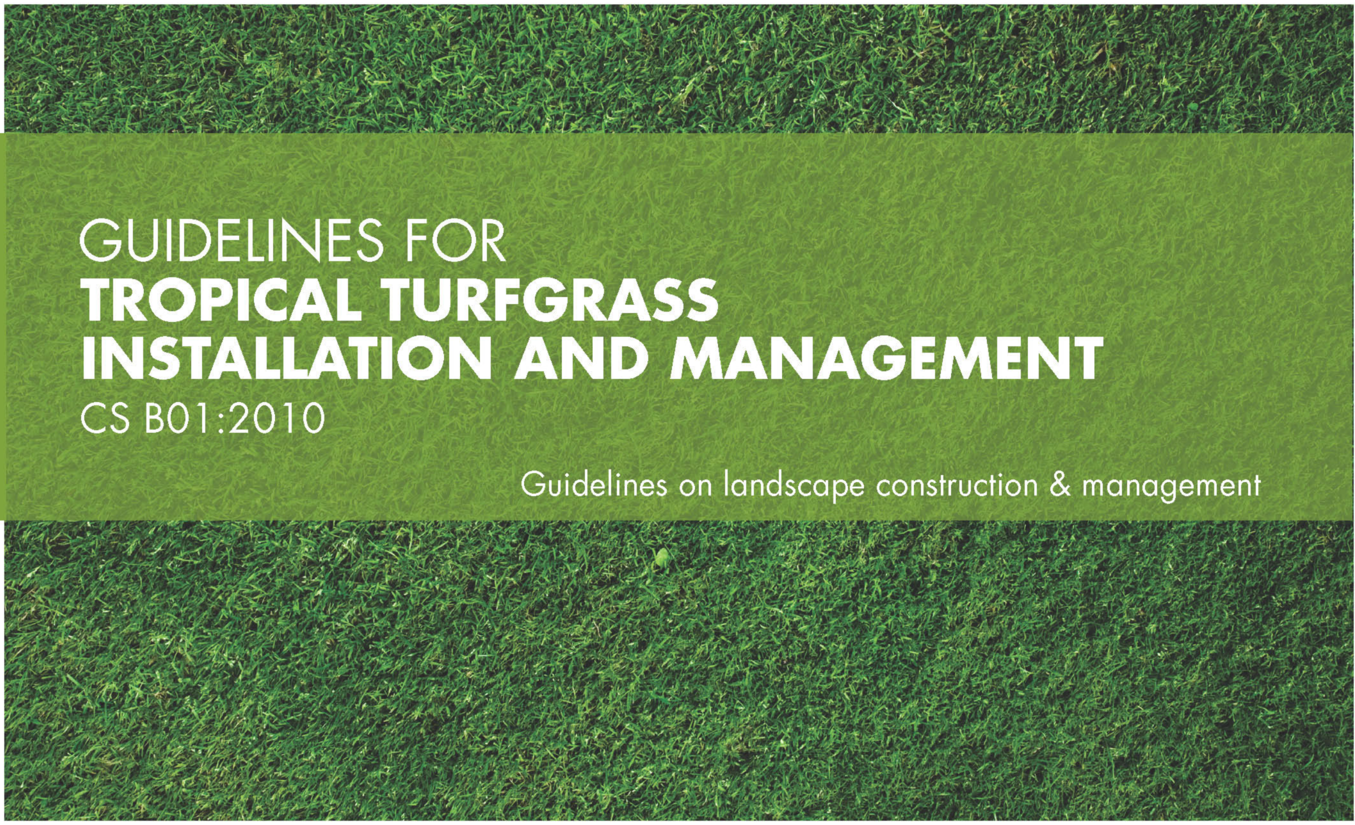
Centre for Urban Greenery & Ecology
CUGE Standards



GUIDELINES FOR **TROPICAL TURFGRASS INSTALLATION AND MANAGEMENT**

CS B01:2010

Guidelines on landscape construction & management

CUGE®
CENTRE FOR URBAN GREENERY AND ECOLOGY

BCA / NPARKS GREEN MARK FOR PARKS

NATIONAL PARKS

CS B: Landscape Construction and Management

CUGE STANDARDS CS B01:2010

GUIDELINES FOR **TROPICAL TURFGRASS INSTALLATION AND MANAGEMENT**

Published by:
Centre for Urban Greenary & Ecology
National Parks Board Headquarters
1 Cluny Road
Singapore 259569

The CUGE Standards Series is a set of written guidelines for adoption in the landscape and horticulture industry. They are written through a formal process that involves consultation with relevant bodies and reaching a consensus across all interested parties so that the final document meets the needs of business and industry. All standards take the form of either specifications, methods, vocabularies, codes of practices or guides.

The CUGE Standards Series comprises:

CS A	Specifications on properties of planting media
CS B	Landscape construction & management
CS C	Urban ecology
CS D	Landscape design
CS E	Skyrise greenery

DISCLAIMER

While the information it contains is believed to be correct, it is not a substitute for appropriate professional advice. In no event shall NParks be liable for any special, incidental, indirect or consequential damages of any kind arising out of or in connection with the use of this Technical Brief, whether or not advised of the possibility of damage, and on any theory of liability.

This publication is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to, the implied warranties of merchantability, trees for a particular purpose, or non-infringement. Descriptions of, or references to, products or publications do not imply endorsement of those products or publications. This Technical Brief will be reviewed periodically and changes maybe made at any time.

ISBN 978-981-08-5230-6

Tropical Turfgrass Installation and Management
First Edition: CS B01: 2010

The CS B01:2010 was written by Dr. Kenneth B. Marcum, with comments provided by the CUGE Standards Technical Committee. The Technical Committee was represented by:

Mr. Neil Power (National Parks Board)
Ms. Kartini Omar (National Parks Board)
Dr. Tan Puay Yok (National Parks Board)
Mr. Kok Chiang Heng (Turf and Irrigation Services Pte. Ltd.)
Mr. Chek Keng Chan (Agri-Supplies Pte. Ltd.)
Dr. Micah Woods (Asian Turfgrass Center)

The CS B01:2010 was approved by the CUGE Standards Review Panel in March 2010.
The CUGE Standards Review Panel was represented by:

Dr. Leong Chee Chiew (National Parks Board)
Mr. P. Teva Raj (National Parks Board)
Mr. Henry Steed (Singapore Landscape Industry Council; Singapore Institute of Landscape Architects)
Mr. Michael Teh (Singapore Landscape Industry Council; Landscape Industry Association Singapore)

The CS B01:2010 is expected to be reviewed every three years as more technical information becomes available, through on-going research. The CS B01:2010 is not intended to be exhaustive. New standards on more specific areas will be developed from time to time.

