so far has been as a parent when crossed with selected strains of common couch to create triploid hybrids such as the 'Tif'-couches bred in the United States of America (U.S.A.) Its contribution as a parent is that it produces fineness, density and quality in the hybrid not found in the common couch.

Most of the improved couches in Australia are vegetatively propagated clones of common couches such as: Greenless Park, Wintergreen and National Park. Less often grown are the sterile hybrids such as Santa Ana, Tifgreen (328), Tifway (419) and Tifdwarf.

In the 1990s, several seed propagated cultivars, Sahara, Sonesta and Cheyene became available. They are said to produce better quality turf than common seeded couch. Nevertheless, their quality is far below that of the vegetatively propagated common selections and the hybrids.

Description of species

Couch is a highly variable, sod forming perennial that spreads by stolons, rhizomes and seed. The stolons readily root at the nodes. Lateral buds develop at the nodes to produce erect or ascending stems that reach 5 to 40 cm in height. The leaf blades are 2 to 16 cm long, 1.5 to 5 mm wide, smooth to sparsely pubescent, folded or loosely rolled in the bud and sharply pointed. The inflorescence consists of 3 to 7 spikes in a single whorl in a finger-like arrangement 3 to 10 cm long.

Couch has a fibrous perennial root system with vigorous, deep rhizomes. Mature roots are yellow to brown while new roots are white. Mature roots deteriorate throughout the growing season while new roots are continuously produced. In cooler climates than that of the south-west of Western Australia, root production and dieback has been reported to be particularly high in the spring at the onset of shoot production.

Cynodon transvaalensis commonly called South African couch, is a fine textured turf grass easily identified by its colour of yellowish-green, erect linear leaves, slender (often red) stolons and abundant, but generally sterile seed heads.

Adaptation and use

Couch is a warm season perennial species adapted to tropical and subtropical climates. It grows best under extended periods of high temperatures, mild winters and moderate to high rainfall. Usually, temperatures below 0° C kills the leaves and stems. Research in the U.S.A. has demonstrated that couch will continue to grow as night temperatures approach 0° C if day temperatures are about 20° C. When the average temperature drops below 10° C, growth stops and the grass begins to discolour. At the onset of low temperatures in autumn and winter, couch may begin to discolour, the protein fractions change in composition and reserve carbohydrates increase in the stems and rhizomes. In our climate in the greater Perth metropolitan area, couch typically remains green throughout the year, but growth is significantly reduced at the onset of cool nights. Couch makes its best growth where average daily temperatures are above 25° C, with an optimum daytime temperature of between 35 to 38° C. Soil temperatures above 18° C are required for significant growth of rhizomes, roots and stolons. Optimum soil temperature for root growth is about 27° C.

Couch has a high requirement for light and does not grow well under low light (shaded) conditions. Both increased light intensity and day length increase rhizome, stolon and leaf growth.

To maintain a quality couch turf in our climate, irrigation is required though couch has the capability of surviving extreme droughts. Rhizomes of couch can lose 50 per cent or more of their weight and still recover under favourable moisture conditions.

Couch grows well on a variety of soils from heavy clays to deep sands providing fertility is not limited. This grass tolerates acidic and alkaline soils and is highly tolerant to saline soil conditions. While couch may persist in soils of low fertility it has a high requirement for nitrogen to produce good quality turf.

Common couch is used for domestic lawns; public parks; playgrounds; sports fields; golf course fairways; roadside verges; cemetery lawns and for other general turf purposes. Hybrid couches and selections of common couch are used for special purposes such as for bowling greens; golf course fairways; tennis courts; cricket and hockey fields and lawns. On the sandy soils of the Swan Coastal Plain, couch must have high inputs of nitrogenous fertilizers and supplemental irrigation to enable it to withstand high wear situations.

Cultivars - (varieties and selections)

In Western Australia, the following selections of common couch are widely used: Greenless Park; Wintergreen; Windsorgreen; National Park; Riverton and CT2.

The hybrid couches, which are crosses between *C. dactylon and C. tansvaalensis,* most commonly grown in this State are: Santa Ana; Tifgreen; Tifway and Tifdwarf.

Propagation

Until about 1990, common couch was the only turf-type couch cultivar that could be established from seed. By the mid 1990s, the seeded cultivars Sahara and Sonesta became available in Western Australia. Couch seed should be planted at a rate of 2 kg/100 m².

Broadcasting shredded turf is the normal way to plant large areas. This is produced by shredding harvested rolls of turf or by collected up vertimowings.

The shredded turf used for planting should be freshly harvested and protected from desiccation by sun and wind. The material should not be subjected to excessive heating which occurs when moist planting material is tightly packed or covered for several days.

The best method to determine planting rates is to determine the ratio of harvested area to the area to be planted. This ratio is usually between 1:10 and 1:20, which depends upon the rate of cover required and the quality of material harvested. The shredded turf should be broadcast on a well prepared seedbed and either disced or rotary hoed into the soil surface. Moist conditions must be maintained for 2 to 3 weeks after planting to ensure a good strike. The material should not be planted before the soil temperature is above 15° C . Planting too early may retard development of a suitable ground cover and extend the critical establishment time for several weeks.

An immediate couch turf cover can be achieved by using strips of turf (instant turf) harvested from a mature sward.

Management

Because couch is very drought tolerant, it can survive dry soil conditions longer than most turf grasses. The reason for this tolerance is that the grass becomes semi-dormant during extended dry periods and then recovers from the stolons and rhizomes when moisture becomes available. When the grass is in this semi-dormant state, the quality of the turf is poor.

Couch responds readily to irrigation. Water requirements rise with increasing levels of maintenance; as temperatures, wind speed and light intensity increase, and at low humidity. Irrigation frequency is dependent upon water use rate and soil type. Where the roots extend 60 cm or more into the soil, thorough and infrequent irrigation produces the most drought tolerant turf. Couch does not tolerate poorly drained soils.

Mowing requirements for couch depend upon cultivar, use and level of maintenance. Cricket outfields can be mown as low as 6 mm, while football fields may be mown at heights of from 25 to 40 mm. To maintain good turf density and colour, the usual practice is that no more than 40 per cent of the leaf tissue should be removed at any one mowing. The lower the mowing height the more frequently must the turf be mowed. Reel type mowers produce the best cut on couch turf.

Nitrogen and potassium requirements

Couch has a relatively high fertilizer requirement to maintain and sustain a quality turf at a high level. Nutritional studies in the U.S.A. show that the lowest rate of nitrogen that needs to be applied to maintain an acceptable couch turf for lawns and fairways is about 25 kg N/ha for each major growing month, September to April in Western Australia. This is a much higher yearly rate than is now used (1996) to maintain golf course fairways in the Perth area.

Nitrogen is one of the most important nutritional elements turf managers apply to couch. In addition to affecting turf colour and growth rate, nitrogen influences thatch accumulation, the incidence of diseases and insects, cold tolerance, heat and drought stress, nematode tolerance, lime requirements and, of most importance to the user, the quality of the playing surface. Turf managers often measure the need for nitrogen based on turf colour, density and/or the amount of clippings.

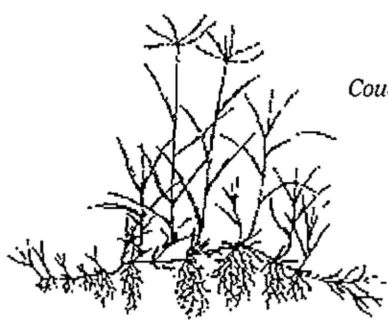
The level of soil nitrogen usually has a direct bearing on turf growth and recovery from injury caused by wear. However, turf growth as measured by the quantity of clippings produced, is a poor determinant of the need for nitrogen. If the turf has an adequate colour and density, the volume or weight of clippings should not be used as the sole determinant of the need for nitrogen. If, however, the turf begins to thin or become excessively damaged, turf growth and density may become good indicators of such a need.

The development of a sound rooting system in couch grass can be adversely affected by the improper use of nitrogenous fertilizers. Couch uses the energy of carbohydrates stored in the roots to support shoot growth. These carbohydrates are produced during photosynthesis. If large amounts of nitrogen are used, excessive shoot growth occurs at the expense of the energy supply in the roots. This means that the roots may not have enough time to replenish their carbohydrate energy supplies before having to again support excessive leaf and shoot growth when nitrogen is re-applied. Researchers in the U.S.A. have observed that couch, when maintained at low levels of nitrogen, has up to twice as much root growth as couch maintained at high levels.

In addition to forcing excessive shoot growth at the expense of root growth, high nitrogen levels can cause physiological changes such as the thinning of the cell wall, succulent growth and reduced carbohydrate levels. This results in increased susceptibility to stress and makes the plant less hardy.

Sandy soils with low levels of organic matter, which are typical of the sandy soils in the Perth area, require light though frequent applications of nitrogen because of the initial low nitrogen content and poor nutrient retention. Such soils are also low in potassium and this nutrient must be applied with the fertilizer. Potassium is particularly important because of its contribution to healthy root growth, the development of environmental stress tolerance such as that caused by heat, cold or drought and a tolerance to wear. Adequate plant potassium has been found to reduce the susceptibility of couch to the leaf spot diseases.

While couch tolerates a wide range in pH soil reaction, it is most suited to a pH range of 6.5 to 8.0. That is, from mildly acidic to slightly alkaline.



Couch grass

Summary

- Couch grass originated in Africa, but has become naturalized in the south-west of Western Australia.
- Couch makes its best growth when average daily temperatures are above 25° C.
- Couch is very drought tolerant. During extended dry periods the grass becomes semi-dormant and then recovers from the stolons and rhizomes when moisture becomes available.
- Couch can survive under very low levels of maintenance. However, high quality couch swards subjected to excessive wear, require high inputs of fertilizer and water.

Kikuyu

K.J. Johnston

Origin and distribution

Common kikuyu *(Pennisetum clandestinum* Hochst.) originated in the Kenyan highlands of eastern central Africa. The area is subtropical with moderate temperatures and with a rainfall of some 1000 to 1500 mm/annum. From its centre of origin it has been taken to other warm season areas throughout the world and can be found in turf sites in distant parts of Africa; Mexico; South America; New Zealand and the United States of America (mainly in the States of California and Hawaii); Australia and the Mediterranean region of southern Europe. It is generally found in areas where the winter temperatures do not fall below 8 to 10° C for significant periods.

Description of species

Kikuyu is a creeping perennial grass with very long, robust stolons and rhizomes that form a mat. The leaf blades are folded and are bright green. It has an inflorescence of 2 to 3 spikelets enclosed in the upper sheaths. The anthers and styles protrude from the leaves at flowering. The species is extremely aggressive, spreading by stolons, rhizomes and seed. Left unmowed, kikuyu is a tall coarse grass with stolons up to 2 to 3 m long which may be some 8 mm thick. The roots are mostly found in the top 20 to 40 cm of soil, with some roots penetrating to about 1 m. Roots proliferate densely in the upper 0 to 15 cm of the soil from the older rhizomes and stolons, becoming less dense towards the growing point of the rhizome or stolon.

Adaptation and use

In Australia, kikuyu is used as a pasture grass, especially on the deeper more fertile soils in coastal, insular or high elevation environments. It is used as a stabilizer of waterway banks in southern California in the United States. The aggressive growth characteristics of kikuyu make it suitable for the above uses, but because of its invasive nature, many turf managers consider it to be a weed. Other undesirable characteristics include its colour of light-green; its ready growth into flower and shrub gardens, and fence lines. Kikuyu also has a tendency to produce a deep layer of thatch, its filament extensions appear silver and it readily invades other turf areas.

The beneficial characteristics of kikuyu as a turf grass include its competitive ability against broad-leaved and grass weeds. It has the ability to withstand varying mowing heights. Kikuyu is tolerant of very low or even nil fertilizer applications and it has a better winter colour than other warm season turf grasses.

Cultivars (varieties)

Most of the kikuyu which grows in the Perth Metropolitan Area is of the common type which produces fertile seed. It would have been used originally in pastures on local dairy farms which no longer exist.

Noonan is a seeded cultivar especially selected as a lawn turf. Its leaves and stems are shorter and more numerous than those of the common type of kikuyu. This gives Noonan a more dense and uniform appearance by comparison with common kikuyu. The cultivar has a degree of tolerance to the water mould fungus which produces 'kikuyu yellows'

Terranora is a seeded cultivar especially selected as a lawn turf, though it is not widely grown in Western Australia.

Management

When properly managed, kikuyu can be a desirable turf grass with good colour and high durability. In the Perth area, kikuyu is considered to be a low maintenance, warm season turf grass species especially because of its low need for fertilizer. On turf sites such as in parks, schools or lawns where it is grown on sands that have accumulated significant levels of organic matter, kikuyu may receive only 25 to 50 kg N/ha per year or even less. This assumes that a light green, moderate density sward is acceptable. ***Results from nutrient experiments as part of the TINS project in the mid 1990s showed that the phosphorus and potassium requirements on such sites are often met by the recycling of nutrients from the organic matter and returned turf clippings.*** Routine soil and leaf tissue testing should be the guide for the need of phosphorus and potassium by kikuyu when used as a turf grass. Trace elements should only be used if there is a site specific problem, such as when iron or manganese chloroses occur, or when deficiencies are revealed by leaf tissue analysis. A rich, deep green can be achieved by adding nitrogen. The response to extra nitrogen is accompanied by tremendously increased growth. This means that the frequency of mowing will increase, more thatch will be accumulated and subsequent major turf renovation will be necessary.

Kikuyu is maintained at various mowing heights depending upon the use of the turf facility. Golf course fairways are kept at 16 mm or lower. In summer, frequent mowings of 2 to 3 times per week using a reel mower will be necessary. For general purpose lawns, the mowing height varies between 15 to 35 mm and should be cut each week using either a reel or rotary mower. Well maintained kikuyu turf sites may require regular attention for thatch control if mowings are not frequent enough. With low mowing heights the density is high and the turf texture fine. The higher the mowing height, density decreases and texture coarseness increases. The correct use of the mower to achieve the result desired is one of the most important tools for the required performance of kikuyu.

As with other warm season turf grasses, kikuyu is a low user of water in comparison with the cool season turf grasses. The species is moderately deep rooted in a uniform sandy soil and has very good drought resistance when water is not supplied either by rain or by irrigation. Evidence of kikuyu's excellent drought resistance is frequently observed in parks in the Perth area when irrigation systems break down during the hot summer months. During extended drought periods, the turf will go brown and become dormant. However, kikuyu recovers quickly when irrigation is applied or rain occurs. On general purpose lawns, kikuyu is watered infrequently. On well maintained and heavily used turf facilities, more irrigating is needed. The amount of water applied at any one irrigation is usually based on about 60 per cent of open pan evaporation. In the north-eastern coastal areas of Australia, reports show that kikuyu is as drought tolerant as it is in Western Australia. During drought conditions, growth slowed then ceased, the turf became brown, but recovered quickly after three days of rain.

Summary

- **Kikuyu originated in eastern central Africa. In addition to its use as a turf grass, kikuyu is used as a pasture grass and for stabilizing waterways.**
- **Kikuyu makes an ideal low maintenance turf grass when nutrient inputs are minimal.**
- **Mowing management is very important in the achievement of a desired quality for kikuyu.**

Turf nutrition

TINS

Soil chemistry

K.J. Johnston

Introduction

The following notes are intended to provide turf managers with some of the basic concepts of soil chemistry of the sandy soils of the Swan Coastal Plain. More detailed analysis of these soils is given by W.M.McArthur in, "Reference soils of south-western Australia, 1991".

The nutrient 'pools'

Plants take up nutrients from the soil solution. These nutrients are held in equilibrium within 'pools' or 'reserves' of nutrients associated with soil organic matter; clay minerals or fertilizer residues.

The nutrients are held within the nutrient pools in different ways. For example, the organic matter contains the major proportion of soil nitrogen and sulphur. In some soils it also contains most of the soil phosphorus. These nutrients become available to the plant by the decomposition of the organic matter.

Soil texture, nutrient supply and electrical charges

Soil texture has a significant effect on the capacity of the soil to retain nutrients. Coarse textured soils, such as sands, have a lower nutrient holding capacity than do fine textured soils such as clays or loams or soils high in organic matter. The nutrient holding capacity of a soil varies inversely with the size of its soil particles. The cation exchange capacity (CEC) is the term used to describe the ability of a soil to retain exchangeable cations. Typical positively charged nutrient cations are calcium; magnesium; potassium and ammonium. These are associated with the negative charges which exist on the clay particles or soil organic compounds. The exchangeable cations rapidly re-supply the soil solution as nutrients are absorbed by the plant. The CEC of soils range from 0.5 to 4 milliequivalents (meq) per 100 grams of soil (meq/ 100g) for sandy soils to some 40 to 60 meq/ 100g for a clay soil. Soils high in organic matter may have CECs over 100 meq/ 100g.

Soil CEC and soil fertility

The cation exchange capacity is an indication of soil fertility. Most of the sandy soils of the Swan Coastal Plain have a very low CEC. As a result, nutrients are readily leached through them as compared with the finer textured soils where the nutrients are held in reserve. Sandy textured soils low in organic matter are often light coloured and considered infertile.

The relative amount of each cation held at the exchange sites on the soil particles, is closely associated with the specific soil properties within the root zone. Highly acidic soils with a pH < 6.0 have a high percentage of hydrogen ions, H^+ adsorbed onto the exchange sites and held in the soil solution. Alkaline soils with a pH of 7.5 to 8.5 have a high percentage of calcium ions Ca^{++} adsorbed on the exchange sites.

It is the CEC of the root zone and the relative abundance of the plant nutrients which determines the fertility of the soil. Infertile soils are those with a low CEC and low levels of nutrients. To grow turf grass on such soils it is necessary to frequently apply fertilizer or use a slow release form of a fertilizer. It is fortunate that, over time, because of the minimal disturbance of the surface soil layers, the level of organic matter will rise under most turf swards provided that the sward receives adequate fertilizer. As the level of organic matter increases so does the soil CEC and also the ability of the soil to retain nutrients. As this happens the soils become more fertile.

The negatively charged anions

In the soil solution, phosphorus exists as the negatively charged anion, phosphate $PO4^{---}$. and sulphur as sulphate $SO4^{--}$. Phosphate is retained or adsorbed in the soil through chemical bonding with oxides of iron or aluminium, or with calcium carbonate, $CaCO_3$. Sulphate is weakly adsorbed compared with phosphate and only in acidic soils. Where the pH is > 6.0, sulphate is not held by the soil and may be rapidly leached away. In the absence of calcium carbonate i.e. non calcareous soils, the capacity of the soil to retain phosphorus depends upon the concentration of iron and aluminium oxides. The ability of a soil to retain phosphorus is determined by the use of laboratory techniques which give a direct measurement of the phosphorus retention index or PRI.

The negatively charged anions of nitrate, NO_3^- and chloride Cl^- are usually not considered to be held by the soil particles and are thus rapidly leached.

Summary

- **The term used to describe the ability of a soil to retain exchangeable cations is the cation exchange capacity or CEC.**
- **Cations are the positively charged nutrients such as calcium; magnesium; potassium and ammonium, i.e. they act as or are metals.**
- **Sandy soils have a low CEC and may be described as infertile.**
- **As organic matter builds up in the soil the CEC rises and the fertility of the soil increases.**
- **The main plant nutrients obtained from air and water are; carbon; hydrogen and oxygen. Those macronutrients obtained from the soil are; nitrogen; phosphorus; potassium; calcium; magnesium and sulphur. The micronutrients obtained from the soil are copper; iron; manganese; zinc; molybdenum and boron.**

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TINS

The nitrogen cycle

K.J. JOHNSTON

Adapted from McCarthy, L.B. et al. *(1993). Plant nutrition, fertilizers and fertilizer programs for Florida golf courses. University of Florida, Bulletin 282.*

The use and management of nitrogenous fertilizers is one of the most important cultural factors in the establishment and maintenance of quality turf grass. Nitrogen is considered a key element because of its influence on colour; growth rate; density and stress tolerance. The leaf tissue of most turf grasses usually contain between 1.5 and 4.5 per cent nitrogen on a dry matter basis. Nitrogen is the element which is applied most frequently in fertilizers. Plants require nitrogen in larger quantities than any other element except carbon, hydrogen and oxygen which are supplied by either water or air.

Nitrogen exists in many forms. For elemental nitrogen (N_2) to become available for plant use, it must combine with hydrogen or oxygen. In nature, this process takes place through the microbial action of free living bacteria in the soil; by the micro-organisms which live in the roots of legumes or by lightning which may combine elemental nitrogen and oxygen. Synthetic nitrogenous fertilizers are made through industrial processes. This enables us to apply nitrogenous fertilizers at desired locations.

Nitrate nitrogen, NO_3^-, is the form of fixed nitrogen most used by plants, followed by the ammonium form, NH_4^+. Once atmospheric nitrogen has been fixed with either oxygen or hydrogen, dissolved in water and washed into the soil profile by rain, it is subject to further change by soil micro-organisms.

Plants cannot use the nitrogen held in the soil organic matter. Such organic nitrogen must first be converted to the inorganic forms of either NO_3^- or NH_4^+ by the soil micro-organisms. This complex process is called mineralization.

Mineralization

Mineralization of organic nitrogen may involve four distinct stages and many different micro-organisms are associated with the process.

- **Aminization.** The soil organic matter is reduced to amino acids.
- **Ammonification.** The amino acids produced by aminization are used as nutrients by soil micro-organisms or further degraded by microbial attack. This degradation always results in the release of ammonia gas, NH_3, which almost immediately combines with water to form the ammonium ion, NH_4^+. This ammonium form of nitrogen is the first plant available form produced by mineralization. In some cases, ammonia gas may be lost to the air.

However, soil micro-organisms cannot complete the ammonification stage of the conversion of organic nitrogen unless the carbon content of the organic matter is 30 times the nitrogen content or less. This critical indice is called the carbon to nitrogen ratio or simply, the C : N ratio. Many of the soil micro-organisms involved in the mineralization process require a C : N ratio of 30 or less to survive and reproduce. If the ratio is above 30, the bacteria will need additional nitrogen from another source for them to continue to degrade organic matter. They can use any inorganic form of nitrogen to complete the process. The micro-organisms convert the inorganic nitrogen into microbial protein which becomes available for plant use.

When the C : N ratio in the soil is high, there will be competition for plant available or inorganic nitrogen by soil micro-organisms. For example, if sawdust with a C : N ratio of about 400 : 1 is incorporated into the soil, the bacteria will have a huge demand for inorganic nitrogen until the sawdust is completely decomposed. This means that plants will suffer a nitrogen deficiency and so it is usual to add nitrogenous fertilizers to assist the soil bacteria.

- **Immobilization.** This is the stage of mineralization during which inorganic nitrogen as either NO_3^- or NH_4^+ is converted into microbial protein or organic nitrogen. If this stage of mineralization dominates the soil matter decomposition process, nitrogen will be less available for plant use and the breakdown process will not be completed. The nitrogen is immobilized in the soil.

- **Nitrification.** This is the final stage during which the bacteria which convert ammonium nitrogen to nitrate nitrogen are the most important. These nitrate synthesizing bacteria require ammonium nitrogen as their source of energy. When organic matter decomposition slows, NH_4^+ can be limiting. If no additional ammonium nitrogen is supplied by either fertilizer or atmospheric fixation, soil nitrate levels rapidly drop. Under such conditions, couch, which has a high requirement for nitrogen, quickly becomes nitrogen deficient.

The final nitrification process involves two types of bacteria. The nitrosomonas bacteria oxidize the ammonium ion NH_4^+ to the nitrite ion NO_2^-. Nitrobacter then oxidize the nitrite ion to nitrate NO_3^- in which form the nitrogen is readily available to plants. The success of the nitrification process depends upon the existence of favourable environmental conditions which suit the growth and reproduction of the soil bacteria. Warm conditions, adequate soil water and soil oxygen are necessary for bacterial function. Extremes of temperature may prevent nitrification, such as freezing or when soil temperature exceeds 40°C in saturated or poorly aerated soil; very dry soil or in soils with a low pH at <4.8. Under such conditions, the nitrifying bacteria will not function properly and ammonium may accumulate. When turf grasses are grown under cool and low-light conditions that reduce nitrification, if ammonium nitrogen levels rise too much then it may become toxic to the grass.

Nitrate nitrogen is readily soluble in water. As it has a negative electrical charge it is repelled by the negative ions in the soil. The effect of this is that unless the roots of the grasses or other plants quickly take up the nitrate it may be lost through leaching if excess water is applied or the soil is already very wet. Other by-products of nitrification are water and hydrogen ions, H^+. This may result in an observable decrease in soil pH. This reduction in pH is especially acute when high rates of nitrogenous fertilizer are applied to sandy soils low in calcium. Such soils are poorly buffered against changes in soil pH induced by the acidifying effect of nitrification.

Denitrification and loss of nitrogen

This is the process whereby soil nitrogen is converted into a gas and lost to the atmosphere. The denitrification bacteria use nitrate, NO_3^-, as their source of energy and produce the gases, NO_2; NO; N_2O and N_2. These bacteria only function when the soil is compacted or saturated with water. Any situation which results in a lack of soil oxygen will create the conditions for the gaseous loss of nitrogen. Even when conditions improve, the loss of nitrate will have an adverse effect on future plant growth.

During the ammonification stage of mineralization, ammonia gas may be lost to the atmosphere. This happens when the ammonium ion NH_4^+ reacts with carbonates and the gas escapes from the soil surface.

The soils on which most turf grasses are grown rarely have sufficient existing nitrogen to maintain quality turf. Under local conditions, existing soil nitrogen supplies are soon exhausted. Because of this, fertilizer nitrogen is needed to maintain turf of the required quality. It is essential that a nitrogenous fertilizer programme is developed which is designed to maintain the level of available soil nitrogen such that the turf is of the required colour and density. Turf growth rate or clippings weight should not be used as the sole guide to the grasses' need for nitrogen. However, if the turf begins to become thin, or losses its resistance to wear, turf growth may become a reasonable good indicator of the need for nitrogen. This is best assessed visually or by the use of leaf tissue analysis.

As of the mid 1990s, no reliable soil test for nitrogen exists and the ability to predict the nitrogen needs of the turf grasses is limited. Such a test would need to measure the amount of inorganic nitrogen in the soil and be able to predict the amount of organic nitrogen available for mineralization. Science has not yet managed to solve this problem and thus nitrogenous fertilizer recommendations will remain somewhat inaccurate and empirical, which means they will largely be determined by experience.

Nitrogenous fertilizers

Of the three major elements in a complete fertilizer, nitrogen, phosphorus and potassium, nitrogen is considered to be the most important for the maintenance of a good mature turf. It is nitrogen which has the most dramatic effect on growth and colour. Most nitrogenous fertilizers are manufactured synthetically by the reaction between atmospheric nitrogen and hydrogen gas. From this process, ammonia gas is produced under conditions of high temperature and pressure. From this basic ammonia stock, many different nitrogenous fertilizers may be produced. It may be liquefied to form anhydrous ammonia, dissolved in water to give an ammonium solution or later formulated into other inorganic fertilizers. Because the synthetic production of nitrogenous fertilizers uses much energy and sophisticated technology, the cost of such fertilizers is usually high.

Soluble sources of nitrogen

The most soluble nitrogenous fertilizers are in either the ammonium or nitrate form. Ammonium nitrogen is more susceptible to volatilization, but in less susceptible to leaching than is the nitrate form.

These soluble forms give a rapid greening response and shoot growth. Normally, the response occurs within two days of application, peaks at 7 to 10 days and then tapers off to original levels in 3 to 6 weeks. The responses depend upon the application rate and the amount of water applied.

Soluble nitrogenous fertilizers have salt-like characteristics. That is, they dissolve readily in water to form cations and anions which are negatively or positively charged. The greater the availability of these ions, the greater is the burn potential of the fertilizer. Burn potential can be lowered by applying the fertilizer only onto dry surfaces when the air temperature is below 30°C. Watering in of the soluble nitrogen immediately after application further reduces the risk of burning the plant tissue. Other disadvantages of using soluble nitrogenous fertilizers may be minimized by the frequent application of the fertilizer at low rates. Rates at or below 2 g N/m^2 will minimize burning problems, but will increase application frequency and treatment costs.

Use of soluble forms of nitrogen

Advantages

- Rapid initial colour change and growth response;
- Nitrogenous fertilizers are high in nitrogen;
- No odour;
- Satisfactory plant nitrogen levels easy to maintain if fertilizer applied frequently in small amounts;
- Reduced dependence on temperature for nitrogen to be available to the plant. Can be used effectively in cool conditions; and
- Nitrogenous fertilizers come in a variety of preparations e.g. granular or liquid.

Disadvantages

- There is a high potential to cause foliar burn, especially if used at high rates and during periods of warm weather;
- Relatively short residual plant response necessitating repeated applications. This increases labour costs on fertilizer application;
- There is an increased potential for the loss of nitrogen because of volatility; leaching and run-off; and
- Some forms of nitrogenous fertilizers are often difficult to physically manage.

Urea

Urea is one of the most widely used sources of nitrogen. It is relatively inexpensive and completely soluble. Urea became readily available because it is a by-product of the explosives industry. It is formed by the reaction of atmospheric nitrogen which methane to produce ammonia gas and carbon dioxide. At high temperature and pressure, the ammonia reacts with carbon dioxide to form urea.

Once urea is applied to the soil, it is broken down into ammonium carbonate by the enzyme urease which is present in plant tissue. Urease is found in soil organic matter. In the soil solution, the positively charged cation NH_4^+ is attracted to the negatively charged clay particles; root hairs and organic matter. The direct application of urea to the surface of a turf may result in the conversion of ammonium carbonate into ammonia and carbon dioxide gas and this results in the excessive loss of nitrogen. Such losses may be avoided by applying water after an application of urea so that the nitrogen is incorporated into the soil.

Because urea has a quick initial release of nitrogen of short duration, it has a high foliar burn potential. Also, the nitrogen from urea is readily subject to leaching and volatilization. Fertilizer programmes which include urea, require that the material be applied frequently at a light application rate of some 2g N/m^2 or less. Such fertilizers should be applied every four weeks to reduce the likelihood of excess nitrogen loss.

Ammonium sulphate and ammonium nitrate

The inorganic salts containing nitrogen are ammonium sulphate; ammonium nitrate; ammonium phosphate; potassium nitrate and calcium nitrate. All are water soluble. Once these nitrogenous fertilizers dissolve in the soil, ammonium ions are produced which can be adsorbed by the negatively charged clay particles and organic matter. Nitrobacter convert the ammonium ions to nitrate ions, the main form of nitrogen which is available to plants. The same process occurs when urea is used as the source of nitrogen. However, potassium nitrate and calcium nitrate do not need conversion to nitrate by nitrobacter because their nitrogen is already in the form of nitrate.

Further sources of nitrogen

Slow release

In an effort to overcome the disadvantages of the quickly soluble nitrogenous fertilizers, manufacturers have developed an array of slow, or controlled release fertilizers. These fertilizers generally produce a more uniform growth response and have a longer residual effect than the more soluble fertilizers. Nitrogen losses are reduced which allows for higher application rates to be used when compared with the more soluble forms. Because of their low salt index values, slow release fertilizers have a lower burn potential. The rate at which these slow release fertilizers release nitrogen varies with the timing of application; source of the nitrogenous material; temperature, soil moisture, soil pH and particle size.

The disadvantages of slow release fertilizers include their high unit cost of nitrogen and their slow initial plant response. Some nitrogenous sources are not able to be used with liquid application systems. This means that turf managers, when determining their fertilizer programmes, must use their knowledge of the various nitrogenous fertilizers and the conditions under which the nitrogen is released to the best advantage.

Natural or organic fertilizers

Such fertilizers usually contain amounts of either composted material, or human or animal waste products. Manure sludges; bone meal; humates and composted plant residues are the most widely used organic nitrogenous materials. The main advantage of these fertilizers is their low burn potential because of their low water soluble nitrogen content; limited effect on soil pH and a reduced nitrogen loss from leaching. Other advantages are that many other plant nutrients may be included in addition to nitrogen and they have the potential to improve the physical condition of the soil. This is most important on the sandy soils of the greater Perth area. Depending upon location and availability, organics may be available at competitive prices.

Some disadvantages of using organic sources of nitrogen, which must be considered, is their low rate of nitrogen release during cool weather because of low microbial activity and low content of nitrogen. Because of this, large amounts of organics will have to be applied. Also, organic nitrogenous fertilizers cost more per unit of nitrogen than do the synthetic soluble fertilizers and they may be more difficult to store, and apply in a uniform manner. This is particularly applicable when the turf is already established. Finally, some organics have an objectionable odour after application and may contain undesirable salts; heavy metals such as mercury and lead, and weed seeds.

Summary

- Nitrate nitrogen, NO_3^- is the form of nitrogen most used by turf grass plants followed by the ammonium form, NH_4^+.
- The nitrogen in soil organic matter cannot be used directly by turf grass. It must first be converted to either NO_3^- or NH_4^+ by the soil micro-organisms.
- The soils on which most turf grasses are grown rarely have enough existing nitrogen to maintain quality turf. Thus, fertilizer nitrogen is needed to maintain turf quality.
- Ammonium sulphate; urea and ammonium nitrate are the most common soluble forms of nitrogen used in nitrogenous fertilizers for turf grass. These give a rapid greening response and shoot growth. However, there is a high potential to cause foliar burn. The growth response is of short duration.
- Nitrogenous fertilizers containing nitrate must be used with care because of their potential to leach.
- To overcome some of the disadvantages of the soluble nitrogenous fertilizers, manufacturers have developed slow release fertilizers. These give a more uniform growth response and have a longer residual effect. The main disadvantage of slow release nitrogenous fertilizers are their high unit cost for nitrogen and their slow initial plant response.

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TINS

The need for nitrogen

K.J. Johnston

The nitrogen status of turf is best determined by observing its colour, density and growth rate. A leaf analysis will provide accurate data as to the nitrogen levels in the turf. Grass which is low in nitrogen will appear a pale yellow-green (photo 1). This chlorosis is caused by decreased chlorophyll production since nitrogen is a major component of this green complex chemical. In couch and kikuyu, chlorosis caused by a nitrogen deficiency first appears on the older or lower leaves. As the deficiency becomes more severe, the leaf colour changes to yellow. This results in a weak turf which has a poor capacity to recuperate when subjected to wear.

Rarely is the application of fertilizer to turf aimed at achieving maximum growth: rather it is aimed at providing end-users with an acceptable surface. This means that only enough nitrogen should be applied to meet these demands. On a monthly basis, the nitrogen required by a turf varies from none to about 50 kg N/ha. The rate applied varies as to factors such as turf grass species, soil type and irrigation practice. Couch grass, for example, has a higher nitrogen requirement than kikuyu.

Experiments conducted as part of the TINS project showed that, for both couch and kikuyu, maximum growth rates were not achieved even when a nitrogenous fertilizer was applied at rates as high as 100 kg N/ha. Table 1 and the corresponding Figure 1 which uses the same information, shows that the growth rate of couch grass increased with increasing rates of applied nitrogenous fertilizer. The concentration of nitrogen in the leaf tissue likewise increased. Experiments with kikuyu grass gave similar results. Because of the numerous factors which influence the response of the turf grasses to applied nitrogen, it is not possible to suggest recommendations for the use of nitrogenous fertilizers for most turf grass locations which are equally applicable throughout the Swan Coastal Plain (photo 2).

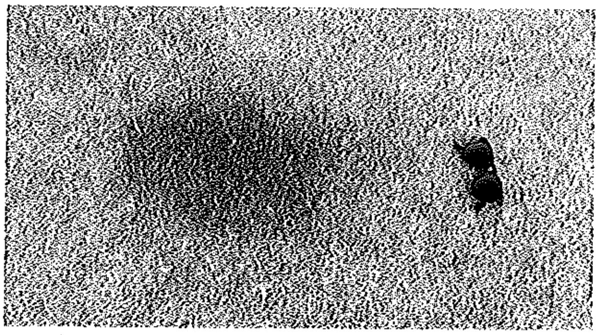

Photo 1. The effect of nitrogen from dog urine on a nitrogen deficient Wintergreen couch turf. Note the light green of the surrounding chlorotic area.

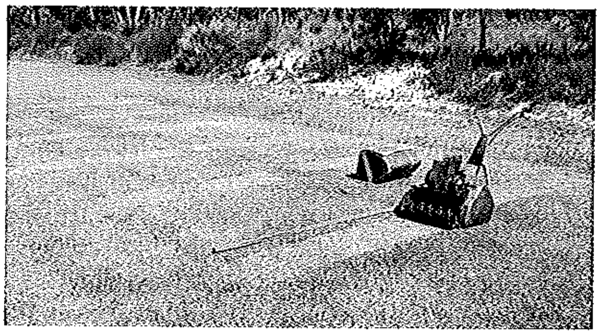

Photo 2. Method of collecting growth rate data from turf areas which received different amounts of a mixed and/or a nitrogenous fertilizer. The strips are mowed and the weight of clippings recorded. Dianella Reserve.

Table 1. The response of couch grass to applications of 20; 40; 75 and 100 kg N/ha as measured by weight of grass clippings in g/m^2 and in the concentration per cent of nitrogen in the leaf tissue.

Rate of N applied kg/ha	Weight of clippings g/m^2	Nitrogen %
20	3.3	1.77
40	10.9	2.12
75	32.4	2.69
100	67.3	2.88

Because the sandy soils of the coastal dune series are very permeable, the quantity of nitrogen applied in any one application should be limited to 40 kg N/ha. This will reduce the risk of severe losses of nitrogen into the water table caused by leaching. Higher rates may be used with proven slow release nitrogenous fertilizers.

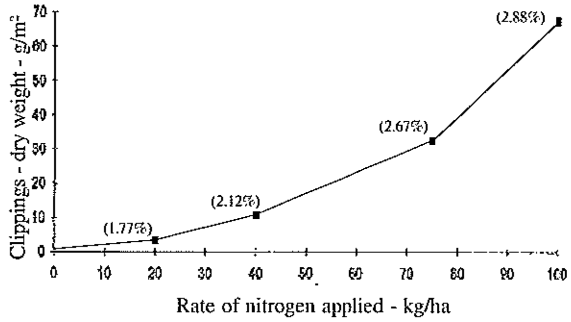

Figure 1. Relationship between the rate of nitrogen applied and the growth of couch. Expressed as both clippings dry weight and the corresponding per cent of nitrogen in the leaf tissue.

Turf use determines need

Passive parks

These are areas of turf which do not have to support organized sport. The wear from human traffic is low. In passive parks the turf density should be maintained at such a level as to resist weed invasion and the colour is light green. The ideal grass for this purpose is kikuyu because of its ability to maintain a relatively dense and green cover throughout the year. Low inputs of nitrogen are required and quality will be maintained provided that the turf is regularly watered during summer.

On old kikuyu turf, high levels of organic matter accumulation will have taken place and nutrient recycling will provide much of turf's need for nitrogen. In such cases, nitrogenous fertilizer need only apply some 25 to 50 kg N/ ha per year. Usually, observation of the turf situation will enable an appropriate decision to be made as to the amount of fertilizer required and when it should be applied. Alternatively, a leaf analysis may be used to obtain an objective measurement of the nitrogen status of the plant. ***Results from surveys done as part of the TINS project stage 2, indicated that, for both couch and kikuyu passive parks, leaf tissue nitrogen levels should be maintained between 1.7 and 2.0 per cent. If the concentration of leaf tissue nitrogen was some 1.5 per cent or less, the turf quality was usually poor.***

Passive parks established with couch cultivars such as Wintergreen, may maintain a high turf density with low inputs of nitrogen though the colour will be poor and unattractive as seen in photo 1. Preferably, nitrogenous fertilizer should be applied during the warmer months whenever the colour or turf density falls to an unsatisfactory level.

Active parks

These are parks used for sport and receive high levels of wear in certain areas. This applies particularly around features such as goals and hockey circles, in the centre of football grounds and under floodlit areas. On rugby fields, the wear is spread more evenly over the playing field. On tennis courts the base lines suffer most wear. However, a large proportion of the area of most active parks and sports grounds do not receive much wear. It is because of the uneven wear pattern on playing surfaces and the passive surrounds that cause turf managers difficulty in determining a suitable fertilizer programme for the entire area (photo 3). Unfortunately, there is often little choice but to fertilize the whole area at a rate adjusted to the minimal wear area of the playing field. The result is that the maximum wear areas are under fertilized while the passive sections are possibly over fertilized. To achieve the best results, extra planning is needed with precise application of fertilizer. The wear areas would get most fertilizer with the passive areas the least.

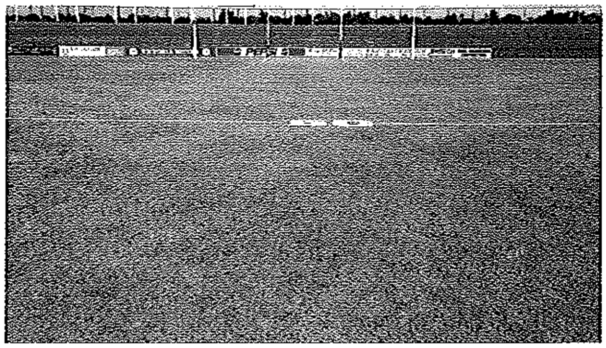

Photo 3: The typical wear effect on a playing surface used for football compared with the adjacent spectator bank area at the Joondalup Arena. Note the areas of little wear near the boundary of the ground. Wintergreen couch. Some Leptospaeria *fungus (spring dead spot) areas on the bank.*

Managers need to be kept informed of the sports schedule for the park's playing surface as this affects the timing of fertilizer application. For example, if a park is used for active sport in the winter months, the critical time for nitrogenous fertilizers to be applied is autumn to early winter. This will keep the turf grass 'winter-active' and better enabled to withstand wear. Parks on which summer sport is played do not have such a critical time for fertilizer application. Often growth rates are sufficient without additional fertilizer. Observation of a deterioration in the density or quality of the turf grass will determine if an application of fertilizer is necessary. Precise application rates of nitrogenous fertilizers for turf are difficult to quantify. ***Couch grass on active parks usually require 100 to 200 kg N/ha while kikuyu on active parks only need some 50 to 100 kg N/ha.***

For active parks, leaf tissue levels of nitrogen should be maintained above 2.0 per cent leading up to and during the time of active use.

Cost of nitrogenous fertilizers

While there are many nitrogenous fertilizers available for use in broad scale agriculture, turf managers are likely to use only three of these which supply only nitrogen, besides the mixed fertilizers formulated especially for turf. The comparitive cost of these are shown in Table 2.

Table 2. Comparison of costs of fertilizers supplying only nitrogen.

Fertilizer	Nitrogen in the fertilizer %	Cost of nitrogen on farm * $/t	Cost of nitrogen ¢/kg
Urea	46	449	97.6
Ammonium sulphate	21	213	101.0
Calcium ammonium nitrate	27	395	146.3

Note 1. Ammonium sulphate contains 24 % sulphur.

Note 2. * Based on the bulk price at Kwinana and Perth, 15/03/1996 with a freight allowance of $15/t.

Note 3. Information from Mason, M. (1996). Nitrogen fertiliser sources for crops. Farmnote 27/96. Western Australian Department of Agriculture.

Summary

- **Turf grass which is low in nitrogen will appear pale yellow-green.**
- **Because of differences between turf species and local environmental factors, no general recommendation as to the amount of nitrogenous fertilizer to apply may be made which is applicable to all situations.**
- **The intended use of the turf largely determines the amount of nitrogen to apply to maintain turf quality.**

Further reading

Mason, M. (1996). Nitrogen fertiliser sources for crops. Farmnote 27/96. Western Australian Department of Agriculture. ISSN 0726-934X Agdex 100/540.

is the Phosphorus Retention Index (PRI). This index gives an assessment of the ability of the soil to retain or adsorb phosphorus. This information is needed to fully determine the meaning of the values obtained from the Colwell bicarbonate test.

Interpretation

This is the component of the soil test which is of most importance to the turf manager. It involves using all the previous information to formulate a recommendation as to how much phosphorus needs to be applied to the turf area from which the soil test sample was taken. Of all the three components of soil testing, interpretation is the most variable. In an extensive review of soil testing for turf culture in the United States of America, it was found that phosphorus recommendations by different laboratories as to the need for phosphorus fertilizer, varied as much as sixfold for a given uniform soil sample sent to each testing facility. This means that soil testing for phosphorus may be more guess work than science. ***Fortunately, local research information from the TINS project shows that soil testing for phosphorus can be done with more confidence.*** The following are guidelines for the interpretation of the Colwell bicarbonate test values of available phosphorus for couch and kikuyu on the Swan Coastal Plain.

Table 1. Phosphorus Retention Index (PRI) Available P and recommendations.

PRI	Available P and recommendations
0 or -ve	No matter what the bicarbonate extractable P level, do not apply P fertilizer
0.1 to 0.5	Bicarbonate P <5, apply P at a rate not >5 kg P/ha. If bicarbonate P >5 do not apply any P (use leaf analysis as a guide)
0.5 to 2.0	Bicarbonate P<7, apply P at 5 kg P/ha. Bicarbonate P >7 do not apply P
2.0 to 5.0	Bicarbonate <10, apply P at a rate of up to 10 kg P/ha. Bicarbonate P >10 do not apply P
>5.0	Bicarbonate P <10, apply P at a rate up to 20 kg P/ha

Leaf analysis

Tissue or leaf analysis for phosphorus may be used as an additional tool or fine tuning the phosphorus requirements of turf. A useful, but little used technique for leaf analysis interpretation is data logging or tracking. The technique is based upon a time series of leaf analysis results. The objective of data logging is to regulate cultural practices so as to maintain leaf tissue phosphorus levels within a set sufficiency range. In Figure 1, which compares leaf tissue phosphorus levels and the critical level for phosphorus, it may be seen that, for this site, P levels remain above the critical level without the application of P.

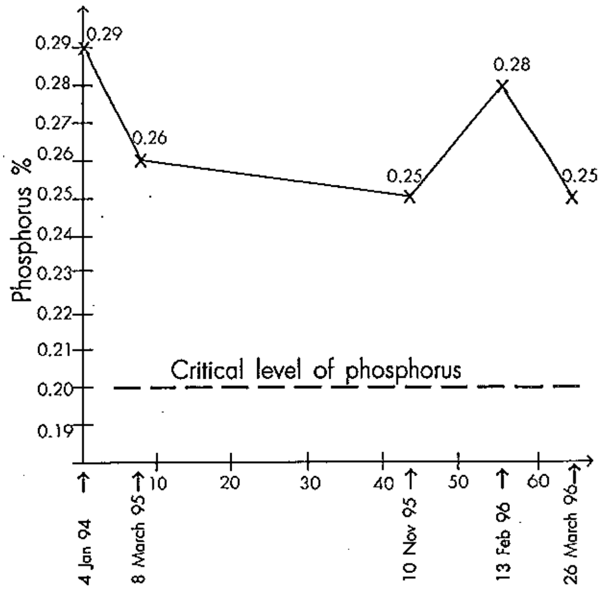

Figure 1. Tracking of leaf tissue phosphorus levels (approximate) for couch grass during TINS project experiment located at Dryandra Pendula Reserve, Mirrabooka.

The interpretation of leaf analysis data is given below in Table 2.

Table 2. The required phosphorus levels for couch grass and kikuyu grass as determined by leaf analysis.

Turf species	Phosphorus concentration (per cent)		
	Low	Sufficient	High
Couch - minimal wear	0.12 - 0.14	0.15 - 0.40	>0.40
Couch - high wear	0.15 - 0.20	0.20 - 0.50	>0.50
Kikuyu	0.15 - 0.20	0.20 - 0.40	>0.40

Sources of phosphorus

The most common fertilizer source of phosphorus is superphosphate. This is calcium phosphate and gypsum and is produced by the addition of sulphuric acid to rock phosphate. Superphosphate is about 9 per cent total phosphorus of which some 80 per cent is water soluble. Once the soluble phosphorus has been dissolved from the fertilizer granule into the soil solution, it can be taken up by the plant roots, adsorbed by the soil or leached from the root zone. Triple superphosphate is rarely used as a source of phosphorus though it contains 21 per cent total phosphorus.

Rock phosphate has sometimes been suggested as an alternative to superphosphate because it possesses almost no water soluble phosphorus. However, rock phosphate has proven to be ineffective on most Western Australian soils because the material is inert and has almost no effect on plant growth.

Organic fertilizers or manures, such as pelletized chicken manure, contain about 1 per cent total phosphorus, a portion of which could be considered as a slow release fertilizer.

Common sense guidelines for phosphorus use

- The required frequency of soil testing varies and is mainly dependent upon soil type. As a general rule, soil testing is done annually and leaf tissue analyses every six months. On the grey or white Bassendean sands, which have a limited ability to retain phosphorus, soil and tissue testing may need to be done at more frequent intervals.
- Use soil testing in conjunction with leaf analysis to determine the phosphorus needs of turf. Make sure the testing laboratory uses the Colwell bicarbonate test and the PRI test. Use this information to interpret the results as described.
- Application rates of phosphatic fertilizers are generally lower, but more frequent on soils that have a limited ability to retain phosphorus.
- Colour is often indicative of the ability of our sandy soils to retain phosphorus. Grey or white sands have the least retention capacity, through to cream, yellow and then orange. This is primarily because of the increasing iron content in the sand as colour changes from grey/white to orange (see article on PRI of soils).
- Care must be taken when phosphatic fertilizers are applied near lakes or other bodies of water. If a broadcast type of fertilizer spreader is used, it is advisable to leave an adequate unfertilized buffer area next to the water. A drop type spreader may be used to complete this area.
- Organic fertilizers, such as raw or pelletized chicken manure contain phosphorus. Care must be taken when such fertilizers are used and the amount of phosphorus in them calculated when determining the total amount of phosphorus to be applied from all sources of phosphorus.

Further reading

Bolland, M. and Glencross, R.N. (1992). Rock phosphates for high rainfall pastures are unlikely to reduce eutrophication of waterways. Department of Agriculture, Western Australia. Technote N. 14/92.

Carrow, R.N. (1995). Soil testing for fertilizer recommendations. Golf Course Management. November, 1995: 61-68.

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TINS

The need for potassium by established turf

K.J. Johnston

Soils which have significant amounts of clay minerals are usually able to supply sufficient plant available potassium to allow for successful turf growth. However, the sandy soils of the Swan Coastal Plain are low in clay and are largely composed of quartz which is very low in potassium.

In these sandy soils, the main vehicle for cation exchange is the organic matter, but because the level of organic matter is low its ability to hold applied potassium is also low. Under such conditions, it is very difficult to effectively and efficiently supply turf with plant available potassium. Leaching of applied potassium is common, especially during periods of heavy winter rainfall and summer irrigation.

Although potassium is an essential element for plant growth, a shortage of this element is not normally associated with a prominent visual response as evidenced by a change in shoot colour, plant density or growth. In fact, maximum tissue production is reached at lower levels of available potassium than some stress related responses often attributed to potassium deficiency. As with many crop plants, an adequate supply of potassium helps turf grass species to overcome the negative effects of too much nitrogenous fertilizer. This is manifest by an increased tolerance to cold; heat; drought; diseases and wear. Since potassium increases the tolerance of turf grass species to such stresses, it is often called the 'health' element. Potassium plays a major role in plant/water relations. When potassium is deficient, plants cannot maintain adequate turgor pressure in the vegetative tissues, especially in the leaves. Leaf water potential declines while the stomata remain open, resulting in high water transpiration losses.

American research

Research in the United States of America showed that applications of potassium tended to increase the traffic tolerance of hybrid couch when compared with those plots which only received nitrogen. In other research, it was found that adequate potassium was essential to provide winter hardness for various species of couch. The severity of several turf grass diseases has been shown to be affected by the level of soil potassium. Low levels of soil potassium has resulted in severe damage from leaf spot diseases in couch. The dollar spot and *Helminthosporium* diseases have been reported as being reduced when potassium is applied to turf.

Inconsistent results

In some cases, the application of potassic fertilizers has not been shown to influence the growth or quality of couch. This inconsistency may be caused by the varied initial potassium status of the soil. Potassium is a primary nutrient essential for numerous plant functions such as in photosynthesis; carbohydrate and protein formation; water relationships and enzymatic activity.

Uptake of potassium

The rate at which potassium is taken up by the plant depends upon the concentration of the potassium ions within the proximity of the root surface. It is absorbed in the water solution which the plants withdraws from the soil. In soils high in potassium, this is the most common method for potassium to be transported towards the roots. However, when soils are low in potassium, the diffusion process of potassium to the root surface assumes greater importance.

Replenishment of potassium

Usually, potassium is quickly replenished from the fraction held by the negative electrical charge on the surface of the clay and organic matter particles. The amount available in this manner is called the 'exchangeable fraction'. The potassium so removed from the clay or organic matter particles is in turn replaced by potassium from decaying organic matter or by potassium leached from clay minerals if any be present.

Potassium deficiency

The most common deficiency symptoms include interveinal chlorosis (yellowing) of the older leaves, and rolling and burning of the leaf tip. As the deficiency becomes more acute, the leaf veins themselves become yellow and the leaf margins look scorched. The turf will appear thin with spindly growth of individual plants. Because potassium is highly mobile within the plant, it will be translocated from older leaves to younger meristematic (growing) tissues if deficiency occurs. Potassium does not form any part of the solid cell structures of the plant, but remains soluble in the plant sap.

Testing for potassium

Because potassium is not readily held in sandy soils, those with a low cation exchange capacity (CEC), it is lost by leaching. Often it is not possible to increase potassium to a level in the soil which will maintain a continuous supply over an extended period.

On the sandy soils in the Greater Perth area, soil tests always show low potassium levels because of leaching. As a result, soil testing on these very low CEC soils is of little value. The best practice is to apply repeated applications of potassium in small amounts to the turf together with other nutrients. Managers often determine the need for potassium by the amount of nitrogen applied. It is becoming an increasingly common practice to use tissue testing to monitor plant potassium levels.

On all other soils such as those which contain clay, or sandy soils which have accumulated significant levels of organic matter, soil testing is the best method to evaluate the need of the plant for potassium. In these cases, soil tests provide the most accurate and predictive information upon which to base fertilizer recommendations. Recreational sites such as football and hockey grounds have a higher demand for potassium than general parks used for passive reaction because it improved the tolerance of the grass to wear. On many parks where clippings are returned to the surface of the turf and the soil contains good reserves of potassium, as determined by a soil test, there is little need for additional potassic fertilizers.

All soil tests for potassium measure the same 'pool' of soil potassium. This includes the water soluble fraction plus the exchangeable potassium that is retained by the organic matter and clay minerals. The method of extraction most commonly used in Western Australia uses sodium bicarbonate to dissolve the available soil potassium so that it may be measured. In addition, it is necessary to obtain an indication of the amount of organic matter in the soil which is determined by measuring the organic carbon content. These two sets of data enable sound recommendations to be made as to the amount of potassic fertilizer required by a particular soil type to ensure adequate plant growth.

Recommendations

The following recommendations are based on the information derived from the various experiments and surveys done as part of the TINS project.

For sandy soils with <1 per cent of organic carbon in the surface 10 cm of the soil.

- For parks subject to low wear, apply potassium and nitrogen together in the ratio of 1 : 0.5 (nitrogen : potassium).

- For parks subject to high wear, potassium and nitrogen together in the ratio of 1 : 0.8 (nitrogen : potassium).

For soils with >1 per cent of organic carbon in the surface 10 cm of the soil.

- For kikuyu, if the soil test value is <30 mg/kg, apply potassium whenever nitrogen is applied at a ratio of 1 : 0.5. If the soil test value is >30 mg/kg, do not apply any potassium with nitrogen.

- For couch, if the soil test value is <50 mg/kg, apply potassium whenever nitrogen is applied at a ratio of 1 : 0.5 (low wear) and 1 : 0.8 (high wear). If the soil test value is >50 mg/kg, do not apply any potassium with nitrogen.

Leaf analysis - data logging

In association with normal leaf analyses, a useful though little used technique is that of data logging or tracking. The technique employs data from a series of results over time. The objective of data logging is to regulate cultural practices so as to maintain leaf potassium levels within a desired sufficiency range.

The data may be recorded on a graph which may be used to warn managers when and as potassium deficiencies develop. By the use of this method, corrective measures may be taken before deficiencies occur which would cause a reduction in turf quality and growth rate (see Figure 1).

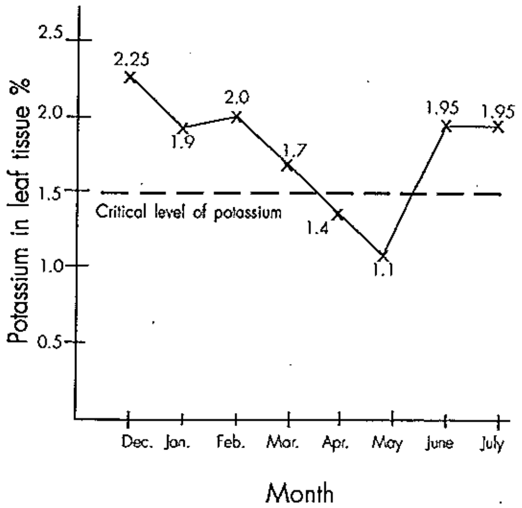

Figure 1. Monthly tissue analysis from couch (high wear) field.

Studies with hybrid couch growing in hydroponic solutions, showed that thinning of turf became noticeable when leaf potassium dropped below 1.8 per cent. Deficiency symptoms were evident at any concentration below 1.0 per cent at which level the grass turned pale green and developed narrow leaves.

The interpretation of leaf analysis is shown in Table 1 below:

Table 1. Required potassium levels for couch and kikuyu as determined by leaf analysis.

Turf species	Potassium concentration (per cent) Low	Sufficient	High
Couch - minimal wear	0.77 - 0.99	1.00 - 4.00	>0.40
Couch - high wear	1.00 - 1.49	1.50 - 4.00	>4.00
Kikuyu	0.60 - 0.99	1.00 - 4.00	>4.00

Sources of potassium

The most common and cheapest potassic fertilizer is muriate of potash or correctly, potassium chloride. It comes from potassium salt deposits which have been processed after mining. Most NPK fertilizers use potassium chloride.

Other potassic fertilizers are potassium sulphate which is made by the reaction between potassium chloride and sulphuric acid, and potassium nitrate made from potassium chloride and nitric acid. These fertilizers are used to reduce the salt index and to supply either sulphur or nitrogen. Some of the characteristics of the various potassic fertilizers are shown in Table 2.

Table 2. Characteristics of the main potassic turf fertilizers.

Source of K	Nutrient - per cent N	P	K	Salt index/ nutrient*	Acidifying effect
Muriate of potash	0	0	50	1.93	Neutral
Potassium sulphate	0	0	42	0.85	Neutral
Potassium nitrate	13	0	38	2.44	Basic

* Generally, the higher the salt index/unit of nutrient, the higher the burn potential of the particular fertilizer.

Useful guidelines

- **Use soil tests in conjunction with leaf analyses to determine the potassium needs of turf. On sandy soils with low organic matter, soil tests are of little use. In such cases, potassium application rates are based upon the rate of nitrogenous fertilizer applied. Use data given in Table 1 to interpret laboratory analyses results.**
- **Although many factors influence the frequency of soil testing, it is usually done annually. Leaf tissue testing should be done every six months.**
- **Application rates of potassium are generally lower and more frequent on soils which have a low CEC. This results in a higher total amount of potassium being applied per year than on soils with a high CEC.**

- **Old established turf areas with high levels of organic matter have a low requirement for potassium.**
- **Turf areas subjected to excessive wear and/or have the clippings removed have a high potassium requirement.**

Further reading

Carrow, R.N. (1995). Soil testing for fertilizer recommendations. *Golf Course Management.* November, 1995: 61-68.

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Snyder, G.H. and Cisar, J.L. (1992). Controlled release potassium fertilizers for turf grass. *Journal of the American Society of Horticultural Science.* 117: 411-414.

TINS

Turf establishment

K.J. Johnston

The problem

The challenge in the establishment of new turf areas is to maintain adequate levels of plant nutrition. This is especially difficult on the sandy soils of the Swan Coastal Plain. This is because the ability of the sands to retain nutrients is low, the initial nutrient level is minimal and the leaching potential is very high. The most common mistakes made by managers of new turf grass areas is to over water and to under fertilize during the 'grow-in' phase of turf establishment.

Nutrient deficiencies

Soil chemistry is a complex science, but one becoming increasingly understood by turf grass managers. The key to the retention of plant nutrients in the soil is its cation exchange capacity (CEC) which is a product of complex electrical exchange processes. These cation exchange sites within the soil are found on the minute clay particles and within the organic matter fractions. During the formation of the clay particles, negative charges arise that allow for positively charged ions to be attached to them, such as Ca^{++}. This electrical attraction reduces the leaching of cations which are then available for uptake by the plant. Organic matter in the soil behaves in a similar way with CEC sites caused by the dissociation of hydrogen ions from various functional chemical groups.

Because the sandy soils of the Swan Coastal Plain are very low in clay and organic matter, the CEC is likewise very low. This means that if the soil is not modified before turf establishment, it will take many years for the CEC in the soil to increase naturally as a result of the accumulation of organic matter. Soil amendments using fine particle materials such as loam or well decomposed organic matter, improves the CEC of the soil. Turf establishment on sandy soils to which amendments have been added, will become more of a standard practice as the long term agronomic and environmental benefits of this practice are realized.

It is important that a soil test is done before a site is planted to turf. This will enable managers to adjust the soil pH if necessary and to formulate a cost effective fertilizer programme.

Nitrogen

On newly established turf on sandy soils, the usual approach is to frequently apply small amounts of a soluble nitrogenous fertilizer. This is commonly called 'spoon feeding'. However, research in the United States of America has shown that this method is not to be solely relied upon for the early 'grow in' period because:

- A slow release formulation of nitrogen is necessary to build up nitrogen levels in the soil and to buffer against rapid changes in soil nitrogen content.
- The 'grow-in' period may be extended if a slow release nitrogenous fertilizer is not used.
- The use of organic fertilizers provide other nutrients which are often in short supply.

Rate of nitrogen

This means that, at planting, a natural organic fertilizer (such as Dynamic Lifter ™ or Organic 2000 Turf Starter ™) should be incorporated into the surface of the soil at a rate equivalent to 100 kg N/ha. Such materials provide a good source of nitrogen that will not leach as readily as do the soluble forms of nitrogen. Furthermore, some micronutrients will be supplied. In addition, there will be some buffering against rapid fluctuations in nitrogen levels for several months after the turf is planted.

During the first year after planting, the turf may go from a healthy appearance with adequate colour and growth, to a turf with a nitrogen deficient yellow within the space of a few days. In contrast to this, in a mature turf profile, such nitrogen deficiency symptoms develop more gradually over a one to three week period. When nitrogen is applied, colour and growth return to the desired condition and the cycle repeats itself over time. In the first years, these cycles are close together, often as close as one to three weeks, but become less frequent as the turf thickens and matures. This shows that the best means to monitor the nitrogen status of a turf during the 'grow-in' period is frequent visual observation.

In the warm summer months, soil temperatures rise and are high enough to allow for the microbial release of nitrogen from organic fertilizers. As such, these materials should be used in the nitrogenous fertilizer programme at about 25 kg N/ha per month. By applying small amounts of organics during summer, the nitrogen in them is released slowly. This aids in moderating wide growth and colour fluctuations which are typical of the responses seen with the use of fast release nitrogenous fertilizers.

In addition to the nitrogen applied in organic fertilizers or other slow release sources, extra nitrogen will be necessary and should be supplied in a fast release form. These rapidly soluble forms of nitrogen should be applied on an 'as required basis' as soon as nitrogen deficiency symptoms become apparent.

Nitrogen application rates may be higher during the 'grow-in' phase than those used for a mature turf. This is caused by the lack of residual nitrogen and the high leaching potential of sandy soils low in organic matter. Slow release fertilizers applied to the turf will provide some residual nitrogen.

Fast release nitrogenous fertilizers may be applied at rates of between 25 to 40 kg N/ha. Initially, such applications may be needed every two to three weeks. As the turf develops the time interval between applications will increase and will be influenced by need. For couch grass, the nitrogen requirement during the 'grow-in' period in the first year may be between 200 and 800 kg N/ha. At the beginning of the second year high nitrogen rates will still be needed. Eventually, the turf will stabilize and the rapid onset of nitrogen deficiency will cease. With increasing maturity, as nitrogen becomes limiting, the turf will only gradually discolour and growth slow.

The buffering effect which prevents rapid changes in nutrient status stems from the use of slow release fertilizers and the build up of residual nitrogen from decaying turf grass tissues.

Phosphorus

Most virgin sandy soils of the Swan Coastal Plain are acutely deficient in phosphorus. These soils have a limited ability to retain applied phosphatic fertilizers and so soil testing is essential to determine the phosphatic fertilizer programme to be implemented.

If a soil has a low Phosphorus Retention Index (PRI), it has a low ability to retain applied phosphorus and applications of phosphatic fertilizers should be frequent and at low rates. If a slow release form is used, the frequency of application will decrease. Organic fertilizers or manures contain a high ratio of phosphorus to nitrogen and are an excellent slow release form of phosphorus. However, some organics also contain considerable quantities of readily available phosphorus and this needs to be considered when formulating fertilizer programmes for soils which have a low PRI.

For soils with a PRI of 2.0 or less, soluble forms of phosphorus should usually not be applied at rates >5 kg P/ha. The timing of the applications may be determined by leaf tissues analysis of phosphorus levels in the plant.

For soils with a PRI >2.0, a significant bank of phosphorus can be achieved by the application of superphosphate in addition to organics. Superphosphate application rates depend on the PRI of the soil and range from 100 kg/ha at a PRI just above 2.0 to 500 kg/ha for soils with a much higher PRI. Further applications of phosphorus will only be required when a soil test shows that the level of phosphorus has dropped below 10 mg/kg or tissue testing produces similar information. In most cases, these applications should not exceed 10 kg P/ha.

TINS research results

As part of the TINS research programme, a virgin soil with a PRI of 5 was selected and treated with several rates of superphosphate, to determine the retention of phosphorus at an initial soil PRI of 5 at which level the leaching of phosphorus should be low.

Superphosphate was applied in September, 1994, at rates of 0; 10; 20; 50; 100 and 200 kg P/ha. In March, 1995, soil samples were taken which was six months after the fertilizer was applied. The samples were taken from two soil levels, 0 to 10 cm and 10 to 25 cm. Analysis showed that for rates of phosphorus up to and including 50 kg P/ha, some 100 per cent of the phosphorus was retained in the surface 10 cm of the soil. For rates of applied phosphorus at rates of 100 and 200 kg P/ha, there was some movement of phosphorus below 10 cm. Even at the highest rate of applied phosphorus, all the remaining phosphorus was retained within the 10 to 25 cm level.

The soil test results showed that in soils with a PRI of 5 the leaching of phosphorus was minimal.

In addition, the March soil test showed that at levels of applied phosphorus at 10 and 20 kg P/ha, the phosphorus concentration was below the critical level of 10 mg/kg (Figure 1). Leaf tissue analysis, also done in March, 1995, confirmed the data from the soil tests. At soil applications of 10 and 20 kg P/ha the leaf tissue analysis gave results of 0.15 and 0.19 per cent respectively which is just below the critical level of 0.20 per cent. The analyses for 50; 100 and 200 kg P/ha gave leaf phosphorus percentages of 0.22; 0.35 and 0.38 per cent respectively which are all above the critical level.

How the critical phosphorus level is determined

The critical phosphorus level is derived from the relationship between the yield of leaf clippings and the phosphorus concentration in the soil or leaf clippings. The critical phosphorus level is defined as that phosphorus concentration that causes a 10 per cent reduction in maximum yield. Alternatively, it may be considered as the phosphorus concentration in the soil or leaf that corresponds to 90 per cent of maximum yield. A knowledge of the critical level enables managers to make decisions as to the need for phosphatic fertilizers.

Because visual deficiency symptoms of phosphorus in couch and kikuyu are difficult to recognize, phosphorus deficiency on new turf sites may be difficult to detect. A poor growth response to an application of nitrogen is often a sign of phosphorus deficiency in the plant.

Potassium

Potassium is easily leached from sandy soils with a low CEC. This makes it impossible to establish a bank of potassium in the soil. A deficiency usually results in chlorosis, especially seen as leaf tip burn; reduced wear, cold and disease tolerance and growth rate.

On newly established turf on sandy soils, potassium should be applied as frequently as is nitrogen, but at about one half the rate. This varies as to the type of fertilizers used. This practice ensures that the turf will receive a constant supply of potassium even though the amount retained in the soil remains low.

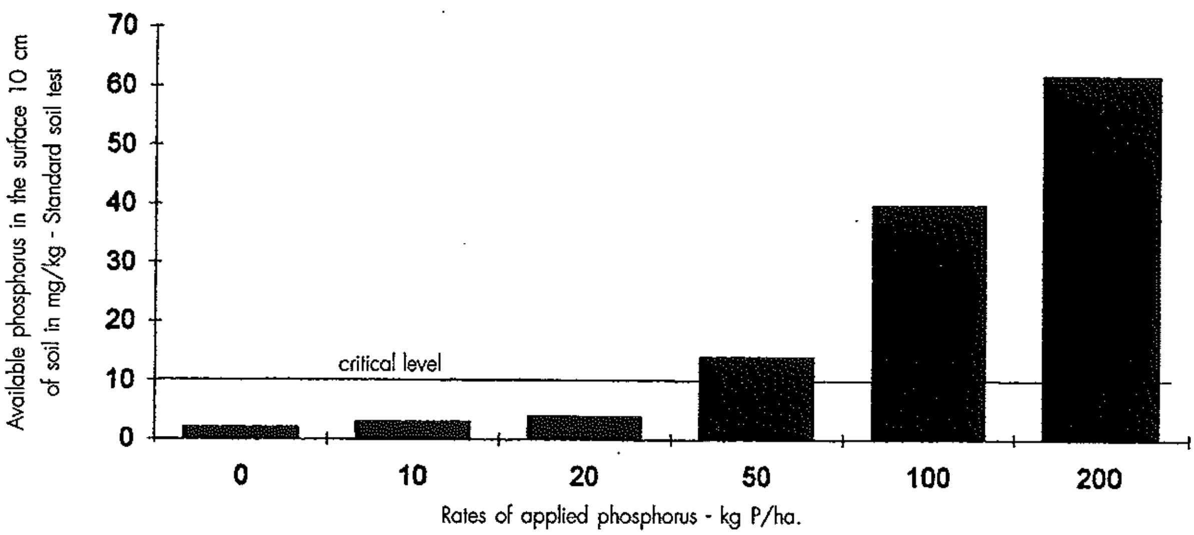

Figure 1. Level of plant available phosphorus in the surface 10 cm of soil six months after phosphorus was applied as superphosphate at rates of 0; 10; 20; 50; 100 and 200 kg P/ha.

Macronutrients

These are the nutrients used by the plant in quite large amounts which are usually not limiting. Typical of these are calcium and magnesium, a deficiency of which is rare. Deficiencies are usually induced by either a very high application of lime containing only calcium carbonate or the use of water high in calcium or magnesium which has the effect of creating a nutrient imbalance in the soil solution.

During the 'grow-in' period, no supplemental calcium or magnesium should be required as these nutrients are contained in both the inorganic and organic fertilizers which are applied at this time. If the soil is acidic, dolomitic lime is recommended which contains both calcium and magnesium carbonate. This material will also increase the soil pH.

Sulphur deficiency has been recorded in pastures on the sandy soils of the Swan Coastal Plain. However, if sulphate of ammonia is used, no deficiency will occur.

Micronutrients

The turf grass species are very efficient at extracting nutrients from the soil solution. Micronutrients are required in very small amounts and are present in almost all materials added to the soil - usually as impurities.

The micronutrients required by turf grasses include iron; manganese; molybdenum; boron; chlorine; copper and boron. On our sandy soils, the most common deficiencies are those of iron and manganese. Occasionally, copper and boron are deficient for plant growth on virgin soils.

Manganese and iron deficiencies occur mainly on the alkaline sands of the western part of the Swan Coastal Plain. Occasionally, manganese is deficient in acidic soils which are irrigated with water high in iron. Similarly, manganese induced iron chlorosis is sometimes found in very acidic soils high in manganese.

On alkaline soils, foliar applications of iron and manganese are used to overcome these deficiencies. On acidic soils, these deficiencies may be overcome by direct application of iron and manganese to the soil.

For the first two or three years of the 'grow-in' period, it is recommended that a complete micronutrient fertilizer be applied once or twice per year.

Summary

- **The challenge in the establishment of new turf areas is the maintenance of adequate levels of plant nutrition.**
- **The retention of nutrients is limited on the sandy soils because of their very low cation exchange capacity (CEC).**
- **Nitrogen should be applied in a slow release form (organic or similar) in addition to the regular small applications of readily soluble forms. This will supply a more uniform supply of nitrogen.**
- **The use of phosphorus must be guided by the data from soil tests. Soils with a low PRI need particular attention by managers.**
- **Regular leaf analyses throughout the 'grow-in' period should be done and used to monitor the supply of all nutrients, including the micronutrients.**

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TINS

The lesser major elements

K.J. Johnston

Adapted from McCarty, LB., Sartain, J.B., Snyder G.H. and Cisar J.L. (1993) Plant nutrition, fertilizers and fertilizer programs for Florida golf courses. University of Florida. Bulletin 282.

The lesser major elements in plant nutrition are those used by plants in large quantities, but they are usually present in such quantities in the soil as to be not limiting to plant growth. Elements such as calcium (Ca); magnesium (Mg) and sulphur (S) are required by plants in almost the same quantity as phosphorus (P). Many of these lesser major elements are present in many mixed fertilizers, often as impurities.

Calcium

Calcium has many functions within the plant including: strengthening the cell walls to prevent their collapse; enhancing cell division; to encourage plant growth; synthesizing protein; the transport of carbohydrates and balancing cell acidity. Calcium aids in the formation and growth of roots. The plant can only use exchangeable calcium ions as Ca^{++}. Deficiencies of calcium occur most frequently in sandy soils, soils that are extremely acidic with a pH <5 or in soils saturated with sodium (Na).

Calcium is an immobile nutrient in plants which means that it is not freely translocated. It does not move from old leaves to new leaves which means that the plant must have a continuous supply of calcium. Lime is the usual material added to the soil to supply calcium and it is often in irrigation water. The calcareous sands at the western edge of the Swan Coastal Plain are high in calcium. Commercial sources of calcium include limestone; lime sand; gypsum; superphosphates and calcium hydroxide. Gypsum, which is calcium sulphate, contains about 23 per cent calcium and 19 per cent sulphur. It has little effect on soil pH.

Magnesium

Magnesium is essential for chlorophyll production. The chlorophyll molecule contains about 7 per cent magnesium. The element is essential for energy reductions such as in the formation of sugars and also regulates the uptake of other plant nutrients. Magnesium deficiencies occur mainly in sandy soils with a low CEC, or in soils with an extremely high pH. This applies particularly when the clippings are removed. High calcium and potassium levels in the soil tend to reduce the uptake of magnesium.

Sources of magnesium include dolomitic limestone; magnesium sulphate (Epsom salts); magnesium oxide and magnesium chelates. Epsom salts contain 10 per cent magnesium and 13 per cent sulphur.

Sulphur

Sulphur is essential for the production of amino acids which are the building blocks of all protein. It confers disease resistance to plants. Sulphur is taken up from the soil solution by the plant in the form of the sulphate anion (SO_4^{--}). The sulphate anion behaves as does the nitrate anion in that it is readily leached from the soil. Deficiencies may occur when the grass clippings are removed and the area is subject to heavy watering. The deficiency is most common on sandy soils.

Over 90 per cent of available sulphur is found in the soil organic matter, which has a nitrogen to sulphur ratio of about 10 : 1. When this ratio reaches 20 : 1, deficiencies of sulphur can occur as it may when the soil pH rises above 7. In alkaline conditions, sulphur may be precipitated out as calcium sulphate ($CaSO_4$), while at low pH levels of <4, the sulphate anion may be adsorbed by iron oxides. Turf clippings with a high nitrogen to sulphur ratio of >20 : 1 only slowly decompose. This may slow thatch biodegradation since micro-organisms require sulphur to decompose plant residues. Sulphur is supplied as a nutrient in fertilizer sources such as superphosphate and sulphate of ammonia.

In poorly drained, water logged soils where free soil oxygen is absent, the sulphate anion and the organic matter present which contains sulphur may be reduced to the toxic hydrogen sulphide gas (H_2S) by sulphur-reducing bacteria.

Further reading

McCarthy, L.B., Sartain, J.B., Snyder, G.H. and Cisar, J.L. (1993). Plant nutrition, fertilizers and fertilizer programs for Florida golf courses. University of Florida. Bulletin 282.

TINS

Micronutrients

K.J. Johnston

Role in plant nutrition

These are the elements used in plants in very small quantities and for many years their role in plant nutrition was not understood. They are necessary for the plant to achieve its maximum growth potential provided that the macro elements are also present in non limiting amounts. Eight elements were identified over time as being essential for plant growth, but this number has now risen to nine with the inclusion of nickel. The nine minor elements are: iron (Fe); manganese (Mn); zinc (Zn); copper (Cu); molybdenum (Mo); boron (B); chlorine (Cl); cobalt (Co) and nickel (Ni).

World deficiencies of these elements are rare in areas where turf grasses are grown. However, this is not true for the sandy soils of the Swan Coastal Plain where deficiencies are common. The micronutrients most commonly deficient in these sands are iron and manganese. Most world recommendations do not propose that micronutrients be included in maintenance fertilizers for turf unless a particular deficiency is known. In Western Australia, most maintenance fertilizer products contain micronutrients because of their known deficiency in sandy soils.

Micronutrient deficiencies

Many micronutrient deficiencies occur in turf grass grown on the Swan Coastal Plain. The symptoms of micronutrient deficiencies are described as follows and are also referred to generally in 'Turf establishment'.

Manganese

The most observed micronutrient deficiency is that of manganese. The symptoms are regularly seen in kikuyu and couch grown on sands with an alkaline pH. Such sands are most common on the western margins of the Plain in the coastal dune soil series. The visual symptoms on kikuyu are most readily seen during autumn. They appear as yellow areas of turf which, on close inspection. reveal droopy leaves covered in necrotic spots. Symptoms of manganese deficiency are most severe on kikuyu while on couch they are not quite so obvious. In couch, the symptoms are seen as blotchy necrotic areas, though sometimes the leaves have necrotic spots. The couch grass grows poorly despite repeated applications of nitrogen (see other topics on nutrient deficiencies).

Many of the alkaline areas which result in induced manganese deficiency occur naturally as in the calcareous dunes of the Quindalup series. The deficiency may be caused in neutral or acidic sands by the application of irrigation water high in calcium carbonate. The deficiency has also been observed in sandy soils which have had high rates of Alkaloam (red mud) added as a soil amendment. In such cases, the Alkaloam raised the soil pH to >8.

Research in Florida in the United State of America, demonstrated that a manganese deficiency could be corrected by reducing the pH to <7. When this was done, applications of manganese were not needed. On deficient sites, if manganese was applied either as manganese sulphate or manganese chelate the chlorosis was markedly reduced, but the response was only temporary.

On the eastern margins of the Plain, manganese deficiency has been observed on the acidic sands common in these locations. These deficiencies are apparently not caused by a shortage of soil manganese, but rather by a high concentration or readily available iron applied in the irrigation water which renders the manganese unavailable to the plant.

Iron

The colour of turf is often enhanced by the application of iron in the absence of or with reduced applications of nitrogen. Golf course turf managers probably have more experience with the use of iron in this way than others in the turf industry. Rates of application on golf greens may be as high as 200 kg/ha of ferrous sulphate. The response of turf grass to iron will depend upon the amount of iron applied, the growth rate of the grass and the sensitivity of the grass species to foliar injury from applications of iron.

Even though the application of iron sulphate to improve turf colour is a common practice on the sandy soils of the Plain, acute iron deficiency is rarely observed in couch and kikuyu where no iron has been applied when compared with the frequent observation of manganese deficiency in similar cases. The most probable explanations for this is firstly, that couch and kikuyu are more susceptible to an acute deficiency of manganese than they are to a shortage of iron and secondly, that there is sufficient iron in the irrigation water to maintain adequate supplies. As the iron in the irrigation water is often in the chelated form it is readily available for plant uptake. ***During the TINS project, a survey of 21 sites found that water from the bores averaged about 1 mg/kg of iron.***

This concentration of iron in the irrigation water is sufficient to maintain the plants with enough plant available iron in what is virtually a hydroponic solution.

Iron deficiency is most common on the alkaline sands that are irrigated with water low in dissolved iron. However, in such cases it is usual to find that the growth of the turf is limited by a deficiency of manganese.

During research on the TINS project, iron deficiency was observed on couch in several parks which were used as test sites. The soils in these areas were extremely acidic with a pH of <4.5 while the irrigation water contained negligible amounts of iron. Leaf tissue analyses showed iron levels usually considered adequate for quality turf. However, the levels of manganese in the leaf tissues were excessively high and in some cases were twice as high as the concentration of iron.

This type of result has been recorded in research with buffalo grass in Florida in the United States of America. In this case the researchers found an iron deficiency in soils with a pH of 5.7 as a result of excessive quantities of available manganese. The buffalo grass tissue contained about as much manganese as iron whereas the proposed Fe : Mn ratio in leaf tissue should be at least 2 : 1. To correct this iron deficiency, iron sulphate was applied at 25 kg/ha thereby increasing the Fe : Mn ratio to about 6 : 1.

On the TINS test sites, iron sulphate was applied as a solid fertilizer at 50 kg/ha to overcome the iron deficiency. An alternative possible strategy could have been to add lime to increase the soil pH which would have reduced the availability of manganese. The success of this treatment would depend upon the level of iron present in the soil. On acidic, coarse textured soils, iron may be leached from the root zone which means that turf managers must be ready to apply iron under such conditions.

Phosphorus induced iron deficiency has been observed in couch turf growing on the sandy soils of the Plain. Excessive phosphorus can tie-up the iron in the soil and render it unavailable to the plant. A leaf tissue analysis showed that the P : Fe ratio was 94 : 1, whereas for healthy green turf the ratio should be around 22 : 1. A soil application of iron sulphate had little effect in correcting the deficiency as the iron was inactivated as soon as it entered the soil. Regular foliar applications of iron overcame the deficiency.

Other micronutrients

No documentation of deficiencies, other than that of manganese or iron, have been recorded for turf grass areas on the Plain. On one site surveyed during the TINS project, a deficiency of copper was suspected in a park established on a calcareous sand. A leaf tissue analysis showed the level of copper at 3.6 mg/kg whereas the accepted level for deficiency to occur is anything < 5 mg/kg. In the horticultural industries, deficiencies of boron and molybdenum are common while zinc deficiency is common in cereals. In view of this it is possible that such micronutrient deficiencies may be discovered in turf grasses in the future.

Mixed fertilizers

Several fertilizer products available in bulk in the Perth market and used as maintenance fertilizers by turf managers contain micronutrients as additives. Examples of these are Turf Special™ (CSBP) which contains iron (1.0%); copper (0.1%) and zinc (01%). Brilliance™ made by Baileys contains iron (0.3%); and manganese (0.3%) whereas Baileys 3.1.1™ contains iron (0.15%) and manganese (0.25%).

A common practice on golf courses is to apply between 10-15 kg of iron sulphate /ha which applies 2-3 kg Fe/ha. Repeat applications of iron at a minimum of 1.5 kg Fe/ha are often used to correct iron deficiency. The usual practice on golf courses is to apply the dissolved iron fertilizer as a foliar spray. A typical rate of application of a solid maintenance fertilizer is 250 kg /ha which means that the amount of iron supplied from Turf Special™, Brilliance™ or 3.1.1™ is equal to 2.5; 0.75 and 0.38 kg Fe/ha respectively other than for the Turf Special™. These levels of iron application are low when compared with the common practice of applying iron sulphate alone to correct an iron deficiency. In addition the effectiveness of iron applied in a maintenance fertilizer is questionable, especially on alkaline soils. This is because the materials are applied as solids and then watered into the soil and then become unavailable.

Because a fertilizer contains iron does not mean that the use of such a fertilizer will correct an iron deficiency. The iron must be applied at an adequate rate and in a manner in which it can be effectively used by the grass.

It is uneconomic to apply micronutrients that are not needed by the turf grass. Many parks are irrigated with water that contains iron and such water often contains sufficient iron to supply some 10 kg Fe/ha over summer. Even if the soil is low in iron, the needs of the turf will be supplied via irrigation.

The evidence is that manganese sulphate needs to be applied at some 10 kg/ha as a foliar spray to correct a manganese deficiency. This applies about 2.6 kg Mn/ha. An application of Brilliance™ or 3.1.1™ at 250 kg/ha only supplies 0.75 and 0.62 kg Mn/ha respectively. Under high pH conditions, the effectiveness of these applications would be significantly reduced as they would favour the precipitation out of the micronutrients. Even if the pH was low, a standard rate of application of these two mixed fertilizers would be too low to correct a manganese deficiency.

The above analysis shows that the micronutrients contained in the commonly available maintenance fertilizers in the Perth market are usually ineffective in correcting micronutrient deficiencies. In most cases where iron and manganese deficiencies occur, soil applications of low rates of micronutrients will not be effective.

Determining the need for micronutrients

It is not possible to provide blanket recommendations as to the need for micronutrients for all turf situations. Factors to be considered are:

- The specific individual requirements of couch grass and kikuyu;
- Soil conditions; and
- Micronutrient content and pH of the irrigation water.

The differential species response to micronutrient deficiency is well known by managers of turf grass and soil testing is not an effective method to determine deficiencies of iron and manganese. However, the source of irrigation water can be important. Water from a surface spring or from the scheme supply may have no capacity to cause a pH induced deficiency of iron or manganese. Irrigation water drawn from a limestone aquifer may result in repeated applications of iron and manganese being necessary.

The excess use of micronutrients may cause toxic conditions which result in reduced plant growth or even death. This especially applies to the excess use of manganese; zinc; copper and boron on acidic soils. Excess iron can reduce turf quality; turf density and induce manganese deficiency.

There are three ways to assess the need for micronutrient fertilizers.

1) By visual observations of turf grass quality as seen in the colour, density and vigour of the grass.
2) By periodic tissue analysis.
3) By making spot tests when micronutrient deficiencies are expected.

Visual symptoms

Micronutrient deficiencies are seen as various forms of chlorosis. Turf density decreases and, as the disorder becomes worse, necrosis of the leaves and other plant parts will develop. The deficiencies are first seen on the newer or younger foliage because the nutrients are not readily translocated throughout the plant. If the turf does not respond adequately to the usual application of a NPK mixed fertilizer, the possibility of a micronutrient deficiency of iron or manganese should be considered. Other problems may exist such as attack by nematodes or deficiencies of sulphur or magnesium.

Tissue analysis

Analysis of the minerals present in the leaf tissue will help to identify deficiencies. When sampling the leaves of the turf grass, care must be taken to avoid contamination with soil which may contain higher levels of iron and manganese than the turf clippings. With time, a nutrient history of an area can be constructed for areas with a satisfactory period of turf growth and quality. This history will apply to particular areas and type of grass. Any departures from what is considered as normal will indicate if nutrient deficiencies or excesses exist and will aid in the development of a corrective fertilizer strategy.

Should micronutrient histories not exist for particular sites, managers may refer to standard recommendations for sufficiency for both couch and kikuyu for the minor elements listed. In addition to the absolute concentrations of micronutrients present, the relative ratios of these nutrients must be considered. This especially applies to the P : Fe and Fe : Mn ratios. This is exemplified in research which shows that the minimum sufficiency level for manganese in couch is normally 25 mg/kg. However, work in Florida in the United States revealed manganese deficiency in couch containing 30 to 40 mg/kg when the level of leaf tissue calcium exceeded 0.8 per cent.

Spot tests

These are useful for diagnosing micronutrient deficiencies and for assessing the effectiveness of a particular micronutrient fertilizer programme. The tests are done by applying the selected micronutrient dissolved in water, over a spot area of 1 to 2 m^2. Several areas of turf should be treated in this way. If there are to be any positive results they will be evident in about 1 to 2 weeks after application. It often occurs that visual results will be seen before laboratory analyses become available. Typical solutions used for spot tests are 5 g/L of iron sulphate (heptahydrate) and 4 g/L of manganese sulphate (monohydrate).

Soil tests

Soil tests for micronutrients is not recommended because of problems with the interpretation of the data. Soil tests are very successful for determining phosphorus and potassium levels and for pH. The pH can be used to formulate a suitable micronutrient fertilizer programme.

Foliar applications

Because high soil pH favours the precipitation of micronutrients rendering them unavailable to the plant, it is preferable to apply foliar sprays to correct deficiencies.

Recommended rates

- Manganese sulphate at 10 kg/ha dissolved in water and applied at 100 to 200 L/ha; and
- Iron sulphate at 25 kg/ha dissolved in water and applied at 100 to 200 L/ha.

It is essential that enough water is applied to provide a thorough covering of the leaves and that a wetting agent be used to ensure that the material adheres to the leaves. The sprays should be applied in late afternoon or when there are low evaporative conditions. Evening dew will prolong the time in which the material stays moist on the leaves. Do not spray if rain is expected. It has often been observed that, when a manganese deficiency is to be corrected, a spray of manganese and iron gives a better results than manganese alone. This is not true for a deficiency of iron alone and the iron spray should be applied by itself.

A greening of the turf should be seen within 2 to 3 days of application and should last for some 3 to 4 weeks. Nevertheless, repeat foliar applications will be needed because of the continual removal of the foliage during mowing.