Enquiries:
Dr. Kenneth Marcum
kenneth_marcum@nparks.gov.sg

Angelia Sia
angelia_sia@nparks.gov.sg

CONTENTS

SECTION 1 TURFGRASS AND THE URBAN ENVIRONMENT

Turfgrasses play a major role in the urban landscapes of Singapore, and worldwide. In the U.S., Australia, Europe, and other developed nations it is among the most economically valuable of landscape commodities. Green lawns increase the utility of home gardens, providing a functional and inviting living space. A well maintained turf lawn offers aesthetic appeal, and increases property values (Fig 1).

Fig 1. Turfgrasses provide aesthetic appeal to landscapes, improve functionality, and increase property values.

Lawns also provide an excellent playing surface. On many school playgrounds, parks, and sports venues, natural turf substantially reduces sports related injuries relative to synthetic surfaces. In hot environments, ambient temperatures are typically much lower on natural turf relative to synthetic surfaces (Fig 2).

Fig 2. Natural turfgrass offers an excellent playing surface for added environmental comfort and safety.

Turfgrasses also perform beneficial functions for the urban environment, including:

- Soil stabilisation and erosion control – Due to densely fibrous root systems and contiguous shoot soil cover, turfgrasses prevent soil erosion and runoff better than any other plant community (Fig 3).
- Pollution control, improved water quality, and remediation of stormwater runoff and urban wastewaters – Due to highly active rootzone rhizospheres, turfgrasses are an excellent biofilter. Research has shown that turfgrass root systems are superior scavengers of contaminants from wastewaters and urban runoff. Turfgrasses are now used in urban communities to remediate urban wastewaters by biofiltration prior to recharge to fresh water catchments and aquifers (Fig 4).

Fig 3. Turfgrasses prevent soil erosion, even on steep slopes: a) slope protected by turfgrass, b) eroded slope.

Fig 4. Turfgrass irrigated with reclaimed urban wastewater. Photo Tanah Merah Country Club, Singapore.

- Cooling of the environment – Turfgrasses cool the ambient environment by evapotranspirational cooling, substantially reducing building cooling costs, and increasing utility of landscapes. For example, typical temperature difference between synthetic surfaces (ex. concrete, bitumen, artificial turf, etc.) and natural turf during midday may be quite large.
- Absorption of air pollutants and dust.
- Turfgrass rootzones accumulate large amounts of organic humus, resulting in benefits:
  - Soil reclamation and improvement of soil structure and fertility.
  - Reduction of greenhouse gas by sequestration of atmospheric carbon dioxide.

SECTION 2 TURFGRASS ESTABLISHMENT – LAWN CONSTRUCTION

Proper construction and establishment are essential for long-term sustainability of turfgrass landscapes. Shortcuts taken during this critical stage will result in numerous problems, including poor drainage, soil compaction, fertility or pH issues, weeds and pests, and poor quality turf.

Prior to starting construction, decisions must be made, depending on the amount of use, and foot traffic the site will sustain. High foot traffic levels sustained on high visibility areas such as event lawns and areas used for sports activities may warrant the added expense of subsurface drains, and modified rootzones (ref. Sect. 2.2 Drainage). However, in normal use areas this may be economically unfeasible.

2.1 GRADING

Proper grading is necessary to provide adequate site drainage. Surface drainage is provided by maintaining grades of 2% (change in vertical/horizontal) or more. It is also critical that all layers follow the same grade, i.e. that they are mirror images of each other. Any depressions in sublayers should be smoothed out prior to laying upper layers. Otherwise there will be wet and dry spots across the lawn. Steps in the grading process are listed below:

1. Remove and dispose of all existing onsite turf sod prior to grading.
2. Eliminate undesirable weeds, particularly perennial grasses and nutsedges (Fig 5). This is usually accomplished by repeat applications of nonselective systemic herbicide (ex. glyphosate).

Fig 5. Perennial noxious weeds must be eliminated prior to planting, especially perennial grass weeds and sedges. a) *Cynodon* spp. (bermudagrass) invading *Axonopus compressus*. b) Purple nutsedge (Cyperus rotundus) in *Axonopus compressus*.

3. In situations where a) projected use and foot traffic are low and b) existing soil has adequate depth and drainage, it may be decided to keep the original soil profile intact. In this case, cut and fill can be used, where the existing soil is simply graded prior to planting. If deep cuts are made, existing topsoil should be saved to cover these cut areas. Where excavation is done for buildings, topsoil should be separated and stored separately for use later.

4. In most situations where moderate to high foot traffic is projected, cut and fill will provide inadequate drainage. In these cases, grading of a sub base is necessary, followed by the addition of drainage layers and/or rootzone layer.

5. If site has a developed soil, with topsoil as upper layer, this valuable topsoil should be saved for the turf rootzone. First remove top 30 cm layer from site, stockpiling in another location, prior to site grading (Fig 6). However, if existing topsoil is not worth saving, and it is decided to import rootzone layer from offsite, then sub base grading can commence immediately.

Fig 6. Stockpiling topsoil during the grading process.

6. Establish sub base grade to provide an even and stable foundation for the rootzone media. Grading is set at this stage to mirror final surface grade.

7. Ideally, 2% grade should be incorporated into turf areas to provide surface drainage.

8. Grading must be away from existing structures, high use areas, and sidewalks, and toward surface drains.

9. Remove all large rocks, construction debris, and undecomposed organic matter (tree stumps, limbs, lumber, etc.) during the grading process (Fig 7).

Fig 7. Rocks left during grading can interfere with subsequent drainage and aeration operations.