Summary

- **The most commonly observed micronutrient deficiencies of turf grass on the sandy soils of the Plain are those of manganese and iron.**
- **Acute deficiency symptoms of manganese are often observed on kikuyu growing on alkaline soils.**
- **Most maintenance mixed fertilizers containing micronutrients are ineffective in correcting micronutrient deficiencies.**
- **Current micronutrient fertilizer programmes can be assessed by the use of visual observations, periodic tissue analyses and by spot tests.**
- **It is usually preferable to correct micronutrient deficiencies by the use of foliar applications.**

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TINS

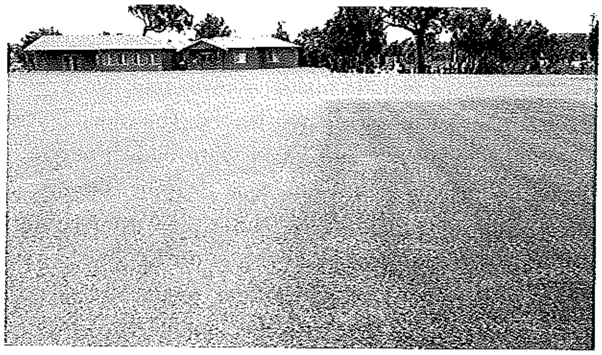
Nutrient deficiency symptoms

K.J. Johnston

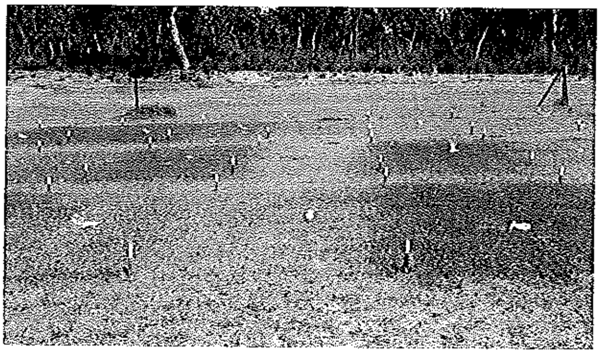
The visual symptoms of nutrient deficiencies in plants are often quite specific to a particular plant nutrient. With time, horticulturalists, farmers and turf managers become skilled at recognizing the deficiency symptoms associated with the major plant nutrient elements. It is with the minor or micronutrient deficiency symptoms that problems of identification often exist, especially if more than one nutrient deficiency is present. Complex deficiencies may occur giving unusual visual symptoms and it may happen that an apparent deficiency exists even when the particular element is present in the soil. Such is the nature of induced nutrient deficiencies or when plant nutrients are present in an unbalanced state.

Environmental stress may cause plants to develop unusual visual symptoms which may be wrongly identified at being caused by a nutrient deficiency. In addition, toxic nutrient affects are often difficult to determine, though toxicity usually results in a rapid and premature death of the plant.

Particular deficiency symptoms and their occurrence are described below.



Effect of a nitrogenous fertilizer applied to a nitrogen deficient Greenless Park couch turf. Dryandra Pendula Reserve, City of Stirling.



A nitrogen deficient kikuyu turf showing test plots to which a nitrogenous fertilizer has been applied at various rates. Highview Park, City of Wanneroo, 15/03/1995. This was the major kikuyu test site.

Nitrogen

Symptoms

As nitrogen deficiency develops the leaves become chlorotic which means that the colour changes from a normal bright green to a pale yellow-green. This chlorosis is caused by decreased chlorophyll production since nitrogen is an essential component of the chlorophyll molecule. The first visual symptoms of nitrogen deficiency usually appear on the lower or older leaves. The leaf colour then progressively changes to yellow and progresses to the growing point of the plant as the deficiency becomes more severe. The growth rate and density of the turf grass will decrease resulting in a weak turf of poor recuperative ability. Leaf size is markedly reduced. In couch grass, a distinctive symptom of nitrogen deficiency is the increased production of seed heads.

A deficiency of other nutrients may produce symptoms akin to those of nitrogen deficiency. Chloroses caused by deficiencies of iron, sulphur or manganese may initially look like that caused by a shortage of nitrogen so it is essential that the turf manager determine the cause of the chlorosis before applying a fertilizer treatment.

Occurrence

Very few soils have enough naturally existing nitrogen to maintain a turf grass of desired quality and recuperative ability throughout the year. Sites that are relatively new with only low levels of organic matter are very susceptible to nitrogen deficiency. Deficiencies are most marked at low temperatures, under waterlogged conditions when denitrification occurs and where the leaching of nutrients is high.

Phosphorus

Symptoms

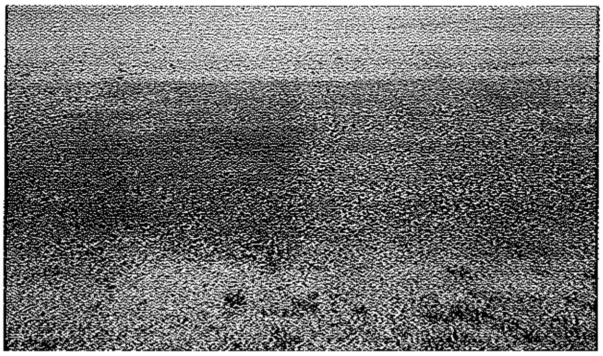
The typical symptoms of a phosphorus deficiency in the turf grasses include a slow growth rate; weak, stunted plants and dark green leaves. The older leaves eventually become a dull green with reddish-purple pigmentation along the leaf blade margins. Finally, the leaf tips turn reddish and this typical colour may then develop into streaks down the blade. Since phosphorus is fairly mobile in plants, such deficiency symptoms initially develop in the older leaves. Similar symptoms are seen in other grasses and pasture legumes.

Phosphorus deficiency symptoms are not as obvious on warm season grasses such as couch as they are on cool season grasses such as *Poa trivialis*. In kikuyu, the most obvious symptom, other than reduced growth, is the senescence or death of the older leaves. In couch, the onset of phosphorus deficiency is initially observed to be a dark purplish-green foliage which later changes to a pale green.

Occurrence

Deficiencies of phosphorus usually appear during turf grass establishment. This is because of the restricted root development of the seedlings or runners and the low phosphorus content of virgin soils. Heavily leached sandy soils with a low Phosphorus Retention Index (PRI) or higher PRI soils with a poor history of phosphorus fertilizer applications are particularly prone to causing phosphorus deficiency in turf grass. During spring, if root development is retarded, the grass may not be able to absorb enough phosphorus from the soil for good growth.

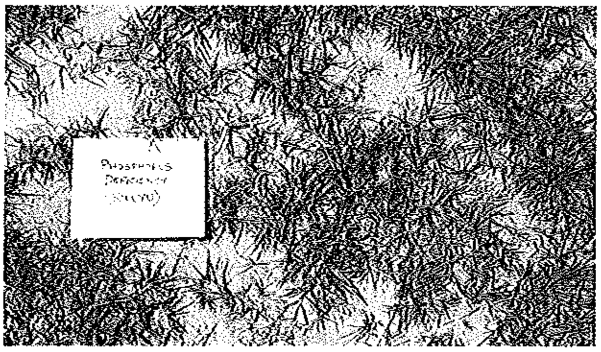
Phosphorus deficiency is common on calcareous sandy soils because of the reaction between the phosphorus and calcium carbonate which makes the phosphorus less available to the plant. On such sands, soil test estimates of plant available phosphorus may be misleading because of the presence of calcium carbonate. This means that a leaf tissue analysis may be required to determine the



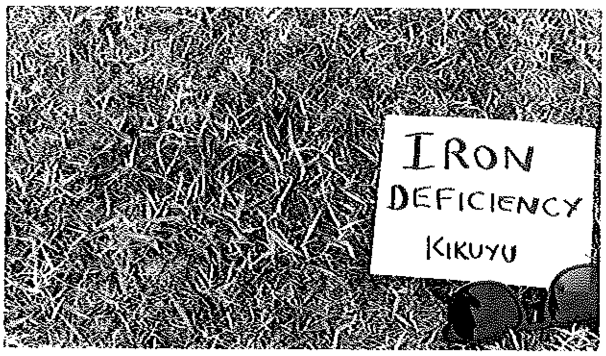
The effect of an application of phosphatic fertilizer to a severely P deficient sward of couch grass. Note the response to the P on the left of the photo, untreated on the right.

Similar responses as in above photo, but on a kikuyu turf. 03/05/1995.

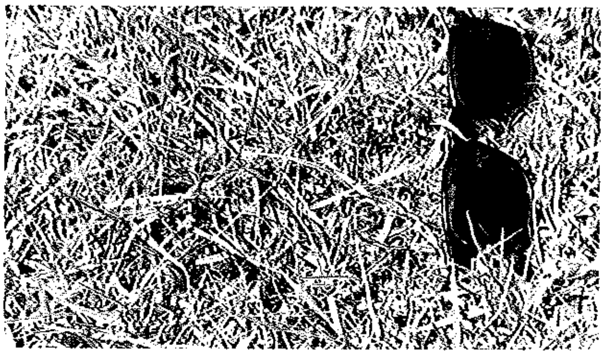
Typical phosphorus deficiency symptoms on Poa trivialis *at a reserve in Mirrabooka. 10/ 12/1993.*



Severe symptoms of a phosphorus deficiency in a kikuyu sward.

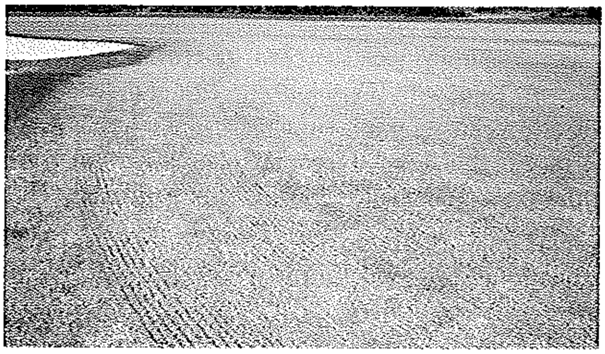


The typical affect of an iron deficiency on a kikuyu turf. Note how some of the leaves have turned white and the leaf death that has occurred. 03/05/1996.

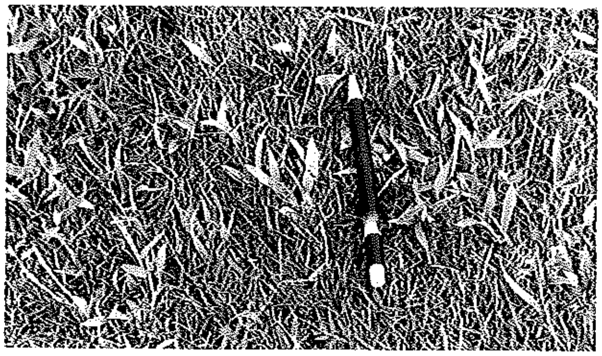


Manganese deficiency symptoms on kikuyu grass. Note the severe chlorosis and death of the leaves.

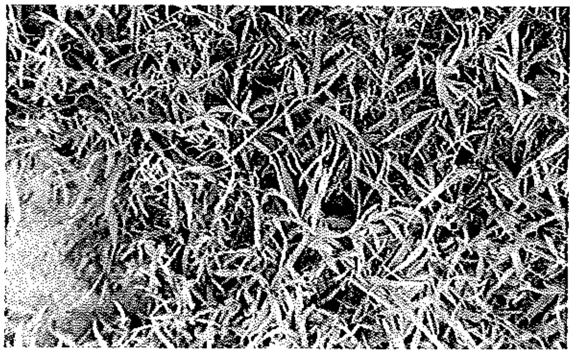
Severe iron deficiency on a couch grass turf.



Manganese deficiency symptoms on a couch grass turf. Note the blotchy appearance of the turf. Carramar Golf Course.



Crab grass showing typical iron deficiency symptoms at Dryandra Pendula Reserve. City of Stirling. Note the interveinal chlorosis. February, 1996.



Very severe manganese deficiency in a kikuyu turf at Mirror Park, Wanneroo. Note the chlorosis and ultimate death of the leaves.

system is poorly developed, the soil is poorly drained and during cold soil conditions. At a low soil pH, phosphorus may combine with iron to form insoluble iron phosphate which is unavailable to the plant. At a high soil pH, excessive phosphorus uptake by the turf may inactivate absorbed iron. For each unit increase in soil pH, there is a 100 fold decrease in the amount of soluble iron available to the plant. The symptoms are most severe during weather conditions of warm days and cool nights when root growth is insufficient to support shoot and leaf growth.

Manganese

Symptoms

A general yellowing of areas of turf, particularly on the youngest leaves is the usual manifestation of a manganese deficiency. This is because manganese is immobile within the plant once it becomes part of the cell physiology. Small, distinct necrotic leaf spots develop, leaf tips may turn grey or brown, droop and then wither. On closely mown turf, the leaves appear mottled or blotchy. There is little or no response to applications of nitrogenous fertilizer.

Occurrence

presence of calcium carbonate. This means that a leaf tissue analysis may be required to determine the actual amount of plant available phosphorus.

Potassium

Symptoms

Interveinal yellowing of the older leaves and rolling and burning of the leaf tip are the common symptoms of a potassium deficiency. As the deficiency progresses, the leaf veins appear yellow and the margins look scorched. The turf stands will become thin, with the spindly growth of individual plants. As potassium is a mobile element in plants it is readily translocated from the older leaves to the growing meristematic tissues if a shortage occurs.

In kikuyu, typical symptoms of potassium deficiency appear as tip burning and senescence of older leaves.

Occurrence

Potassium deficiencies are common in sandy soils with a low cation exchange capacity as it cannot be retained in such soils. The deficiency has been observed on couch at low levels of nitrogen nutrition. A low soil nitrogen status seems to interfere with the uptake of potassium by the plant.

Research results from the TINS experiments showed that kikuyu was very efficient at obtaining and using potassium from soils low in this important element. Because of this, potassium deficiency in kikuyu is unlikely to be a problem, particularly when the grass clippings are returned to the turf.

Calcium

Symptoms

The typical deficiency symptoms associated with a shortage of calcium include a distortion of the young leaves; leaves that turn reddish-brown along the leaf margin before becoming rose-red, and leaf tips and margins that wither and die. The roots become short and bunched.

Occurrence

Calcium deficiencies are most common on sandy soils; soils that are extremely acidic, which is those with a pH of < 5 .0, or soils saturated with sodium.

Magnesium

Symptoms

In magnesium deficiency, there is general loss of green in the young leaves while the veins remain green. The older leaf margins turn a blotchy cherry-red with stripes of light yellow or white between the parallel veins. Leaf necrosis eventually develops.

Occurrence

A deficiency of magnesium is most common in sandy soils with a low CEC or in soils with a very high pH level. The deficiency is aggravated when the turf clippings are continually removed.

Sulphur

Symptoms

The initial indication of a sulphur deficiency is that the leaves become light yellow-green with the yellowing being most pronounced on the younger leaves. The older leaves then become pale and then turn yellowish-green in the interveinal areas. The leaf tips become scorched along the margins.

Occurrence

Deficiencies may occur where the grass clippings are removed, the turf is excessively watered and where sandy soils predominate.

Iron

Symptoms

With a deficiency of iron, a chlorosis develops which is somewhat similar to that of a nitrogen deficiency except that the chlorosis is interveinal and first occurs in the youngest leaves. This is because iron is immobile in the plant so that the older leaves only become affected later. Ultimately, leaves deficient in iron turn white. The iron chlorosis tends to be in randomly scattered spots, creating a mottled appearance. It looks most severe when the turf is closely mowed.

Occurrence

Deficiencies of iron occur when the soil pH is > 7.0 and there is an excess of either calcium, zinc, manganese, phosphorus or copper in the soil and / or excessive bicarbonate levels in the irrigation water.

Occurrence

Manganese deficiency is common in alkaline soils high in calcium. For each increase in soil pH, there is a 100 fold decrease in the amount of soluble plant available manganese. Conditions of low temperatures and poor soil drainage are conducive to the development of manganese deficiency. High soil levels of iron; copper; zinc; potassium and sodium can reduce the uptake of manganese by the plant. The iron to manganese ratio in the leaf tissue should be at least 2: 1. Adjusting the soil pH to < 7.0 usually reduces the incidence of manganese deficiency.

Zinc

Symptoms

The typical symptoms of zinc deficiency are the development of mottled and chlorotic leaves; rolled and thin leaf blades; stunted growth and dark leaves which appear desiccated, starting with the youngest leaves. In severe cases the leaves finally turn white.

Occurrence

Because alkaline soils decrease the solubility and availability of zinc, deficiencies are most common in such soils. Zinc deficiencies may be induced by excessive soil levels of copper; iron; manganese; nitrogen and phosphorus and during periods of high soil moisture. The problem is exacerbated during periods of low light intensity which reduces the uptake of zinc by the roots.

Copper

Symptoms

A yellowing and chlorosis of the leaf margins are the first typical symptoms of a copper deficiency. The leaf tips initially turn bluish, wither and droop. They eventually turn yellow and die. The youngest leaves become light green and necrotic. The plants become dwarfed with inward rolling of the leaves which turn blue-green. The symptoms progress from the leaf tips to the base of the plant.

Occurrence

Many soils are low in copper and excessive soil levels of iron; nitrogen; phosphorus and zinc coupled with a high soil pH encourage the development of a copper deficiency.

Irrigation

TINS

Soil and water

K.J. JOHNSTON

Adapted from R.N. Carrow (1985), in Practicum 8, Soil/water relationships in turf grass. In: Gibeault V.A. and Cockeram, S.T. (Eds) 1985, Turf grass water conservation, University of California, Riverside, Division of Agriculture and Natural Resources, Publication 21405.

The fundamental resource

Soil and water are the two resources fundamental for the growth of turf grass. Like most other plants, the turf grasses require light; oxygen; carbon dioxide; water; mechanical support and nutrients. With the exception of light, and oxygen and carbon dioxide from the air, soil is involved in supplying the essentials for plant life. In addition, the presence of a soil atmosphere is essential for turf grass growth.

Soil may be viewed as a three-phase system comprising solids (the soil matrix), liquids (the soil water solution) and gases (the soil atmosphere). Each phase comprises the following;

- Solids - minerals and organic matter
- Liquids - water plus dissolved substances
- Gases - carbon dioxide, oxygen and other gases

While the soil matrix may change slowly over time, the liquid and gaseous components are in dynamic flux and may change rapidly over time and space. Extremes in the latter two phases such as waterlogging and dry soils markedly affect the growth of turf grass. Figure 1.

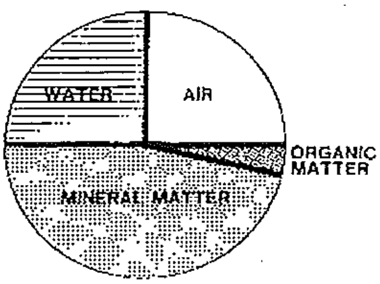


Figure 1. Illustration of the three phases of a typical loam soil. The approximate volume of each phase when the soil is at field capacity is (a) solids 50 per cent, composed of 47 per cent mineral matter plus 3 per cent organic matter; (b) liquids 25 per cent, and (c) gases or air at 25 per cent.

The chemical, biological and physical properties of soils are those characteristics which most affect plant growth. The chemical and biological properties are shown in Table 1.

Colloidal particles of clay and organic matter have a high surface area. Sandy soils with low levels of organic matter have a low colloid content.

Cation Exchange Capacity (CEC)

Colloidal particles have a negative electrical charge. These particles attract and retain cations which are positively charged and stops them from being leached e.g. K^+ and Ca^{++}.

These cations are then available to be taken up by the plant roots. Sandy soils, low in organic matter have a low CEC. (see topic on 'soil chemistry')

Soil reaction or pH

Soil pH refers to the hydrogen ion concentration in the soil solution. The pH affects the solubilities of the soil mineral fraction which contains many types of chemical compounds. Most soils have a pH range of from 4.0 to 8.5. Depending upon the pH, the various essential nutrients become either more or less available for absorption by the roots. See graph 1 on nutrient availability as influenced by soil pH.

Biological

Soil organisms

Soils contain many genera and species of micro-organisms such as bacteria; fungi; algae; actinomycetes and protozoa. These organisms are involved in many important processes such as the transformation of nitrogen; sulphur; phosphorus and iron in soils to plant usable forms. They contribute to the soil organic matter and to the decomposition of soil organic matter. Most soil micro-organisms are beneficial to plants though some may result in soil

Table 1. Soil chemical and biological properties

Soil property	Comments
Chemical properties	
Soil colloids	Colloidal particles of clay and organic matter have very high surface area. Unless these particles are flocculated and aggregated; the soil will have poor aeration and drainage. A clay or organic soil has a higher colloid content than a sandy soil.
Cation exchange capacity (CEC)	Colloidal particles have negative electrical charges which attract and retain cations (positively charged ions -K^+, Ca^{++}) from leaching. These cations are available for plant uptake. If the CEC has a high percentage of Na^+, the soil will become dispersed and have very poor physical properties (i.e. sodic soil).
Soil reaction	The soil mineral fraction contains many different chemical compounds which exhibit different solubilities depending on soil pH. Soil reaction (i.e. soil pH) refers to the hydrogen ion activity in the soil solution. A neutral soil has a pH of 7.0; an acidic soil is <7.0, and an alkaline is >7.0. Soils generally range in reaction from pH 4.5 to 8.2. Depending on the pH, various essential nutrients become more or less available for plant uptake.
Biological properties	
Soil organisms	Soil contains many micro-organisms—bacteria, fungi, algae, actinomycetes, and protozoa. These micro-organisms are involved in many important processes such as: transformations of nitrogen, sulphur, phosphorus, and iron in soils; contribution to soil organic matter; and decomposition of soil organic matter. While most micro-organisms are very beneficial, some may cause soil borne diseases. Macro-organisms (larger) also exist, such as nematodes, ants, moles, worms, and insects. These may at times cause problems on turf grasses.
Soil organic matter	The transformations of organic matter in soils are complex. Basically, raw, undecomposed matter organic matter is continually broken down (decomposed) into more and more complex organic compounds. During this process micro-organisms derive energy and food. The resulting material is termed humus, and because of its complex nature, humus is resistant to further decomposition. Humus aids in the formation of stable soil aggregates, which are essential for structure formation of heavy soils. Also, humus contains many chemical functional groups that contribute to soil CEC. During decomposition, many nutrients are made available for plant uptake.

micro-organisms are beneficial to plants though some may result in soil borne diseases.

Yet larger organisms may exist in vast numbers such as nematodes; ants; worms and insects. There are also burrowing animals of yet larger size that may live in burrows such as rabbits. Occasionally, the larger fauna may cause damage to areas of turf grass.

Soil organic matter

The biodegradation of soil organic matter is a complex process. The original undecomposed organic matter is continually being broken down or decomposed into more complex organic compounds. From this process, micro-organisms derive food and energy. The result of this decomposition is humus, which, because of its complex nature, is resistant to further decomposition. Humus contains many functional chemical groups which contribute to the soil CEC. It is during the process of decomposition that many plant nutrients are rendered available for plant uptake.

Physical properties of soil

The physical properties of soils include its texture; structure; bulk density and porosity. These interact with the other properties of soils.

Texture

The solid phase of soil does not change appreciably over time. Soils require hundreds to thousands of years to develop. Soil particles comprise primary and secondary minerals, the latter being formed after the primary minerals have been decomposed by weathering. Examples of such secondary minerals are the amorphous mineral compounds of aluminium oxide and iron oxide. Humus contributes to the texture of the soil.

Soil texture is an important property of soils. The soil particles are classified into three textural fractions according to size - sand; silt and clay. If a sand contains > 20 per cent by weight of organic matter it is classed as an organic soil. Each textural group is classified as shown in Table 2.

Table 2. Textural fractions of soil - United States Department of Agriculture

Classification	Diameter mm	Surface area per 1g (cm²)	Type of mineral
Sand			Primary
Very coarse sand	2.00 - 1.00	11	
Coarse sand	1.00 - 0.50	23	
Medium sand	0.50 - 0.25	45	
Fine sand	0.25 - 0.10	91	
Very fine sand	0.10 - 0.05	227	
Silt	0.05 - 0.002	454	Primary
Clay	< 0.002	8,000,000	Primary/secondary

The sand and silt fractions are relatively chemically inert because they do not have a cation exchange capacity. It is these fractions which form the main matrix or skeleton of the soil. They have a great influence on the retention of soil water and in soil aeration. Because the clay fraction has an exchange capacity it has a major influence on the nutrient status of the soil. Clays attract and hold water by adhesion and fill the voids between the sand - silt matrix.

Because of this, clays have an important influence in the soil moisture status and in soil aeration.

By using the weight ratios of the sand, silt and clay fractions, soils may be assigned to one of 12 textural classes. (Figure 2.) Most of the sandy soils of the Swan Coastal Plain contain about 1 to 2 per cent of clay plus silt and are thus placed in the textural class of sand. Knowledge about the particular textural class of a soil provides inferred information as to the soils' water holding capacity; water infiltration rate; aeration status and nutrient retention capabilities.

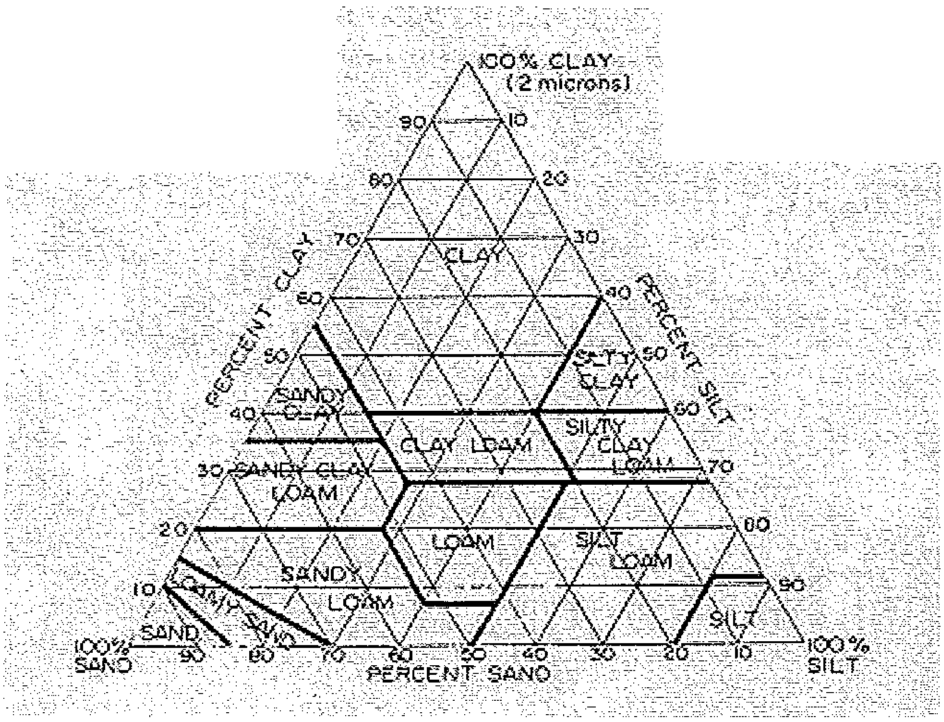


Figure 2. The soil textural triangle.

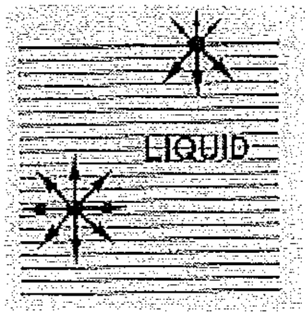


Figure 3. Illustration of surface tension in liquid water.

Structure

The individual particles of sand, silt or clay may be so organized and arranged in the soil as to form a soil structure. In soils with an appreciable amount of silt and clay, structure is most important since an open structure opens the soil for better air movement; drainage and root growth. Three categories of structure are identified for practical purposes.

- Single grained - This is typical of the sands where the individual particles remain unattached to each other.
- Massive - A typical example is a dispersed or compacted clay where the soil acts as one large mass.
- Aggregated - The most desirable soil structure. The soil particles are arranged into small, reasonably stable aggregates.

Bulk density and porosity

The density of a soil is usually termed bulk density and is measured as the mass of soil per unit volume. Bulk density includes the solid fraction and pore space of a soil. The pore space is the amount of space or voids within a soil which contain water or air. The higher the bulk density, the lower the total pore space. An increase in bulk density is seen where soils are compacted by machinery or grazing animals. In a well aggregated clay, bulk density usually is about 1.1 g / cm^3. A fine sand has a bulk density of about 1.7 g/ cm^3.

A soil contains pores of varying size. Large pores are essential for root growth, air movement and water drainage. Small pores are required for the retention of water. Sandy soils consist mainly of large pores.

Soil air

The soil air status is directly influenced by pore size, and the plant roots and micro-organisms use soil oxygen for respiration. At the same time, they give off carbon dioxide and other gases. This means that the soil atmosphere may differ in composition to the above ground atmosphere. If adequate gas exchange does not occur via diffusion, root growth will decline and the population and diversity of the micro-organisms will be affected.

The diffusion of gases into the soil is adversely affected by waterlogging and soil compaction. Waterlogging is usually the result of poor drainage; a high water table; excessive irrigation or rain.

Soil temperature

Because plant growth is directly influenced by temperature, it is an important physical property of soils. Temperature also affects the activity of the microflora and fauna, and has some impact on water movement. Solar radiation is the main source of heat in soils. A high surface soil temperature is harmful to the growth of turf grass roots. Moderation of surface temperatures, as well as temperatures at depth, are achieved by a dense turf cover, the maintenance of some thatch and by a moist soil.

Soil water

Electrical properties

Although water has an apparently simple molecular structure of H_2O, the atoms are arranged in a somewhat triangular configuration. Thus, while the whole molecule is electrically neutral, the arrangement of the atoms result in the electrons being spacially separated creating an electrical dipole. The water molecule has both a negative and a positive pole. Because of the existence of these electrical poles, water molecules are attracted to other water molecules by cohesion. Water molecules are also attracted to the electrically charged portion of soil particles or chemical ions in the soil solution by adhesion. Hydrogen bonding occurs when there is a weak mutual attraction between the positive hydrogen atoms of one water molecule with the negatively charged oxygen atom of another water molecule.

Surface tension

This property of water results from its polarity. A water molecule within a mass of water experiences electrical forces from all directions. A water molecule at the surface of the liquid has greater forces of attraction from the liquid phase than it has from the gaseous air phase. The greater tension from the liquid phase creates a water surface which acts as a virtual film. Figure 3.

It is the combination of cohesion, adhesion and surface tension which controls water movement and retention in soils and in plants. Without such forces, all water would drain away from the surface areas of the soil and be unavailable to plants unless it was held in place by a physical barrier. In some cases, favourable soil root zones for turf have been made to take advantage of the water properties of adhesion and cohesion. The perched water tables that have been constructed at the Western Australian Cricket Association cricket ground in Perth and the football ground at Subiaco Oval are such examples.

Soil - water relationships

A soil is saturated when all the pore space is filled with water. Drainage starts because of gravity, with the largest pores rapidly losing the water they held. Within sands, drainage decreases to a slow rate within one to two hours, but may take two to three days for a heavy clay. This level of soil water content is often termed the field capacity (Note: The classification of soils as either light or heavy is an arbitrary one based upon the relative amounts of sand or clay in the soil. Sandy soils are light and clay soils are heavy). Field capacity is not an exact characteristic of soils. It is an approximation of soil - water content after the initial rapid drainage, but water redistribution continues after the initial phase is over. In turf grass areas, where irrigations are often frequent, field capacity is a useful concept to apply since water redistribution will be minimal.

After the phase of rapid drainage, water is held in the soil by adhesion to the soil particles and solutes (ions) in the soil. Cohesion is likewise important in the retention of water. This may be envisaged as layers of water molecules around a soil particle or solute with the inner layers being tightly held by adhesion and the outer layers less tightly held by cohesion which is the attraction between water molecules.

Plants easily extract water from the soil when it is at near field capacity. As the water is extracted it becomes increasingly more difficult for the plant to obtain water because it becomes more firmly held by the forces of attraction exerted by the soil particles and solutes. Eventually, the soil water is held so firmly that the plant cannot extract enough to survive. The point when this is reached and the plant dies, it is termed the permanent wilting point.

The water release characteristics of the three main coastal dune systems, has been studied by H. Cochran at UWA. His results are illustrated in Figure 4.

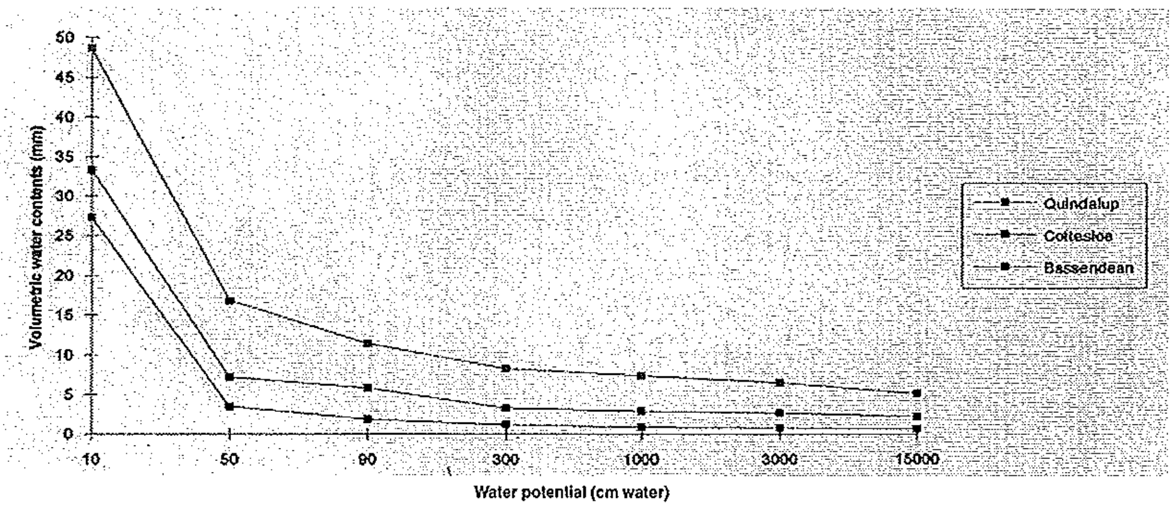
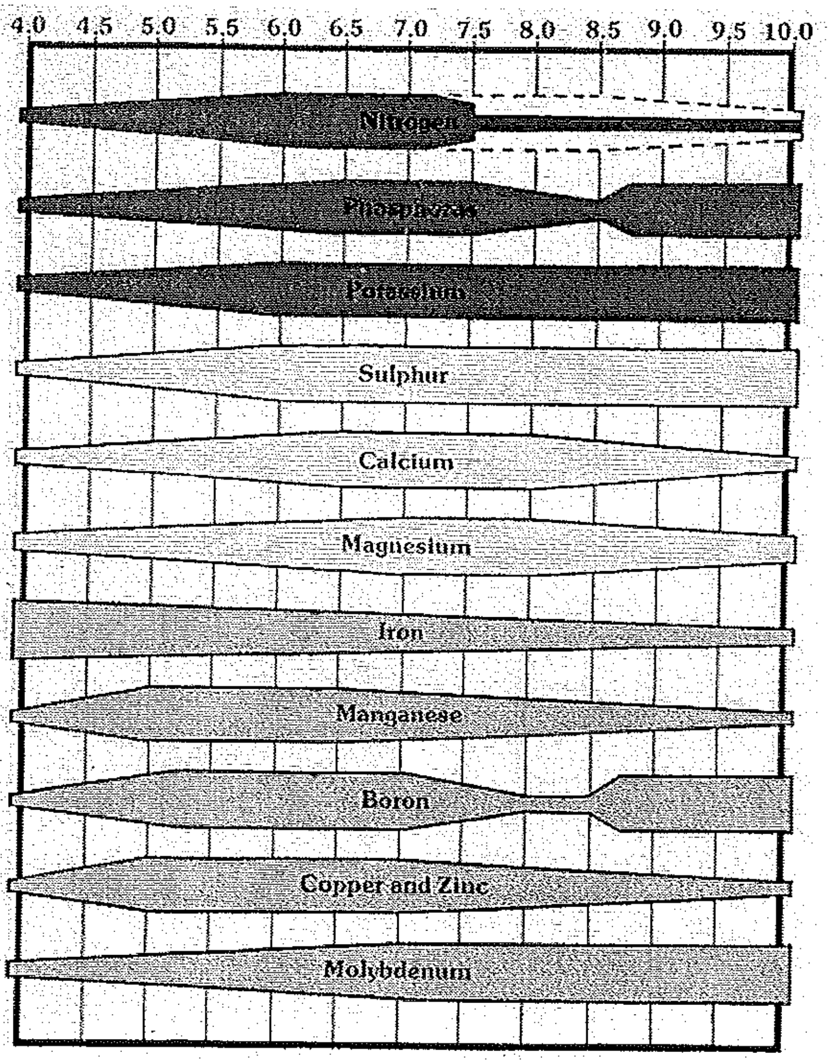


Figure 4. Water release characteristics for typcial Quindalup, Cottesloe and Bassendean sands (subsoils).



Graph 1. Nutrient availability as influenced by soil pH.

The plant available water

The moisture held by the soil between field capacity and the permanent wilting point is the plant available water. The main influence on the quantity of plant available water is soil texture. For example, sands have the lowest contents of plant available water. The measurement of plant available water is useful in the determination of how much water is available for extraction by the plant. A typical sand of the coastal dunes of the Swan Coastal Plain has a volumetric plant available water holding capacity of about 4.0 cm^3 of water /100 cm^3 of soil. In the first 30 cm of such a soil there is about 12 mm of plant available water.

To maintain a good quality turf and to reduce the incidence of dry patch, the turf should be irrigated before the permanent wilting stage is reached. This means that not all the plant available water is actually available to the plant. Good quality turf is often irrigated when between 25 to 50 per cent of the plant available water has been used.

When a soil is moist, the water films around the soil particles are several layers thick with the outer layers being held by relatively weak forces. Upon drying, the water films become thinner with the inner layers held by strong adhesive forces. This likewise means that not all the soil water is equally available to the plant.

Further reading

Carrow, R.N. (1985). Soil/water relationships in turf grass. *In*: Practicum 8. V.A. Gibeault and S.T. Cockeram Eds. Turf grass water conservation. University of California, Riverside, Division of Agriculture and Natural Resources, Publication 21405.

The water budget

K.J. Johnston

Adapted from a paper by R.N. Carrow, (1985), In: *Practicum 8. Soil/water relationships in turf grass pp 87-103 in Gibeault, V.A. and Cockeram, S.T. (Eds) 1985, Turf grass water conservation, University of California, Riverside, Division of Agriculture and Natural Resources, Publication 21405.*

Water budget concept

Turf water management may be considered as a water budget, similar to a bank account system where there are inputs and outputs (Figure 1). By visualizing the use of water in this way, the addition of water is an input and losses of water from the plant and soil are outputs. At any one time the plant has available to it certain reserves of available water. The objective of the manager of turf grass is to maximize inputs, minimize outputs and maintain large reserves.

The typical inputs of water are by irrigation; rain; dew and the rise of water from below the root zone by capillary action. During summer, the main water input is via irrigation followed by whatever falls as rain. On the sandy soils of the Swan Coastal Plain where the water table is >1 m below the soil surface, capillary movement to the grass roots from below the root zone is negligible. On sports fields built upon a perched water table, drainage is impeded by the change in soil texture and this results in more water being retained in the soil. This water then provides some of the plant's water needs by capillary rise into the root zone.

Outputs of water are losses caused by run-off; leaching beyond the root zone; evaporation and leaf transpiration. Usually, run-off is not a problem on sandy soils. However, on sloping sites that have been heavily compacted or have excess thatch, surface flows may occur. Often these problems can be corrected by cultivation; thatch control or by reducing the water precipitation rates of the sprinkler system.

Water movements below the root zone is most significant and is often unrecognized on the sandy soils of the Plain. Those irrigators, whose watering practice is based upon the needs of the driest turf areas to maintain an even appearance and to prevent dry patch, over water other areas. To reduce losses caused by leaching, irrigators must know the effective depth of the root zone. They must also know the depth to which a specific quantity of water will penetrate in a given time. Well designed irrigation systems apply water uniformly and thus reduce losses caused by leaching. Similar turf areas should be 'zoned' and watered in the same manner. An example of this is that sloping sites should be watered at the same time or in the same way. Such methods reduce water losses.

Evaporation is the vaporization of water from the leaf or soil surface as water vapour. In turf grass areas, this form of water loss is usually from the moist surfaces of the leaves. Evaporation can have a beneficial effect through the cooling of the leaves, but excessive evaporation is wasteful. One method used to reduce water loss by evaporation is to reduce the frequency of irrigation. Immediately after an irrigation event, the evaporation rate from the soil and leaves is very high, but as the surfaces dry the rate of water loss rapidly decreases. Another method to reduce evaporative losses is to maintain a dense turf cover to shade the soil surface and to avoid day time irrigation.

Transpiration is the vaporization of water inside the leaf during its biological processes, which must then diffuse out through the open stomata. During this process, heat is removed from the plant. In many cases, more than 90 per cent of the water taken in by the turf grass plant is used for cooling purposes. During hot conditions, transpiration is a desirable use of water. However, if excessive transpiration occurs, water may be wasted. Over watering of turf promotes excessive transpiration. Plant species vary in their ability to control water loss by transpiration, but most turf grass species do not have effective control mechanisms during either hot or drought conditions.

The reserves of plant available water at any one time depends upon soil texture and the extent of the plants root system (Figure 1). Over time, irrigation and rain are the sources of this reserve water. A sand will not retain as much available water as a loam or clay. Turf managers can markedly improve the water reserve by developing turf with a good, deep extensive root system. This requires careful mowing; irrigation; the use of nitrogenous fertilizers; the control of root feeding insects; the reduction of toxic substances such as salts and herbicides and, where necessary, cultivation.

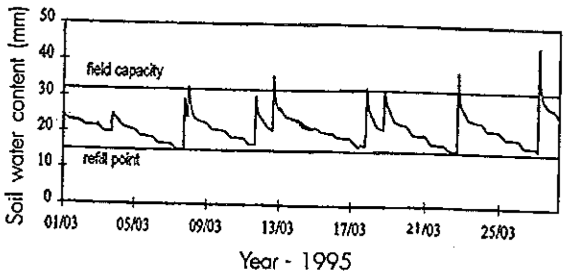


Figure 2. Graph of water content within the turf grass root zone during the TINS research project, City of Stirling 1995,as monitored by the EnvironSCAN® equipment.

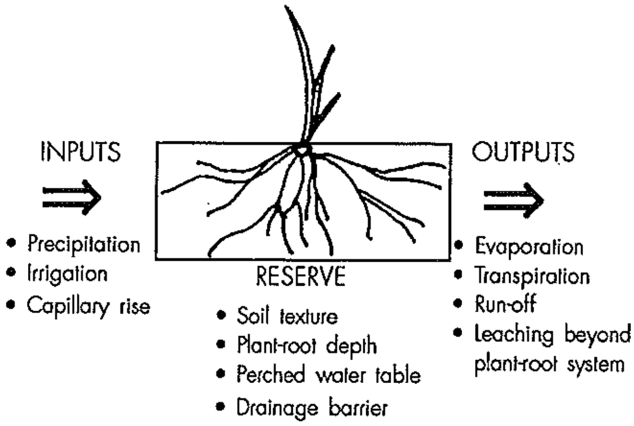


Figure 1. Water budget concept for turf grass water management.

Summary

- The water budget concept may be used by turf managers to visualize the use of water and then adopt appropriate water management strategies.
- The objective of the water budget is to conserve water while maintaining turf of the required quality.
- The water budget concept lends itself for use together with modern water monitoring systems.

Application of a water budget

The conceptual basis of the water budget technique was that used for the EnvironSCAN® soil moisture monitoring system which was used in research work done as part of the TINS project (see: Irrigation management for turf grass). Data from the soil moisture sensors was used to determine field capacity and the refill point (see Figure 2). The differences in water content between field capacity and the refill point is considered as the total water reserve. An irrigation event was not scheduled until the water reserve was almost depleted and it was then fully replenished. This method minimizes luxury water consumption by the turf grass; reduces evaporation; minimizes the water movement below the root zone and increases the likelihood of making the maximum use of any rain.

Further reading

Carrow, R.N. .(1985). Soil/water relationships in turf grass. *In:* Turf grass water conservation; Eds: V.A. Gibeault and S.T. Cockeram. Publication 21405, University of California.

TINS

Factors affecting water management

K.J. JOHNSTON

Adapted from R.N. Carrow (1985), in Practicum 8, Soil/water relationships in turf grass. In: Gibeault V.A. and Cockeram, S.T. (Eds) 1985, Turf grass water conservation, University of California, Riverside, Division of Agriculture and Natural Resources, Publication 21405

Characteristics of soils

Because most land plants obtain water directly from the soil, it is from the soil that water conservation must start. Soils influence water movement and retention. An understanding of some of the physical and biological properties of soils is a necessary basis for effective water management.

Water holding capacity

Soils differ as to their total water holding capacity and plant available water content which are not the same determination of soil water. (Table 1). Soil texture is the most important factor determining water holding capacity. Loams have the most plant available water (Table 1).

Pore size

The space between the soil particles or pore size is critical for water storage. Sands have few small pores for water retention, whereas clays have a high percentage of small pores. However, water in many clays is held too tightly for it to be taken up by the plant.