Other construction debris may include concrete layers where cement was mixed. Leaving these for incorporation into the lawn will cause numerous problems:

a. Large rocks & construction debris –
   i. Nonuniform drainage and dry spots
   ii. Prevention of cultivation operations such as tining
   iii. Nonuniform turf surface and park user injuries
   iv. Alkaline patches from construction mortar
b. Undecomposed organic matter –
   i. Anaerobic rootzone
   ii. Nutrient deficiencies
   iii. Fungal diseases, including fairy ring
   iv. Gradual formation of depressions as organic material decays (Fig 8)

Fig 8. Depression in turf resulting from decomposition of unremoved tree stump.

10. To prevent settling, compact sub base prior to placing subsurface drains and/or rootzone layer.

    a. To avoid compaction of subsequent layers, heavy equipment should be kept off the area following installation of drainage layers or rootzone layer (Fig 9).

Fig 9. Heavy equipment on wet soils results in compaction.

11. Install marked stakes in a grid pattern throughout sub base, with depth of subsequent layer(s) marked. This will allow for grading of layers to exactly mirror one another (Fig 10). Failure to mirror the grading of various layers will result in wet and dry areas.

Fig 10. Marker stakes used to mirror layers in grading process.

2.2 DRAINAGE

Inadequate drainage is a major issue in Singapore, resulting in waterlogging (Fig 11). Drainage should be adequate to ensure rootzone water infiltration rates of at least 50 mm/hr. For high traffic areas, this should be increased to 100+ mm/hr.

Fig 11. Waterlogged turf, due to inadequate drainage.

2.2.1 Surface Drainage

1. Ideally, 2% or more surface grade (slope) is necessary to allow for adequate surface drainage.
2. Surface run should be no more than 25 metres to a surface drain.

2.2.2 Subsurface Drainage – High Use Lawns

High use lawns receive frequent foot traffic, as well as occasional events and sports activities. Both high use and very high use lawns (ref. sect.2.2.3) require subsurface drainage to minimize waterlogging. Though high use lawns require substantially higher installation costs, failure to follow drainage and rootzone guidelines will likely result in major downstream management problems.

1. For subsurface drains, use “herringbone” or “gridiron” drain pipe pattern (Fig 12). Primary drain pipes should be 100 mm diameter, central collection pipes 150 mm diameter.

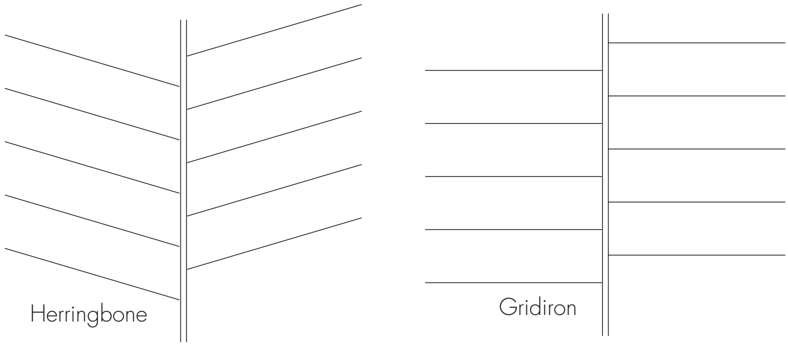


Fig 12. Herringbone and gridiron subsurface drainage patterns

2. Cut 300 mm deep trenches into sub base (Fig 13). Primary drain pipes should run along primary slope. Width of trenches should be 300 mm. Distance between trenches will vary depending on permeability of rootzone.

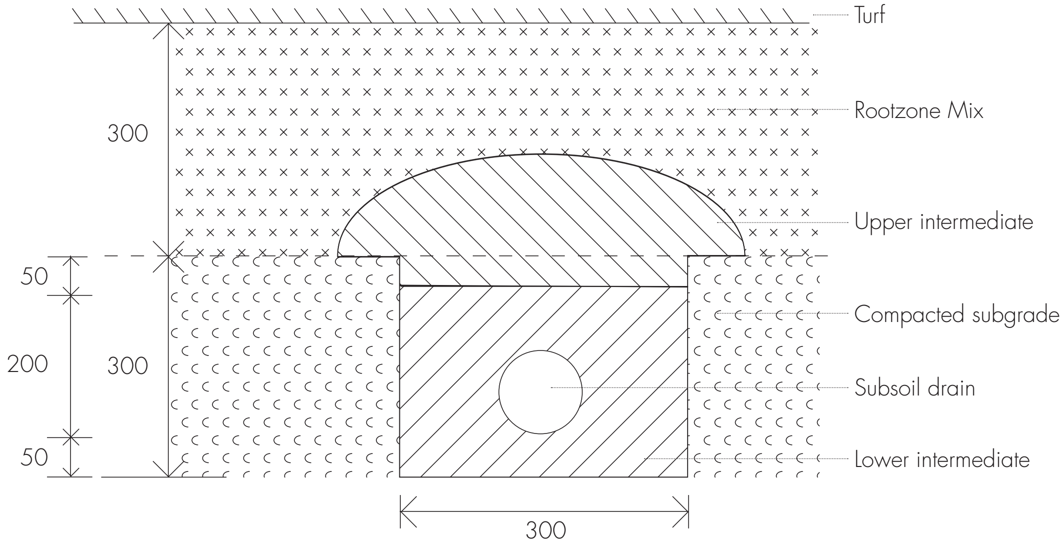


Fig 13. Subsurface drainage for high use lawns.

3. Place 50 mm layer of uniform diameter aggregate on trench bottom (follow "lower intermediate" particle size specifications in Fig 14).

a. Lower intermediate aggregate should be washed, and of mechanically stable and weatherproof material – limestone, shale, and sandstone are unsuitable.

4. Place primary drain pipes atop 50 mm layer.

5. Continue filling trench with lower intermediate aggregate to within 50 mm of top.

6. Fill remainder of trench, spilling over onto sub base surface, using "upper intermediate layer" material (Fig 14).

7. Install rootzone layer 300 mm deep. This will be a soil-based rootzone mix, preferably Approved Soil Mix[a] (ASM, consisting of 3 parts soil, 2 parts mature compost, 1 part sand), or a sand-soil mix[b].