Soil amendments

Sometimes sandy soils are amended with a soil containing clay or silt to enhance water holding capacity. Two commercial amendments used successfully on the sands of the Swan Coastal Plain are fly ash and Alkaloam. Fly ash is the fine, grey, silty like material that is recovered from the flue gasses of coal fired power stations. The addition of 100 t/ha of fly ash can double the amount of water held in the soil and increases the water retention time of a sandy soil by as much as seven days. It also overcomes any water repellency in the soil. Alkaloam, formerly called red mud, is the residue left over after dissolving out the alumina in bauxite with caustic soda (sodium hydroxide). When Alkaloam is used at rates over 200 t/ha there is enough fine material to overcome water repellency and improve water holding capacity.

Table 1. The totals of plant available and unavailable water holding capacities for different soil texture classes.

Soil	Water holding capacity mm / 1 metre of soil depth		
texture	Total	Available (1)	Unavailable (2)
Sand	5 - 14	3 - 8	2 - 6
Sandy loam	14 - 21	7 - 10	7 - 11
Loam	21 - 31	10 - 15	11 - 16
Silt loam	31 - 36	15 - 18	16 - 18
Clay loam	32 - 38	14 - 16	18 - 22
Clay	35 - 38	14 - 15	31 - 23

(1) *Amount of water available for plant uptake*
(2) *Amount of water unavailable for plant uptake*

Organic matter

The water holding capacity of sands is improved by the addition of organic matter. A well decomposed organic amendment such as peat is usually added at the rate of 5 to 15 per cent by volume of soil. Dynamic Lifter™ or Organic 2000 Turf Starter™ are not classified as well decomposed organic amendments because they break down rapidly in the soil to supply nutrients. They are classified as organic fertilizers. Too much organic matter may be detrimental as it may reduce soil aeration and may lead to excessive water retention in the organic matter. This would be an unlikely situation on our sandy soils.

Use of a perched water table

Soil water content may be controlled by methods which maintain the water table in the surface 30 to 60 cm of the soil profile. A construction method which is used is that of the establishment of a perched water table. This technique involves the disruption of internal water drainage which has the effect of retaining water above the site of disruption. The capillary rise of water from the perched water table provides some of the water needs of the turf grass. To construct a standard perched water table, a medium to coarse sand is placed over a layer of gravel. This creates a distinct textual change with six to nine times the difference in soil particle size diameter. Water flow takes place through the unsaturated sand. Water does not enter the gravel because of the poor water film contact with the gravel. A small saturated zone develops above this interface and drainage does not occur until the saturated zone attains sufficient depth to break the surface tension and initiate a saturated soil water flow.

Water availability

Total water content is not a good measure of plant available water. Because plants must compete for soil water with the forces of adhesion and cohesion within the soil matrix and for solutes, water availability is determined by the water potential or energy status which exists.

The relationship between the soil water potential and the volumetric water content is shown in Figures 1 and 2 which illustrates a 'Water characteristic curve" for a typical coastal sand. In this case a Rocla sand plus or minus a peat amendment was studied. (Note: This is sand mined from the Rocla Quarry Products sand pit at Gnangara) The shape of the curves are similar, but the quantity of water retained at a particular potential varies as to whether the soil had received peat or no peat. The water characteristic curve for both treatments show the rapid water drainage at high matrix potentials followed by very little water loss at the lower potentials. The interpretation of these water characteristic curves explains why turf swards on sandy soils may exhibit rapid wilting.

Field capacity for the Rocla sand without peat was 3.4 per cent and for the sand with peat was 7.7 per cent. The field capacity is the soil water content after the water has finished draining away expressed as a percentage of the soil volume. The permanent wilting point values for the Rocla sand without peat was 0.5 per cent and for the sand amended with 20 per cent peat was 2.0 per cent. The permanent wilting point is defined as that water content of the soil when the plant is unable to extract more water and thus dies. It is expressed as a percentage of the soil volume similar to field capacity. The information in Figure 1 shows that the sand to which peat had been added retains a small amount of water which is not available for plant use.

The plant available water capacity may be calculated from the field capacity and permanent wilting point values. Plant available water capacity is defined as the volume of water held in the soil between the field capacity and the permanent wilting point expressed in millimetres of water per metre depth of soil. It was found that, on the Rocla sand, the addition of 20 per cent by volume of peat to the sand almost doubled the plant available water capacity for the sand by raising the plant available water from 29 to 57 mm. Even so, 57 mm/1 m of soil a very low value and emphasises the problems associated with water management on coastal sandy soils. In sands, most of the soil pores are large and water drains away between pressures of 0 to -10 kilopascals(kPa). Beyond this point, the small surface areas of the sand particles result in little water retention.

Infiltration

Infiltration is the movement of water into the soil and this means that surface conditions of the soil are of prime importance. Factors which influence water infiltration are soil texture; soil structure; slope and soil water content. Typical coastal sands of the Swan Coastal Plain may have infiltration rates > 500 mm/h, while clay soils are often < 2 mm/h. A sloping surface will result in a much lower infiltration rate which complicates irrigation zoning

Matric potential - kPa	per cent gravimetric moisture content	per cent volumetric moisture content
0.1	21.49	36.10
1	17.33	29.12
4	2.06	3.45
9	0.74	1.24
100	0.52	0.87
300	0.40	0.67
1500	0.32	0.53

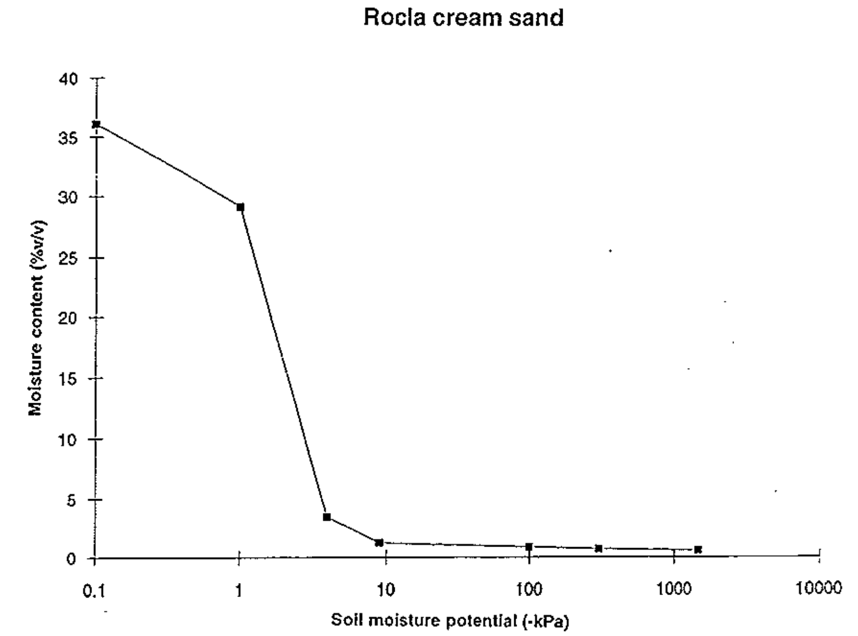


Figure 1. Water characteristic curve. Graph of soil moisture contents and soil moisture capacity for Rocla cream sand.

Matric potential - kPa	per cent gravimetric moisture content	per cent volumetric moisture content
0.1	34.95	50.33
1	28.50	41.04
4	5.36	7.72
9	3.59	5.16
100	2.88	4.15
300	1.90	2.73
1500	1.40	2.01

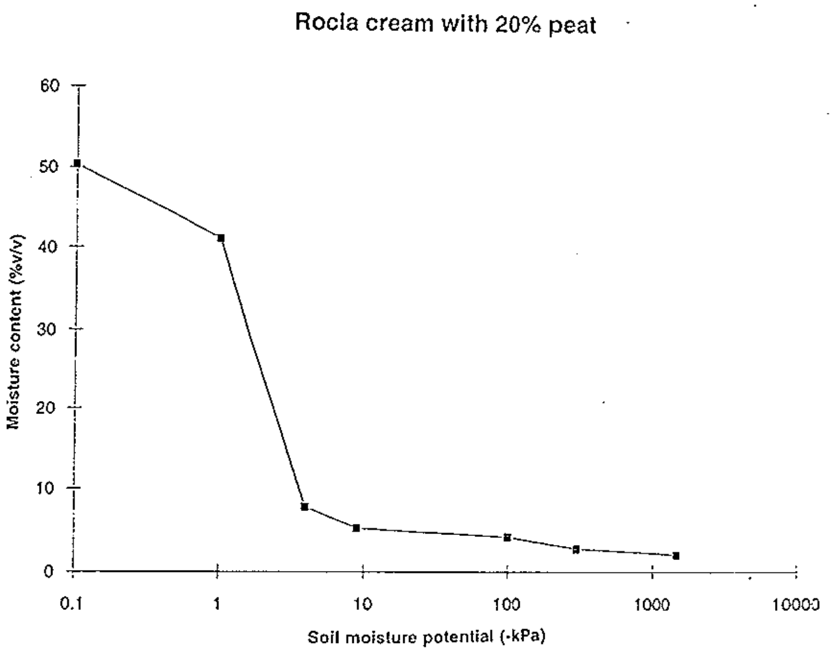


Figure 2. Water characteristic curve. Graph of soil moisture contents and soil moisture potentials for Rocla cream sand plus 20 per cent peat.

and water scheduling. Thatch may reduce infiltration if it becomes naturally hydrophobic (water repellent). Turf managers often observe hydrophobic sands with low infiltration rates This is caused by the deposition of organic coatings on the sand particles which repel water. On many long established turf sites in the Perth area it has been noted that accumulated organic matter has lead to the clogging of the large pores between the sand particles. This problem is accentuated by heavy turf wear and compaction from winter sport, and this results in a serious decline in infiltration rates.

On soils with unfavourable infiltration rates there are two techniques which may be used to overcome the problem. The first is cultivation which can be very beneficial. The second method is by coring or slicing affected areas. This is an effective technique which may need to be done frequently on areas of high traffic.

If hydrophobic sand is the cause of poor water infiltration, it may be beneficial to use a wetting agent to wet the soil surface. Such wetting agents also enhance water infiltration through a hydrophobic thatch. Within about 15 to 20 minutes after a light watering used as a pre-irrigation cycle, the thatch will moisten sufficiently to allow for a heavier irrigation. If thatch accumulation is the main cause of low water infiltration, it will be necessary to remove the thatch.

Percolation

Percolation is defined as the internal drainage of water within the soil. Water movement in the soil may be either a saturated flow in which all the soil pores are filled with water, or an unsaturated flow in which some of the soil pores contain air.

Hydraulic water conductivity is not a static value, but varies with soil water content. The hydraulic water conductivity is greatest when the soil is saturated and lower in unsaturated soils. The main reason for a reduction in hydraulic conductivity in unsaturated soils is the decrease in cross sectional area for liquid flow as the water drains away from the large pores. The drier the soil becomes, the less water redistribution occurs.

In sands, saturated water flows are common because of the existence of many large soil pores. However, in a clay soil, the number of saturated water flows is low because few large soil pores exist. In this case, most water movement is through water films. Saturated water flow is a feature of the larger soil pores while an unsaturated water flow is water movement in the water films around and between the soil particles. As the soil dries, the water films around the soil particles become thinner and less continuous so that the flow rate is reduced. Because soils with fine pores offer a high resistance to water flow, they have low unsaturated flow rates. Likewise, unsaturated water flow in sands is very slow because there are few water films and fewer points of contact to maintain water continuity. The direction of water flow is always from the moist to the driest area.

The rate of internal drainage in sandy soils can be reduced by the addition of either mineral or organic soil amendments. This will be beneficial on new sites where the leaching of plant nutrients is likely to be high.

Layered soils

Soil layering is a common occurrence under turf grass swards and is of two types.

- Thin layers of soil that differ in physical properties from the overlying or underlying soil.
- Thick layers of soil where the profile consists of distinctly different soils. An example of this would be where there is a layer of coffee rock beneath a layer of sand.

The most common causes of the formation of thin layered soils are: a) poor topdressing where the topdressing mix contains an excessive quantity of fine particles: b) the use of instant turf where the soil contains considerable organic matter or is comprised of fine soil particles, laid over a coarse sand which is to become the major part of the root zone: c) the improper mixing of soil amendments which will result in the formation of discontinuous layers: d) the development of thatch either on the soil surface or buried and e) soil compaction within the surface 5 cm which acts like a soil layer.

Irrespective of the type of layering, watering problems may arise in layered soils. Infiltration is reduced if a fine textured soil layer occurs at the soil surface. Infiltration may be further restricted if soil compaction develops. This means that a sandy soil within the main part of the root zone may have poor water infiltration if it is capped with a fine textured soil layer. A typical example of where this may occur is the area surrounding a turf cricket pitch.

Percolation can be markedly reduced by a thin zone of soil of a different texture to that above it. For example, a thin silt layer some 15 cm below the soil surface of a sandy soil will impede drainage and cause the water above it to pond. This results in a temporary perched water table. The reason for this is that the hydraulic conductivity of the silt layer is less than that of the sand. Should the fine textured layer be several centimetres thick, percolation will be greatly affected.

Poor infiltration and percolation in soils on which turf grass is established can result in numerous problems associated with excessive water. Typical examples are: scald; the encouragement of *Poa annua;* increase in disease; poor cold, heat and/ or drought tolerance; poor soil aeration for root development and interference with the use and proper management of the turf because of the wet soils. The correction of such problems in layered soils depends upon the type of layering. Coring may be used if there are thin layers near the soil surface. If the layers are composed of fine particles or organic matter, the cores may be removed and the holes filled by topdressing with sand. Deep soil corers may be used such as the Verti-drain™ which can be used to reach depths of 15 to 25 cm.

Soil compaction

Effective water management can be hindered by soil compaction. High use recreational areas are especially vulnerable. In most turf grass swards, compaction is confined to the surface 5 cm. Even so, this narrow compacted zone can adversely affect plant growth and water movement.

Soil compaction reduces soil aeration and soil porosity. It increases bulk density; soil strength and water retention by increasing the number of soil pores of small size. Compaction creates an environment unfavourable for root penetration; water movement and gas exchange. Infiltration and percolation rates may be significantly reduced while soil oxygen levels drop. Sandy soils resist compaction because the large soil particles provide a resistant soil matrix. However, on old turf sites on sandy soils that have accumulated much organic matter, compaction may become a problem.

Compacted soils in turf grass areas present numerous managerial problems to solve. Principal among these are those associated with excess water. Also, the grass becomes susceptible to drought and suffers stress from high temperatures. This is caused by the reduced root development of the grass which results in a loss of density in the sward. Damage caused by wear will be accentuated because of the decrease in growth rate. Efficient irrigation programming becomes difficult and maintenance costs of the irrigation system increase.

In the final analysis there are only three techniques which may be used to eliminate or reduce the effects of soil compaction. They are:

- Remove traffic from affected sites
- Soil cultivation by either coring or slicing
- Soil modification

Summary

- **A knowledge of the main characteristics of the soils on which turf is established is essential for effective water management.**
- **Sands have a low water holding capacity and a low amount of plant available water.**
- **Soil amendments can be used to improve the soil water holding capacity.**
- **Internal drainage of soils varies as to its water holding capacity. Hydraulic conductivity is greatest when the soil is saturated and lowest when unsaturated.**
- **Soil layering and soil compaction within the root zone usually results in irrigation problems.**

Further reading

Handreck, K (1993). Root zone amendments: What they can and can't do. Proceedings AGCSA National Seminar. Canberra. pps 22 - 26.

McIntyre, D.K., and Jakobsen, B. (1993). The perched water table and its use in sports turf. *Turf Craft Australia.* No. 31, March 1993.

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TINS

Irrigation management for turf grass

P. Moller, K.J. Johnston and H. Cochrane

This work was done in Western Australia and demonstrated the agronomic, economic and environmental benefits of irrigation management. The revised form of the report is as follows while the original paper was given at the Irrigation Association of Australia, National Conference, Adelaide, May 14 to 16, 1996.

Introduction

There are over 13 500 ha of turf grass irrigated from ground water reserves (del Marco 1990) in the Perth metropolitan area. The majority of this turf is grown on highly permeable sandy soils. Careful management is required to achieve an acceptable balance between the maintenance of turf quality, the reduction of water use and the minimization of water and nutrient loss below the root zone

One of the difficulties in doing irrigation research on sandy soils is in measuring the rate of water movement through the profile. In the early 1990s, advances in technology saw a range of soil moisture sensors and monitoring systems come on the market. Agriculture Western Australia carried out an appraisal of several soil moisture sensors (Aylmore *et. al.* 1993) (See topic in manual) and now use the EnviroSCAN® Soil Moisture Monitoring System for their water/ nutrient management studies with horticultural crops. These systems now replace former technologies used in this type of research, such as the neutron probe. These techniques were labour intensive and were incapable of detecting changes in soil moisture content within the short time intervals which were necessary to describe water movement patterns throughout the soil profile. Also, frequent simultaneous monitoring at a number of profile depths for prolonged periods is required to give an understanding of water movement patterns. The new equipment provides the technology to fulfil these needs.

The research was done in two parts and the results are presented to reflect this. Part A deals with the water regime data while Part B presents the economic analyses associated with the research.

Materials and methods

The EnviroSCAN® system uses capacitance sensors that measure the complex dielectric constant of the soil/water medium. Because a change in soil dielectric properties is attributed almost exclusively to a change in water content, the measured change can be interpreted by the system as changes in the volumetric soil water content to within an accuracy of 0.1 per cent (Buss, 1993). The sensors are mounted one above the other on a probe installed within a vertical PVC access tube inserted into the ground at selected, representative monitoring sites. Subsurface probes are now available for use in turf grass applications. The probes are networked via buried cables to a central logging facility. This enables continuous monitoring of the soil water data at different sites at a frequency of one minute if so needed. The data are then down loaded via a cable to a portable computer on site or transmitted via radio to an office computer off site.

The software used for data collection and analysis is user friendly. This enables rapid and versatile graphic display of data recorded at multiple depths. The visual interpretation of the data to determine the soil water dynamics is straightforward and intuitive and the equipment requires only basic computing skills to operate.

The site used for the study was within the City of Stirling north of Perth and the turf was some 18 months old planted with Wintergreen couch grass. It was a low use intensity sports reserve. The soil was a deep sand of the Karrakatta association with the surface well above the water table. The irrigation system was a Hunter 130 sprinkler system, nozzle number 9 on an 18 m, equilateral triangle spacing. An automatic control system was used. Ground water was pumped to the surface using a Grunfos SP 45/15 submersible pump.

Two irrigation regimes were used on the site between 17 February, 1995 and 1 May, 1995. They were:

1) The then current management practice. The turf was irrigated using the then practice of the City of Stirling. This comprised daily waterings of 40 minutes duration which applied about 42 mm / week throughout the summer irrigation period. This was the irrigation strategy used for over 500 ha of turf by the City.

2) A managed irrigation system. Under this system, irrigation commenced when moisture levels in the root zone (0 to 50 cm) declined to the level known to induce mild drought stress in the turf. Sufficient water was applied at each irrigation to return the soil moisture level in the root zone to about field capacity. This irrigation treatment maintained moisture content limits referred to in our definitions as:

- The refill point. Defined as the moisture content at which mild drought stress first becomes apparent.

- Field capacity. Defined as the moisture content at which water movement beyond the root zone drops to an acceptably low rate.

These limits were determined empirically for each treatment during the observation period before commencement of the trial during which visual assessment of turf grass performance was related to the EnviroSCAN® data.

Irrigation events averaged about 70 minutes duration under the managed regime compared with 40 minutes per event under the then City practice regime with water application rates being the same for both treatments.

The EnviroSCAN® equipment was set to record soil moisture content continuously at 10 minute intervals. Two probes set 10 m apart, monitored the then practice site and two probes 10 m apart monitored the managed test regime site. All probes were below the soil surface with sensors located at 10; 20; 30; 40 and 50 cm deep. The system operated between September, 1994 to February, 1996. In the managed regime, the irrigation events were initiated manually after inspection of the soil moisture profiles as shown on the down loaded EnviroSCAN® system.

Results

Part A. Water regime data

The EnviroSCAN® software allows for inspection of the data for one year in a single view. The Excel spreadsheet format used to prepare Figures 1 to 5, can display data from only 4000 recorded events. This means that the data chosen to illustrate the soil moisture dynamics of the two irrigation systems comes mainly from a four week period between 1 March, 1995 and 28 March, 1995.

During this time, the then current practice regime required 19 irrigations - a total of 760 minutes pumping (19 irrigations at 40 minutes/ event). If the normal irrigation practice had not been interrupted by two pump breakdowns, the total pumping time would have been 1150 minutes. During the same time, the managed irrigation regime required only seven irrigations - a total of 500 minutes pumping.

Figure 1 shows the volumetric water content of the soil under the then current practice regime between 1 March, 1995 and 28 March, 1995. Water content is expressed as the depth of water within the root zone of 0 to 50 cm. Figure 2 shows the volumetric water content of the soil under the managed regime for the same time. The field capacity (32 mm) and refill points (15 mm) shown on both figures indicate the desirable upper and lower moisture contents respectively.

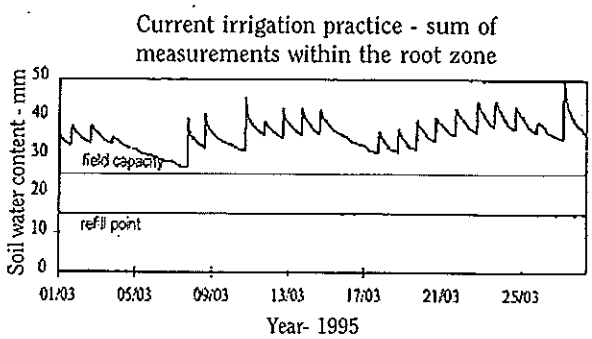

Figure 1. Soil moisture regime in the root zone of turf grass under current irrigation practice.

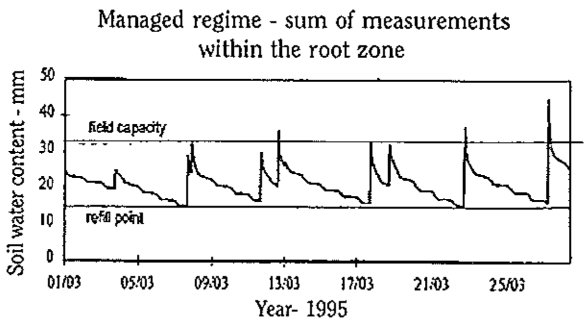

Figure 2. Soil moisture in the root zone of turf grass under managed irrigation.

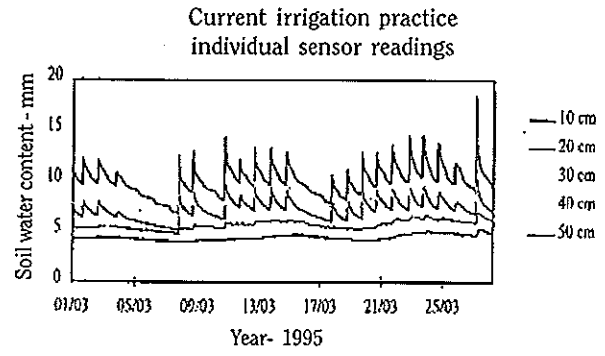

Figure 3. Soil moisture regime at five depths within the root zone of turf grass under current irrigation practice.

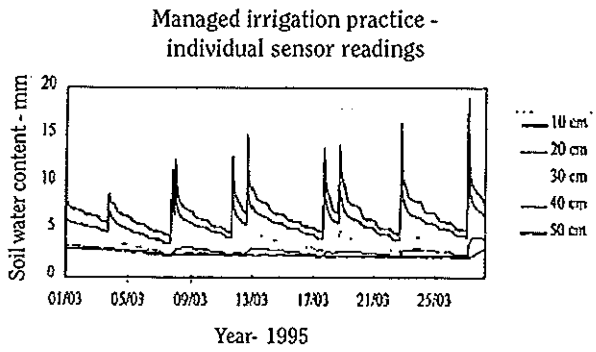

Figure 4. Soil moisture regime at five depths in the roots zone of turf grass under managed irrigation.

Figures 3 and 4 show the water dynamics within the root zone. Figure 3 shows the volumetric soil moisture content at mean depths of 10; 20; 30; 40 and 50 cm between 1 March, 1995 and 28 March, 1995 for turf irrigated under the then current practice. Figure 4 shows the equivalent data for turf under the managed irrigation regime.

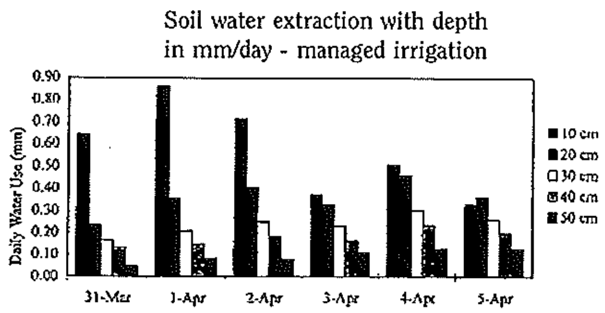

Figure 5. Daily water extraction from five soil depths from 31 March to 5 April, 1995.

Figure 5 shows the water use data from the managed turf area for six days following a period of rain when 18 mm fell in three days. The histogram shows water usage for depths of 10; 20; 30; 40 and 50 cm for each day of the drying period.

Table 1 presents data from the same time lapse as shown in Figure 5. It shows daily water use, pan evaporation and the derived percentage of water use compared with open pan evaporation.

Table 1. Water loss and evaporation data managed irrigation from 31 March to 5 April 1995.

	31-Mar	1-Apr	2-Apr	3-Apr	4-Apr	5-Apr
Water Used (mm)	1.2	1.7	1.6	1.2	1.6	1.3
Pan Evaporation (mm)	5.0	6.4	6.8	4.2	12.2	6.0
% Pan Evaporation	24.5	25.9	24.1	28.8	13.4	21.4

Discussion

A comparison of the data shown in Figures 1 and 2 indicate that, while the then current irrigation practice maintained soil moisture contents above field capacity within the desired limits for much of the time, managed irrigation was able to maintain soil moisture within the desired limits for the whole time. The final watering event shown in Figures 1 and 2 was caused by a heavy rain, the only significant precipitation recorded within the monitoring period. The ability to delay or modify irrigation events in anticipation of rain enhances the water use efficiency advantage which can be achieved under the managed regime. Dry soil has the capacity to accept and store rain as plant available water which would drain away rapidly through an initially moist soil.

Figures 3 and 4 give the soil water content at five different depths. In the managed regime, where soil moisture content at 50 cm remained low and fairly constant, soil under the then current practice was maintained at a higher moisture content throughout the profile. There is also evidence of significant drainage below 50 cm From this data we conclude that implementing the managed irrigation regime minimized water drainage below the zone of greatest root activity; minimized the loss of nutrients by leaching and reduced the requirement for irrigation for the maintenance of an adequate turf condition by over 60 per cent. One of the advantages of reduced irrigation frequency lies in the promotion of a more uniform exploitation of the soil water reserves by the plant roots This effectively increases the root accessible volume of the soil water reservoir.

Figure 5 and Table 1 show that the daily water use varies in response to evaporative demand and soil moisture status. The measurements for Figure 5 were taken over a six day period after 18 mm of rain fell in three days. The data show that the proportion of daily water requirements met from the upper part of the profile decreases and from lower in the profile increases with duration of drying time.

Similar results to our findings were reported by Garrot and Mancino (1994) working with a couch turf in Arizona in the United States of America. They found that, after an irrigation, water use increased in the top 30 cm of soil and decreased at lower depths. As the top 30 cm of soil dried, soil water from the 30 to 60 cm and 60 to 90 cm depths in the profile contributed a progressively greater proportion of total use of water by the turf.

Conclusion

The EnviroSCAN® system affords frequent and continuous monitoring of the soil water content. As such, it is of great assistance to turf managers in scheduling irrigations to meet plant requirements as they vary with management practice and environmental conditions, which are mainly those caused by evaporation. With frequent monitoring and provided that an adequate set of criteria on which to base decisions is available, turf managers no longer need to play safe with frequent irrigations. Such irrigation regimes promote greater evaporative losses during water application, luxury consumption of water by the turf and the potential for greater drainage. The EnvioSCAN® system takes the risk out of implementing more adventurous irrigation regimes.

Results

Part B - Economic analyses

A series of analyses were done which reflect the various economic factors associated with this work. The results are shown in tabular form in Tables 2 to 7.

Table 2 shows the effect of what is known as regulated deficit irrigation (RDI). It shows the comparison between the dry matter weight of clippings from both the then current practice and managed practice irrigation regimes for the 69 day period from 21 February, 1995 to 1 May, 1995. Vegetative growth was reduced by 73 per cent under the managed regime.

Table 2. Comparison of vegetation growth for the two irrigation regimes - 21 Feb. to 1 May, 1995 - (69d).

	Current	Managed
Sample 1	13.8	2.6
Sample 2	6.8	2.0
Sample 3	7.8	3.2
Mean *	9.5	2.6

* Dry matter of clippings per cut - g/m

Whole field mown 14 days before commencement of trial.

Yields determined by mowing 10 m long strips with a 50 cm wide walk behind reel mower.

Tables 3; 4; 5 and 6 show the savings made in both water and energy costs between the two irrigation regimes by comparing the respective data. They are shown below:

Table 3. Comparison of two irrigation regimes - 21 Feb. to 1 May, 1995 (69 d).

	Current	Managed	% Reduction
Number of Irrigations	58	11	81
Total Run Time (mins)	2320	870	63
Quantity Irrigation (mm)	387	145	63
Total Epan (mm)	508	508	-
% of Epan	76	29	-

Table 4. Comparison of two irrigation regimes over an irrigation season (220 d).

	Current	Managed	Saving
Pump costs (hr)	$2.26	$2.26	-
Application rate (mm/hr/ha)	3.96	3.96	-
Quantity Irrigation (mm)	1382	518	864
Pump hrs (hr/ha)	349	131	218
Pump costs ($/ha)	789	296	493

Table 5. Water savings achieved over the irrigation season of 220 days.

Water Applied	Current	Managed	Saving
megalitres/ha	13.82	5.18	8.64
megalitres/100 ha	1,382	518	864
megalitres/500 ha	6,910	2,590	4,320

Table 6. Power savings achieved over the irrigation season of 220 days.

Power Usage	Current	Managed	Saving
$/ha	789	296	493
$/100 ha	78,800	29,600	49,300
$/500 ha	394,000	148,000	246,500

Table 7. Return on investment for 100 ha and 500 ha of turf grass - amortized over five years.

Area (ha)	Management Units	Capital Cost $	Capital Cost $/per annum	Saving $/per annum	Return on Investment %
100	3	60,000	12,000	49,000	408
500	15	300,000	60,000	245,000	408

Table 7 shows the return on investment which could be gained by adopting a managed irrigation regime. It assumes an EnviroSCAN® management unit cost of about $20,000. The data is based on savings made in energy costs alone over five years.

Discussion

The monitoring system used enabled scheduling to closely match the water requirements of the turf. The savings made in water and energy were because of the capacity to reduce drainage below the root zone and reduce luxury water consumption by the grass. These savings are shown in Tables 3 to 6. Table 3 used a 69 day measuring period, while the data for Tables 4 to 6 used a 220 day period.

During the 220 day season, there was a 69 per cent reduction in water use with no adverse effects on turf quality under the managed irrigation regime compared with the then current practice. The economic benefits arise from savings in water; fertilizer and energy costs incurred by reduced pumping. For example, an area with 500 ha of irrigated turf, this can be readily assessed in dollars and megalitres of water saved. For the 220 day season this could amount to some $246,000 in electricity costs saved and over 4320 megalitres of water/annum.

Irrigated turf grass areas of local Councils could be divided into management units based upon turf units which have similar characteristics such as location; soil type; turf grass species; age and usage. This would mean that there could be a number of parks and/or sports fields grouped into one management unit of like characteristics. Each unit would require a separate irrigation regime to meet the specific requirements of the site.

It will be seen that the return on investment on expenditure on an EnviroSCAN® soil moisture monitoring system can be assessed on the savings achieved. This is seen in Table 7 which shows that over five years the return on investment is 408 per cent on an initial cost of about $20,000.

Conclusion

The use of meteorological data to determine plant water requirements is the main method used by irrigation managers in the turf growing industry to schedule irrigations. This is because atmospheric conditions dictate the rate of soil water loss by evaporation and transpiration. The fault in this method is that it is a global; indirect; single point estimation of turf grass water use and is not site specific. Nor is it a direct continuous measurement of the soil dynamics and changes that may rapidly occur within a sandy soil profile.

Until the early 1990s, the measurement of soil moisture by soil sensors to schedule irrigations has met with mixed results in the Western Australian turf industry. This has been caused by poor reliability of the product used; inadequate installation and diagnostic procedures, little local technical support; poor training of the irrigation operators who interpreted the data collected and no on-going agronomic support from industry. The EnviroSCAN® system has proved to be reliable in this experiment over 550 days with no loss of time caused by product failure. Only five days of logging time were lost because of an external loss of power. Local technical support provided a 6 to 12 hour turnaround time when the necessity arose and on-going agronomic support and operator training was provided.

While irrigation management in Australia has made significant commercial gains and achieved environmental benefits since 1980, guesswork costs the turf industry unnecessary financial losses. This causes harmful impacts on sensitive ground water resources, waterways and estuaries. We have shown how a new technology can provide an efficient; cost effective; sustainable management system of water resources.

Schedule coefficients

Three schedule coefficients may be used to determine watering practice. These are multipliers used to adjust run time determined from the mean precipitation rate. An example of a hypothetical situation is where the turf manager decides to irrigate turf with 8 mm of water when the mean precipitation rate of the system is 10 mm/h. The sprinkler run time calculates to 48 minutes:

8 mm ÷ 10 mm x 60 minutes = 48 minutes

However, the catch can data showed that one area received only 6 mm/h, which means that if the system operated for 48 minutes, the dry area would be under irrigated by 40 per cent. Depending upon the level of turf quality required this may be or not be acceptable.

Option 1. Scheduling coefficient (S.C.)

This numerical value is derived by dividing the mean precipitation rate by the water measurement from the single lowest catch can figure or driest area.

S.C. = 10 mm [mean] ÷ 6 mm [driest area] = 1.67

The S.C. of 1.67 is used as a multiplier to adjust the base run time of 48 minutes. The new adjusted time using this coefficient is:

48 minutes x 1.67 = 80 minutes

The larger the S.C. adjustment, the longer the irrigation system must run. This creates the problem that by adjusting the system to water the single driest area, other areas will be overwatered. As the S.C. is the most severe case adjustment that may be made, it should only be used where turf quality and performance needs are maximum and loss of turf quality from under irrigation is unacceptable.

Option 2. Distribution uniformity (D.U.)

Catch can data may be used by managers to derive the D.U. multiplier. In this case the irrigation system base time run determination only uses the lowest 25 per cent of the catch can measurements.

If from the 12 catch can measurements taken, the lowest three recorded were 6 mm; 6.5 mm and 6.9 mm, the D.U. may be calculated by:

D.U. = 10 mm [mean of all cans] ÷ 6.5 mm [mean of lowest 25%] = 1.54

The new base run time using the D.U. multiplier is:

48 minutes x 1.54 = 74 minutes

The distribution uniformity multiplier applies less water than the scheduling coefficient and may be used for maintaining turf at moderate maintenance levels.

Option 3. Midpoint uniformity (M.U.)

This is the most conservative of the three scheduling options available to turf managers. The M.U. is similar to the D.U. except that the lowest 50 per cent of the catch can measurement data are used for the calculation. The M.U. coefficient may be used to determine the time required to irrigate low maintenance turf areas with lower quality turf expectations than turf irrigated using either the S.C. or D.U. multipliers to calculate irrigation time. The use of this coefficient will result in the greatest amount of under irrigated areas.

If from the 12 cans the six lowest measurements were 6.0; 6.5; 6.9; 8.0; 8.5 and 8.9 mm, the M.U. may be calculated as:

M.U. 10 mm (mean of all cans) ÷ 7.5 mm (mean of lowest six cans 50%) = 1.33

The new run base time using the M.U. multiplier is:

48 minutes x 1.33 = 64 minutes

Accuracy of the adjustment factors

The accuracy of the above adjustment factors depends upon the number of catch cans used for determining the schedule coefficients. The specific set of irrigation conditions which apply at one site may not apply at another. If sites have the same sets and type of sprinkler heads, and spacings, the information from one site may be used on another. However, under the summer conditions which prevail in the greater Perth Metropolitan Area, wind is the major factor which affects the uniformity of water application.

Summary

- It is important for managers to know the output of the irrigation system and its variation in output across the field.
- The use of catch can measurements is the most practical means by which to obtain the above information.
- Three scheduling coefficients may be calculated using this data. The choice of which coefficient to use to determine run time of the irrigation system depends upon the quality of the turf required.
- Further information on the use of scheduling coefficients is discussed in the topic on irrigation scheduling.

Further reading

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TINS

Irrigation scheduling

K.J. Johnston

The aim of irrigation is to replace the amount of water either used by the turf grass; evaporated from the grass surface or drained away below the root zone so as to ensure continued plant growth. The prime objective is to maintain an even coverage of green turf with as little applied irrigation water as possible. The efficiency of water application is controlled by the design of the irrigation system and the manner in which the irrigations are scheduled.

Irrigation scheduling requires decisions as to the frequency of irrigation and the amount of water to apply at any one time. To do this, managers rely on one or more of three methods;

1) From experience
2) By using some estimate of evapotranspiration
3) By monitoring soil moisture levels.

Experience

In the 1960s there were no simple and effective methods of measuring water loss from crops. This led to the gradual development of instruments over the next 20 years to measure soil water loss and evapotranspiration in on-site situations. This meant that managers of turf areas had to rely upon experience to develop irrigation schedules which produced an acceptable turf. The considered opinion among managers as reported by del Marco (1990), was that a kikuyu turf needed between 30 to 38 mm of water each week in summer. Any variation in this rate of application would depend upon the experience of the operator.

The major problem with a strict reliance upon experience to determine the irrigation schedule was that it often led to over watering. Managers know that to err on the side of over watering on a sandy soil will give a better turf than one which is under watered. In an under watered turf, the grass will develop an uneven appearance and often dry patch will result. However, over watering causes:

- Wasted water and unnecessary electricity costs because of extended pumping times.
- The inefficient use of applied nutrients by the turf grass. This results in the leaching of nutrients into the ground water and adjacent wetlands

The need to improve on previous methods of irrigation scheduling stems from the need to conserve water; reduce costs and protect the environment.

Replacement of evaporation

An effective irrigation schedule may be developed by replacing the amount of water transpired by the turf. Evaporative pan water loss measurements or other mathematical methods may be used to estimate evapotranspiration (E.T.) of a turf sward. The amount of water lost from an open body of water in the evaporative pan or evaporimeter is a useful guide. In addition, local meteorological stations can provide climatic data with which to calculate E.T.

For both of these methods, the E.T. for turf is adjusted using a specific crop coefficient factor (k) for each turf grass species. The (k) value for the two methods may be different.

Crop coefficients were determined from research associated with the TINS project for couch and kikuyu under site specific conditions. For kikuyu growing on an old established site and couch on a new area, both at low levels of soil nitrogen, the crop coefficient was about 0.5. This closely approximated the crop coefficient of 0.6 determined for a good quality couch sward at high soil nitrogen levels in an American study. (Garrot *et al.* 1994)

Soil moisture

By using only experience or measurements of evaporation it is only possible to estimate the water loss from an area of turf. A more accurate method is to measure the amount of soil water used by the sward on a regular basis. Various sensors have been developed to monitor soil moisture levels and each type of instrument has its advantages and disadvantages.

The EnviroScan® soil moisture monitoring system was used during the TINS project with considerable success. It is possible to accurately determine with this equipment how much water has been used by the turf and the quantity of irrigation which should be applied to replace that which has been used.

Method to calculate an irrigation schedule using evaporation replacement

The amount of irrigation required by turf may be based upon the amount of water lost by evaporation. This is affected by the same climatic factors that affect water use by the turf, namely: temperature; wind speed and humidity.

The irrigation time is set at the beginning of the month according to the historic average daily evaporation for that month. (Table 1) This irrigation time may be adjusted for any day during that month in which the climatic conditions differ from the norm. e.g. on mild days the irrigation time is reduced while on hot and windy days it is increased. It is recommended that the frequency of irrigation should be every two days, even though the results from the TINS project indicated that savings in water and pumping costs may be made by increasing the irrigation interval. However, any attempt to extend the interval between irrigations will require close visual observations of the turf and/ or the use of soil moisture sensors.

Table 1. Average daily pan evaporation in mm from an evaporimeter at Perth airport for each main irrigation month. September to April.

Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
3.7	5.1	7.2	8.5	10.0	9.6	7.8	5.3

Setting the irrigation time

1) From Table 1 select the daily pan evaporation for the month.

2) Select the appropriate crop coefficient factor (k) for the species of turf grass and the proposed rate of growth. For couch and kikuyu (k) may vary from 0.5 to 0.6 depending mainly upon the level of soil nitrogen at the site. Other factors may be involved.(Table 2) ***Results from the TINS project experiments showed that a good quality turf of either couch or kikuyu was maintained for low soil nitrogen by using a (k) factor of 0.5.***

Table 2. Crop factors (k) for couch and kikuyu at two levels of soil nitrogen

Level of N nutrition	Crop factor (k)
Low soil N	0.5
High soil N	0.6

3) Calculate the amount of water required by multiplying the average daily pan evaporation for that month by the appropriate crop factor (k) for that specific site as determined by the level of soil nitrogen. e.g.

Water requirement = Average daily pan evaporation for that month x crop factor (k)

4) Divide the calculated water requirement by the sprinkler output to determine the duration of watering per day.

Example
How much water should be applied (average per day) in December to a sward of kikuyu with a high soil nitrogen regime?

1) From Table 1 select the average daily evaporation for December which is 8.5 mm / day

2) From Table 2 select the appropriate crop factor (k) = 0.6

3) Water required = 8.5 mm x 0.6 = 5.1 mm /day
Note: If the turf is watered every second day then 10.2 mm of water should be applied at each irrigation event.

4) To determine the duration of watering, assume for example that the rate of application from the irrigation system is 11 mm /h = 0.18 mm/min

Total watering time = 5.1 mm ÷ 0.18 mm /min = 28 min/day = 56 minutes every second day

5) If the turf is to be watered three days every week, the amount of irrigation required per watering is determined as:

Total irrigation / week = 7 x 28 min = 196 min
Irrigation / watering = 196 ÷ 3 = 65 minutes

Correcting irrigation times

Irrigation times may be adjusted for evaporative conditions which vary from the normal. This is done by varying the irrigation time by the same percentage as the variation percentage in the daily average of pan evaporation.

In the previous example, assume that the daily evaporation for the next irrigation period was 4.0 mm / day rather than the historical average of 8.5 mm / day.

Per cent reduction in evaporation is;

(8.5 mm - 4.0 mm) ÷ 8.5 mm x 100 = 52.9 %

The irrigation reduction time is:

65 min - (52.9% x 65 min) = 65 - 34 = 31 minutes

Similarly, if the evaporation is above the normal average, the irrigation time may be increased.

Summary

- **Irrigation scheduling relies on using one or more of the following methods:**
  - **Experience**
  - **Replacement by the measurement of evaporation**
  - **Replacement by the measurement of soil water loss by monitoring such losses by soil moisture sensors.**
- **The recommended approach is to use the evaporation replacement method supplemented by knowledge gained from experience and data from soil moisture sensors.**
- **Use the crop coefficient (k) of 0.5 for couch and kikuyu on sites with a low soil nitrogen status and 0.6 for sites with a high soil nitrogen status for both couch and kikuyu.**
- **Irrigate every second day. The time between irrigations may be increased if data from reliable soil moisture sensors indicate that this would give satisfactory results.**
- **Set irrigation times at the beginning of each month. Alter irrigation times in response to evaporative conditions that vary from the average.**

Further reading

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Further information

TINS

pH and alkaline soils

K.J. Johnston

Soil pH

No understanding of either acidic or basic soils is complete without reference to pH. This is a measure of the potential hydrogen ion concentration in the soil solution. pH measures the relative amount of hydrogen ions (H^+) and hydroxyl ions (OH^-) in the soil sample which should be taken from the root zone. A predominance of hydrogen ions makes the soil acidic, while a predominance of hydroxyl ions means that the soil is basic or alkaline.

On a pH scale of 1 to 14, a soil with a pH of between 1 to 7 is acidic, a pH of 7 is neutral and a pH of 7 to 14 is basic. Soil pH is defined as the logarithm of the reciprocal of the hydrogen ion concentration. Because the measurement is logarithmic, a change of one pH unit represents a 10 fold increase or decrease in hydrogen ion concentration. A change of two units equals a 100 fold decrease or increase.

Measuring soil pH

From the site to be tested, at least 10 soil samples should be taken from 0 to 10 cm deep using a standard 'pogo' stick type sampling tool. The 10 samples are put into a single bag and thoroughly mixed. The standard technique used is to prepare a soil solution using a 1 : 5 (soil : 0.01 M $CaCl_2$ mixture). Previously, a 1 : 5 (soil : water) solution was used, but most laboratories now use the $CaCl_2$ method as it more closely approximates the natural conditions in the soil. Managers may use pH testing kits, such as those available from the CSIRO, or sophisticated laboratory instruments. It is essential that the required procedures be followed carefully as all techniques have their limitations.

It is advisable to measure soil pH several times during the year to determine fluctuations caused by irrigation or rain.

The alkaline soils

Such soils are found along the western edge of the Swan Coastal Plain, such as in the Quindalup dunes near the coast. These calcareous sands contain free calcium carbonate. The Quindalup dunes extend from about Bunbury almost to Dongara. In the Perth area a good example of an unspoilt Quindalup dune is in Bold Park. At a pH above 8.2 calcium carbonate precipitates out. A pH of 8.2 to 8.3 indicates that the soil has abundant calcium carbonate.

A simple test for calcium carbonate is to add a few drops of either sulphuric or hydrochloric acid to a soil sample. If the solution begins to bubble and emit gas it is clear that calcium carbonate is present. The gas emitted is carbon dioxide. The simple formula for such a chemical reaction is:

acid + base $\rightarrow$ salt + water

In the case above the reaction is:

$$2HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2 \text{ (gas)}$$

Hydrochloric acid + calcium carbonate $\rightarrow$
calcium chloride + water + carbon dioxide (gas)

If the exact amount of calcium carbonate needs to be determined, more precise testing methods have to be used.

On the Spearwood sands of the Coastal dune system, the soils developed on them are naturally slightly acidic to neutral. After irrigation with high pH water they become alkaline. This is because the irrigation water is extracted from aquifers in the underlying limestone.

Management of alkaline soils

The availability of nutrients to plants is affected as soil pH becomes too high or too low. As pH rises, the availability of phosphorus; manganese; iron; boron; copper and zinc is greatly reduced leading to nutrient deficiencies. The root zone may be acidified using sulphur; sulphuric acid or acidifying fertilizers although this is not effective in all situations. In soils where water is used which is high in lime, such methods as described may be non economic.

Fortunately, managers of turf growing in strongly alkaline conditions can still maintain a high quality turf by a process termed 'spoon feeding'. A balance of the essential elements in which the turf is deficient, may be applied through foliar applications directly onto the leaf tissue. Iron and manganese are the elements most likely to be often required in small quantities. On alkaline soils, the preferred nitrogenous fertilizer is sulphate of ammonia as this has a strongly acidifying effect. This fertilizer assists in reducing the pH in the soil solution, though the effect may be rather short lived.

Correcting deficiencies of iron and manganese

A common method of controlling these deficiencies has been to reduce soil alkalinity by the addition of acidifying materials such as elemental sulphur or very dilute sulphuric acid. When elemental sulphur is applied to the soil it is oxidized by micro-organisms to form sulphuric acid. The rate of oxidation varies as to soil type and environmental conditions. However, elemental sulphur can only be used when there is no free calcium carbonate in the soil. Furthermore, this material must be applied strictly as directed to avoid leaf burning of the turf. Sulphuric acid is applied through the irrigation system at low concentration so as to lower the soil pH.

The safest and usually the most effective method to lower soil pH is by the use of acidifying fertilizers such as sulphate of ammonia or urea. During the process of nitrification an acid is produced. The nitrate produced is not completely taken up by the plant, but leached.

The availability of manganese to the plant is inversely related to soil pH. Thus the higher the pH the less is the manganese available. The oxidation of the divalent manganese ion to less soluble forms occurs at a pH of 7 to 8, primarily as a result of microbial activity. Experiments in the United States of America on a couch turf grown on a sandy soil, showed that reducing the pH from 7 to <5 by the application of sulphate of ammonia, overcame a manganese deficiency. The application of granulated manganese sulphate at 50 kg/ha gave only temporary relief to the deficiency of manganese in the turf when the soil pH was 7. The conclusion was that the best method to alleviate the deficiency was by reducing soil pH.

Foliar applications of Fe and Mn

There are occasions when it is difficult to lower soil pH to control deficiencies of iron and manganese. Likewise, the turf may show a poor response to applications of sulphate of ammonia to which iron sulphate and manganese sulphate has been added. In such cases, a foliar application of trace elements is recommended. Because a high soil pH makes the iron and manganese unavailable, foliar uptake of these nutrients is the most efficient means by which the turf may obtain iron and manganese.

The recommended rate of application is 25 kg/ha of iron sulphate and 10 kg/ha of manganese sulphate. These two fertilizers may be tank mixed and applied at volumes of 100 to 200 L/ha. A wetting agent should be used to ensure that the nutrient spray sticks to the leaves of the turf grass. The best time to apply sprays containing minor elements is late afternoon to maximize the time that the leaves remain wet. Alternatively, when air temperatures are low will also provide low evaporative conditions. Do not irrigate the turf after a spray application or apply a spray if rain is expected. Ensure that the most soluble forms of these plant nutrients are purchased from the supplier.

Usually, a response is observed within 2 to 3 days after a foliar application of iron and manganese, though it is not uncommon for a visual response to be seen within a few hours in some cases. Foliar responses to the application of micro-nutrients may only last for a few weeks. Iron and manganese are immobile within the leaf and leaf growth which takes place after the application of the spray is not supplied with the micronutrients. This means that the deficiencies continue in the new growth and thus regular spraying with iron and manganese may be necessary.

Summary

- Monitor soil pH by the use of soil tests.
- Know the ideal pH range for each turf grass species.
- If the soil pH is >8, determine if it contains free calcium carbonate.
- If the soil contains free calcium carbonate, any attempt to lower pH significantly by using sulphur will be ineffective.
- If the soil does not contain free calcium carbonate, the cost of using sulphur or other pH lowering techniques needs to be carefully assessed.
- Nutrient deficiencies caused by alkaline conditions can be overcome by skilled management.

Further reading

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TINS

The management of acidic soils

K.J. Johnston

Soil pH

Soil reaction or pH (potential hydrogen) is a measure of the degree of acidity or alkalinity of a soil, more particularly that soil within the root zone of the plant. The pH of a soil is determined by the relative amounts of hydrogen ions (H^+) or hydroxyl ions (OH^-). A predominance of hydrogen ions makes the soil acidic while the predominance of hydroxyl ions makes the soil alkaline or basic.

Soil pH is measured on a scale of 1 to 14. On this scale, a pH of 1 to 7 is acidic while 7 to 14 is alkaline. A pH of 7 is neutral. At this pH the concentration of hydrogen ions and hydroxyl ions are equal. Pure distilled water has a pH of 7. Mathematically, pH is defined as the logarithm of the reciprocal of the hydrogen ion concentration. This means that as the pH decreases form 7 to 6 the hydrogen ion concentration increases ten fold i.e. by 1 x 10. Because the scale is logarithmic, a change of two pH units from 7 to 5 means that there has been a hundred fold increase in the concentration of hydrogen ions. The reverse is true as soils become more alkaline and hydroxyl ion concentration increases. Most plants prefer the soil solution to be slightly acidic at around pH 6.5 or so. At this pH most plants nutrients are available for plant growth.

Measuring pH

To determine the pH of a soil, samples should be taken from at least 10 locations on the site to be tested. Normally these are taken from a depth of 0 to 10 cm and bulked together. A standard 'pogo' sampling tool is used to collect the samples. Because soil pH fluctuates throughout the year caused by irrigation, rain or cultural treatment, soil pH should be measured several times each year.

The standard method is to form a soil solution using a 0.01M $CaCl_2$ solution in a ratio of 1 : 5 (1 part soil to 5 parts of solution). This method has replaced the historic technique of using a 1 : 5 soil : water solution. Because the calcium chloride method most approximates the actual soil solution, most laboratories now use this technique for the determination of pH.

For quick practical pH determinations, turf managers may use test kits with which to do their own analyses. These kits range from a simple CSIRO test kit, or similar, to a more sophisticated laboratory instrument. However, it is important for managers to be aware of the limitations of the techniques used in such cases and carefully follow the required procedures.

The management of soil acidity

Plant growth is affected adversely as soils become more acidic. Turf is rarely grown on very acidic or alkaline soils as this is not their natural habitat. Managers need to know the current level of soil acidity and how the pH fluctuates over time during the year. When this information is available, the following alternatives are possible:

1) Attempt to raise the soil pH.
2) Reduce the rate of acidification.
3) Add extra nutrients.
4) Do nothing.

Raising soil pH - The most common method used is to add lime. Lime sand and crushed limestone are the cheapest sources. The Romans used lime as an improver of certain soils.

Reducing the rate of acidification - The most common method is to change the type of fertilizer used. e.g. calcium nitrate could be used instead of sulphate of ammonia (ammonium sulphate). This will decrease the rate of change in soil pH.

Add extra nutrients - This is often a satisfactory strategy provided there is little risk of a decline in turf quality.

Critical pH ranges for turf

The turf grasses such as couch, kikuyu and bent are adapted to slightly acidic soils. The aim of management is to maintain a soil pH range of 6.0 to 6.5 where these grasses are grown. The critical pH is where the pH value starts to cause a major reduction in growth and quality. This is caused by an increasing degree of root damage. Decreasing soil acidity eventually causes plant growth to cease. Turf grass species differ in their sensitivity to declining pH and root impairment usually begins when the pH drops below 5.0. Couch grass has an intermediate tolerance to acidic soils whereas buffalo grass has a low tolerance. Some species such as *Paspalum vaginatum*, known as saltene, are fairly tolerant of low pH.

Rate of soil acidification

Many factors influence the acidification rate of soils, principal among these are the initial pH; the buffering capacity of the soil and management practices. The buffering capacity of a soil is its ability to resist pH changes when hydrogen ions are added to or removed from the soil. When hydrogen ions are added to the soil, such as with nitrogenous fertilizers, the ions either remain in the soil solution or are sorbed by the soil particles. Sorption is the process whereby the hydrogen ions balance negatively charged soil particles or chemically bond with the surface of the particle. Sandy soils, which have a low cation exchange capacity (CEC) have few sorption sites and so cannot buffer against an increase in hydrogen ions and pH changes readily occur. These changes are generated during the process of acidification. Clay soils have a high buffering capacity and pH changes are slow. Soils high in organic matter are also highly buffered.

Causes of soil acidity

Biological processes and the application of nitrogenous fertilizers are the causes of soil acidification by an increase in hydrogen ions. The carbon and nitrogen cycles are the two biological processes causing acidity. By far the major reason for increasing soil acidity in turf areas is by the use of ammonia and urea based nitrogenous fertilizers which, by the process of nitrification, produce nitrate. Much of this nitrate may not be taken up by the turf and is lost through leaching. This leaching removes the basic cations from the soil leaving the reserve acidity produced by nitrification in the root zone.

In this complex system of chemical reactions, the electrical charge on the exchange sites is usually maintained by the presence of the positive cations of calcium; magnesium; potassium and sodium with the negative nitrate anions. When the nitrate ions are leached away they are unable to complete the nitrogen cycle and acidification accelerates. This means that the nitrate ions are not taken up by the roots to form hydroxide ions. The problem which arises is that the acidity derived from ammonium or urea based fertilizers is usually permanent.

Sources and use of lime

Lime is calcium carbonate ($CaCO_3$) and agricultural lime usually contains impurities of various kinds, such as silica as sand and/or magnesium carbonate. There are large deposits of limestone and lime sand in the coastal areas of the Swan Coastal Plain. Some lime sands are very high in lime derived from sea shells and chemical deposits. They usually contain some 6 to 8 per cent magnesium carbonate ($MgCO_3$), while limestone has very little.

Lime increases the pH because it replaces hydrogen ions by a process of neutralization. The simple equation is:

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

In the case of lime, the neutralizing effect is achieved by the removal of hydrogen ions freed from the soil particles by the calcium ions which are more reactive than the hydrogen ions. e.g.

$$2H^+ + CO_3^- \rightarrow H_20 + CO_2 \text{ (gas)}$$

This is achieved by the calcium ions displacing the hydrogen ions that balanced the negative charge on the soil particles. The hydrogen ions are then able to react with the carbonate ions as shown.

Burnt lime

The term 'lime' is often applied to the lime used in the building industry. This is usually burnt lime which reacts violently with water to form slaked lime. Burnt lime is readily made by heating crushed limestone to form calcium oxide (CaO).

Lime quality

Neutralizing value

Pure calcium carbonate is defined as having a neutralizing value of 100 per cent. The neutralizing value of all other sources of lime are graded relative to this standard.

Alternative acid neutralizing materials, their reactions with acid and their acid neutralizing values relative to pure calcium carbonate.

Type of acid neutralizing material and its reaction with acid	Neutralizing value (%)
Calcite ($CaCO_3$)	100
Burnt lime (CaO)	178
$CaO + 2H^+ \rightarrow Ca^{++} + H_2O$	
Hydrated lime $Ca(OH)_2$	134
$(Ca(OH)_2) + 2H^+ \rightarrow Ca^{++} + 2H_2O$	
Magnesite ($MgCO_3$)	119
$MgCO_3 + 2H^+ \rightarrow Mg^{++} + H_2O + CO_2$	
Dolomite (a mixture of $CaCO_3$ and $MgCO_3$)	100 - 119
LKD (Lime kiln dust: a mixture of $CaCO_3$ and Ca)	>100
G-Lime LKD pelletized with water, then recrushed. Result is mixture of $CaCO_3$ and $Ca(OH)_2$	typically 90
CKD (Cement kiln dust: similar to LKD but with a high potassium content)	110
Lime sand	50 - 95
Limestone	50 - 85
Ecomin	2 - 4
Red mud	2 - 7
Rock dust	2 - 4

Fineness

The finer the liming material, the quicker it will react to neutralize the soil and ameliorate soil acidity. Value for fineness are:

1) >2 mm = too coarse, no value.
2) 0.1 mm to 0.2 mm = fine, reacts within normal time.
3) <0.1 mm = very fine, reaction rate to neutralize soil acidity is rapid, but the material is difficult to manage, spread and mix through the soil.

Application rate

A useful guide for determining the required rate of application of lime to a turf grass to effect the soil profile to a depth of 10 cm is as follows:

1) apply - 1t/ha of good quality lime with a neutralizing value of over 80 per cent, the proportion of which passes through a 0.6 mm sieve exceeds 80 per cent.
2) by - spreading onto the surface of the turf.
3) which is - growing on a sandy soil with a pH range of 4.0 to 6.0 and a low (<1.0 per cent) organic carbon content.
4) will result in - a pH rise of 0.5 to 1.0 unit.

Because many factors affect the resultant pH change from the application of 1 t/ha of crushed limestone or lime sand, managers of turf areas will have to use their experience to determine the most beneficial rate of application to be used.

Frequency of application

Should the initial application of lime achieve the desired pH within the root zone, another application will not be needed until the pH drops once more to a level which is considered as too low to maintain quality turf. However, a regular programme of treatments will need to be adopted if the initial lime application did not achieve the desired soil pH. Soil testing must be done to monitor the effects of lime applications. By this means, managers will soon be able to determine the required frequency of application.

Guidelines to follow

- Monitor soil pH by the use of soil testing;
- Know the ideal pH range for each turf species; and
- Adopt a liming strategy to maintain or raise soil pH as required.

Further reading

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The soil PRI

K.J. JOHNSTON

Adapted from Allen, D.G. and Jeffery, R.C. (1990). Methods for analysis of phosphorus in Western Australian soils. Report on investigation, No. 37: Chemistry Centre of Western Australia.

Because of the serious pollution of waterways and estuaries with phosphorus in the Swan Coastal Plain, an understanding of the soil Phosphorus Retention Index or PRI is valuable for all users of phosphatic fertilizers.

The effectiveness of water soluble phosphatic fertilizers such as superphosphate is greatly reduced by sorption of the phosphate onto the various soil components, particularly the hydrous oxides of iron and aluminium. The sands of the Plain have a very low phosphorus retention capacity. On these sands, the leaching of water soluble phosphorus reduces the effectiveness of fertilizers such as superphosphate. It is the development of agriculture on these sandy soil types and the existence of an extensive system of streams, rivers and estuaries which has led to the serious pollution problem which now exists. The excessive leaching of phosphates into the drainage water has caused the eutrophication of many estuarine systems south of Perth. This has caused the excessive growth of algae and a reduction in water quality. There is considerable research into the means whereby the concentration of phosphorus in the drainage water may be reduced, coupled with management techniques to improve the efficiency in the use of phosphatic fertilizers.

Sorption of phosphorus

The processes of adsorption and desorption of phosphate in soil are of fundamental importance in understanding the role of phosphorus in plant growth and water pollution. Plants can only use phosphate which is present in the soil solution. This is controlled by the amount of phosphorus adsorbed by the soil and the affinity of the soil for phosphorus which is its adsorption capacity. When a soil of low phosphorus-fixing capacity such as a sand is given a water soluble fertilizer, the concentration of phosphorus in the soil solution will be high. In a soil high in clay or iron or aluminium oxides, the concentration of phosphorus in the soil solution will be lower for the same amount of fertilizer applied. This means that a higher level of phosphorus is available temporarily in the sandy soil or that more fertilizer is required on a clay soil to achieve the same level of plant growth.

This effect is largely caused by the buffering capacity of the soils which retain phosphorus. However, such soils will usually be able to supply plant available phosphorus over time compared with the sandy soils in which the phosphorus will be lost by leaching.

The measurement of the phosphate-fixing properties of a soil serves two purposes:

- It identifies soils which may now or potentially have the ability to lose phosphorus by leaching.
- It assists in the formulation of recommendations for the use of phosphatic fertilizers in conjunction with soil tests which give data as to the amount of available phosphorus in the soil.

Phosphorus adsorption isotherms

The term 'isotherm' is applied to lines of equal temperature as on a temperature map. In this case the term has been appropriated to mean the relationship between the amount of phosphorus adsorbed by the soil and the concentration of phosphorus in equilibrium with the soil.

This phosphorus adsorption isotherm determination is done in a laboratory by calibrating the sorption reaction of phosphate with a soil with different levels of phosphate under controlled conditions. These soil conditions include the soil : solution ratio; temperature; ionic strength; time and shaking speed.

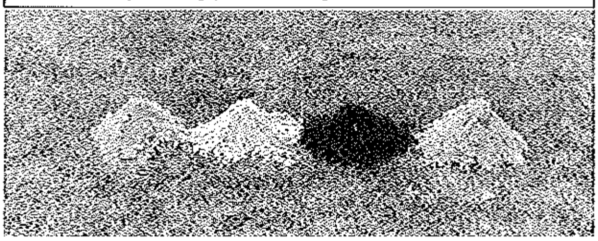
Phosphorus Retention Index

Because the calculations involved in constructing a phosphorus sorption isotherm is not a convenient routine test for a large number of soil samples, there was a need to develop a single determination for a soil's ability to adsorb phosphorus. The Chemistry Centre (W.A.) developed the PRI test at the then Government Chemical Laboratory and this test is now widely used by other laboratories in this State. This test was developed specifically for use with Western Australian soils which usually have very low phosphorus fixing capacities.

Western Australian agricultural soils have a low capacity to fix phosphorus in comparison with similarly used soils in the eastern States and overseas. This has been caused by their long history of weathering which has resulted in mainly coarse soils. The grey Bassendean sands, for example, in the Perth area and the sands of the west and south coasts, have almost a zero capacity to retain applied soluble phosphate. Exceptions to this are the loams and gravels developed on the lateritic deposits along the south-western edge of the Darling Plateau. Table 1 illustrates the effect of soil type on the Phosphorus Retention Index.

Table 1. Classification of the phosphorus-sorbing properties of some Western Australian soils based upon the Phosphorus Retention Index (PRI).

PRI	Classification	Soil type
<2	Very weakly adsorbing or desorbing	Bassendean sands Grey sands
2-5	Weakly adsorbing	Karrakatta sands. Cream sands
5-20	Moderately adsorbing	Spearwood sands. Yellow/orange sands
20-70	Strongly adsorbing	Darling Range gravel
>70	Very strongly adsorbing	Karri loams



Sands of the coastal dune series from left: **Yellow** - colour of a typical sand of the Karrakatta association which is the eastern development of the Spearwood Dune System. Almost zero organic carbon with a PRI of about 3.0 to 5.0. **Cream** - a sub-series of the Bassendean Dune System from near Jandakot, but not as severely non-wetting as the Jandakot sand. Low organic matter with a PRI about 2.0 **Grey** - a typical Bassendean sand from Collier Park in Como. This surface sample has some organic carbon and the PRI is about 0 to 0.5. The sand grains are well rounded. **Light grey** - a sample of the Bassendean sand taken at a shallow depth. The PRI is about 0 to 0.5.

Using the PRI

Use of the PRI allows turf grass managers to assess the risk of phosphorus loss by leaching and assists them to make informed decisions as to fertilizer use. For example, if a soil has a PRI of 2 or <2, high application rates of water-soluble phosphatic fertilizers would lead to leaching losses of phosphorus. When the PRI is used in conjunction with a soil test analysis of available phosphorus, an informed formulation of fertilizer use may be made. ***During the TINS survey, it was found that many turf sites had a PRI of zero or even negative. This meant that the soil was saturated with phosphorus and that applications of fertilizer should cease until either soil or leaf tissue tests indicated otherwise.***

Even if a soil has a high PRI of 5 when in the virgin state, it still needs to be managed carefully. Although the likelihood of leaching losses from such soils will be initially low, it will increase in time if excessive amounts of phosphatic fertilizers are applied over time. Because the PRI may change with different management practices, it needs to be regularly monitored.

The PRI is a useful tool to use in assessing the fertilizer programme being used and in determining the risk to the environment of that programme.

Summary

- **Most sands of the Swan Coastal Plain have low phosphate-fixing capacities.**
- **The PRI was developed to provide a simple method of determining the soil's ability to adsorb phosphorus.**
- **A soil with a PRI at about zero or less should not be given phosphatic fertilizer until a tissue or soil test indicates otherwise.**

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TINS

Fertilizer spreaders—calibration

K.J. JOHNSTON

The proper application of a fertilizer is as important as the selection of the fertilizer itself. Poor application may result in reduced fertilizer efficiency; erratic results; waste of fertilizer and damaged turf. In some cases the turf may be killed in certain areas. The use of a good fertilizer spreader which is properly adjusted is necessary to achieve optimum results at minimum cost.

Fertilizer application

The two main factors to be considered in the application of a fertilizer are:

1) The rate of application.

2) The uniformity of distribution.

The rate of application means the quantity of fertilizer applied to a unit area. This could be measured as g/m^2 or t/ha. An application higher than that recommended may result in turf damage; excessive leaching and is costly in wasted product. An application rate which is too low may result in poor product performance and will be costly if a repeat fertilizer application is required.

Of equal importance is that the fertilizer should be applied uniformly. Unfortunately, this factor is often overlooked. Fertilizer spreaders adjusted to apply the correct rate of fertilizer may not apply the material evenly. This will result in uneven and unsatisfactory turf growth because some areas received more fertilizer than others.

Rotary spreaders

When calibrating a rotary spreader, it is first necessary to determine the distribution pattern. This is done by placing fertilizer collecting trays on the ground perpendicular to the line of travel of the spreader. The collecting trays should be placed equidistant from the centre of the spreader on either side. Such trays may be made of cardboard or plastic. A square 2L ice cream container is the minimum size recommended. To obtain an adequate fertilizer sample, the spreader should pass over the collecting area at least twice in the same direction. The fertilizer in each tray is then placed into glass vessels of uniform size and shape. When these glass vessels are placed in sequence corresponding to the trays which they represent, the level of fertilizer in them will give an immediate graph of the distribution pattern of the spreader.

An example of uneven application of fertilizer showing the effect of faulty adjustment of a rotary spreader.

Setting the rate

Of the various methods which may be used to determine the rate setting of a spreader, the following gives good results with the use of minimum equipment. This method applies to those machines which the operator walks behind as it operates.

1) Determine the rate of fertilizer application in kg/100 m^2.

2) Calculate the distance to travel by the spreader to cover 100 m^2. This is done by dividing 100 m^2 by the spreading width of the spreader in metres. The width of spread may vary with different kinds and formulations of fertilizer.

3) Place 10 kg of the fertilizer into the spreader.

4) Apply fertilizer for the required distance as determined in stage 2.

5) Empty the remaining fertilizer from the spreader and weigh.

6) The loss in weight is the application rate per 100 m^2.

7) If the rate of fertilizer applied was too high or low, adjust the settings on the spreader and repeat the test.

Tractor mounted spreaders

The same principles apply except that a larger area will be needed on which to set out the test. Also, more fertilizer will be needed. It will be necessary to repeat the procedure at least three times to ensure accuracy and to confirm the results.

Benefit of calibration

The time spent in calibrating the fertilizer spreader is a small investment when compared with the savings that can be made by the efficient use of fertilizer. With better use of materials and efficient application, considerable savings may be made.

Further reading

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TINS

Sampling techniques

K.J. Johnston

Sampling for laboratory analysis

There are three common laboratory analyses used by turf managers in common with other crop producers. They are:

Soil analysis

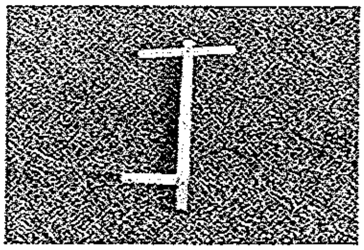
Soil testing is used to obtain information on the following:

- Soil pH;
- Soil salinity;
- The level of plant available phosphorus and potassium; and
- The ability of the soil to retain phosphorus. This is called the 'Phosphorus Retention Index' or P.R.I.

Current soil testing methods are not able to accurately determine deficiencies of trace elements. Soil samples should not be taken if fertilizer has been applied to the soil within the past month.

It is essential that soil samples should be taken at random from the site to be tested. At least 12 samples are taken and bulked together in a sample bag. This will allow for any variation in the soil on the site. An instrument such as a soil sampler should be used to take samples from a standard depth of 10 cm.

Ensure that the laboratory uses the Colwell bicarbonate test for the determination of available phosphorus and potassium and that the P.R.I. of the soil is measured.



CSBP Soil Sampler

Leaf tissue analysis

Care must be taken to avoid contamination of leaf samples taken for analysis. For this reason, samples are collected using a mower or by hand using stainless steel scissors. Scissor sampling is preferable because there is less chance of contamination. Mower blades may give metal and or soil contamination. On a low cut fine turf there is little option but to use mower sampling.

Do not take leaves for tissue analysis if there has been a recent application of fertilizer.

Sufficient leaf tissue should be collected so as to one-third fill a small paper bag such as used by bakers of cakes and pies. Paper bags are necessary as this reduces the sweating of the leaves in the bag. The samples must be immediately forwarded to the laboratory where they will be dried at 80°C. before testing.

Leaf tissue analysis gives the most useful information on the level of all essential nutrients. Most laboratories will have standard tests for nitrogen; phosphorus; potassium calcium; magnesium; copper; iron; manganese and zinc.

Water analysis

Take about 500 mL of water from the irrigation line after the system has been operating for some time. Use a thoroughly washed and rinsed cordial or cool drink container. Do not use containers that have been used to store strong acids or alkalis, such as vinegar or detergent. Standard tests of water are those of pH and salinity. Salinity is measured in milli Siemens per metre (mS/m) by electrical conductivity.

TINS

Organic sources of nitrogen

K.J. Johnston

Organic fertilizers are those derived from previously living creatures. Manures; blood and bone; humates; some sludge residues and composted plant residues are traditional organic sources of nitrogen and other plant nutrients. The early pioneers in Western Australia record how they used crushed and broken bones, and whatever manure they had to put into the holes where they planted fruit trees. Domestic gardens were fertilized with various animal manures and composts. An important addition to these organic materials were wood ashes and later guano from the Abrolhos islands.

Organic fertilizers are valued for their low burn potential since they have a low water soluble nitrogen content. They have a limited effect on soil pH and are not readily lost by leaching. An important advantage of organic fertilizers is the variety of plant nutrients these materials contain and their ability to improve the physical condition of soils. Such improvement in sandy soils is most valued.

Characteristics

Organic fertilizers contain between 1 and 13 per cent nitrogen (Table 1). Those with a high protein content have the highest content of nitrogen. The organic forms of nitrogen are found in proteins and other complex molecules. This nitrogen is tightly held by the organic matter and partial decomposition must take place before there is a release of nitrogen. Most of the nitrogen is present as an amine group within the protein molecule ($-NH_2$) and must be converted to the ammonium ion (NH_4^+) before it can be absorbed by the plant

The process which results in the release of ammonium ions from decomposing organic matter is ammonification and begins with the initiation of microbial action upon the organic matter. As this process continues, more and more of the amine groups are converted to ammonium ions. These ammonium ions are available for microbe or plant use or they may be adsorbed onto the cation exchange sites on the soil or organic matter particles.

The rate of ammonification is directly correlated to the rate of microbial decomposition. Such activity is greatest in warm; moist; slightly acidic soils that have an adequate supply of nitrogen and organic matter. Decomposition of organic matter is slower in dry and cold soils.

Table 1. Chemical analyses of some organic fertilizers. Note: *Urea is not included as the form most often used is synthetically made.*

Nutrient source	Nitrogen %	Phosphorus %	Potassium %
Animal by-product			
Dried blood	13.0	1.0	0.8
Bone meal, steamed	3.0	11.0	0.0
Dried fish meal	10.0	3.0	0.0
Tankage, animal	7.0	4 .0	0.8
Blood and bone, Bailey's	5 .0	3.0	0.0
Manures			
Cattle manure	2.0-5.0	0.7	1.7
Horse manure	2.0-8.0	0.5-1.5	1.5-5.0
Poultry manure	5.0-15.0	1.3	1.2
Pig manure	7.0	1.7	4.0
Sewage, dried	2.0	0.9	0.0
Organic 2000 Turf Start ™	4.0	1.0	1.5
Organic 2000 Turf Restore ™	8.0	1.0	4.0
Dynamic Lifter ™	3.0	2.5	1.6

Ammonium ions may be converted into nitrates during the process of nitrification. The ammonium ion is firstly oxidized into nitrite and then secondly oxidized into nitrate. Nitrates are available as nutrients for the soil microflora and other microbes and for uptake by plants. The same weather conditions which favour ammonification also favour nitrification. Likewise, the nitrification process is impeded when the soil is cold; too dry or lacks a sufficient supply of oxygen.

Adverse features

One of the most important limitations of organic fertilizers is their slow release of nitrogen during cool weather caused by a slow down in microbial activity and their initial low content of nitrogen. To counteract this problem, high rates of organic fertilizers would have to be applied. This practice could become very costly because, in most cases, the natural organic sources of nutrients are more expensive per kilogram than similar nutrients in synthetic soluble forms. Organic fertilizers are often difficult to store and apply evenly. High rates of application may cause problems with soil drainage and such fertilizers are often associated with objectionable odours after application. In addition, organic fertilizers may contain undesirable salts; heavy metals and weed seeds.

Use of organic fertilizers

On the sandy soils of the Swan Coastal Plain, the use of organic fertilizers is important on new sites for the establishment of turf and during the early stages of growth. These fertilizers provide a steady supply of nitrogen and other nutrients as well as adding much needed organic matter to the soil. While the initial contribution to soil organic matter is small, as these fertilizers are applied over time, the accumulative effect may become significant. Because of their valuable properties, organic fertilizers have a role in most fertilizer programmes, especially during the warmer months when a cost effective slow release fertilizer is required.

Raw poultry manure is and has been used at high rates on market gardens since the industry was established. The benefits of such manures are:

- The physical condition of the sandy soils is improved.
- The manure supplies a full range of plant nutrients.

The turf industry also uses poultry manure, but commonly in the form of pellets for both turf establishment and as a maintenance fertilizer. The pellets are preferred because they are easy to handle, store and spread. Furthermore, the original poultry manure has been composted and this eliminates the risk of turf burn which is often a problem if raw manure is used.

Another benefit in the use of pelletized poultry manure is the reduction in the movement of soil nitrate when compared with the movement of nitrates from the soluble nitrogenous fertilizers. One problem with the use of organic fertilizers and poultry manure pellets is the imbalance in the N: P ratio. If the organic fertilizer is used mainly as a slow release form of nitrogen, then the turf will receive more phosphorus than it needs. This results in an increase in the loss of phosphorus via leaching. This is most evident in sandy soils that have a low ability to retain phosphorus - they have a low PRI. Thus, managers must use soil tests to determine the most effective fertilizer programme to adopt.

To overcome the problem of an imbalance in the N: P ratio in normal poultry pellets, there are pelletized poultry manure products to which extra nitrogen has been added by the incorporation of a soluble nitrogenous fertilizer

Summary

The advantages of natural organic nitrogenous fertilizers are:

- **The slow release of nitrogen and other nutrients.**
- **Their low burn potential.**
- **Limited effect on soil pH.**
- **Reduced risk of nitrogen leaching.**

The disadvantages of natural organic fertilizers are;

- **Cost per unit of nitrogen is high compared with that of the soluble inorganic sources of nitrogen.**
- **Very slow release of nutrients in winter and cool weather.**
- **The high ratio of P: N increases the risk of phosphorus leaching.**

Note: Fertilizers such as potassium nitrate (saltpetre) and sodium nitrate, though they occur naturally and are derived from decayed vegetation, are not considered as organic fertilizers.

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TINS

Dry patch

K.J. JOHNSTON

Definition

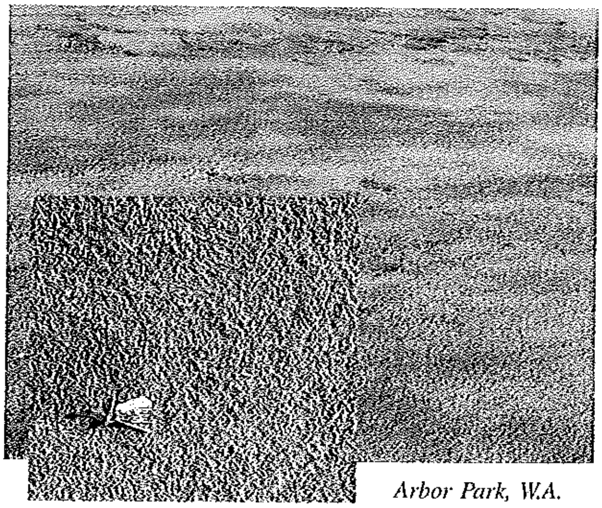
A dry area of turf of variable size which is difficult to wet because of the water repellency characteristics of the soil or thatch. The repellency has the primary effect of reducing the rate of water infiltration. The most obvious symptoms of dry patch are the resultant brown areas of dead or dormant turf which become most severe during hot, dry weather. Non wetting soils are a feature of many of the coastal sands and may cover large areas.

The cause

Water repellency develops as a result of the formation of a hydrophobic coating of organic matter on the surface of the soil particles. The more extreme cases are found in sandy soils. The sand grains are readily coated by organic material because of their low specific surface area. Water repellent soils are widespread on the Swan Coastal Plain because, in many areas, the residues of the native vegetation have been incorporated during the initial clearing.

Research during the 1990s in the United States of America, found that a non-hydrophobic soil with a 100 per cent sand root zone, on which a turf was established, developed water repellency within 6 to 18 months after establishment. This water repellency developed because of the organic matter added to the soil by the turf. A sand with no vegetation growing on it did not become hydrophobic. The same researchers found that the type of vegetation grown on the sandy soil affected the rate of development of water repellency. Bent grass resulted in the most rapid development of hydrophobicity, followed by couch and tall fescue.

Dry thatch is not a prerequisite for the development of dry patch in soils. A study of water repellent areas in the field showed that the removal of thatch from these areas did not significantly increase water infiltration into the soil. Thus, while thatch control is an important tool in the management of dry patch, thatch control alone will not prevent the development of dry patch and water repellency.

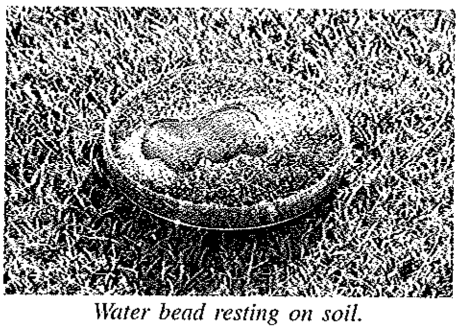


Arbor Park, W.A.

Fungi may also contribute to the coating of soil particles by organic material. These particular fungi are those mainly involved in the breakdown of thatch. When a dense population of such fungi occur, as in the case of 'fairy rings', the fungi may affect the development of water repellency.

Testing for water repellent soils

Remove a core sample from the area where dry patch is suspected. If the sand is very dry and readily falls away from the plant roots, it is a clear indication that the area has dry patch. Another simple test is to place a drop of water on the sand removed from the soil hole. If the soil is water repellent, the water drop will remain as a water bead on the surface of the soil.



Water bead resting on soil.

Control options

There are three main options available for the control of water repellent soils.

1) Soil amendments

The best long term option for the control of water repellent soils is to add a wettable soil amendment to the area. Ideally, these soil amendments should not contain too much clay. This is because the clay may set into hard lumps and is then difficult to mix into the soil. Similarly, soil amendments should not contain too much coarse sand. The fine particles in mineral soil amendments act to increase the water holding capacity of the soil. By this means, the water repellency is reduced as a large wettable surface area is difficult to coat with water repellent organic matter.

While some local soils make good soil amendments for the coastal sandy soils, they are often available in only limited supply and are cost prohibitive. Because of this, one approach is to use mineral by-products from industrial sources. Two such by-products which have been tested in turf areas are Alkaloam and fly ash.

Alkaloam

Alkaloam is the residue derived after the alumina in bauxite has been dissolved out with caustic soda. The material that does not dissolve is called bauxite residue or red mud. It is now named Alkaloam. When Alkaloam is applied at rates of from 100-500 t/ha and incorporated into the surface 20 cm of the soil, there is enough fine material to overcome water repellency and improve the water holding capacity of the soil. Alkaloam is an alkaline fine red loam which rapidly changes the pH of acidic sandy soils. Depending upon the initial soil pH, application rates of >200 t/ha will result in a final pH above 8. This adversely affects the availability of manganese in some turf grass areas.

The disadvantages of using Alkaloam are:

- Its ability to stain carpets and clothing;
- Its poor preparation which results in clods or hard lumps in the product when delivered; and
- Its high pH.

There are several advantages in the use of Alkaloam which are:

- Its high surface area caused by its fine particle size. This helps to overcome water repellency and increases the water holding capacity of the soil;
- Its ability to make acidic soils alkaline; and
- Its ability to strongly retain environmentally sensitive nutrients such as phosphorus and reduce the leaching of such nutrients.

Fly ash

Fly ash is a fine, grey, silty-like material that is recovered from the flue gases of coal fired power stations. It has a pH of between 6.5 and 7.5 and is often about neutral in reaction. The material has been used on turf farms at the rate of 150 t/ha incorporated into the surface 10 cm of soil. It improves the water holding capacity of the soil and reduces the effects of water repellency. The water holding capacity of fly ash is greater than that of sand and its particles have a surface area some 27 times that of a coarse sand.

The main advantages in the use of fly ash are because, as it is such a finely divided product, it is easily mixed with sand; there are few if any lumps; it has a high water retention capacity and its almost neutral pH. The main disadvantage of fly ash is the problem of dust generated from the material if it is allowed to dry out before use and incorporation into the soil.

2) Soil wetting agents

Wetting agents are surfactant chemicals which are of the same chemical group as household detergents. Certain of these surfactants are used on water repellent soils to increase water infiltration. These materials are used to prevent or to treat areas of dry patch. Wetting agents work by reducing the contact angle between the solid soil particles and the applied water. This increases the infiltration rate of the water applied either as irrigation or rain.

Wetting agents vary widely in their initial ability to increase water infiltration rates and in their residual effects. The effectiveness of these products depends upon the type of material used; the application rate and the concentration of the material applied. Care must be taken to select a proven product which must be applied as directed.

There may be some negative effects from the use of wetting agents caused by foliar contact or root uptake. Foliar contact can rarely be avoided, so that the best way to avoid leaf burn is to use the recommended application rate; spray during the coolest part of the day and water immediately after application. Phytotoxicity caused by root uptake should not be a problem for deep rooted warm season grasses at recommended rates of application.

The best time for the first application of a soil wetting agent is in early spring, before dry patch develops, at a rate of 50 L/ha. Follow up sprays may be needed on severely affected areas, or over the entire area if the effective life of the material does not cover the full dry season. Some managers have adopted the method used in agricultural practice of band spraying of the wetting agent. This technique appears to give acceptable results at a reduced rate (volume) of application per unit area.

3) Irrigation

Irrigation may be used in many turf situations to maintain soil moisture levels and thereby avoid the development of dry patch. Irrigation water must be applied evenly, and at the optimum rate and frequency. This method of controlling dry patch is limited by the uniformity of water distribution from the irrigation system. With poorly designed systems, over watering may result. Also, wetting agents alone will not prevent the development of dry patch if areas are inadequately watered.

Summary

- **Dry patch is commonly observed on the sandy soils of the Swan Coastal Plain. It is caused by the low surface area of the sand particles becoming coated initially with the hydrophobic residues of the native vegetation.**
- **The most simple method of testing for dry patch is to remove a core of turf. If the sand is dry and readily falls away from the plant roots, this is a clear indication of dry patch.**
- **Prevention is the best means to manage dry patch. This may be done by applying a soil amendment before turf establishment; by applying a soil wetting agent in spring before the soil begins to dry out and by not allowing the soil to dry out during summer by maintaining regular irrigation.**
- **Further research is needed to determine the cost effectiveness of soil amendments in overcoming the problem of non wetting sandy soils; in improving their water capacity and in nutrient retention.**

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TINS experiments

TINS

Phosphorus—determining the amount required

K.J. JOHNSTON

Introduction

The role that phosphorus plays in plant nutrition has been known since the 19th Century. Among the first experiments done in Australia with phosphatic fertilizers were those of Professor Custance at Roseworthy Agricultural College in South Australia in 1881. In Western Australia, guano from Houtman's Abrolhos, west of Geraldton was mined and exported from 1884. In 1894, Cross super was imported from Scotland for P.D. Padbury at Moora. The first experiments with phosphatic fertilizers by the Department of Agriculture were those of G. Berthoud with wheat at Hamel,100 km south of Perth from 1899 to 1903. Local manufacture of superphosphate commenced in 1910 by Cumming Smith and Company at Bassendean.

Although Western Australia has a long history of research with fertilizers in the cereal industries and later in pastures and horticulture, there has been little study of the use of phosphatic fertilizers on the establishment of turf grasses on the sandy soils of the Swan Coastal Plain. ***When the TINS project was initiated, the fact finding survey, which began in 1990, found that most established turf grass sites had adequate levels of soil phosphorus.*** Furthermore, many of the soils had limited ability to retain further applied phosphorus. Because of the community concern regarding the contamination of waterways with phosphorus and other plant nutrients, increasing efforts are now being made to minimize the use of phosphorus to that which will sustain turf grass quality.

It is important to improve the efficiency of uptake of phosphorus by turf as this decreases the excess loading of phosphorus into the environment. There are four ways in which this goal may be achieved:

1) The selection of realistic goals for turf grass quality.
2) The selection of appropriate phosphatic fertilizer application rates to meet these quality goals.
3) The use of soil and leaf tissue tests to assist in the establishment of suitable application rates.
4) The keeping of good records of fertilizer histories for turf grass areas.

To determine the residual effect of phosphatic fertilizer, various sandy soil sites, established to turf, were selected which had a range of phosphorus absorption capacities as measured by the Phosphorus Retention Index (PRI). The areas selected were:

1) Dryandra Pendula Reserve, Mirrabooka. This turf area was about eight years old planted to Greenlees Park couch. Phosphorus Retention Index, 2 at the surface and 3 at depth. Bicarbonate extractable phosphorus in the surface 10 cm was 8 mg/kg (8 ppm).

2) Highview Park, Alexander Heights. A new turf area being established to kikuyu. Phosphorus Retention Index, about 5 at the surface and greater at depth. Bicarbonate extractable phosphorus was 2 mg/kg (2 ppm).

3) Dianella ROS, Dianella. A turf about seven years old planted to an unknown cultivar of couch. Phosphorus Retention Index, zero. Bicarbonate extractable phosphorus was 6 mg/kg (6 ppm).

The aim of the experiment was to monitor the retention and movement of phosphorus in the surface 25 cm of soil following a single application of a phosphatic fertilizer applied at different rates. The purpose was to show which rate of fertilizer was most effective at each site to limit leaching and to sustain turf quality. Furthermore, to determine how such information could be used by turf managers to improve the use efficiency of phosphatic fertilizers.

Materials and methods

Superphosphate was applied at rates of 0; 10; 20; 50; 100 and 200 kg P/ha. The plots measured 5 m x 2 m = 10 m^2. There were three replications. The fertilizer was applied at the beginning of spring on September 27, 1994 on all plots except the control. Soil samples were taken for phosphorus analysis in March, 1995, September, 1995 and March, 1996. The soil samples were taken from two profile depths; 0 to 10 cm and 10 to 25 cm. Three plugs of soil were taken from each replicate and bulked together with samples from other replicates of that treatment. Leaf tissue samples were taken in March, 1995 and in March, 1996 at the same time as the soil sampling. The leaf tissue samples were used to correlate growth differences between the treatments and nutrient concentrations in the tissue. Growth was determined by leaf dry weight measurements from the treatments.

All treatments, including the control, received monthly applications of sulphate of ammonia during the 1994/95 and 1995/96 growing seasons of September to April at the rate of 50 kg N/ha. Potassium chloride was likewise applied to all plots at the beginning of each growing season at the rate of 100 kg K/ha.