Layer	Particle Size Specification
Gravel	No more that 10% > 12 mm At least 65% are 8 – 12 mm No more than 10% < 2 mm
Lower Intermediate	At least 80% are 4 – 9 mm
Upper Intermediate	At least 80% are 1 – 4 mm

Fig 14. Particle size specifications for subsurface drainage layers.

2.2.3 Subsurface Drainage – Very High Use Lawns

Very high use lawns sustain heavy foot traffic from frequent public events and sports activities. In situations where very high traffic use is expected, a layered drainage system will perform best (Fig 15).

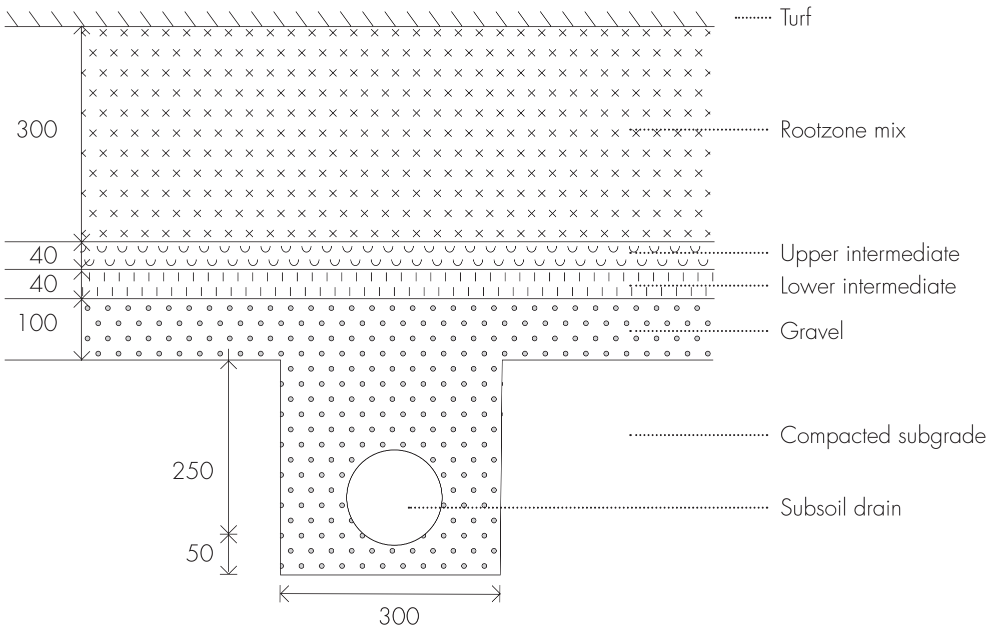


Fig 15. Subsurface drainage for very high use lawns, showing drainage layers and subsurface drains.

The same steps should be followed up to and including #3 above. Subsequent steps are as follows:

1. Gravel Layer: Fill trenches with washed, mechanically stable uniform gravel (Fig 14). Continue filling to provide a smooth graded layer (following sub grade) 100 mm deep (depth is measured from sub base surface, NOT from bottom of drainage trenches). Do not use geotextile.
2. Lower Intermediate Layer: Install washed fine gravel layer 40 mm deep, following particle size specification in Fig 14.
3. Upper Intermediate Layer: Install washed coarse sand layer 40 mm deep, following particle size specification in Fig 14.

4. Rootzone Layer: Install rootzone layer 300 mm deep. Rootzone should consist of at least 75% sand, following sand particle size specification in Fig 16. Use only stable washed sand – coral sand should not be used. Sand particle sizes should be as uniform as possible.

Particle	Diameter (mm)	Recommended Weight
Fine gravel	2.0–3.4	Not >10% of total particles within this range, Including max. 3% fine gravel
Very coarse sand	1.0–2.0	
Coarse sand	0.5–1.0	> 60% of particles
Medium sand	0.25–0.5	
Fine sand	0.15–0.25	<20%
Very fine sand	0.05–0.15	<5%
Silt	0.002–0.05	<5%
Clay	< 0.002	<3%
Total fines	Very fine sand Silt, clay	<10%

Fig. 16. Particle size specifications for sand in rootzone layer.

2.3 ROOTZONE MEDIA

2.3.1 Essential Qualities

Rootzone consists of the upper surface layer, where the majority of turfgrass roots are found. Proper rootzone conditions are an essential component of quality lawns. For a rootzone media to support healthy turf, it must provide:

1. Physical properties
   a. Good drainage
   b. Adequate gas exchange
2. Chemical properties
   a. Nutrient holding capacity
   b. Optimum fertility
   c. Optimum pH
   d. Low salinity

2.3.2 Rootzone Physical Properties

Physical properties of a soil include texture and structure, which directly affect soil porosity. This in turn affects soil aeration, permeability and drainage, and soil moisture content.

2.3.2.1 Soil Texture

Texture describes the size of particles, and their relative proportion within a soil. Soil particles are grouped into three sizes. Soil texture class is determined by the relative proportions, in percentages, of each size (Fig 17). Most Singapore soils are classified as clay or clay loam.

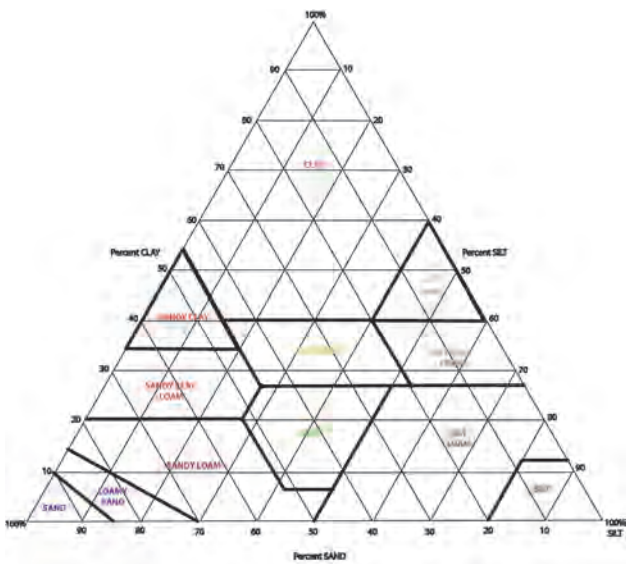


Fig. 17. Soil texture triangle.