All plots were mowed each week with the clippings being returned to the plots. The irrigation practice applied was that as used by the respective local government authorities. The Highview Park experiment ended at the conclusion of the 1994/95 season when the park was topdressed with sand to correct variations in the surface levels.

The results were not statistically analysed. This means that the results are indicative only.

Results

Six months after the application of superphosphate in March, 1995, the levels of bicarbonate extractable phosphorus (B.E.P.) in the surface 10 cm of soil at each site, was higher than that of the control plots at each site (Figures 1; 4; 7). The greatest increase in B.E.P levels in the surface 10 cm was for the highest application of phosphorus at Highview Park. Superphosphate applied at the other two sites at the highest rate of application gave comparatively small, increases in B.E.P. in the surface 10 cm at Dianella ROS and intermediate increases at Dryandra Pendula.

The B.E.P levels at the 10 to 25 cm soil depth did not always corresponded with the results obtained for the 0 to 10 cm soil depth. The B.E.P levels were higher for all plots treated with phosphorus as compared with the controls. With the exception for Highview Park where there was no difference for rates of applied phosphorus up to and including 50 kg P/ha (Figures 2; 5; 8). The largest increase in B.E.P. in the 10 to 25 cm soil layer was for the highest rate of applied phosphorus at Dryandra Pendula when this might have been expected to occur at Dianella ROS.

Soil tests taken in March, 1996, one year after the initial soil tests, showed that the B.E.P. levels had declined slightly for both soil depths at the remaining sites of Dianella ROS and Dryandra Pendula. The same trends were evident as recorded in the March, 1995 results (Figures 1; 2; 4; 5).

Leaf tissue samples taken in March, 1995 and March, 1996, showed that the level of phosphorus in the leaf increased as the level of the B.E.P. in the soil increased (Figures 3; 6; 9). Leaf dry weight data from the kikuyu sward at Highview Park showed that the growth rate of kikuyu was reduced when leaf tissue levels of phosphorus fell below 0.2 per cent (Figure 10).

Leaf dry weight data from Dryandra Pendula and Dianella ROS indicated that the growth rate of couch had not been affected by the declining soil levels on B.E.P. (Table 1).

Table 1. Leaf dry weight data from Dryandra Pendula and Dianella ROS reserves, March 1996. Samples taken using a reel mower.

Rate of P application kg P/ha	Dry weights - g/m²	
	Dryandra Pendula	Dianella ROS
0	22	33
10	36	44
20	29	39
50	35	38
100	24	36
200	30	44

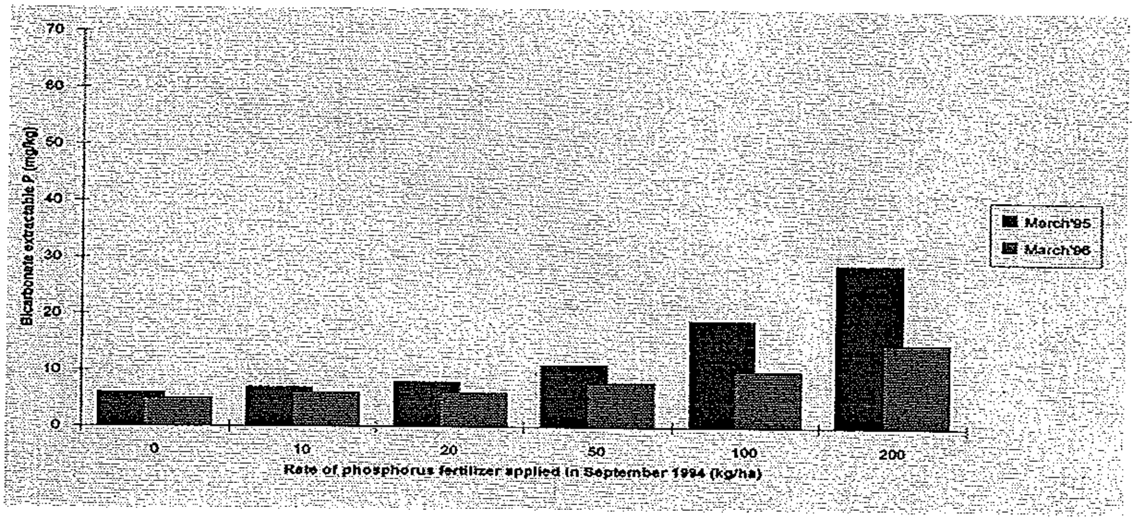

Figure 1. Dryandra Pendula. Greenlees Park couch grass. Soil depth 0 - 10 cm. Samples taken in March, 1995 and March, 1996.

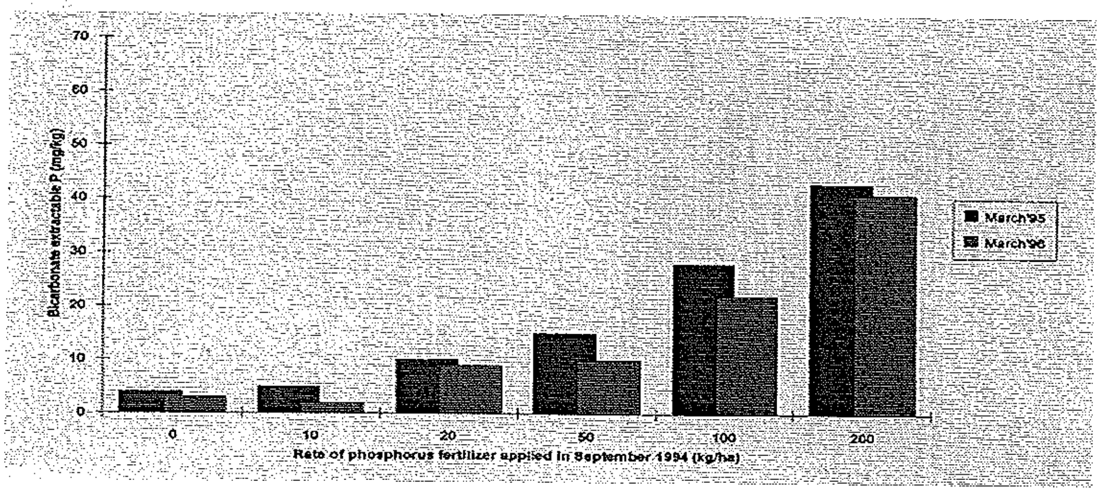

Figure 2. Dryandra Pendula. Greenlees Park couch grass. Soil depth 10 - 25 cm. Samples taken in March, 1995 and March, 1996.

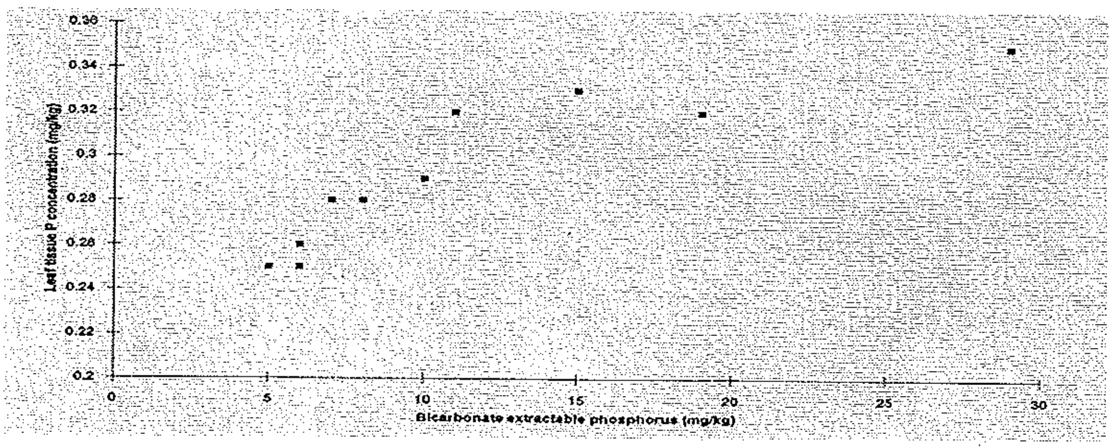

Figure 3. Dryandra Pendula. Relationship between soil P concentration (0 - 10 cm) and leaf tissue P concentration for Greenlees Park couch.

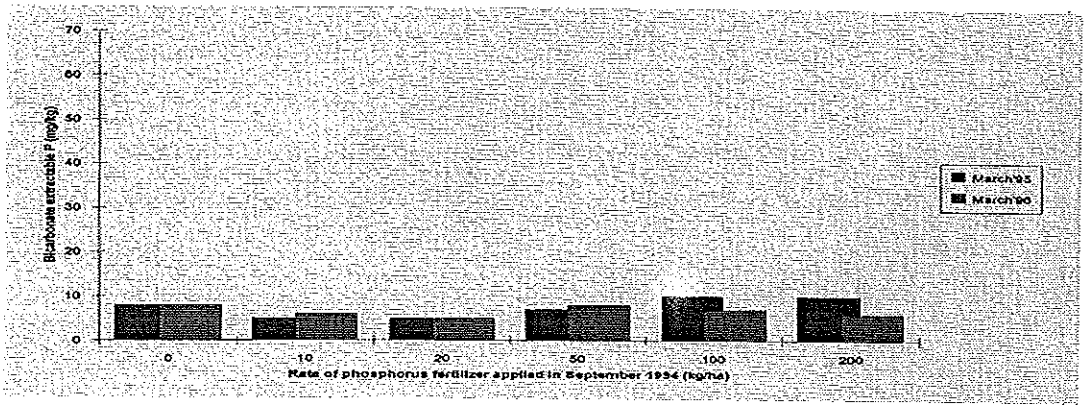

Figure 4. Dianella ROS. Soil depth 0 - 10 cm. Samples taken in March, 1995 and March, 1996.

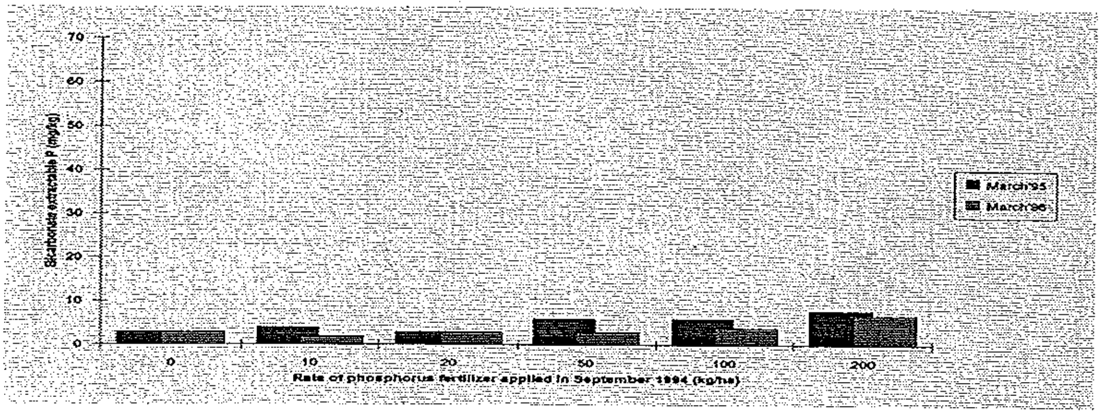

Figure 5. Dianella ROS. Soil depth 10 - 25 cm. Samples taken in March, 1995 and March, 1996.

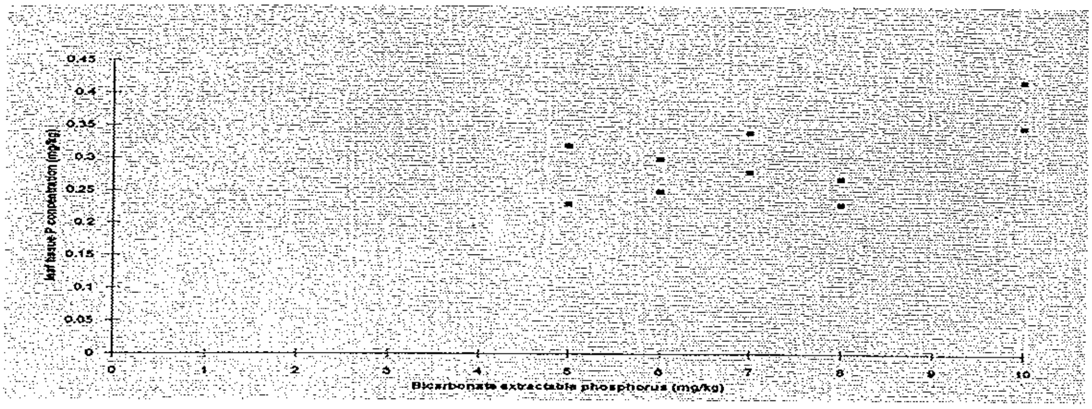

Figure 6. Dianella ROS. Relationship between soil P concentration and leaf tissue P concentration. Soil depth 0 - 10 cm. Couch grass.

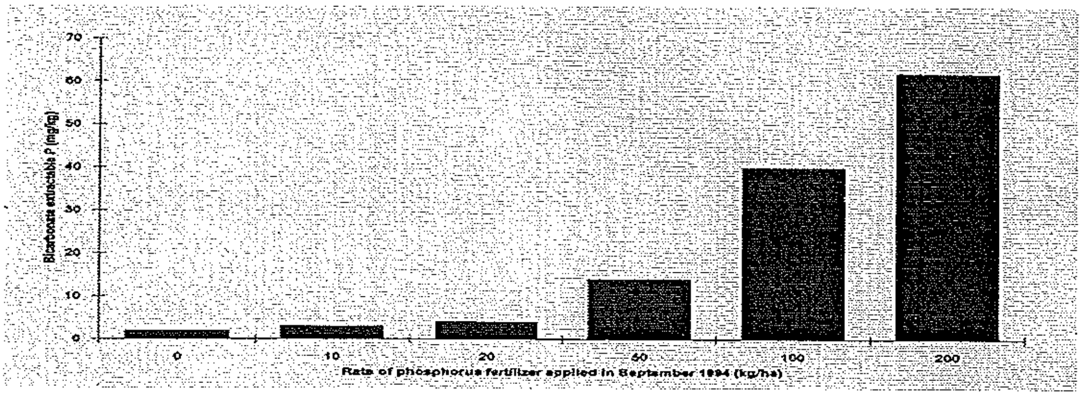

Figure 7. Highview Park. Relationship between rate of soil P application and bicarbonate extractable phosphorus. Soil depth 0 - 10 cm. Kikuyu grass.

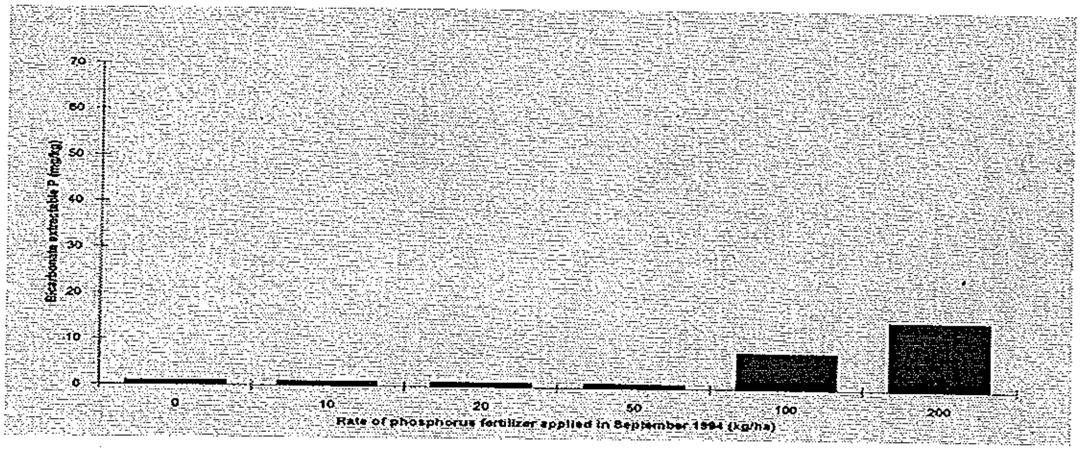

Figure 8. Highview Park. Relationship between rate of soil P application and bicarbonate extractable phosphorus. Soil depth 10 - 25 cm. Kikuyu grass.

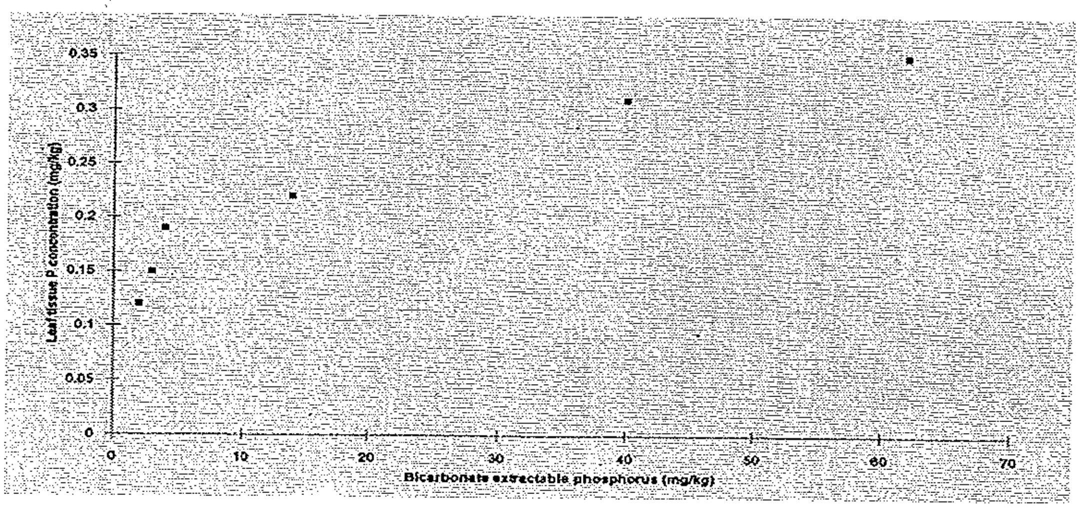

Figure 9. Highview Park. Relationship between rate of soil P application and leaf tissue P concentration - mg/kg.

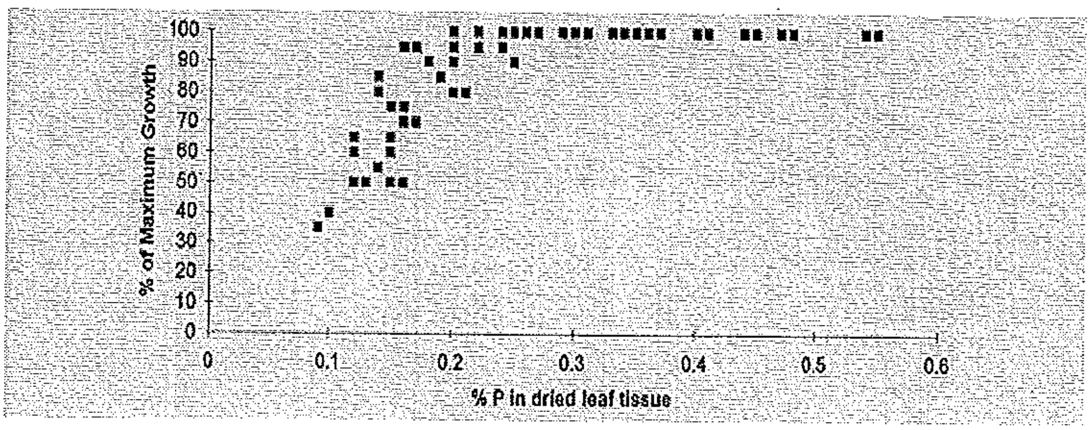

Figure 10. Highview Park. Relationship between the growth of kikuyu and the concentration of P in the leaf tissue - all harvests.

Discussion

The results showed that applied phosphorus is readily retained in sandy soils with a relatively high PRI and that it moves quickly through a sandy soil with a low PRI. There was no movement of phosphorus below the surface 10 cm of soil at Highview Park after six months for an application rate as high as 50 kg P/ha. High rates of phosphorus application resulted in slightly elevated B.E.P levels at a soil depth of 10 to 25 cm. However, it is considered unlikely that significant quantities of phosphorus moved beyond the 25 cm layer.

At Dianella ROS the results were different with a higher amount of phosphorus passing through both layers of soil which could not be accounted for by the B.E.P. determinations. At Dryandra Pendula, much of the applied phosphorus was retained in the surface 25 cm of soil with most being held in the 10 to 25 cm layer. This was because of the higher PRI of the soil at this depth.

The main implication of the findings from this research was the need for testing of the sandy Swan Coastal Plain soils so as to determine the rate at which phosphorus should be applied. Sites that have a low PRI should not receive > 5 kg P/ha. Rates of 5 - 100 kg P/ha should only be used on soils with a high PRI and then only when such a need is demonstrated either by low B.E.P. soil levels or low leaf tissue levels of phosphorus.

The B.E.P. level at which turf grass growth is affected is dependent upon the phosphorus adsorption properties of the soil. In the first year of the experiment at Highview Park, phosphorus became limiting at B.E.P. levels of about 10 mg/kg. At the other two sites, the B.E.P. levels were down to 5 mg/kg at the end of the second season without any measurable differences in growth.

It is not known when turf grass growth becomes limited by a deficiency of phosphorus as may be shown by the soil B.E.P. levels. Likewise, the level of leaf tissue phosphorus at which growth is reduced is unknown.

Further work on soil phosphorus levels as part of the TINS project on another couch grass site, indicated that the critical leaf tissue concentration for phosphorus is about 0.2 per cent. ***Growth was reduced by almost 50 per cent when leaf tissue phosphorus levels were 0.18 per cent.***

Summary

- **Many turf grass sites established on sandy soils in the Perth area have a low PRI.**
- **For low PRI soils in this experiment, for the high rates of phosphorus application of 100 to 200 kg P/ha, a high percentage of the phosphorus had leached through the surface 25 cm of the soil six months after application.**
- **Most of the phosphorus from the high rates of application was retained in the surface 25 cm of soil which had a high PRI.**
- **Sites with a low PRI should not receive > 5 kg P/ha.**
- **Sites with a high PRI may have up to 100 kg P/ha applied with a minimal risk of losses through leaching.**

TINS

Potassium—determining the amount required

K.J. Johnston

Introduction

Sandy soils which are low in organic matter have a low cation exchange capacity (CEC) and thus have a limited ability to retain applied potassium. Because of this, it is not possible to build up the level of potassium in the soil and amounts in excess of plant requirements will be readily leached. This means that the recommendation for such soils is to apply a potassic fertilizer regularly and at low rates.

To test the residual effect of a potassic fertilizer, a suitable sandy site was selected on a turf area about eight years old planted to Greenlees Park couch. This was located at the Dryandra Pendula Reserve in Mirrabooka. The soil had some 0.7 per cent of organic matter in the surface 10 cm. The aim of the experiment was to monitor the retention of potassium within the first 10 cm of the soil surface from a single application of a potassic fertilizer over a period of ten weeks. The purpose was to show which rate was the most effective under the conditions which existed at the site and how this information could be used by turf managers to improve the efficiency of use of potassic fertilizers.

Materials and method

The potassic fertilizer used was potassium chloride applied at rates of 0; 25; 50; 100 and 200 kg K/ha. All plots measured 5 m x 2 m (10 m^2) and there were three replications. The fertilizer was applied on September 26, 1995 at the beginning of spring on all plots except the control plot. Soil samples were taken at intervals of two weeks which began two weeks after the initial fertilizer application. There were five series of soil samples. Leaf tissue samples were taken at six weeks and ten weeks after the fertilizer application. In addition, sulphate of ammonia was applied four weeks and eight weeks after the original application of the potassic fertilizer, at the rate of 50 kg N/ha.

There was 126 mm of rain during the test period, with 68 mm of rain during one day. This latter event was between the two and four week sampling time.

The turf was mowed each week with the clippings being returned to their respective plots. Irrigation was as per the standard practice of the City of Stirling which meant that the plots were watered five nights per week during which about 8 mm of water per irrigation was applied.

The results were not statistically analysed.This means that the results are indicative only.

Results

Two weeks after the application of the potassium chloride fertilizer, the levels of bicarbonate extractable potassium in the soil were elevated for all rates of applied fertilizer. Thereafter, the level of soil potassium declined over time.

After six weeks, the potassium levels were almost equivalent to the original levels for all rates of application except for the 200 kg K/ha rate which did not reach base levels until week 10 (Table 1 and Figure 1).

Table 1. Soil levels of bicarbonate extractable potassium from two to 10 weeks following application of a potassic fertilizer at prescribed rates. Applied 26/09/1995.

Soil bicarbonate extractable potassium - mg/kg					
Rate of K	Weeks				
kg/ ha	2	4	6	8	10
0	19	24	19	18	16
25	27	23	20	21	19
50	30	32	22	26	19
100	56	40	23	26	23
200	86	53	30	39	22

Note: 69 mm of rain between weeks 2 and 4. Total rain for the 70 day period was 126 mm. Otherwise, irrigated 5 days/week at 8 mm/irrigation.

Leaf sample analyses taken at six and 10 weeks, showed that the level of potassium in the leaf increased as the level of potassic fertilizer applied increased. (Table 2.) This was most evident in the sampling done at six weeks after fertilizer application. At 10 weeks, the differences in the concentration of potassium in the leaf appeared minimal for all fertilizer rates of potassium applied.

Table 2. Per cent of potassium in leaf tissue tested at six and 10 weeks after potassic fertilizer applied at prescribed rates.

Per cent potassium in leaf tissue		
Rate of K kg / ha	6 weeks	10 weeks
0	1.29	1.47
25	1.28	1.50
50	1.38	1.65
100	1.44	1.57
200	1.52	1.75

Note: The cause of the increased percentage in levels of potassium in the leaf between six and 10 weeks needs further investigation.

Discussion

The results show that applied potassium moved quickly through the sandy soil profile on which the turf grass was growing. About 80 per cent of the applied potassium at the two highest rates of fertilizer application had passed through the surface 10 cm of soil within two weeks. This was in the period of standard irrigation before there was a heavy fall of rain. For deep rooted turf grass species such as couch grass, the root system still has the ability to intercept much of this potassium even after it has passed through the surface 10 cm. However, for bent grass which is shallow rooted, much of the potassium moving beyond the surface 10 cm the soil will evade the effective root system and escape.

In most Council managed parks and reserves, potassic fertilizers are applied at rates of between 10 to 20 kg K/ha. The results of this experiment indicative that low rates of potassic fertilizers should be applied every six to 12 weeks where the CEC of soil is low. By this approach, an adequate supply of soil potassium may be maintained without excessive losses caused by leaching.

Leaf analyses showed that even at high rates of potassic fertilizer application, the level of leaf potassium only slightly increased. In couch grass, a leaf potassium level of below 1.0 per cent is considered as deficient.

Summary

- **Sandy soils which are low in organic matter have a low CEC and thus have a limited ability to retain applied potassium.**
- **At the high rates of applied potassium in this experiment, some 80 per cent of the nutrient had leached through the surface 10 cm of the soil within two weeks.**
- **Even at the high rate of potassic fertilizer application of 100 kg K/ha, the level of potassium in the couch grass leaf tissue only slightly increased above that of the lower rates of fertilizer. At 200 kg K/ha of fertilizer, the leaf potassium per cent was higher, but still only marginally better than that of the 100 kg K/ha rate.**
- **The evidence is that potassic fertilizers should be applied 'little and often' on soils with a low CEC to achieve efficient use by the plant of the applied potassium.**

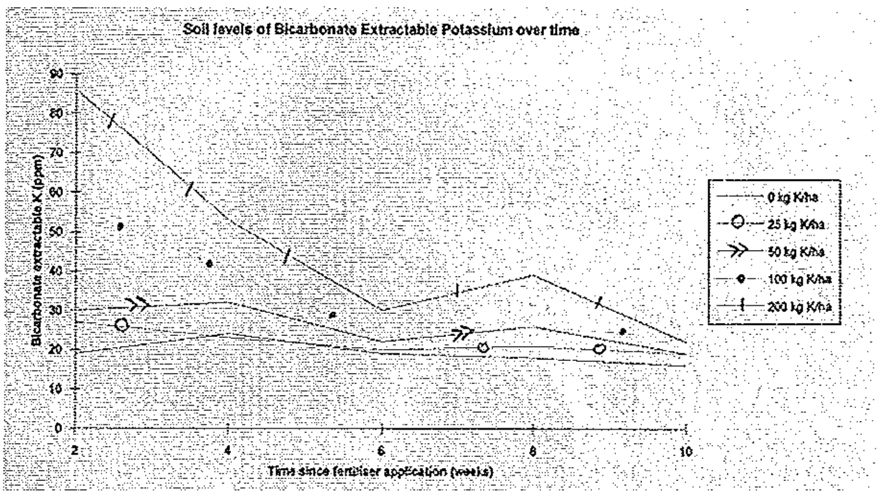

Figure 1. Soil concentration of bicarbonate extractable potassium at 2; 4; 6; 8 and 10 weeks after potassic fertilizer application. Measured in mg/kg (ppm).

TINS

Foliar applications of Fe and Mn

K.J. Johnston

Introduction

Many turf swards adjacent to the coast in the Perth area are established on alkaline soils. Some of these calcareous sands have a pH of 8.2 or greater. This means that turf established on these sites commonly suffer from deficiencies of iron and manganese.

Unfortunately, these deficiencies are difficult to correct with applied fertilizers which contain iron and manganese, because these micronutrients become unavailable to the plant when they come in contact with the soil. This means that iron and manganese are often applied as foliar sprays with the nutrients being taken into the plant via the leaves. Alternatively, lowering the soil pH is an effective way to overcome deficiencies of iron and manganese as shown in turf research in Florida in the United States of America.

An experiment was done to compare the response of three common turf grass species to foliar applications of iron and manganese either alone or in combination. The site of the test plots was at Mirror Park, City of Wanneroo, using couch, kikuyu and saltene as the test species. The aim of the work was to determine which treatment method gave the best result in the control of the deficiencies of iron and manganese.

Materials and method

Leaf samples were taken of the three turf species before either the basal and foliar fertilizers were applied. The soil applied basal fertilizer was broadcast on the plots. This comprised:

- Sulphate of ammonia (ammonium sulphate) at 50 kg N/ha
- Muriate of potash (potassium chloride) at 100 kg K/ha
- Superphosphate at 100 kg P/ha

The plots measured 2 x 2 m. There were no replications.

Foliar treatments

The foliar sprays were applied on December 12, 1994 and the treatments were:

- Control - no treatment
- Manganese sulphate at 1.25 kg Mn/ha
- Iron sulphate at 1.25 kg Fe/ha
- Manganese sulphate and iron sulphate each at 1.25 kg/ha active ingredient, mixed together.

Leaf samples

Leaf samples from the twelve plots were taken two weeks after the foliar sprays were applied and analysed for iron and manganese. Further leaf samples were taken in February, 1995 to determine the residual effects of the nutrient application.

Visual assessments

These were made one week and two weeks after the initial spray treatment.

Results

Table 1 shows the extremely low levels of iron and manganese in the three turf grass species as determined by leaf analysis before any fertilizer was applied. All grass species had poor leaf colour and density. The best of the three grasses was saltene.

Table 1. Leaf tissue levels of micronutrients for couch, kikuyu and saltene before basal fertilizer applied.

	Cu mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg
Couch	7.9	70	4.1	35
Kikuyu	9.2	65	3.2	33
Saltene	8.2	65	5	25

Cu Copper   Fe Iron
Mn Manganese   Zn Zinc

The data in Table 2 shows the relative comparisons which may be made between the leaf tissue levels of nutrients at the first sampling before fertilizer applied. Kikuyu had the highest leaf tissue levels of nitrogen; phosphorus and potassium of all the grass species. Couch had the highest levels of calcium, but was low in potassium and magnesium. Saltene had the highest levels of all cations including sodium and was high in sulphur.

Foliar applications of iron and manganese caused significant increases in the leaf tissue levels for these nutrients in the three grass species. See Figures 1 and 2. However, when the iron and manganese applications were combined, the iron and manganese concentrations in the leaf tissue were lower than when each element was applied alone.

Leaf tissue samples taken two months after the foliar application showed that the nutrient levels had returned to their original low levels. See Figure 3.

Visual assessments showed that only the couch grass plots showed treatment differences. The couch control plot did not 'green-up' as evenly as the plots which received iron and/or manganese in addition to the basal fertilizer. See photos 1 and 2. The foliar treatments on the kikuyu and saltene plots did not result in any further improvement over the response to the basal fertilizer. See photos 3 and 4.

Discussion

A comparison of the data from this experiment, and that from other TINS surveys and literature research, indicated that the initial leaf tissue levels of iron and manganese were sufficiently low for growth and metabolism to be affected in the couch and kikuyu. Leaf tissue levels of iron and manganese in the saltene plots were equally low. No information has been sighted of the nutrient sufficiency levels for saltene.

Saltene had a superior visual quality when compared with couch and kikuyu. This may be caused by saltene being better adapted to the alkaline conditions. It seems that saltene has a different mechanism for nutrient uptake to that of couch and kikuyu. This is indicated by the higher levels of sodium and sulphur in the leaf tissue of saltene when compared with couch and kikuyu grown under the same soil and environmental conditions.

Both kikuyu and saltene gave an excellent response to the application of the basal fertilizer alone. This showed that a beneficial colour and growth response may be obtained without the need for a foliar application of micronutrients. Nevertheless, the leaf tissue levels of iron and manganese were only raised marginally by the basal fertilizer. This may have been caused by the diluting effect of the increased growth.

The increase in the availability of micronutrients to the grass could have resulted from three causes:

- From impurities in the basal fertilizer.
- The acidifying effect of the fertilizer.
- An increase in nutrient uptake because of the increased availability of nitrogen.

The poor and patchy response of the couch grass is typical of field observations when a nitrogenous fertilizer is applied to a turf which is deficient in iron and /or manganese.

Table 2. Leaf tissue levels of macronutrients for couch, kikuyu and saltene before basal fertilizer applied.

	N %	P %	K %	Na %	Ca %	Mg %	S %
Couch	2.39	0.28	1.22	0.22	0.85	0.16	0.30
Kikuyu	2.87	0.45	2.89	0.16	0.57	0.30	0.23
Saltene	2.34	0.28	2.06	0.52	0.81	0.36	0.82

N	Nitrogen	Ca	Calcium
P	Phosphorus	Mg	Magnesium
K	Potassium	S	Sulphur
Na	Sodium	%	per cent

Photo 1. Mirror Park. The four couch plots. Control plot at right rear showing typical blotchy appearance one week after the test plots sprayed. Taken 19/12/94.

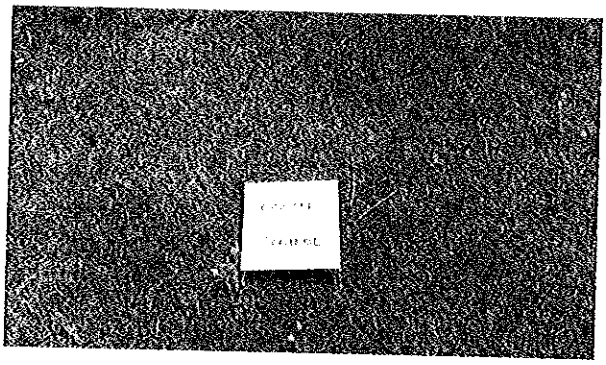

Photo 2. Couch control plot. Taken 19/12/94. Note blotchy appearance.

Photo 3. The four kikuyu plots with control at left rear. Taken 19/12/94 one week after foliar application. Right rear = Mn; left front = Fe; right front = Mn + Fe.

Photo 4. Saltene plots one week after foliar application. Taken 19/12/94. Left rear = control; right rear = Mn; left front = Fe; right front = Mn + Fe.

Photo 5. Mirror Park. Couch grass on left and saltene on right. Shows the better colour retention of the saltene under conditions of low nitrogen and alkaline soil. Taken 6/12/94.

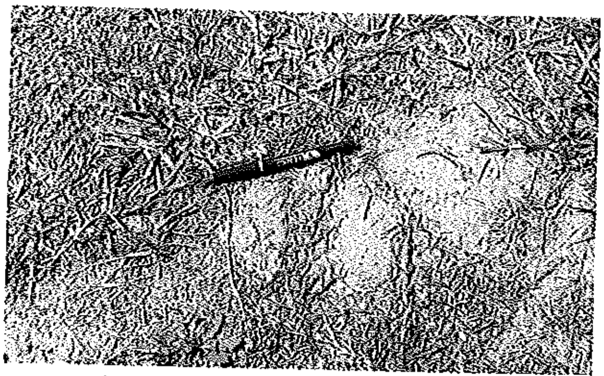

Photo 6. Mirror Park. The invasion of the kikuyu sward by saltene. Taken 6/12/94.

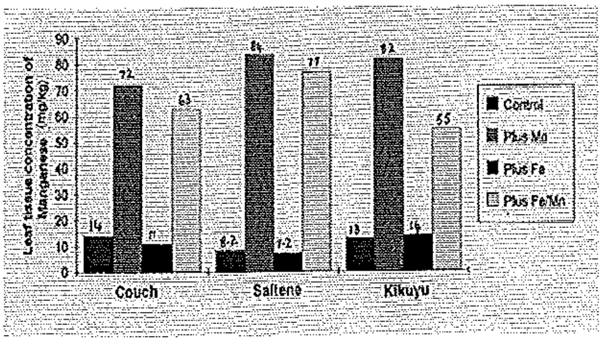

Figure 1. The effect of foliar applied iron and manganese on the concentration of manganese in the leaf tissue of the three turf grass species.

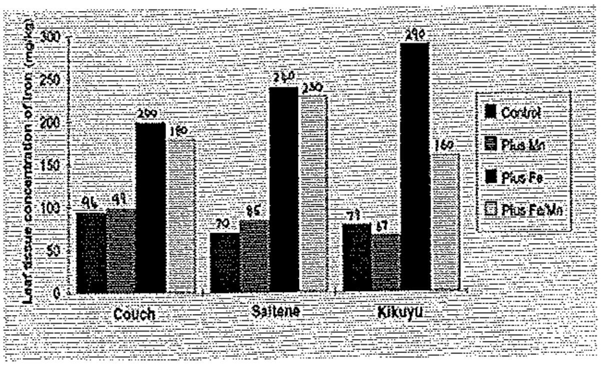

Figure 2. The effect of foliar applied iron and manganese on the concentration of iron in the leaf tissue of the three turf grass species.

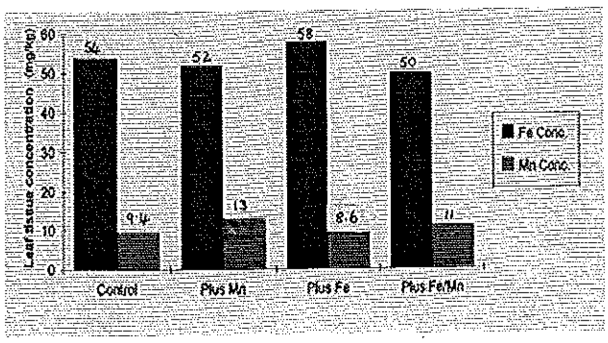

Figure 3. The concentration of iron and manganese in the leaf tissue of kikuyu for the four treatments, two months after foliar application.

Conclusions

There are practical difficulties with the management of turf on alkaline soils.

While an adequate growth response may be achieved with an application of maintenance fertilizer, such a response may often be limited by a deficiency of iron and manganese. This means that iron and manganese should be applied on a regular basis as a foliar spray if it is not possible to lower the soil pH to below 7.0 by the use of acidifying fertilizers such as sulphate of ammonia.

Observations of the test plots showed that saltene is better adapted to such severe calcareous alkaline conditions than are couch and kikuyu. See photos 5 and 6.

The initial results from this work showed that much research could be done to investigate the micronutrient nutrition of turf grasses on alkaline soils. If grasses could be selected which perform well under such alkaline conditions, turf management could be made easier and obviate the need for foliar applications of micronutrients.

Summary

- **If the turf site is alkaline, poor growth responses to nitrogenous fertilizers may be caused by deficiencies of micronutrients.**
- **Leaf tissue analysis is the only effective method to determine if deficiencies of micronutrients are limiting growth.**
- **Foliar application of micronutrients, such as iron and manganese, will rapidly correct such deficiencies.**
- **Foliar applications need to be made regularly. This is because plant tissue levels of iron and manganese decline over time as the plant grows and the nutrients are not translocated.**
- **Careful consideration must be given in the selection of grass species which may be grown on alkaline soils. Determine the relative performance of the main grass species available.**
- **Research needs to be done in the management of micronutrient nutrition on alkaline sites and in the development of species and cultivars suited to such conditions.**

TINS

Nutrient investigations

K.J. Johnston

Introduction

Leaf tissue analyses of turf grasses during the TINS experiments showed that the level of nitrogen availability in the soil appeared to affect the uptake of other plant nutrients such as phosphorus and potassium. This indicated that while the soil within the root zone may contain adequate levels of these nutrients, they virtually became unavailable because of the low level of available nitrogen.

In many turf areas it has become common practice to apply a compound fertilizer mix containing NPK in the ratio of about 8: 1: 4 . The accepted theory is that this ratio of applied nutrients will keep the nutrition of the turf grass in balance. Under certain circumstances, the application of nitrogen alone could encourage unnecessary leaf growth at the expense of the health of the turf.

To investigate the effect of nitrogen on the uptake of other plant nutrients, a series of simple experiments were designed to compare applications to turf of either nitrogen alone and that of a complete fertilizer.

Materials and methods

Six test sites were selected by staff of the City of Stirling on which to conduct the experiments. They were:

Lake Gwelup Reserve
Morley/Woodchester Reserve
Reader Reserve
Robinson Reserve
Ted Cross Reserve
Woodlands Reserve

The dominant grass on each reserve was kikuyu. Soil samples from 0 - 10 cm deep and leaf tissue samples, taken with a mower, were collected on January 18, 1996. At each site, two adjacent plots each 2 x 1 m, were marked out for future testing. On March 11, 1996, the following fertilizers were applied by hand:

Plot 1. Sulphate of ammonia (21 % N). Applied at 480 kg/ha equivalent to 100 kg N/ha

Plot 2. NPK Blue Special ™ (11.8 % N; 6.0 % P; 15.6 % K; 8.3 % S; 0.05 % Cu; 1.0 % Mg; 0.13 % Mn and 0.05 % Zn). Applied at 830 kg/ha equivalent to 100 kg N/ha

The fertilizer applied to each plot was watered in immediately after application. Visual assessments and leaf tissue samples were taken on March 26, 1996. The leaf samples were analysed for N; P; K; Na; Ca; Mg; S; Cu; Fe; Mn and B.

Results

Table 1 shows the soil test data before the application of fertilizer to the test plots. General comments on the status of each test site before fertilizer application are as follows:

- Lake Gwelup Reserve. High pH, normal levels of organic matter, good levels of phosphorus and potassium; low PRI.
- Morley / Woodchester Reserve. Ideal pH; high levels of organic matter; good levels of phosphorus and potassium; low PRI.
- Reader Reserve. Low pH; very high organic matter; good levels of phosphorus and potassium; very high PRI
- Robinson Reserve. Ideal pH; high levels of organic matter; good levels of phosphorus and potassium; low PRI.
- Ted Cross Reserve. Slightly high pH; high levels of organic matter; good levels of phosphorus and potassium; low PRI.

- Woodlands Reserve. Ideal pH; high levels of organic matter; adequate levels of phosphorus; good levels of potassium; low PRI.

All sites had good levels of phosphorus and potassium; high levels of organic matter; low PRI, but variable soil pH.

Comments on these analyses are as follows:

- Lake Gwelup Reserve. Low in nitrogen; good levels of phosphorus and potassium, marginal for manganese.

- Morley / Woodchester Reserve. Marginal for nitrogen; good levels of phosphorus and potassium; adequate manganese.

- Reader Reserve. Good levels of nitrogen and phosphorus; marginal for potassium; high manganese.

- Robinson Reserve. Marginal for nitrogen; good levels of phosphorus and potassium; marginal for manganese.

- Ted Cross Reserve. Good level of nitrogen, phosphorus and potassium; marginal for manganese.

- Woodlands Reserve. Low level of nitrogen; good levels of phosphorus and potassium; deficient in manganese.

All sites had good levels of phosphorus and potassium, variable levels of nitrogen and marginal for manganese except Reader Reserve which had a high manganese level.

Tables 2 and 3 also show the leaf tissue results following the application of fertilizer. These data are discussed as follows in some detail.

Table 1. Results from six sites from which soil was taken for analysis from 0 to 10 cm. January 18, 1996. Reserves not listed in alphabetical order.

	EC (1:5) mS/m	pH ($CaCl_2$)	Org. C (W/B) %	P (HCO_3) mg/kg	K (HCO_3) mg/kg	P (PRI) mg/kg
Robinson	12	5.7	2.01	14	83	1
Morley/Woodchester	13	5.6	2.46	12	79	0.4
Woodlands	15	6.2	2.66	10	100	0.6
Ted Cross	15	6.9	2.22	21	97	0.3
Reader	19	4.4	3.58	14	110	12
Lake Gwelup	14	7.4	1.26	80	89	1.2

EC	(1:5)	Electrical Conductivity (1 : 5) at 25 degrees Celsius
pH	($CaCl_2$)	pH (1 : 5) in 0.01M $CaCl_2$
Org C	(W/B)	Organic Carbon C, Walkley and Black method
P	(HCO_3)	Potassium K, extracted in 0.5M $NaHCO_3$ (1 : 100)
K	(HCO_3)	Potassium K, extracted in 0.5M $NaHCO_3$ (1 : 100)
P	(PRI)	Phosphorus Retention Index
mS/m		milliSiemens per metre
%		per cent
mg/kg		milligrams per kilogram
ml/g		millilitres per gram

Table 2. Leaf tissue analysis results for macronutrients. Sampled January 18, 1996 and March 26, 1996

Site	Treatment	N %	P %	K %	Na %	Ca %	Mg %
Robinson	Before	2.06	0.37	1.86	0.11	0.24	0.22
	Complete	3.72	0.54	3.36	0.11	0.22	0.24
	N only	3.62	0.45	2.48	0.12	0.25	0.24
Morley/ Woodchester	Before	1.94	0.29	1.86	0.07	0.23	0.19
	Complete	3.24	0.42	2.02	0.14	0.3	0.29
	N Only	3.04	0.32	1.97	0.16	0.25	0.28
Woodlands	Before	1.84	0.27	1.74	0.14	0.3	0.21
	Complete	4.44	0.55	3.08	0.13	0.32	0.27
	N Only	4.58	0.41	2.48	0.15	0.35	0.26
Ted Cross	Before	2.42	0.38	1.93	0.08	0.32	0.18
	Complete	4.4	0.58	2.64	0.12	0.36	0.24
	N Only	4.6	0.56	2.32	0.14	0.38	0.23
Reader	Before	2.69	0.27	1.16	0.1	0.33	0.19
	Complete	3.54	0.48	3.3	0.16	0.2	0.3
	N Only	3.27	0.34	2.41	0.17	0.25	0.32
Lake Gwelup	Before	1.72	0.32	1.73	0.14	0.56	0.14
	Complete	3.5	0.53	2.48	0.16	0.74	0.21
	N only	4.1	0.5	2.46	0.16	0.64	0.19

N	Nitrogen	Ca	Calcium
P	Phosphorus	Mg	Magnesium
K	Potassium	%	per cent dry basis
Na	Sodium		

Table 3. Leaf tissue results for sulphur and micronutrients. Sampled January 18, 1996 and March 26, 1996.

Site	Treatment	S %	Cu mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg	B mg/kg
Robinson	Before	0.24	8.5	290	23	33	8
	Complete	0.27	10	310	30	48	8
	N only	0.33	10	420	41	51	8
Morley/ Woodchester	Before	0.19	8.5	370	38	33	
	Complete	0.26	10	540	46	42	7
	N only	0.32	9	450	44	42	6
Woodlands	Before	0.24	7.4	490	15	32	
	Complete	0.38	12	410	71	57	13
	N only	0.41	14	450	88	65	15
Ted Cross	Before	0.24	9.1	650	21	35	
	Complete	0.31	12	370	17	50	
	N only	0.33	12	310	31	44	12
Reader	Before	0.28	9.6	530	140	45	
	Complete	0.35	11	290	150	45	10
	N only	0.46	10	350	180	46	9
Lake Gwelup	Before	0.26	6.2	530	14	28	
	Complete	0.52	8	680	28	38	11
	N only	0.62	8.1	510	30	38	12

S	Sulphurr	Zn	Zinc
Cu	Copper	B	Boron
Fe	Iron	%	per cent dry basis
Mn	manganese	mg/kg	milligrams per kilogram

Lake Gwelup Reserve
Nitrogen leaf levels increased slightly with the nitrogen only fertilizer. The levels of phosphorus and potassium were increased by the same amount. Manganese and sulphur levels were raised by both fertilizer treatments.

Morley/Woodchester Reserve
The application of the complete fertilizer increased the levels of leaf nitrogen; phosphorus and potassium more than did that of the nitrogen fertilizer alone. Manganese levels were increased slightly with both fertilizer treatments. Sulphur levels were increased more with the nitrogen only fertilizer.

Reader Reserve
The complete fertilizer application cased a greater increase in the nitrogen; phosphorus and potassium levels than did the nitrogen alone. Manganese and sulphur levels increased more with the nitrogen only treatment.

Robinson Reserve
Nitrogen levels were high for both fertilizer treatments. The levels of phosphorus and potassium increased at each fertilizer treatment, but more so with the complete fertilizer. Sulphur levels increased more with the nitrogen only treatment.

Ted Cross Reserve
Both fertilizer treatments raised the status of nitrogen, phosphorus and potassium to high levels. The nitrogen only treatment raised the level of manganese whereas the complete fertilizer cause a slight decrease.

Woodlands Reserve
The leaf tissue results from this site were distorted by an application of sulphate of ammonia and manganese sulphate to the reserve by the Council about the same time as the treatments were applied. Nevertheless, the results showed that the nitrogen only treatment caused a large increase in leaf nitrogen and also a large increase in phosphorus and potassium. Both fertilizer treatments increased leaf manganese to levels of sufficiency from levels of deficiency.

The effect on leaf nitrogen levels were similar for both fertilizer treatments. The levels of leaf phosphorus and potassium were raised markedly by both treatments, though more so with the complete fertilizer. Manganese and sulphur levels were raised though usually more so with the nitrogen only treatment.

Visual assessments

In most cases the nitrogen only treatment gave the same response as the complete fertilizer. At the Ted Cross Reserve, the turf was greener with the nitrogen only treatment than was observed at the other reserves.

Discussion

The results show that for sites in which a soil test showed good levels of phosphorus and potassium, an application of a nitrogen only fertilizer may achieve the result desired. An application of a nitrogenous fertilizer such as sulphate of ammonia alone, will boost the nitrogen levels in the plant and the levels of phosphorus and potassium. If turf managers can identify sites which do not require regular applications of phosphorus and potassium, costs can be reduced as may the loss of phosphorus into waterways.

An important result was the raising of the levels of manganese in the leaf tissue by the addition of sulphate of ammonia. This is probably caused by the effect of the fertilizer on the soil pH. Only small decreases in soil pH can lead to a significant increase in plant available manganese. If the soil pH is below 7.0, as was the case at the Woodlands Reserve, the addition of sulphate of ammonia blended with manganese sulphate, caused a large increase in the availability of manganese.

Leaf analysis proved to be an effective means to monitor the response of turf to fertilizer applications. Together with soil testing, it is a useful tool with which to match fertilizer applications with the requirements of the plant.

Summary

- Many of the older turf sites in the Perth area, which have accumulated an adequate amount of organic matter and in which a soil test shows good levels of plant available phosphorus and potassium, should be fertilized with a nitrogen only fertilizer such as sulphate of ammonia or urea.
- Balanced fertilizers are required for new sites where soil nutrient levels are low and cation exchange capacities are also low.
- Soil tests should be done to identify sites that will adequately respond to applications of nitrogen only fertilizer.
- Leaf tissue analysis may be used to monitor the response of turf to the fertilizer applied. This will safeguard against the development of nutrient deficiencies being undetected as a result of the use of nitrogen only fertilizer.
- The use of the above techniques will enable turf quality to be maintained or improved, reduce fertilizer costs and minimize the loss of phosphorus caused by leaching.

TINS

Water use by couch grass

K.J. Johnston

Introduction

Couch grass produces deep and extensive root systems. Because of this, the adoption of less frequent irrigation regimes may result in an acceptable turf while significantly reducing water use. A small scale experiment was designed to investigate the water extraction patterns and the rate of water use by a couch grass sward growing on a deep sandy soil at Mirrabooka East Reserve.

Materials and method

The test site at Mirrabooka East Reserve was a two year old sward of Wintergreen couch with an extensive and deep (about 1 m) root system. A year before the start of the experiment, an EnviroScan® soil moisture monitoring system was installed on the site. This equipment was set to record soil moisture contents continuously at 10 minute intervals. The sensors were placed at depths of 10; 20; 30; 40 and 50 cm.

The experiment ran from January 6, 1996 to January 10, 1996. The soil profile was brought up to field capacity with 20 mm of irrigation at the start of the experiment. No further irrigation was applied during the time of the trial. The time from January 6 to January 10 was described as the 'dry-down' cycle. Measurements were taken for five days to determine what was taking place to the soil moisture levels within the soil profile.

Results

The volumetric water content of the surface 50 cm of soil reached its maximum during the initial irrigation. It then decreased over the duration of the trial. (Figure 1.) Immediately following the irrigation, the total water content curve was at is steepest. As the dry-down cycle progressed, the water content curve assumed a step-like appearance.

The volumetric water content for each 10 cm depth layer during the drying cycle is seen in Figures 2 to 6. For the first 10 cm layer the initial curve was very steep, but had become almost a flat line parallel to the X axis of the graph within five days. (Figure 2.) Similar results were seen for the 20 and 30 cm layers. A steep decrease in the slope of the curve in the initial stages of drying, followed by a virtual flattening of the curve at the end of the cycle was apparent. The volumetric water volume content curve at 40 and 50 cm depth was different insofar that the curve was not as steep initially and had not flattened out as much at the end of five days as had those at lesser depth.

Transpiration and drainage

Transpiration rates were determined for days 2; 3; 4 and 5 after the initial irrigation. This was done by estimating and subtracting the drainage component of the water loss for each day. (Table 1.) Drainage was estimated by a determination of the drainage rate for the five days before and after the transpiration period. The average of these assessments were used in the subsequent calculations. It was impossible to determine the drainage component the day following irrigation.

The results show that total water use by the couch grass decreased over the period of the drying cycle when considered as a percentage of the evaporation from the evaporimeter (Epan). A graph of the changes in the contribution of water for transpiration from varying depths is shown in Figure 7. This shows that, as the profile dries, a greater percentage of the water used comes from the deeper layers of the soil.

Table 1. Water use by couch grass (transpiration) for each layer of soil during days 2 to 5 of the drying cycle. (Data calculated by H. Cockran, U.W.A)

Day	Soil depth - cm							
	10	20	30	40	50	Total	Epan mm	Epan %
2	1.47	1.01	0.94	0.84	1.01	5.27	12.4	42
3	1.02	1.04	1.17	0.76	0.89	4.88	11.4	43
4	0.31	0.35	0.78	0.97	0.96	3.37	10.2	33
5	0.06	0.25	0.49	0.58	0.76	2.12	11.2	19

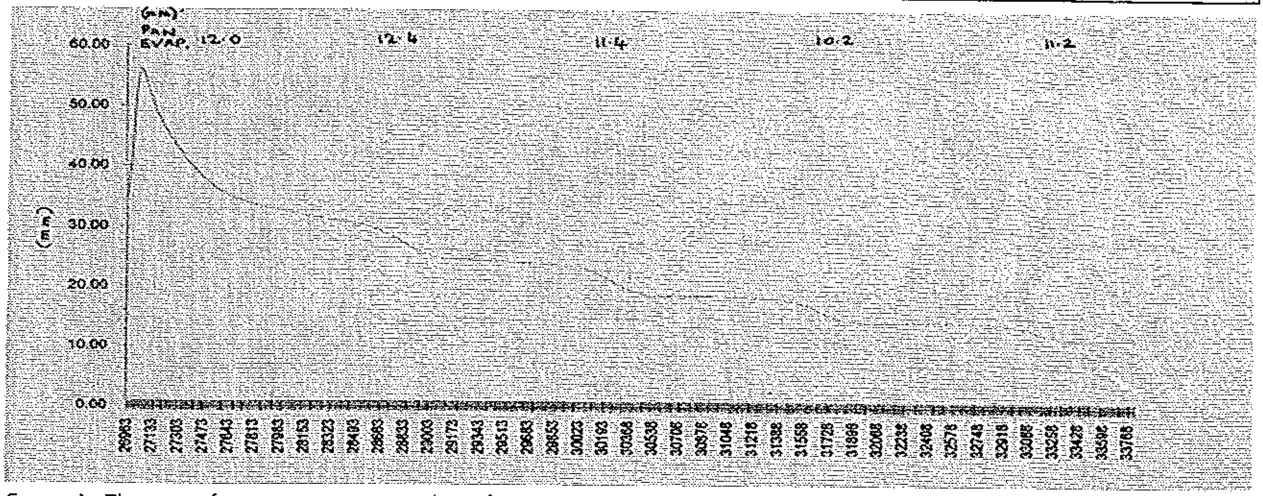

Figure 1. The sum of moisture sensors readings from O to 50 cm. January 6,1996 to January 12, 1996. Moisture readings taken at intervals of 10 minutes.(Data calculated by H. Cockran, U.W.A)

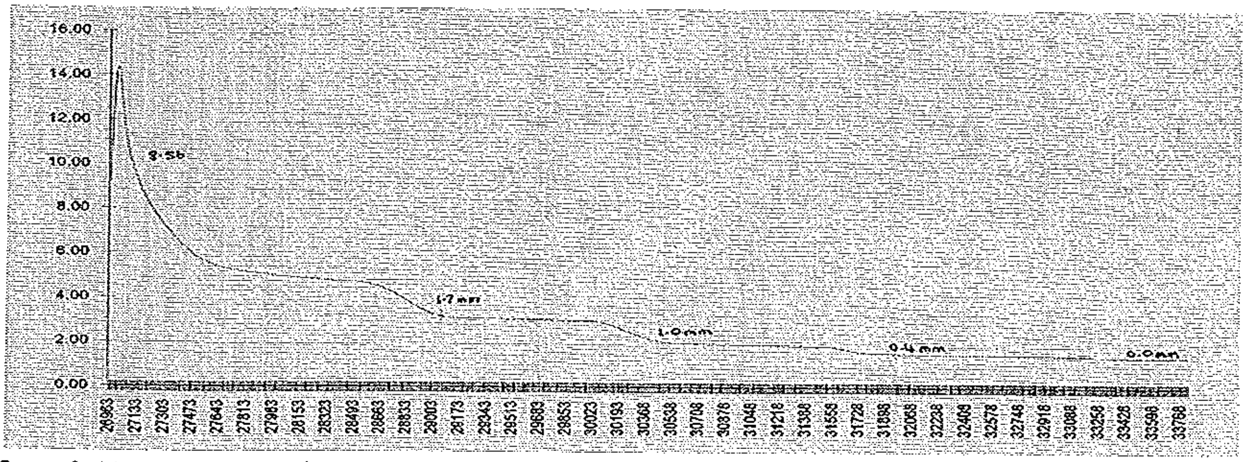

Figure 2. Moisture sensor readings at 10 cm. January 6, 1996 to January 12, 1996. Moisture readings taken at intervals of 10 minutes. (Data calculated by H. Cockran, U.W.A)

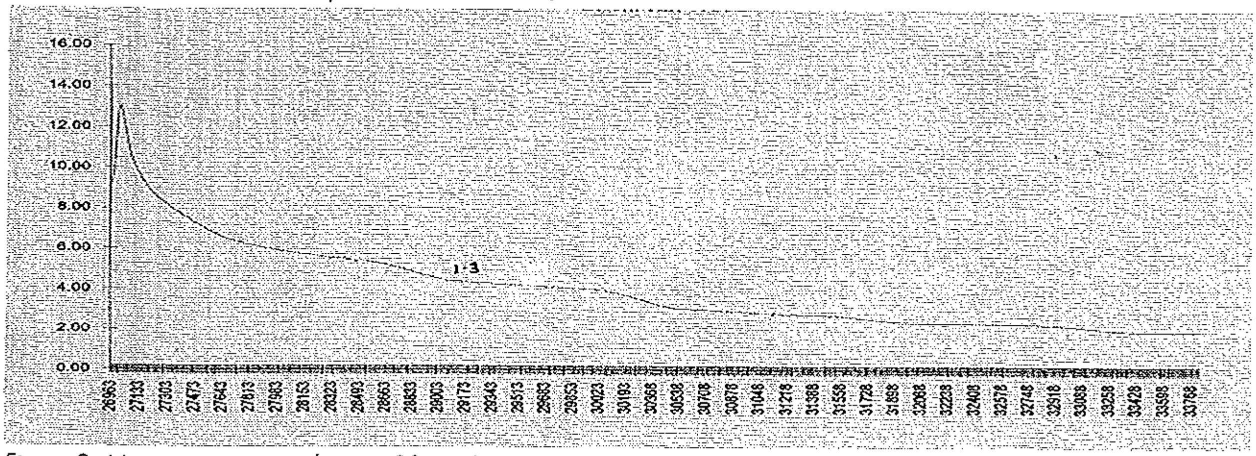

Figure 3. Moisture sensor readings at 20 cm. January 6, 1996 to January 12, 1996. Moisture readings taken at intervals of 10 minutes.(Data calculated by H. Cockran, U.W.A)

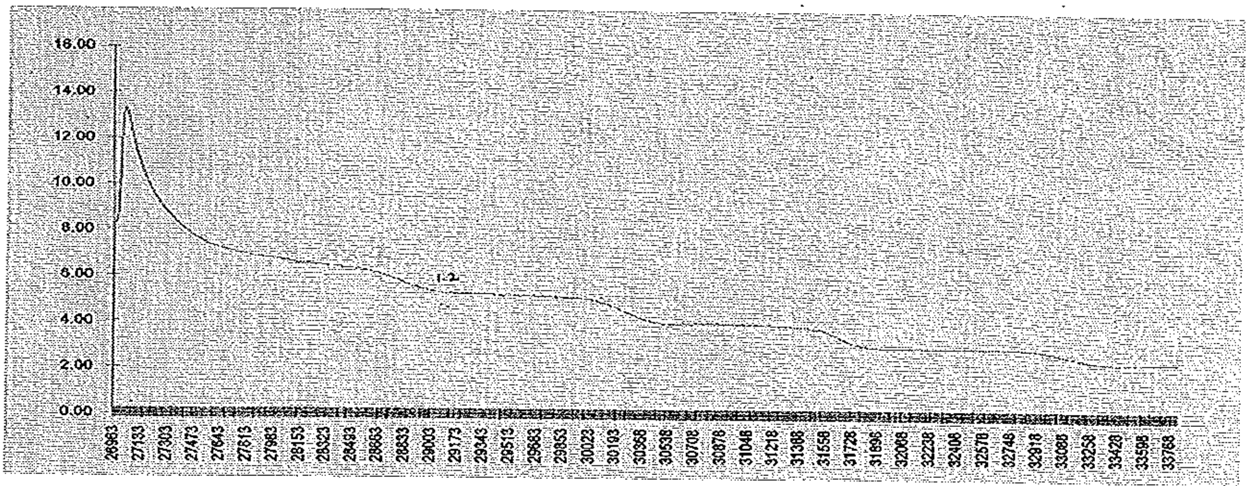

Figure 4. Moisture sensor readings at 30 cm. January 6, 1996 to January 12, 1996. Moisture readings taken at intervals of 10 minutes. (Data calculated by H. Cockran, U.W.A)

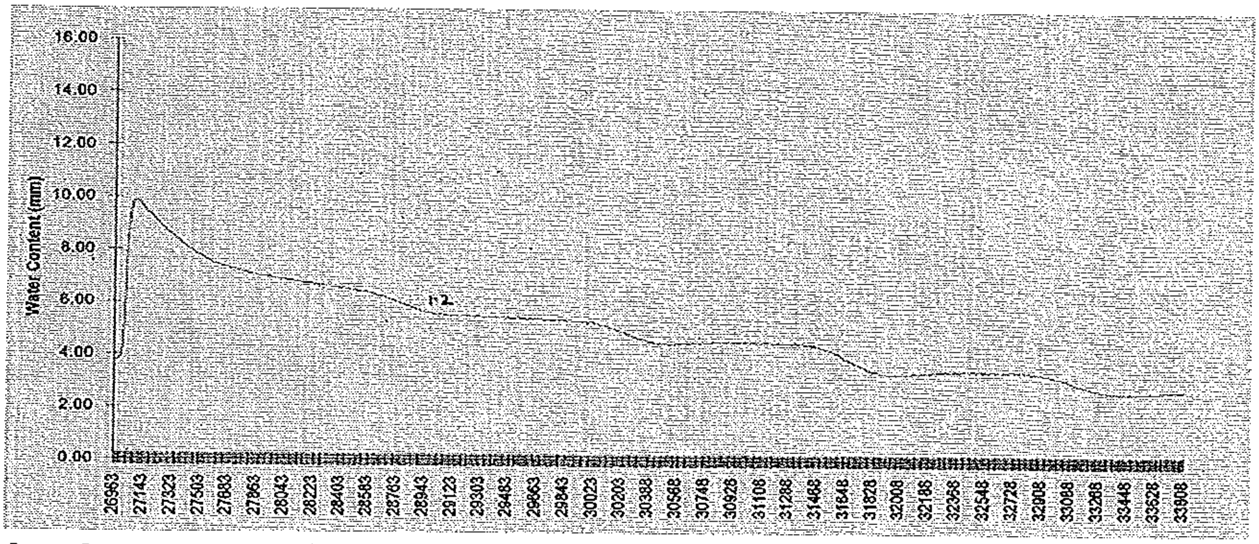

Figure 5. Moisture sensor readings at 40 cm. January 6, 1996 to January 12, 1996. Moisture readings taken at intervals of 10 minutes. (Data calculated by H. Cockran, U.W.A)

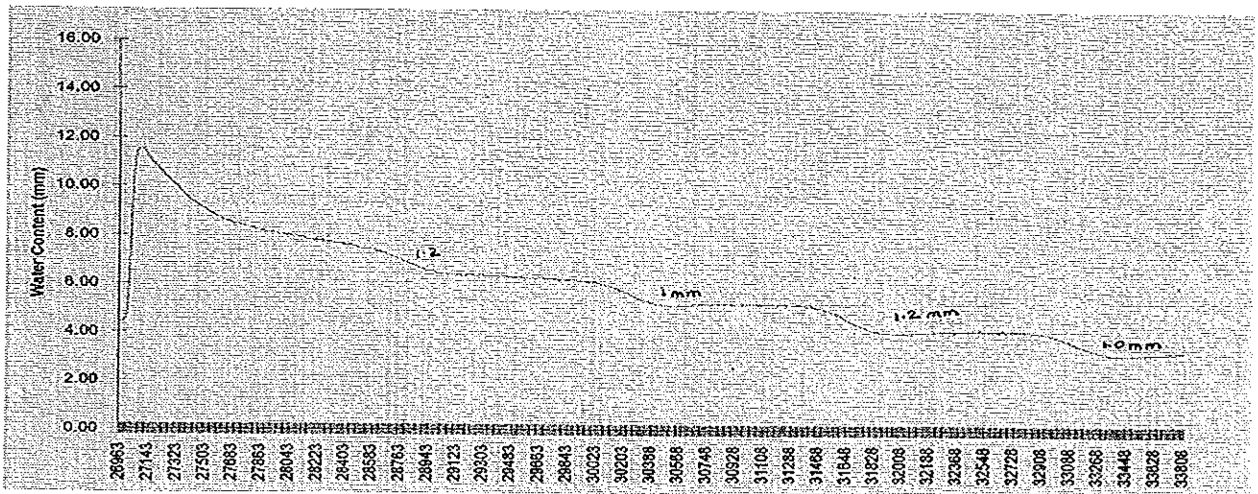

Figure 6. Moisture sensor readings at 50 cm. January 6, 1996 to January 12, 1996. Moisture readings taken at intervals of 10 minutes. (Data calculated by H. Cockran, U.W.A)

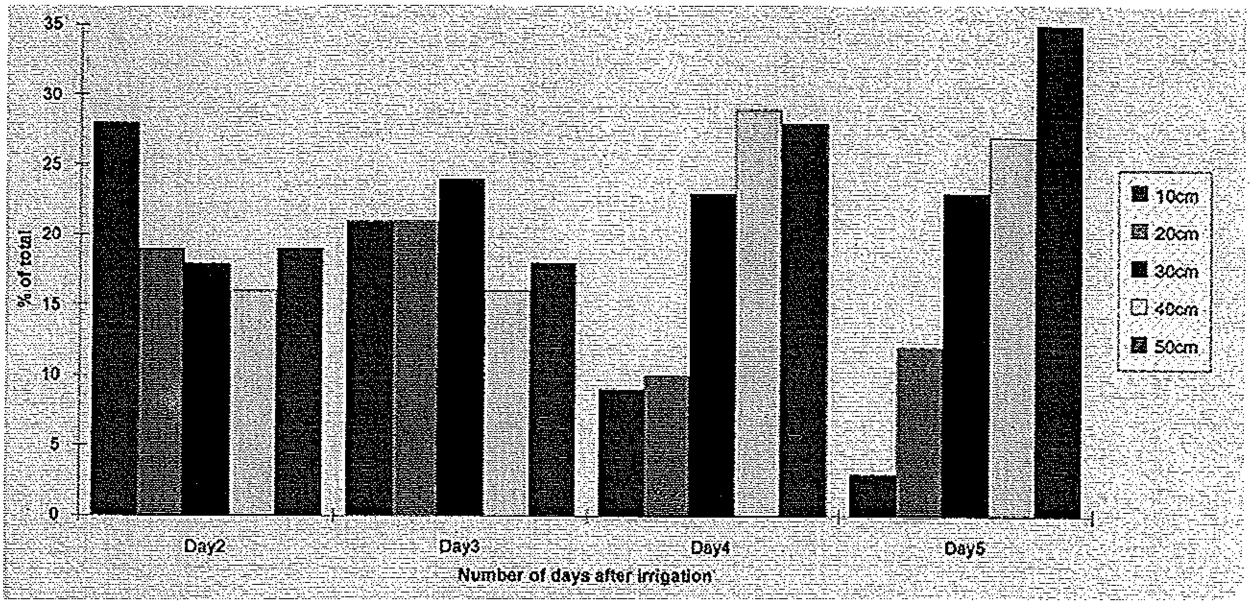

Figure 7. Changes in turf grass water use at various soil depths. Per cent of total. (Data calculated by H. Cockran, U.W.A)

Discussion

A very steep downward slope to the volumetric water content curve directly after an irrigation event indicates rapid water loss from a soil layer or layers caused by drainage. In this experiment, the results show that there was a significant loss of water below the 50 cm layer following irrigation before water loss occurred from transpiration. The phase when water loss is caused primarily by transpiration is characterized by the graph having a step-like appearance. This is because of the effect of the couch grass extracting water from the soil during the day and ceasing uptake at night. Observation of the slope of the curve during the period of non-transpiration (night), shows that for each successive recording period, the curve becomes less steep. This is because the drainage rates decrease as the water content of the soil profile decreases.

When each 10 cm soil layer is measured separately, it may be seen that the surface layers of the soil have a steeper downward water volumetric content curve after irrigation than have the layers beneath them. The probable cause of this is the higher rate of drainage from the surface layers and possibly the higher rate of transpiration. As the drying cycle proceeds, the water loss from the surface layers is caused by transpiration. At the end of the drying cycle, water loss from transpiration likewise declines because of an increase in water potentials. For the soil layers at 40 and 50 cm depth, transpiration rates were still high at the end of the drying cycle. These soil layers still had reserves of available water unlike the surface layers where it had been depleted by day 5.

Transpiration

The calculated rates of transpiration indicated that total use of water by the couch grass drops markedly over the time of the drying cycle when considered as a percentage of pan evaporation. However, as the root system of the couch grass is deeper than 50 cm, it is this portion of the root system which supplies the plant with water to meet its evaporative demand. This is shown in the results which indicates that, as the soil dries, a greater percentage of the water used by the grass comes from the deeper soil layers. Similar results were noted in Arizona in the United States of America, where water use after an irrigation event is predominantly from the surface soil layers. At the end of the drying cycle, when water use was low, the water used by the plant came from the deeper layers in the soil profile.

Irrigation after five days

When the turf was irrigated at the end of the five days of the experiment, the surface 10 cm layer rapidly resumed water use. This showed that what drought stress had occurred during the drying cycle did not severely damage the surface roots. Because the water moisture sensors only recorded to 50 cm further information on plant available water at depths below 50 cm is not present. Even so, the evidence suggests that the adoption of a less frequent irrigation regime may still result in the production of an acceptable turf and significantly reduce water use.

Conclusion

The importance of the surface layers of the soil in controlling the water use of turf cannot be underestimated. If turf swards are watered each day the surface layer will remain at field capacity and water use rates will remain high for all soil layers.

The best opportunity to reduce water use while maintaining turf quality is to adopt a less frequent irrigation regime. ***However, the surface layer must not be allowed to become too dry so that damage is done to the root system or for dry patch to develop.*** Turf managers need to be confident that the irrigation system applies water evenly and that the 're-watering' point is well established. The use of effective soil moisture sensors will assist turf managers to extend the drying cycle and so reduce water use. In addition, their use will guard against the application of water which drains away below the root zone. The use of water sensors as described will lead to significant advances in turf grass water conservation.

Further research

The limitations of the experiment showed that research needs to be done with water sensors that extend to the full depth of the root zone of the turf grass species. In addition, research is required with different turf grass species and on a selection of soil types and sites. The University of Western Australia, commenced a study into water use by different turf grass species in 1996.

TINS

Survey sites—comparisons

K.J. Johnston

Selection of sites

In November, 1992, 21 turf grass sites were selected in the Perth Metropolitan Area for study. This entailed a description of the sites and analyses of soils, leaf tissues and bore water supplies.

Analyses

Soil samples taken from the surface 0 to 10 cm were tested for: pH; salinity; bicarbonate extractable phosphorus (B.E.P.); potassium; PRI; total phosphorus; organic carbon and exchangeable cations.

Leaf samples tested for: Nitrogen; phosphorus; potassium; calcium; magnesium; sulphur; copper; iron; manganese and zinc.

Bore water samples tested for: pH; salinity; calcium; magnesium; sodium; iron; ammonium ions; nitrate ions; phosphorus and potassium.

Description of survey sites

1) Aldersea Park
- Brown sand at surface, orange at depth
- Greenlees park couch with low vigour
- Rooting depth - 60 to 70 cm
- Established 1990
- Severe spring dead spot fungus

2) Alexander Heights
- Dark grey sand at surface, light grey at depth
- Kikuyu, light green-yellow with low vigour
- Rooting depth - 20 cm
- Established 1982

3) Brian Burke Reserve
- Yellow-brown sand at surface, dark grey at depth
- Kikuyu, good density
- Rooting depth - 30 cm
- Few weeds

4) J Carine Lower Reserve
- Brown sand at surface, orange at depth
- Couch sward with large numbers of crab grass seedlings
- Rooting depth - > 1 m

5) Dianella ROS 1
- Grey-brown sand at surface, yellow at depth
- Couch of low density
- Rooting depth - > 1 m

6) Frederick Baldwin Reserve
- Brown-orange sand at surface, orange-brown at depth
- Couch of very low density
- Rooting depth - 40 cm
- Established about 1987

7) Glengarry Reserve
- Brown sand at surface, orange at depth
- Kikuyu with good density
- Rooting depth - 20 cm
- Established 1977

8) Heathridge Reserve
- Brown sand at surface, colour variable at depth
- Kikuyu cover patchy
- Rooting depth - 30 cm
- Established 1979

9) Jackadder Reserve
- Brown sand at surface and at depth. Poor profile uniformity
- Kikuyu sward
- Rooting depth - undetermined because of subsurface rocks

10) Jeff Joseph Reserve
- Brown sand at surface, white at depth
- Kikuyu with excessive thatch
- Rooting depth- 25 cm
- Established about 1962
- Water-table at 1 m

11) Kevan Langdon Reserve
- Brown sand at surface, white at depth
- Couch, pale colour
- Rooting depth - 60 cm

12) Lake Gwelup Reserve
- Black-orange sand at surface, white at depth
- Couch, fair density
- Rooting depth- 50 cm
- Soil profile contains small lumps of limestone

13) Len Shearer Reserve
- Brown-grey sand at surface, yellow at depth
- Kikuyu of good density
- Rooting depth - 50 cm
- Established about 1983
- Water-table at 70 cm

14) Marmion Reserve
- Coloured sand at surface (variable), white at depth
- Kikuyu with high levels of thatch
- Rooting depth - 30 cm
- Established about 1957
- Water-table at 70 cm

15) Neil Hawkins Reserve
- Brown sand at surface, white at depth
- Kikuyu sward
- Rooting depth - 15 cm
- Established 1982

16) Percy Doyle Reserve
- Brown sand at surface, yellow at depth
- Kikuyu cover patchy
- Rooting depth- 50 cm
- Established 1978

17) Peter Ellis Reserve
- Grey sand at surface, white-gray at depth
- Rye grass cover
- Rooting depth - 20 cm
- Originally seeded with couch about 1985

18) Scenic Drive Reserve
- Brown sand at surface, orange at depth
- Kikuyu with notable green colour
- Rooting depth- 20 cm
- Establishment date unknown

19) Tompkins Park
- Brown sand at surface, grey then white at depth
- Kikuyu, average density
- Rooting depth- 1 m
- Established about 1972
- Water-table at 60 cm, many roots

20) Webber Reserve
- Brown-orange sand at surface, yellow-orange at depth
- Kikuyu of good density
- Rooting depth - 30 cm
- Established about 1957

21) Yokine East Reserve
- Brown sand at surface, white to yellow at depth
- Couch of low density and many weeds
- Rooting depth- 1 m
- Kikuyu areas have few weeds

Survey results

Comments

- There were significant differences in the pH values for each site according to the method used to determine pH. Determinations of soil pH in water gave higher values than determinations made in calcium chloride (Table 1). The pH values in water showed that 71 per cent of the sites were alkaline. Only 33 per cent of the sites were alkaline at shown by the pH measured in calcium chloride. Soil pH measured at other sites not included in this survey as part of the TINS project also showed a wide variability in soil pH values in the Perth Metropolitan Area (Figure 1).

- All sites had very low levels of soil salinity (Table 1). Some sites had high levels of salt in the irrigation water. This indicates the permeable nature of the soils.

- Using the methods as described for measuring the phosphorus requirement of established turf, only three of the 21 sites has available bicarbonate extractable phosphorus (B.E.P.) levels that indicated that an application of phosphatic fertilizer was required (Table 1). These sites were:

Aldersea Park = B.E.P = 9mg/kg
PRI = 3.1

Frederick Baldwin Reserve = B.E.P. = 3.0 mg/kg
PRI = 3.1

Tompkins Park = B.E.P. = 9 mg/kg
PRI = 3.6

For soils with a PRI between 2.0 and 5.0 the soil B.E.P levels need to be > 10 mg/kg

Leaf tissue analysis for the above sites confirmed the information gained from the soil tests.

Aldersea Park - Per cent P in leaves = 0.22

Frederick Baldwin Reserve - Per cent P in leaves = 0.19

Tompkins Park - Per cent P in leaves = 0.22

The above three sites had the lowest level of leaf tissue phosphorus of the 21 sites tested. These sites were considered marginal for the maintenance of quality couch at Aldersea Park and Frederick Baldwin Reserve and for kikuyu at Tompkins Park.

As all three sites had a PRI above 3.0, an application rate of 10 kg P/ ha could be made with a relatively low risk of nutrient loss through leaching. A fertilizer such as Turf Special ™,applied at the standard rate of 250 kg/ha, will supply 5 kg P/ha. Two applications of Turf Special ™,or a similar fertilizer, will raise the soil available phosphorus to an adequate level. Future applications of phosphatic fertilizers should be determined by soil and leaf tissue tests.

In the above example, if a fertilizer such as diammonium phosphate (DAP) was used at the rate of 250 kg/ha, this would apply 50 kg P/ha. This not a desirable option as it would significantly increase the risk of phosphorus leaching from the soil.

- The majority of the initial 21 sites tested for phosphorus, and the results from subsequent tests at other sites, showed that most soils had < 30 mg/kg of B.E.P. (Figure 2). Most of these soils also had PRI values of 2.0 or less (Figure 3). These results mean that the traditional phosphorus soil test standards and recommendations as mainly used until the 1990s, may lead to over application of phosphatic fertilizers on the sandy soils of the Swan Coastal Plain. For example, if a soil test value was < 40 mg/kg, an application of at least 50 kg P/ha was recommended. This would lead to a high risk of phosphorus leaching taking place.

- Some 71 per cent of surveyed sites had PRI values of <2.0. This showed that phosphorus inputs into these sites have to be closely monitored because of the risk of leaching of the applied phosphorus. This would also include inputs from organic sources such as Dynamic Lifter™and irrigation water. (Table 6). Dynamic Lifter™ applied at 750 kg/ha, supplies about 20 kg P/ha. Should this be applied twice per year in addition to soluble phosphatic fertilizers, excessive amounts of phosphorus will be applied to the turf without any improvement in turf quality, but at a high risk to the environment. The levels of phosphorus in irrigation water were very low at all surveyed sites.

  If a soil has a high PRI of about 5.0, continued applications of high rates of phosphatic fertilizer will saturate the soil and bring the PRI down to zero.

- The survey showed that many sites with a history of adequate applications of a phosphatic fertilizer, had built up a phosphorus reserve in the soil. As such, they could go without further phosphorus applications for extended periods. Such soils should only be given fertilizer when soil and leaf tissue tests show that phosphorus levels have become marginal for the maintenance of quality turf. Such a method of nutrient management will save money, reduce the risk of leaching and have little effect on turf quality.

- The Len Shearer Reserve had a high PRI level because of the amount of iron applied in the irrigation water (Tables 1 and 5). The iron in the water acted as a soil amendment and increased the soil's capacity to retain applied phosphorus.

- Soil potassium levels were adequate at most of the 21 surveyed sites. On all kikuyu swards tested it would be possible to delete applications of potassic fertilizer. ***In the various TINS experiments, it was shown that kikuyu was very efficient at using potassium.*** A soil level of 20 mg K/kg was sufficient to maintain turf grass quality. Irrigation water also supplied significant amounts of potassium (Table 6). For example, if it is assumed that 1 m of irrigation water is applied per year, the mg/ kg value for each site may be converted to kg/ ha by multiplying this value by 10. At Alexander Heights Reserve some 20 kg K/ ha would be applied in the irrigation water each year.

Table 1. Soil test results from the TINS survey of 21 sites - 1992.
Soil samples taken from the surface 10 cm.

Site/Reserve	pH (H2O)	pH (CaCl2)	EC (1 : 5) mS/m	P (HCO3) mg/kg	K (HCO3) mg/kg	P (PRI) mL/g	P (total) mg/kg
Alexander Heights	6.2	5	4	9	48	1.2	58
Scenic Drive	7.7	7	10	21	64	0.2	160
Aldersea	8.6	7.6	6	9	25	3.1	78
Neil Hawkins	8.6	7.8	10	18	48	2.4	170
Heathridge	8.2	7.6	10	33	64	1.8	200
Percy Doyle	8.4	7.5	8	11	65	1.4	110
Glengarry	7	5.6	7	20	78	2.2	190
Yokine East	5.7	4.5	6	22	24	1.3	140
Dianella ROS 1	6.9	6.4	8	25	54	0.8	110
Brian Burke	6.9	6.2	6	29	57	0.2	160
Carine Lower	7.4	6.6	5	11	35	1.4	120
Lake Gwelup	7.9	7.2	7	74	47	2	550
Kevan Langdon	8.7	7.9	9	24	26	2	200
Jackadder	8.1	7.4	14	19	90	0.8	220
Jeff Joseph	7.4	6.5	10	8	55	0.4	120
Tompkins Park	7.6	6.9	9	9	87	3.6	210
Marmion Reserve	7.3	6.6	7	9	42	1.6	170
Len Shearer	6.5	5.1	7	34	62	6.3	200
Webber Reserve	7.2	6.6	7	12	56	1.4	210
Frederick Baldwin	7.4	6.7	4	3	30	3.1	75
Peter Ellis	7.3	6.6	5	17	25	0.6	82

pH (H2O) : pH (1 : 5) in water
pH (CaCl2) : pH (1 : 5) in 0.01M CaCl2
EC (1 : 5) : Electrical Conductivity (1 : 5) at 25 degrees celsius
P (HCO3) : Phosphorus P, extracted in 0.5M NaHCO3 (1 : 100)
K (HCO3) : Potassium K, extracted in 0.5M NaHCO3 (1 : 100)
P (PRI) : Phosphorus Retention Index
P (total) : Phosphorus P, total
mg/kg : milligrams per kilogram
mS/m : milliSiemens per metre
mL/g : millilitres per gram

Table 2. Soil test results from the TINS survey of 21 sites - 1992.
Samples taken from the surface 10 cm.

Site/Reserve	N (total) %	Org C (W/B) %	Na (NH4Cl) me%	K (NH4Cl me%	Mg (NH4Cl me%	Ca (NH4Cl me%
Alexander Heights	0.055	1.16	0.1	0.2	0.8	2.1
Scenic Drive	0.104	1.3	0.2	0.2	1.1	6.3
Aldersea	0.034	0.63	0.1	0.1	0.2	2.3
Neil Hawkins	0.08	0.87	0.3	0.1	0.8	3.5
Heathridge	0.108	1.21	0.1	0.2	0.4	4.5
Percy Doyle	0.059	0.77	0.1	0.1	0.4	1.9
Glengarry	0.14	1.89	0.5	0.3	1.7	3.2
Yokine East	0.088	1.1	0.2	0.1	0.3	0.6
Dianella ROS 1	0.068	0.98	0.1	0.1	0.6	3
Brian Burke	0.104	1.38	0.1	0.1	0.5	3
Carine Lower	0.077	0.9	0.1	0.1	0.3	3
Lake Gwelup	0.056	0.76	0.1	0.1	0.5	4.7
Kevan Langdon	0.081	0.82	0.1	0.1	0.3	3
Jackadder	0.181	2.04	0.4	0.2	1.4	5.6
Jeff Joseph	0.141	1.87	0.4	0.1	2.9	3.2
Tompkins Park	0.191	2.4	0.2	0.2	1.3	10.1
Marmion Reserve	0.132	1.48	0.1	0.1	0.6	6.8
Len Shearer	0.094	1.22	0.3	0.2	0.7	0.8
Webber Reserve	0.178	2.03	0.1	0.2	0.8	6.6
Frederick Baldwin	0.054	0.8	0.1	0.1	0.5	3.3
Peter Ellis	0.054	0.85	0.1	0.1	0.5	4.5

N (total) : Nitrogen N, total
Org C (W/B) : Organic Carbon C, Walkley and Black method
Na (NH4Cl) : Sodium Na, extracted in 1M NH4Cl
K (NH4Cl) : Potassium K, extracted in 1M NH4Cl
Mg (NH4Cl) : Magnesium Mg, extracted in 1M NH4Cl
Ca (NH4Cl) : Calcium Ca, extracted in 1M NH4Cl
% : per cent
me% : milliequivalents per 100g of soil

Table 3. Leaf tissue results for macronutrients from the TINS survey of 21 sites - 1992. Leaf samples taken using scissors.

Site/Reserve	N %	P %	K %	Ca %	Mg %	S %
Alexander Heights	1.5	0.28	1.55	0.27	0.28	0.2
Scenic Drive	2.15	0.38	2.45	0.32	0.19	0.2
Aldersea	1.91	0.22	1.29	0.78	0.15	0.32
Neil Hawkins	2.42	0.41	2.31	0.32	0.2	0.2
Heathridge	2.31	0.37	2.14	0.41	0.18	0.2
Percy Doyle	2.54	0.32	2.79	0.65	0.26	0.92
Glengarry	1.98	0.32	2.03	0.19	0.2	0.2
Yokine East	2.5	0.33	1.37	0.35	0.21	0.33
Dianella ROS 1	2.28	0.38	1.46	0.46	0.2	0.3
Brian Burke	2.05	0.4	2.24	0.3	0.16	0.19
Carine Lower	2.9	0.36	1.78	0.5	0.15	0.32
Lake Gwelup	2.43	0.4	1.6	0.65	0.15	0.38
Kevan Langdon	2.53	0.36	1.43	0.94	0.21	0.33
Jackadder	2.07	0.39	2.55	0.43	0.22	0.19
Jeff Joseph	1.5	0.29	1.67	0.3	0.28	0.14
Tompkins Park	1.76	0.22	1.86	0.44	0.18	0.16
Marmion Reserve	1.79	0.31	2.12	0.38	0.18	0.17
Len Shearer	1.59	0.29	1.86	0.17	0.18	0.16
Webber Reserve	2.18	0.32	2.23	0.48	0.18	0.18
Frederick Baldwin	1.72	0.19	1.18	0.68	0.17	0.34
Peter Ellis	4.01	0.51	2.76	0.63	0.25	0.42

N : Nitrogen, N
P : Phosphorus, P
K : Potassium, K
Ca : Calcium, Ca
Mg : Magnesium, Mg
S : Sulphur, S
%db : per cent dry basis

Table 4. Leaf tissue results for micronutrients from the TINS survey of 21 sites - 1992. Leaf samples taken using scissors.