- Sand: 0.05 – 2.0 mm diameter (macroscopic)
  Soils having predominately sand are considered coarse textured soils.
- Silt: 0.002 – 0.05 mm diameter (microscopic)
  Soils having predominately silt are considered medium textured, or loamy soils.
- Clay: less than 0.002 mm diameter (microscopic)
  Soils having predominately clay are considered fine textured soils.

2.3.2.2 Soil Structure

Individual soil particles group together to form aggregates, resulting in soil structure and good porosity (Fig 18). Organic matter plays a major role in aggregation by providing cementing agents, with root growth and aerobic microorganisms also playing a role. In most soils, structure is essential to maintain healthy turf growth. Without good structure, a fine textured soil becomes densely compacted, with loss of macropores, drainage and aeration.

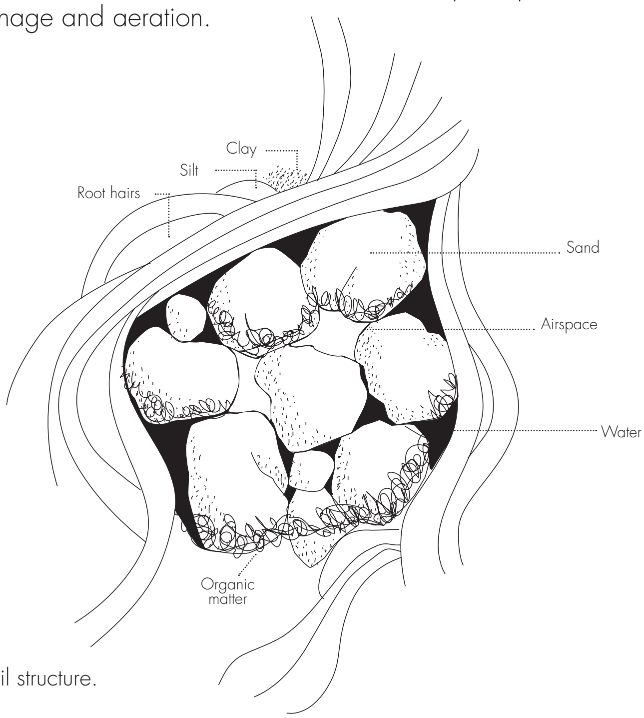


Fig 18. Soil structure.

2.3.2.3 Soil Porosity

Porosity indicates the amount of air spaces present in a soil. Soils supporting healthy turf growth typically have about 50% total pore space. Soil pores are of two types:

- Macropores – large (macroscopic) pores
  - Macropores provide air exchange (aeration) essential for healthy root growth. Good soil structure provides good macroporosity.

Symptoms of poor rootzone aeration include formation of black or gleyed soil layers, which release reduced compounds toxic to roots (Fig 19). These toxic compounds can often be detected as a "rotten egg smell", due to release of reduced sulfur compounds.

Fig 19. Soil gleying formation caused by anaerobic conditions.

- Provide water movement required for good drainage. Waterlogged soils do not provide air exchange essential for healthy rooting, as oxygen diffusion through water is very slow.

- Micropores – small (microscopic) pores
  - Provide surface area for water storage. Soils without significant micropores are droughty, often requiring irrigation.
  - Provide charged sites (cation exchange capacity) for holding nutrients in an available form for plant growth. Soils lacking in micropores (sands) require frequent, careful fertilization to maintain plant-available soil nutrients, and to avoid leaching.

2.3.3 Maintenance of Soil Structure and Macroporosity

With the exception of sand rootzones, maintenance of soil structure is critical to allow adequate drainage and aeration in tropical soils.

2.3.3.1 Important Steps to Maintain Soil Structure

1. Provide for drainage in construction design (ref. Sect. 2.2 Drainage).
2. Maintain soil organic matter by:
   a. Incorporating mature compost into soil mix at planting.
   b. Leave clippings on turf following mowing operations.
3. Utilise Approved Soil Mix (ASM)[a] for the rootzone, consisting of 3 parts uniform soil, 2 parts mature compost, and 1 part sand, well mixed, recommended depth 300 mm.
4. In very high traffic situations (ex. event lawns), a sand based rootzone media may be used, recommended depth 300 mm (ref. 2.2.3 Subsurface Drainage – Very High Use Lawns).

5. Thoroughly mix rootzone materials offsite, prior to installation. Poor mixing results in layering (Fig 20). Layering, regardless of whether coarse material is above or below, will impede drainage and cause an anaerobic soil layer.

Fig 20. Inproperly mixed rootzone, resulting in layering.

6. Do not traffic turf soils when wet:
   a. Minimise foot and machine traffic, mowing, and other operations when soil is wet.
   b. Schedule irrigations to allow soil drying prior to turf use.
7. Cultivation practices (ref. Sect. 7 Turf Management – Cultivation):
   a. Aerification via hollow or solid tines may:
      i. Temporarily improve structure by introducing macropores, especially when followed by topdressing using a desirable rootzone mix.
      ii. Improve aeration, encouraging rooting, thus improving structure.

2.3.3.2 Monitoring Changes in Soil Structure

Loss of rootzone structure and macroporosity usually occurs gradually, resulting in gradual loss of drainage, aeration, rooting, and turf health. Therefore it is important to monitor soil structure, and to modify management practices when changes begin to occur. Monitoring methods are described below:

1. Saturated hydraulic conductivity – the best way to monitor soil drainage, which is directly affected by structure and macroporosity. Water infiltration rate into the turf soil is measured when the soil is wet – at this point the infiltration rate is steady state. To avoid lateral flow, two concentric rings (300 and 600 mm diameter) are sunk into the soil to a depth of 60–100 mm, with water movement being measured within the inner ring (Fig 21). If a two ring system is not available, a single ring may be used. Optimum hydraulic conductivities depend on the necessary drainage rate required to maintain well drained conditions. This in turn depends on the expected average and maximum precipitation rates, as well as the intended turf usage intensity. Minimum recommended hydraulic conductivity for turf rootzones in Singapore is 50 mm/hr, and 100+ mm/hr for high use areas.

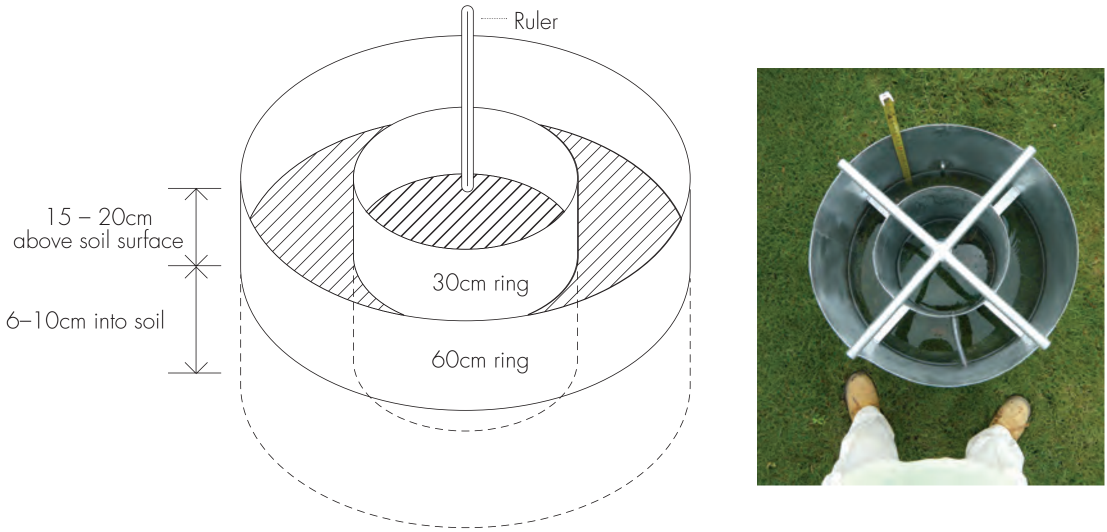


Fig 21. Hydraulic conductivity rings for measuring soil drainage.

2. Soil bulk density – the mass per unit volume (g/cc) of a soil. Soil bulk density samplers take a known core volume of undisturbed soil (Fig 22). When sampling, make sure that turf shoots and thatch are not included. The soil core is dried at 60+ C, then weighed. Bulk density values vary depending on soil type. Within a given soil, monitoring for changes in bulk density is a valuable tool to keep track of changes in compaction levels. Optimal bulk densities range from 1.3 to 1.6, while values above 1.6 indicate compacted soils.

Fig 22. Soil bulk density sampler.

3. Soil hardness – Measurements are affected by soil moisture status, so repeat readings should be taken when soil is at similar moisture levels. A penetrometer measures resistance with depth using a soil probe with a resistance sensor or "penetrometer" (Fig 23). This instrument gives a rough estimation of soil compaction with depth. Readings above 200 psi indicate compacted soils.

Fig 23. Soil penetrometer.

4. Visual assessment of water infiltration rate – A rough estimation of water movement in soils can be obtained by observing the time it takes for ponded water to move into a soil following heavy rains (Fig 24). Observance of a slowing of infiltration rate with time indicates that soil compaction is occurring.

Fig 24. Drainage rate can be estimated by observing turf ponding.

2.3.4 Rootzone Chemical Properties

2.3.4.1 Soil Testing

- Soil testing is an essential aspect of turf management, yet is frequently overlooked. Quality turf lawns are impossible if soil chemical properties are not addressed. Important chemical properties include cation exchange capacity, pH, nutrient availability (ref. Sect. 6 Turf Management – Fertilisation), and salinity.
- All chemical properties should be tested prior to installation of rootzone. This is because some essential nutrients (ex. phosphorus and calcium) are immobile in soils, and are therefore best mixed throughout the soil volume. Adjusting pH also requires mixing amendments throughout the soil volume. Soil samples should be taken from various places in the rootzone pile, and thoroughly mixed before testing. After testing, soil amendments should be thoroughly mixed into rootzone material offsite, prior to installation.

- Following turf establishment, soil sampling should be done annually to monitor all chemical properties except cation exchange capacity, which generally does not change in a particular soil.
- Annual soil sampling after establishment should be done with a soil probe (Fig 25).

Fig 25. Taking a soil sample.

- Sampling should be done in a grid pattern across the lawn. Break up and thoroughly mix samples prior to sending for analysis. Remove all non-soil organic matter from samples prior to mixing.
- Depth of sampling should be approximately 150 mm.

2.3.4.2 Cation Exchange Capacity

The nutrient holding capacity of a rootzone is determined by its cation exchange capacity (CEC), indicated as meq/100 g dry soil, which is an indication of the number of positively charged sites in a soil. These sites hold (exchange) nutrient ions. Fine textured soils and soils high in organic matter have higher CECs than coarse textured soils. Typical CEC ranges from sands (2-4) to clays (>10) to soils high in organic matter (100). High CEC soils tend to be more fertile, holding a greater store of plant nutrients. Low CEC soils do not hold nutrients well, and are subject to leaching and nutrient loss, and therefore must be carefully fertilised at more frequent intervals.

2.3.4.3 pH

Soil reaction (pH) is a measure of acidity or alkalinity, with 7 being neutral, less than 7 acid, and more than 7 alkaline.

- Turfgrass tolerance to pH – Though the primary effect of pH is on nutrient availability, turfgrasses do differ in their tolerance to strongly acidic or alkaline soils (Fig 26)

pH	Soil Reaction	Turfgrass sp.
3	Strongly acidic	None
4	Strongly acidic	*Eremochloa ophiuroides*
5	Acidic	*Axonopus compressus* Bahiagrass
6	Slightly acidic	Zoysiagrass *Cynodon* spp.
7	Neutral	*Stenotaphrum secundatum*

Fig 26. Turfgrass adaptation to pH.