Site/Reserve	Cu mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg
Alexander Heights	5.5	180	120	35
Scenic Drive	7.5	94	22	31
Aldersea	7.7	200	8.7	29
Neil Hawkins	8	230	11	35
Heathridge	10	590	27	29
Percy Doyle	7.6	290	30	23
Glengarry	7.4	320	39	32
Yokine East	8	190	210	49
Dianella ROS 1	6.8	240	57	38
Brian Burke	6.6	300	31	33
Carine Lower	7	210	38	31
Lake Gwelup	7.7	840	9.9	32
Kevan Langdon	3.6	110	21	37
Jackadder	6.7	270	7.6	37
Jeff Joseph	5.1	90	9.6	25
Tompkins Park	5.6	210	27	25
Marmion Reserve	6.1	78	47	28
Len Shearer	6.3	1200	58	36
Webber Reserve	7	91	19	32
Frederick Baldwin	6.6	200	13	45
Peter Ellis	9	160	40	24

Cu : Copper, Cu
Fe : Iron, Fe
Mn : Manganese, Mn
Zn : Zinc, Zn
mg/kg : milligrams per kilogram

Table 5. Analyses of bore water from the TINS survey of 21 sites - 1992.

Site/Reserve	pH (SS)	EC (SS) mS/m	Ca (SS) mg/kg	Mg (SS) mg/kg	Na (SS) mg/kg	S (SS) mg/kg	Fe (SS) mg/kg
Alexander Heights	6.5	26	4	7	36	9	0.6
Scenic Drive	7.3	94	55	19	120	18	0.2
Aldersea	7.7	97	84	15	96	12	0.1
Neil Hawkins	8.1	200	71	36	320	5	0.8
Heathridge	8.1	25	20	3	22	1	1
Percy Doyle	8	110	65	20	150	11	0.6
Glengarry	8.3	140	25	21	250	13	2.5
Yokine East	6.8	74	19	17	100	30	1.4
Dianella ROS 1	6.7	50	9	14	67	20	0.5
Brian Burke	7.2	47	29	9	53	6	0.5
Carine Lower	7.7	86	84	12	82	8	0.9
Lake Gwelup	7.8	110	140	20	76	54	3.1
Kevan Langdon	7.7	110	120	16	100	33	0
Jackadder	8.2	140	85	25	190	16	1.5
Jeff Joseph	7.9	240	36	53	430	39	0.3
Tompkins Park	8	86	57	17	90	5	0.6
Marmion Reserve	8	61	59	8	55	7	0
Len Shearer	7.3	140	12	18	250	14	2.6
Webber Reserve	7.9	62	69	9	54	10	0
Frederick Baldwin	8.1	58	32	12	64	7	0.3
Peter Ellis	7.7	41	35	5	42	4	0.9

pH (SS) : pH of soil solution
EC (SS) : Electrical Conductivity of soil solution
Ca (SS) : Calcium in soil solution
Mg (SS) : Magnesium in soil solution
Na (SS) : Sodium in soil solution
S (SS) : Sulphur in soil solution
Fe (SS) : Iron in soil solution
mS/m : milliSiemens per metre
mg/kg : milligrams per kilogram

Table 6. Analyses of bore water from the TINS survey of 21 sites - 1992. Macronutrients.

Site/Reserve	N NH4 mg/kg	N NO3 mg/kg	P (SS) mg/kg	K (SS) mg/kg
Alexander Heights	0.2	<0.2	<0.02	2
Scenic Drive	0.7	<0.2	<0.02	5
Aldersea	<0.2	0.5	<0.02	6
Neil Hawkins	2.7	<0.2	0.02	12
Heathridge	0.2	<0.2	<0.02	4
Percy Doyle	<0.2	1.2	<0.02	8
Glengarry	0.2	<0.2	0.03	14
Yokine East	0.3	0.2	<0.02	6
Dianella ROS 1	0.2	<0.2	<0.02	3
Brian Burke	<0.2	0.8	<0.02	3
Carine Lower	<0.2	<0.2	<0.02	5
Lake Gwelup	1	<0.2	<0.02	11
Kevan Langdon	<0.2	2.1	0.02	4
Jackadder	1.2	<0.2	0.06	14
Jeff Joseph	0.3	3.7	<0.02	18
Tompkins Park	0.2	<0.2	<0.02	4
Marmion Reserve	<0.2	2.7	<0.02	4
Len Shearer	0.2	<0.2	0.02	12
Webber Reserve	<0.2	4.9	<0.02	4
Frederick Baldwin	<0.2	<0.2	<0.02	7
Peter Ellis	0.2	<0.2	<0.02	3

N (NH4)+ : Ammonium nitrogen N in leacheate
N (NO3)- : Nitrate nitrogen N in leachate
P (SS) : Phosphorus in soil solution
K (SS) : Potassium in soil solution
mg/kg : milligrams per kilogram

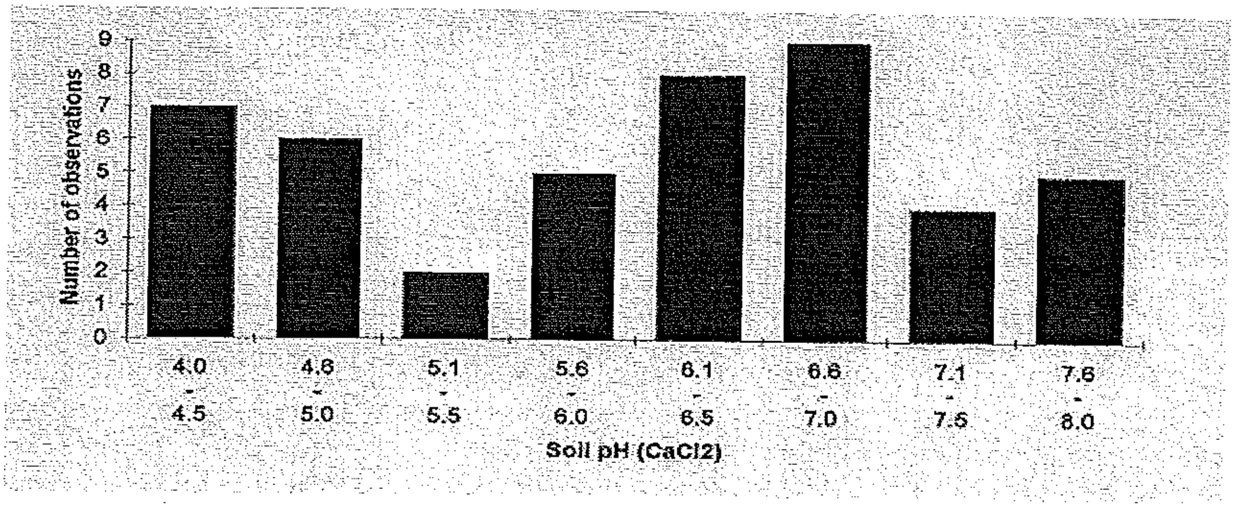

Figure 1. Soil pH as measured in calcium chloride solution in the TINS survey of 21 sites 1992.

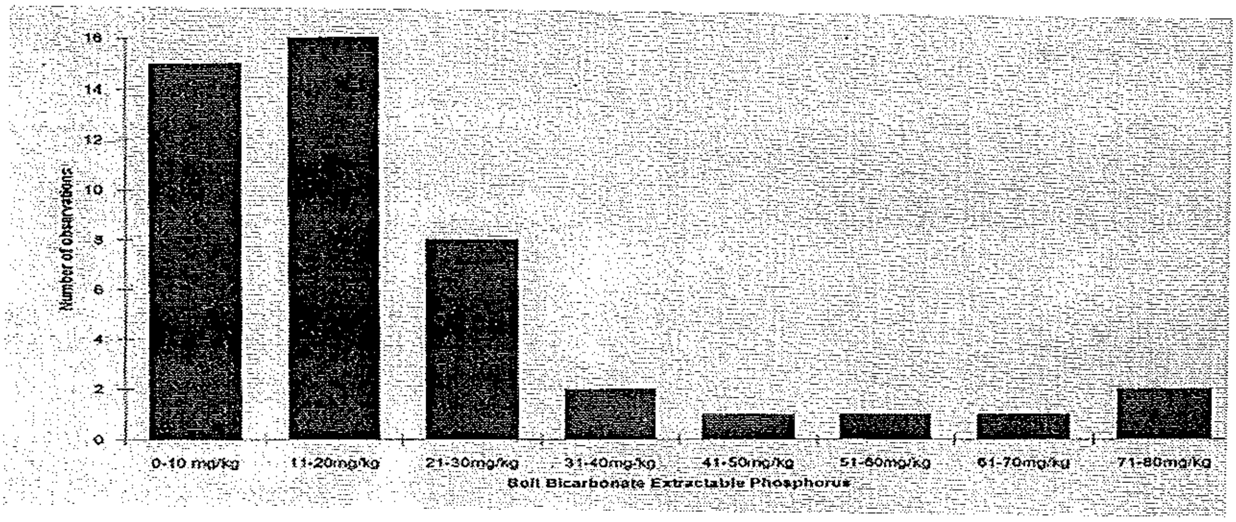

Figure 2. Available phosphorus in soils sampled as part of the TINS survey of 21 sites - 1992.

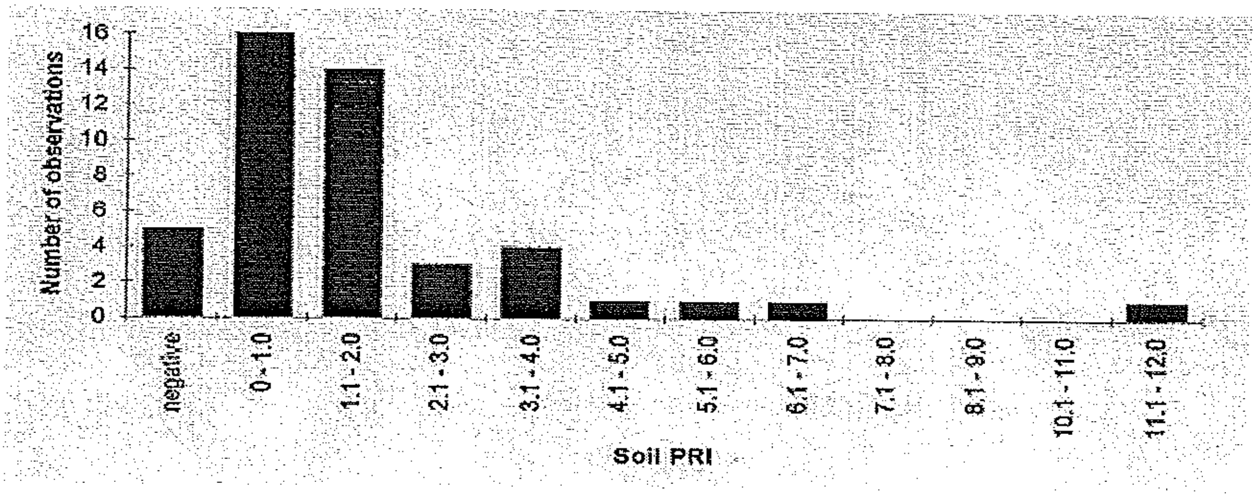

Figure 3. PRI for soils sampled as part of the TINS survey for 21 sites - 1992.

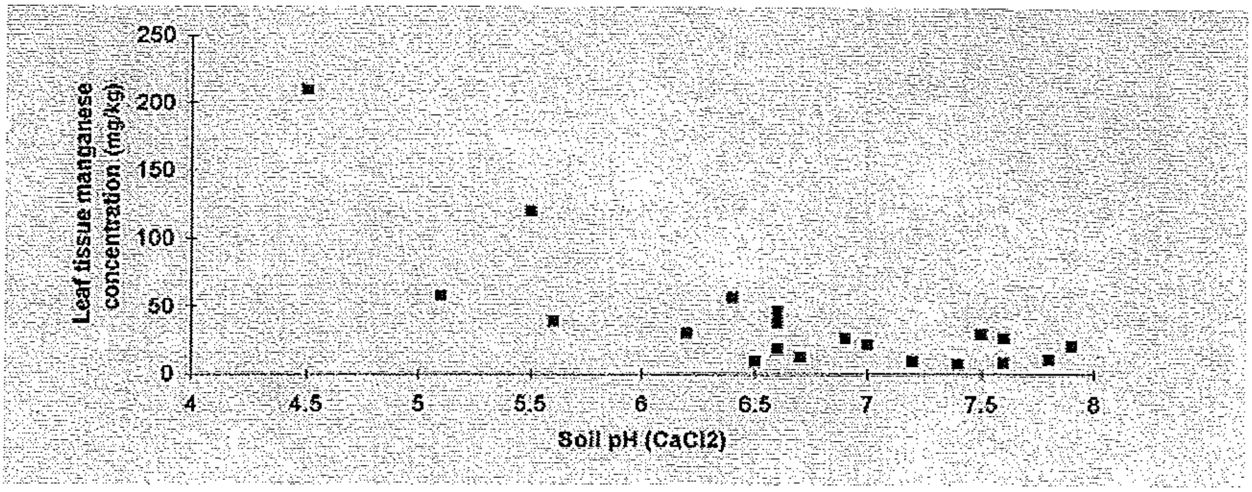

Figure 4. Relationship between soil pH and the concentration of manganese in the leaf tissue.

- Soils in the Lake Gwelup Reserve had a high phosphorus content. This is probably because the soil was transported from the coastal dunes and some of these dune soils are relatively high in phosphorus in the limestone material.

- The highest levels of soil nitrogen were found in the oldest turf sites (Table 2). As the turf swards age, the level of organic matter increases as does the nitrogen in the soil profile. The average organic carbon content in the soil organic matter is about 57 per cent. To calculate the per cent of organic matter in a soil, either divide the per cent of organic carbon by 0.57 or multiply by 1.75. At the Webber Reserve for example, the per cent of organic carbon was 2.03 giving an organic matter content of 3.55 per cent. Under local conditions, this is a high value when it is considered that the original soil organic matter content in a virgin soil could have been as low as 0.2 per cent.

- The levels of the macronutrients as determined by leaf tissue analysis showed that some sites were very low in nitrogen (Table 3). Alexander Heights Reserve had very poor colour and low vigour because of nitrogen deficiency. Potassium levels were lowest at Frederick Baldwin Reserve, a site with little organic matter and low levels of soil potassium. At the Kevan Langdon Reserve, calcium levels were excessive and the soil contained free calcium carbonate. In addition, the irrigation water was high in calcium (Table 5).

- Leaf tissue tests for micronutrients showed that deficiencies of manganese were found at many sites (Table 4). There was a strong correlation between soil pH and the concentration of manganese in the leaf tissue. (Figure 4). As the pH increased so the level of manganese in the leaf tissue decreased. This effect is caused by soil manganese being oxidized into plant unavailable forms as pH increases.

- At the Kevan Langdon Reserve, leaf tissue levels of copper were very low. This site had a high soil pH (Table 4).

- Low levels of iron in the leaf tissue were found a several sites where the pH was about neutral or slightly alkaline and where the irrigation water contained little or no iron. The availability of iron in the soil was affected by the pH (as with manganese). Water with no iron showed up in low levels of iron in the leaf tissue.

- At some sites, the bore water contained nitrogen and, at the Webber Reserve, the irrigation water supplied 49 kg N/ha per year. This constant supply of nitrogen could result in more growth than required.

TINS

Soil moisture sensors for sandy soils

P. Aylmore, G. Luke, K. Burke and R. Deyl

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Introduction

Accurate measurements of soil moisture in the root zone of horticultural crops grown on the sandy soils of the Swan Coastal Plain would improve irrigation management. This would conserve water and reduce production costs. Overwatering causes many problems including inefficient use of fertilisers by plants as a result of leaching and unnecessarily high pumping costs.

We investigated eight soil moisture sensors to check their accuracy and reliability when used on sandy soils in the critical soil moisture range between 6 and 16 per cent (see Tables 1 and 2).

The sensors were installed and operated according to manufacturer's specifications. Instrument readings and gravimetric soil moisture samples were taken at regular intervals throughout a ten week period.

Sensors evaluated

Tensiometers

A tensiometer is a hollow, water filled tube that has a porous ceramic tip and is sealed at the top with a rubber vacuum stopper. A vacuum gauge is either permanently or temporarily attached for recording a vacuum measurement. The tube is inserted in the soil with the ceramic tip at known depths. Frequently, tensiometers are inserted at two depths; one within the root zone and one below the root zone.

As the soil dries, water is drawn out of the instrument through the porous wall of the ceramic tip. This creates a partial vacuum inside the tensiometer and this is recorded and displayed on the vacuum gauge. The drier the soil, the higher the tensiometer reading.

Table 1. List of sensors investigated

Sensor		Retail price (recommended) 10/3/94	Operating range tested in sandy soil ** (% volumetric water)	Solenoid switching
Irrometer®	(Manual)	$100 - 130	5 - 28	No
	(Automatic)	$170 - 190	5 - 28	Yes
Loktronic®	a. Tubes	$30 - 35	2 - 16	No
	b. Meter	$765 *		
Quickdraw®		$600 - 800	1 - 16	No
Hydrovisor®		$320	10 - 17	Yes
Aquaterr®		$1190	3 - 16	No
EnviroSCAN (Standard configuration)		$8650	2 - 16	No
Hydroprobe®		$16550	5 - 16	No
Watermatic®		$680 - 725	2 - 19	Yes

* Portable electronic monitor used to read Tensiometer tubes
** Tested range, not necessarily limits of operation

Table 2. Ability of sensors to enable effective irrigation scheduling of various horticultural crops in sandy soils

Sensor	Annual	Perennial drought susceptible	Perennial drought tolerant
Irrometer® (Manual)	x	x	x
Irrometer® (Automatic)	?	?	x
Loktronic®	√	√	?
Quickdraw®	√ *	√ *	? *
Hydrovisor®	? *	? *	? *
Aquaten®	√ *	√ *	? *
Enviroscan®	?	√	√
Hydroprobe®	x	?	√
Watermatic®	x	√	√

* See text for detail of operational problems during evaluation
? The sensor's effectiveness in this crop should be evaluated
√ Potential to schedule irrigation effectively
x Ineffective for irrigation scheduling

When the soil is rewetted, water is drawn back into the tensiometer tube which reduces the vacuum and results in a lower tensiometer reading.

Tensiometers measure the force that the root system of a plant must exert to extract water from between the soil particles. This force is called the 'soil metric potential' (also referred to as 'soil tension') and provides a direct measurement of water availability to the plant.

In this investigation, four different types of tensiometers were evaluated. Tensiometer tube lengths range from 150 mm to 1200 mm, depending on type and model.

Irrometer®

The Irrometer® is equipped with a vacuum gauge that continuously registers available soil moisture. It is available in two models, standard and automatic (solenoid switching).

The manual Irrometer® was reliable in heavier soils, but not so in coarse sandy soils. At high tensions, the vacuum within the reservoir broke down and the unit malfunctioned. However, the Irrometer® did perform well over the volumetric water range between 8 and 28 per cent.

The main problem with the Irrometer® is that the high tensions which are associated with 'breakdown' occur at soil moisture levels around 6 to 8 per cent. Such soil moistures occur frequently in crops on sandy soils. Furthermore, these tensions develop quickly, giving the irrigator little margin for error. The instrument may be suitable for use under high frequency, pulse irrigation systems.

Some of the automatic Irrometers®) (solenoid switching) provided for testing were faulty. This prevented a proper evaluation of the equipment's effectiveness. A number of Irrometers® had mismatched magnet polarities on their gauges and triggers, this caused the Irrometer's®) switches to operate incorrectly.

Effective operation of the automatic Irrometer® may enable the instrument to continuously trigger irrigation before high tensions are reached and associated malfunctioning occurs. This would make the automatic Irrometer® an effective tool for scheduling irrigation for those crops that are water sensitive such as annuals and drought sensitive perennials.

Loktronic®

The Loktronic® consists of two principal components:

- A normal tensiometer tube sealed at the top with a rubber vacuum diaphragm.
- A portable electronic monitor with digital display. Tensiometer readings are obtained by piercing the rubber diaphragm on the tube with a syringe connected to the digital monitor. A vacuum measurement in centibars is then recorded.

The Loktronic® tensiometer performed reliably over soil moistures from 6 to 16 per cent. Like other tensiometers investigated, the Loktronic® will inevitably break down when the soil becomes too dry. However, with this instrument, breakdown occurred at a much lower soil moisture content than with other makes of tensiometer. Therefore, the Loktronic® may be useful for irrigation scheduling in sandy soils.

The Loktronic® tensiometer's range of soil moisture sensitivity indicates it should be particularly useful in scheduling irrigation for crops that have a critical moisture range between 4 and 12 per cent. This may preclude drought tolerant perennials, but probably includes annuals and drought susceptible perennials.

Quickdraw®

The Quickdraw® tensiometer is a portable tensiometer. The main components comprise the probe itself, the coring tool and its cleaning rod.

The probe consists of a sealed, water filled stainless steel tube equipped with a vacuum gauge (reading centibars) and a porous ceramic tip. The coring tool produces a hole which is tapered at the bottom for insertion of the probe. The sensing tip is pushed firmly into the tapered portion of the hole to provide tight soil/probe contact, ensuring a fast soil suction measurement. A moisture measurement should be made within a few minutes.

The Quickdraw® tensiometer was very slow to respond in sandy soils. On occasions it would take up to 15 minutes before a stable measurement could be obtained. This compares with a few minutes quoted in the manufacturer's instruction manual.

During the sensor's testing, the porous ceramic sensing tip and 'O' rings required replacement. The coring tool frequently became blocked.

The Quickdraw® tensiometer's range of soil moisture sensitivity would suggest it is best suited to scheduling irrigation for annuals, drought susceptible perennials and possibly drought tolerant perennials.

Hydrovisor®

The Hydrovisor® is a solid state tensiometer designed to trigger irrigation. It has a porous ceramic tip which is filled with spherical glass beads of a specific size. The size of the beads determines at what soil metric potential the unit will trigger irrigation.

Hydrovisor® tensiometers are available in three ranges to allow irrigation above a preset metric potential: 8 - 12 centibars for light soils, 20 - 30 centibars for medium soils, 40 - 50 centibars for heavy soils.

The Hydrovisor® tensiometer (8 - 12 cb model) displayed a trigger range between 11 and 13 per cent volumetric soil moisture.

Quality control was a major problem. Of the 12 Hydrovisor® units purchased, only four worked, and after working efficiently for two weeks, these sensors failed. Even when placed in water, these units failed to switch off.

Notably, during the two weeks in which four of the Hydrovisor® sensors operated, there was an extremely high frequency of short irrigation cycles (< 1 minute duration). Such occurrences would create problems with automatic pump starts and any sort of sequencing arrangement in a controller.

The Hydrovisor's® trigger range indicates it could be useful in scheduling irrigation for annuals, drought susceptible perennials and probably drought tolerant perennials, given improved reliability.

Capacitance meter

Aquaterr®

The Aquaterr® soil moisture probe is a portable capacitance sensor. The capacitance principle uses the soil's dielectric constant to determine the volumetric water content.

A 7.5 cm capacitance sensor located at the tip of the probe's 2 cm diameter stainless steel shaft should instantly determine the amount of water and air near the soil particle. The raw measurement is internally corrected to read volumetric water content.

To obtain a reading, the sensor is pushed into the soil to the required depth, the test button pressed and the moisture content indicated by digital meter readout.

The Aquaterr® was similar to the Ouickdraw® tensiometer in that it also took considerably longer to obtain a measurement than the few minutes claimed by the manufacturer. The electronic drift was large on this instrument; this may have been the result of poor sealing of the capacitance sensor in the probe's tip.

The Aquaterr's® range of soil moisture sensitivity suggests it could be useful in scheduling irrigation.

EnviroSCAN®

The EnviroSCAN® is a soil water monitoring system that records the water content of soils by measuring the dielectric constant of the soil. The EnviroSCAN® uses capacitance sensors mounted at predetermined depths within P.V.C. access tubes to measure the surrounding soil environment. All sensors are connected to a central logging unit which enables frequently logged data to be downloaded to a computer. Software permits irrigators to view, via graphs, the soil moisture content, crop water usage and depth of irrigation.

A soil-site specific calibration of the EnviroSCAN® may be essential to calculate the 'absolute' soil water content for research purposes, but this need is still being investigated.

The EnviroSCAN® performed reliably, in accordance with manufacturer's instructions over the soil moisture range of interest. The manufacturer's calibration equation is reasonable in sandy soils, however, investigative work to verify its accuracy is continuing.

The EnviroSCAN's® range of soil moisture sensitivity indicates it should be useful in scheduling irrigation for tree crops that have a critical moisture range between 6 and 16 per cent. Research is continuing to determine the EnviroSCAN's ® suitability for use with shallow rooted vegetables possessing compact root zones. Sensor placement in relation to plant position appears critical.

Neutron probes

Hydroprobe®

The Hydroprobe® or neutron moisture meter provides a rapid non-destructive measurement of volumetric water content.

To measure soil moisture content the Hydroprobe® must be calibrated for specific soil types. This involves the establishment of a relationship between the count rate and volumetric soil water.

The principle components of a Hydroprobe® are, a radioactive source of fast neutrons, a detector tube of helium that is responsive to reflected weak slow neutrons, an associated electronic supply and an amplifying unit.

The soil moisture is measured by lowering the source of fast neutrons and the detector tube to the required depth in an access tube positioned in the soil (aluminium or P.V.C.).

Fast neutrons are emitted from the radioactive source passing through the access tube into the soil. When water is present in the soil, neutrons are slowed and reflected to the detector tube where they are counted. In most soils, the greater the count, the wetter the soil.

The Hydroprobe® results are repeatable in a uniformly wetted soil. However, because of its large sphere of influence, unreliable estimates of soil moisture were given in the surface layers of the sandy soil, where moisture content was non-uniform in the presence of roots.

The Hydroprobe's® inaccurate moisture measurements in the unevenly wetted surface layers of the soil mean its usefulness is limited to deeper rooted perennial crops, not shallow rooted vegetable or perennial crops.

Differential dehydration

Watermatic®

The Watermatic® uses a fired ceramic block as its sensor and operates on the basis of differential dehydration within this porous medium. The tension at which this sensor switches on or off is determined by the size of the pores in the sensor medium.

The response of the sensor to a change in soil water status is rapid and the ceramic block should hydrate within seconds of water reaching its surface.

Soil moisture control is achieved by locating the ceramic sensor in the root zone of the plants being watered. A moisture control unit (M.C.U.) located remote from the sensor, but connected to it by four wires, monitors the moisture content of the block.

As the moisture level falls, the M.C.U. can switch on the irrigation. Once the moisture level in the block is restored, the M.C.U. can terminate the irrigation.

The Watermatic® sensor is available in two models only. A sensor which switches at 8 kPa tension and a sensor which switches at 15 kPa tension. Our evaluation was on the 8 kPa sensor ('potting mix' sensor).

The Watermatic® was the only solenoid switching sensor that performed reliably during testing. The trigger point for the 8 kPa Watermatic® block was about 8 per cent volumetric water content. However, previous work indicates this trigger point could be too dry for effective irrigation management of most horticultural crops in coarse sandy soils, particularly vegetables.

The Watermatic® requires installation before planting because of the destructive nature of installation. As a result, reliable performance depends upon uniform crop establishment and growth.

Clearly, limitations would exist if using the Watermatic® for irrigation scheduling of annual horticultural crops. Efficient soil moisture control could not be achieved until such time that the crop established its roots around the sensor block. Other work suggests that it is during this early stage of crop growth at which greatest water savings are possible.

Notably, the Watermatic® has operated successfully in the irrigation management of some avocado and lemon trees at the Medina Research Station.

Conclusion

Of the eight sensors tested, only the Watermatic®, Hydroprobe®, EnviroSCAN® and Loktronic® performed reliably, in accordance with manufacturer's instructions over the soil moisture range between 6 and 16 per cent.

The Watermatic® and Hydroprobe® both displayed problems that limited their usefulness for shallow rooted annual horticultural crops.

With experience and development of appropriate operating procedures, the Aquaterr®, Quickdraw® and Irrometer® could also be used to give reliable estimates of soil moisture under the conditions investigated.

The automatic Irrometer® would appear very attractive in coarse sandy soil if the problem of vacuum breakdown can be overcome. Its main advantages include its cost effectiveness and solenoid switching ability.

Unknown manufacturing or quality control problems made the Hydrovisor® sensors unreliable. It is likely that the Loktronic® could be useful for shallow rooted annual and drought susceptible perennial crops.

The rapidity with which soil moisture changes under crops on sandy soils, and the consequent need for frequent readings by the irrigator, reduces the value of many of the manually operated sensors. It limits their potential usefulness to anything other than an 'after the event monitoring tool'.

Technical terms and conversion tables

TINS

Technical terms used in turf culture

Adapted from: "Technical terms in turf culture" by Dr Peter Hayes, The Sports Turf Research Institute, Bingley, West Yorkshire, England.(n.d).Terms selected and compiled by K.J. Johnston. Revised by D.A.W. Johnston.

Acid(ic) turf - Turf with a low pH. Note: It is not the grass which is acidic, but the soil.

Acidity - acid(ic) soil - A soil condition where the pH is below 7.0

Agronomist - A person who specializes in agronomy

Agronomy - The theory, study and practice of field crop production and soil management. In Australia, this includes work with pastures, horticultural crops, pulses, cereals and turf culture

Alkalinity - An alkaline soil condition where the pH is above 7.0

Amendments - Physical substances such as sand; calcined clay; peat; charcoal or sawdust added to the soil to alter its physical properties. In Western Australia, includes materials such as fly ash and Alkaloam.

Ammoniacal nitrogen - An immediate release source of nitrogen used in some fertilizers.

Anaerobic - Soil conditions where there is little or no oxygen e.g. compacted, badly drained soils.

Anions - Negatively charged atoms or groups of atoms i.e. molecules.

Available nutrient - That quantity of a nutrient element or compound in the soil that can be readily absorbed and assimilated by growing plants.

Available water - That portion of water in a soil that can be absorbed by plant roots.

Broadcast application - Distribution of a material over the surface of an entire area, e.g. fertilizer or sand.

Bulk density - The mass of soil in a specific volume. This measure can give an idea of the amount of compaction in a soil.

C3 and C4 grasses - Abbreviations used for cool season grasses and warm season grasses respectively.

Calcareous - Containing limestone or other forms of calcium carbonate.

Calcined clay - Clay minerals such as montmorillonite and attapulgite that have been fired at high temperatures to obtain absorbent, stable, granular particles. Sometimes used as a physical amendment in soil modification.

Calibrate - Measure of the rate of application of a fertilizer spreader or sprayer under defined conditions.

Capillary action - Movement of water between soil particles by virtue of surface tensional forces at the soil (particle) interface and between the cells of any organism.

Carbon : nitrogen ratio - The ration of C : N in the soil or of an organic amendment.

Carrier - The material added to a product e.g. fertilizer, to facilitate its distribution.

Cation - Positively charged atoms or groups of atoms i.e. molecules.

Cation exchange - The interchange between a cation in solution and another cation on the surface of the soil colloid. This process retards the loss of some nutrients from the soil by leaching.

Centrifugal spreader - An applicator from which dry, particulate material e.g. granular fertilizer, is broadcast outward as it drops onto a spinning disc or blade beneath a hopper.

Chlorophyll - The green pigment in plants which is vital for photosynthesis.

Chlorosis - The yellowish colour in normally green plants caused by poor chlorophyll production.

Clay - Soil particles of <0.002 mm diameter.

Clay soil - A soil type containing 40 per cent or more of clay sized particles.

Clipping removal - Collecting cuttings by mowing and removing them from the turf.

Clippings - Leaves and, in some cases, stems cut off by mowing.

Clone - A genetically uniform group of plants originating from a single plant by vegetative propagation.

Colloidal complex - The soil component made up of the very fine particles of clay and humus. It is responsible for many of the soils' physical and chemical properties.

Compaction, soil - The process in which the soil aggregates and soil particles are forced into close proximity by the application of an external force.

Consultant - An agronomist who has specialist knowledge and from whom a client would seek advice and information about agronomy or turf management.

Cool season turf grass - Turf grass species best adapted to growing during the cool, moist periods of the year. Commonly having temperature optima of 15 to 24° C.

Couch grass - Common name for *Cynodon dactylon,* an important turf grass species.

Cultivar - A variety of a species in cultivation. Cultivars of a single species differ from other cultivars in specific characteristics e.g. disease resistance, leaf width, growth habit.

Cultivation, turf - The working of a soil without the destruction of the turf, e.g. coring; slicing; grooving; spiking and shattering.

Cutting height - Of a mower, the distance between the plane of travel, the base of the roller or wheel and the parallel plane of cut.

Cylinder mower - A grass mower where the cutting blade moves in a vertical plane and cuts caused by the action of the cylinder blades against the sole plate, as does a pair of scissors. Also called a reel mower.

Decomposition - The breakdown of living matter into more simple chemical forms.

Decumbent - Lying flat, postrate with the apex growing upwards.

Denitrification - The biochemical reduction of nitrogenous forms of nitrogen in the nitrate and nitrite forms into elemental nitrogen.

Dethatch - To remove excessive thatch accumulation either by: (a) mechanical means as in vertical mowing and (b) biologically as in topdressing.

Dormant turf - Turf that has temporarily ceased shoot growth as a result of extended drought, heat or cold stress.

Drought - A prolonged period of dry weather.

Dry patch - A dry area of turf, variable in size, which is difficult to wet because of the hydrophobic or water repelling nature of the soil.

Environment - All external conditions which affect the growth of an organism.

Establishment, turf - Root and shoot growth following seed germination or vegetative planting needed to form a mature, stable turf.

Eutrophication - A condition which occurs in water bodies where the water is deficient in oxygen and aquatic plants, including algae, are abundant. This process is accelerated by surface run-off and leaching of nutrients such as nitrogen and phosphorus.

Evaporation - The process by which a liquid is changed to a vapour or gaseous form.

Evapotranspiration - Water loss caused by the combined effects of direct evaporation from a surface and transpiration by plants.

Fertigation - Fertilizer application through an irrigation system.

Fertilizer analysis - The percentage by weight of the components in a fertilizer. e.g. a fertilizer with an analysis of 12: 2: 6 contains 12 per cent nitrogen (N), 2 per cent phosphorus (P) and 6 per cent potassium (K). This information must be stated on the fertilizer bag.

Granular fertilizer - Fertilizer in the form of granules. Each granule typically is about 3 mm in diameter.

Gypsum - Calcium sulphate, $CaSO_4$, used in soil management to improve sodic soils. The calcium ions from the gypsum replace the sodium ions on the soil particles.

Height of cut - the height above ground level at which the sward is cut.

Infiltration - The downward entry of water into the soil by gravitational force.

Inorganic - Not organic which means not derived from living or dead organisms. Natural or synthetic elements or chemicals of non-living material.

Irrigation - The controlled application of water to turf or other cultivated plants.

Irrigation, automatic - A water application system in which valves are automatically activated, either hydraulically or electrically, at times preset on a control panel.

Kikuyu - The common name of *Pennisetum clandestinum,* an important turf grass species.

Lawn - Ground covered with closely grown and mown vegetation, usually a grass surrounding a house, factory or on recreational areas.

Leaching - The removal of materials in solution by the passage of water through the soil.

Lime - Calcium carbonate, an alkaline substance spread on turf to correct acidic conditions. The form most commonly used on turf is ground limestone which may also contain magnesium carbonate.

Liquid fertilization - A method of nutrient application as a solution of dissolved fertilizer.

Loam - A soil that contains 7 to 27 per cent clay, 28 to 50 per cent silt and ≈ 52 per cent sand.

Low maintenance - Turf maintained with few inputs, i.e. nil or little fertilizer and infrequently cut.

Major nutrients - The major plant nutrients are nitrogen, phosphorus and potassium. In addition, it is common to include calcium, sulphur and magnesium because of the amount required by the plant.

Micronutrient - A chemical element necessary only in extremely small amounts for the growth of plants, usually < 50 mg/ kg in plant tissue, e.g. boron; copper; iron; zinc; manganese and molybdenum.

Micro-organism - Small sized organisms including protozoa, bacteria and some fungi.

Mineral soil - A soil which contains mainly mineral matter which usually contains ≤ 20 per cent organic matter.

Monoculture - A turf grass community composed of one cultivar.

Mowing frequency - The number of mowings per unit of time, or the interval in days between one mowing and the next.

Muriate of potash - Potassium chloride. Muriate of potash has an analysis of 50 per cent potassium.

Native plant - An indigenous plant species.

Nitrogen - Chemical symbol N. One of the major nutrients necessary for healthy plant growth. Used by the plant for the production of chlorophyll, and plant and leaf growth.

Nitrogen cycle - The circulation of nitrogen through its compounds in living organisms. Also includes the inorganic stages of the cycle as in atmospheric nitrogen.

Nutrient - Any food or material that nourishes or promotes plant growth. Usually applied to soil nutrients though water, oxygen and carbon dioxide also fit this definition.

Organic - Compounds which contain carbon. All life contains organic compounds.

Organic fertilizers - Usually refers to fertilizers made from living material or manures.

Organic soil - A soil which contains a high percentage of organic matter, >15 to 20 per cent.

Osmosis - The movement of a solvent usually water, to a more concentrated solution when the two solutions are separated by a semi-permeable membrane.

Parts per million (ppm) - The number of parts by weight or volume of a compound in one million parts of the final mixture. Now replaced by the international term of mg/ kg or mg/ L.

Percolation - The downward movement of water through the soil, to ooze through . Similar in context to infiltrate.

Permeability - The ease with which gases, water or plant roots penetrate or pass through a soil.

pH - A value related to the hydrogen ion concentration in a solution, used to express acidity or alkalinity on a scale of 0 to 14. On this scale, a measurement below 7 is acidic, 7.0 is neutral and above 7 is alkaline.

Phosphorus - Chemical symbol P. One of the major nutrients necessary for healthy plant growth. Used in root growth, plant development and seed formation.

Pore space - The total space not occupied by soil particles in a volume of soil.

Potash - A co[illegible] material containing the [illegible] usually as potassium carbonate. Originally made by washing vegetable ashes and evaporating the material in iron pots.

Potassium - Chemical symbol K. One of the major plant nutrients necessary for healthy plant growth.

Residual response, fertilizer - A delayed or continued turf grass response to a slow release fertilizer, lasting longer than the initial response from water soluble fertilizers.

Rhizome - A jointed underground stem that can produce roots and shoots at each node.

Root hair - Very delicate, whitish, outward extensions of an epidermal root cell. Occur a short distance back from the root cap in great numbers. Important for the absorption of nutrients and water.

Root system - The underground downwards growth of a plant. The roots anchor the plant in the soil and absorb moisture and nutrients from the soil solution for use by the plant.

Root zone - The soil layer which constitutes the growing medium in which the majority of the plants roots grow.

Rotary mower - A mower that cuts turf by the high speed impact of a blade or blades rotating in a horizontal cutting plane. There are both power propelled and operator propelled mowers.

Sand - Soil particles ranging from 0.05 to 2.0 mm diameter.

Saturation - A soil moisture state in which all spaces between the soil particles are filled with water.

Silt - Soil particles within a size range of 0.002 to 0.05 mm diameter.

Slow release fertilizer - A fertilizer with a rate of dissolution less than that of completely water soluble fertilizers. May involve compounds which dissolve slowly, materials that must be decomposed by microbial activity, or soluble compounds coated with substances highly impermeable to water. The term, 'slow release' is used interchangeably with 'controlled release' See definition for 'residual response'.

Soil - The natural medium for plant growth, usually containing inorganic and organic materials. Note: there are some plants which do not grow in soil.

Soil acidity - The degree of acidity or alkalinity of a soil. The soil reaction or pH is the measure used to determine soil acidity. On this scale, 0 is very highly acidic and 14 is very highly alkaline. See definition of 'pH'.

Soil air - The air which occupies the pore space in a soil.

Soil fertility - This refers to the plant food status of the soil and to its aeration, moisture supply, organic matter content and level of acidity.

Soil organic matter - The organic matter fraction of the soil which includes plant and animal residues at various stages of decomposition, tissues of soil organisms and other products formed by the soil population.

Soil tests - Laboratory tests to determine such matters as the soil pH and the soils' nutrient status.

Soil texture - Soils are classified into various textural classes according to particle size such as sands, loams or clays by their percentage of clay, silt and sand. See definitions for clay, sand, silt.

Soluble - Matter which is capable of being dissolved by a liquid.

Solution - A liquid containing a dissolved substance.

Species - A group of individuals, (animals or plants) similar in structure and physiology, which are generally capable of interbreeding to produce fertile offspring which are like their parents. A group of plants subordinate in classification to a genus. Note: Not all individuals in certain plant species produce fertile seeds, many are reproduced vegetatively.

Sprigging - The establishment of a new turf by planting stolons in the soil. An example of vegetative reproduction.

Sulphate of potash - Potassium sulphate. A potassic fertilizer containing 41 per cent K.

Superphosphate - A phosphatic fertilizer containing 9 per cent P. Manufactured from rock phosphate and sulphuric acid.

Sward - The above and below ground parts of a population of herbaceous plants, usually grass, characterized by relatively short growth habit and a relatively continuous ground cover.

Symptom - A change of appearance indicating the existence of disease, injury, nutrient deficiency or toxicity.

Texture - In turf, the composite leaf width, taper and arrangement.

Thatch - A layer of intermingled dead and living shoots, stems and roots that develops between the zone of green vegetation and the soil surface.

Topsoil - The upper layer of soil usually containing organic matter and living material.

Trace elements - Essential plant nutrients required in very small amounts. See definition of micronutrients.

Translocate - Chemical products transported in solution within the plant.

Transpiration - The transfer of water vapour from the plant to the atmosphere.

Turf - A covering of mown vegetation growing intimately with the upper soil stratum of intermingled roots and stems.

Turf grass - A species or cultivar of grass usually spreading in habit, which is maintained as mown turf and used in a non-agricultural manner.

Turf grass colour - The composite visual colour of a turf grass community perceived by the human eye.

Turf grass culture - The composite cultural practices involved in growing turf grasses for purposes such as lawns, greens, sports facilities and road sides i.e. non-agricultural use.

Turf grass management - The development of turf standards and goals which are achieved by planning and directing labour, capital and equipment with the objective of manipulating cultural practices to achieve those standards and goals.

Turf grass quality - The degree to which a turf conforms to an agreed standard of uniformity, density, texture, growth habit, smoothness and colour as judged by subjective visual assessment. There are different turf grass qualities for different sporting activities.

Turf grass uniformity - The degree to which a turf grass community is free from variations in colour, density and texture over the surface as judged by visual assessment.

Turf, lush - A term used for over watered, over fertilized turf which is growing vigorously and is often of a deep green colouration.

Variety - A botanical division of a species. An obsolete term now replaced by the term cultivar which is defined as a variety in cultivation.

Verdure - The layer of green living plant tissue remaining above the soil surface following mowing.

Vertical mower - A power mower that cuts turf by the high speed impact of blades revolving in a vertical plane. The blades can be of varied shapes and fixed or free swinging e.g. used as a flail.

Warm season turf grass - A turf grass species best adapted to growth during the warmer part of the year, commonly having a temperature optimum of 27 to 35 °C, e.g. kikuyu and couch grass.

Water table - The upper surface of the ground water or that level in the ground where water is at atmospheric pressure.

Watering in - The watering of turf immediately after the application of chemicals to dissolve and/or wash materials from the plant surface into the soil e.g. fertilizer.

Wear - The collective direct injurious effects of traffic on a turf. This is distinct from the indirect effects of traffic caused by soil compaction.

Weed - Any plant growing where it is not wanted. A plant is out of place.

TINS

Conversion factors and conventions

Throughout this manual, metric units have been used instead of the former Imperial units. As some users may still be familiar with the Imperial units, appropriate conversion factors are listed below. The text of the manual has been prepared using standard Australian Oxford English Dictionary spellings. English rather than Germanic word constructions have been used.

Conversion factors

To convert	Into	Multiply by
Electrical conductivity		
EC units		
mS/m	µS/cm	10.0
	dS/m	0.01
	mS/cm	0.01
Water salinity		
mS/m	mg/L or ppm	5.5
µS/cm	mg/L or ppm	0.55
mS/m	grains/gallon	0.38
µS/cm	grains/gallon	0.038
mg/L	grains/gallon	0.07
	mS/m	0.18
	µS/cm	1.8
grains/gallon (TDS)	mS/m	2.5
	µS/cm	25.0
	mg/L	14.3
Soil salinity (1 : 5 soil : water extract)		
mS/m mg/L	mg/L or ppm	6.4
µS/cm mg/L	mg/L or ppm	0.64
mg/L	µS/cm	1.6

Per cent soluble salt = TDS (mg/L) x 5 x 10^{-4}

To convert	Into	Multiply by
Area		
hectare	acre	2.47
acre	hectare	0.405
Mass		
kilogram	pound	2.204
pound	kilogram	0.454
Rate of application		
kilograms per hectare	pounds per acre	0.983
pounds per acre	kilograms per hectare	1.12

Temperature

Celsius	Fahrenheit	(9/5 x C°) + 32
Fahrenheit	Celsius	5/9 (F° - 32)

Concentration

grams per kilogram	per cent	0.1
per cent	grams per kilogram	10.0
milligrams per kilogram	parts per million	1.0

1 milligram per kilogram (1 mg/ kg) = 1 part per million (1 ppm)

References: Australian Standard 1376 -1973 - Conversion factors

Australian Standard 1000 -1979 - The International System of Units (SI) and its application