- Effects of pH on nutrient availability – Primary effect of pH is on rootzone nutrient availability. Nutrients are optimally available under slightly acidic to neutral pH (6–7). As rootzones become more acidic or alkaline, certain nutrients become insoluble and unavailable for root uptake (Fig 27). As most tropical rootzones fall in the acidic range, phosphorous deficiencies are commonly seen (ref. Sect. 6.1.2 Turf Management – Fertility, Phosphorous). Effects of pH typically do not affect availability of other nutrients in Singapore, except for the case of iron and manganese in alkaline soils impacted by construction backfill.

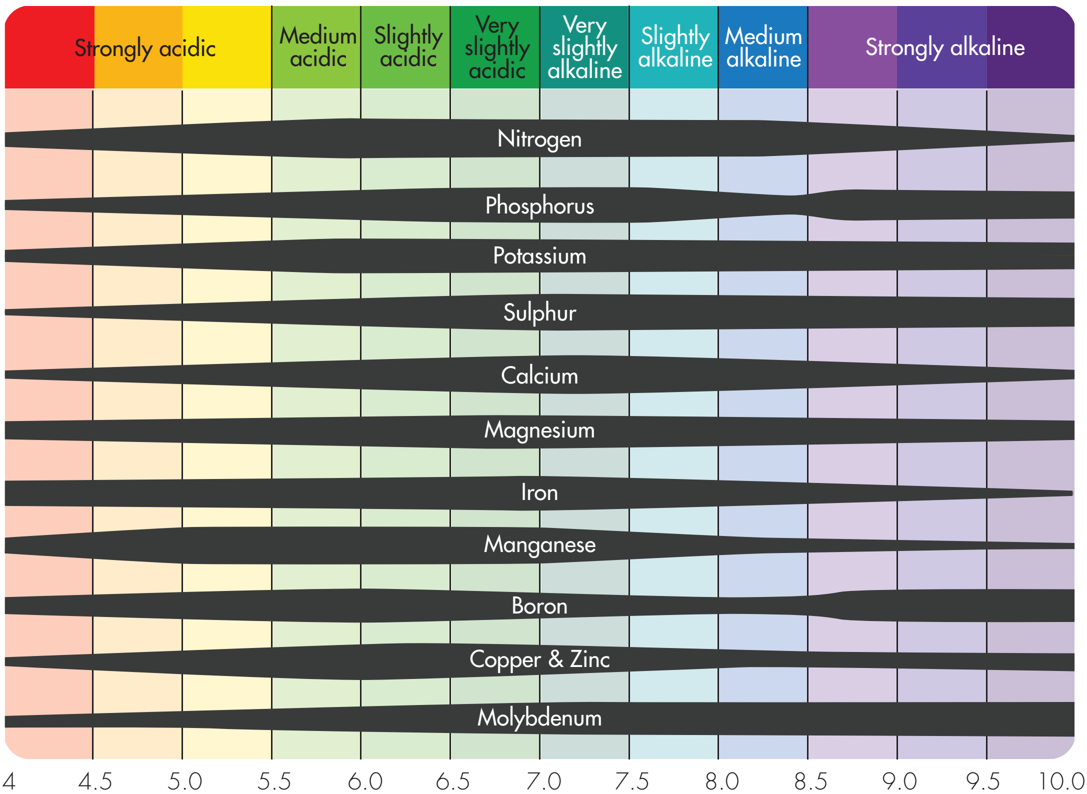


Fig 27. Soil pH and nutrient availability.

2.3.4.4 Liming

- For optimal turfgrass growth, rootzone pH should be adjusted and maintained between 5.5–7. For acidic soils, addition of lime can raise pH by replacing H^+ in soil by Ca^{2+}:

$$H^+ + CaCO_3 \rightarrow H_2O + CO_2 + Ca^{2+}$$

- However for alkaline soils, addition of sulfur can lower pH by production of H^+:

$$S + H_2O \rightarrow H_2SO_4 + H^+$$

- The amount of lime or sulfur required to change rootzone pH will depend on the CEC. High CECs will require larger amounts of amendment, due to larger numbers of ion exchange sites, resulting in larger numbers of ions to replace. Soil laboratory can give precise liming recommendation based on testing results for CEC and existing soil pH. Fig 28 is a general table to estimate liming requirements:

Soil pH	Sand – Loamy Sand	Sandy Loam	Clay Loam – Clay
>6	0	0	0
5.1–6.0	24	36	48
<5.0	48	60	85

Fig 28. Kilograms limestone needed per 100 square metres to adjust roozone pH.

2.3.4.5 Salinity

- Soil salinity can be an issue in Singapore in coastal areas subject to ocean salt spray or salt water intrusion.
- Initial salt injury on turf includes yellowing and leaf burning, followed by thinning and death (Fig 29).

Fig 29. Salt injury on turf.

- A primary ion in ocean salt is sodium, which breaks down soil structure, causing compaction, loss of drainage and aeration, and leaching potential.
- Soil salinity can be monitored using a hand-held conductivity metre. To measure salinity, make a solution of 1 g dry soil in 5 cc water. Units are generally expressed as ppm (parts per million) salts.
- Turfgrasses differ widely in salinity tolerance. If saline conditions are anticipated, plant a salt tolerant turfgrass (Fig 30).

HIGH

Paspalum vaginatum
Zoysia matrella
Zoysia pacifica
Stenotaphrum secundatum
Cynodon spp.
Zoysia japonica
Axonopus compressus
Axonopus sp. 'Pearlgrass'
Eremochloa ophiuroides

LOW

Fig 30. Salt tolerance of turfgrasses.

NOTES:
a For more information on specifications for composts and mulches, please refer to CS A02:2009.
b For more information on specifications for soil mixture for general landscaping use, please refer to CS A01: 2009.
c For common names, see Sect.3 Turfgrass Selection.

SECTION 3 TURFGRASS SELECTION

3.1 SELECTION OF TURFGRASS SPECIES

To achieve quality turf, correct species must be selected based on the intended use and adaptability to the environment and on-site growing conditions. Turfgrass species differ in the quality achieved under different uses. For example, for event lawns where high traffic is anticipated, a species should be selected that has high traffic tolerance. Or, in areas subject to tree shading, a shade tolerant species should be selected. If species is improperly selected, it will be difficult to achieve a quality turfgrass. Listed below are the names and origins of existing tropical turfgrass species, followed by estimated criteria for selecting the optimum turfgrass species. These lists are estimations based on available research data to date.

Botanical name: *Axonopus* sp.
Common name: Cowgrass, tropical carpetgrass
Native to: South America
Propagation: Vegetative only
Uses: Lawns

Botanical name: *Axonopus* sp.
Common name: Pearlgrass
Native to: South America
Propagation: Vegetative only
Uses: Lawns

Botanical name: *Cynodon dactylon*, or *C. dactylon x C. transvaalensis*
Common name: Bermudagrass, green couch grass
Native to: Africa
Propagation: Seeded or Vegetative
Uses: Lawns, Sports fields

Botanical name: *Digitaria didactyla*
Common name: Serangoongrass, blue couch grass
Native to: Africa
Propagation: Seeded or Vegetative
Uses: Lawns, Sports fields

Botanical name: *Eremochloa ophiuroides*
Common name: Centipedegrass
Native to: China
Propagation: Seeded or Vegetative
Uses: Lawns

Botanical name: *Paspalum vaginatum*
Common name: Seashore paspalum
Native to: South America
Propagation: Seeded or Vegetative
Uses: Lawns
Sports fields

Botanical name: *Stenotaphrum secundatum*
Common name: St. Augustinegrass, buffalo grass
Native to: South America
Propagation: Vegetative only
Uses: Lawns

Botanical name: *Zoysia japonica*
Common name: Japanese lawngrass, Korean lawngrass
Native to: Asia
Propagation: Seeded or Vegetative
Uses: Lawns
Sports fields

Botanical name: *Zoysia matrella*
Common name: Manilagrass, carpetgrass
Native to: S.E. Asia
Propagation: Vegetative only
Uses: Lawns
Sports fields

Botanical name: *Zoysia pacifica (tenuifolia)*
Common name: Templegrass, mascarene grass
Native to: S.E. Asia
Propagation: Vegetative only
Uses: Lawns
Sports fields

3.2 SHOOT DENSITY

Shoot density is the number of shoots per unit ground area. Shoot density is the primary attribute of turfgrass quality. Other quality attributes include colour, leaf texture (leaf blade width), and canopy uniformity. Shoot density is dependent on turfgrass species (Fig 31). Within a species, shoot density can be increased by higher levels of maintenance, including reducing mowing height and increasing mowing frequency, maintaining optimum fertility and water relations, and eliminating weeds and pests. However, reducing mowing height beyond the optimum for a given species (ref. Fig 54) will actually result in reduced density.

Zoysia matrella HIGH
Zoysia pacifica
Paspalum vaginatum
Cynodon spp.
Digitaria didactyla
Zoysia japonica
Axonopus compressus
Axonopus sp. 'Pearlgrass'
Stenotaphrum secundatum
Eremochloa ophiuroides LOW

Fig 31. Shoot density of turfgrasses.

3.3 TRAFFIC TOLERANCE

Traffic tolerance is the sum of wear tolerance + recuperative (growth-spreading) potential. Zoysiagrass has very high wear tolerance, due to silica present in the leaves (Fig 32).

Cynodon spp. has less wear tolerance, but high recuperative potential. The effect of traffic in killing turf is often due to soil compaction, resulting in anaerobic rootzone (ref. Sect. 2.3.2 Rootzone Physical Properties). Traffic damage shows up as thinning turf and hard compacted surface (Fig 33).

If high trafficking is expected, use a traffic tolerant turfgrass (Fig 34). Installing a permeable rootzone with adequate surface and subsurface drainage is also critical. Finally, cultivation operations such as hollow and solid tining will reduce soil compaction and improve aeration (ref. Sect. 7.4 Coring).

Fig 32. Zoysiagrass overtaking *Axonopus compressus* on a highly trafficked site.

Fig 33. Traffic injury on turfgrass.

Zoysiagrasses	HIGH
Paspalum vaginatum	↑
Digitaria didactyla	
Cynodon spp.	
Stenotaphrum secundatum	
Eremochloa ophiuroides	
Axonopus compressus	↓
Axonopus sp. 'Pearlgrass'	LOW

Fig 34. Traffic tolerance of turfgrasses.

3.4 SHADE TOLERANCE

Though tropical turfgrasses have a relatively high light requirement, Singapore skies are often cloudy, resulting in low annual cumulative light intensities. Compounding this are the high density of trees in Singapore's parks and streetscape environments (Fig 35).

Fig 35. Singapore's abundant trees in parks and streetscapes.

Effects of shade on turfgrass include slowed growth, reduced rooting, elongated stems and leaves, increased susceptibility to weeds and diseases, and reduced shoot density (Fig 36, 37). Measures for counteracting shade stress include increasing mowing height to increase light capture, decreasing traffic, improving soil drainage to prevent fungal diseases, reducing nitrogen fertilisation, thinning tree canopies by selective pruning, and using shade tolerant turfgrass species (Fig 38).

Fig 36. Thinning turfgrass under shade stress.

Fig 37. Shade tolerant *Stenotaphrum secundatum* overtaking *Axonopus compressus* under tree shade.

HIGH

Stenotaphrum secundatum
Axonopus sp. 'Pearlgrass'
Zoysia matrella
Zoysia pacifica
Zoysia japonica
Axonopus compressus
Eremochloa ophiuroides
Digitaria didactyla
Paspalum vaginatum
Cynodon spp.

LOW

Fig 38. Shade tolerance of turfgrasses.

3.5 DROUGHT TOLERANCE

Drought stress often results during dry periods in Singapore, resulting in turf injury, yellowing, and thinning (Fig 39). Improving drought stress involves increasing rooting, as deeply rooted turf will be able to extract water from deeper in the soil profile. Thus, maintaining good drainage and reducing compaction during the wet season will improve drought tolerance during the dry season. Irrigated turf may be acclimated to improve drought tolerance by allowing soil to dry between irrigations. Turfgrasses differ widely in drought tolerance (Fig 40).

Fig 39. Drought injury on turfgrass.

HIGH

Cynodon spp.
Zoysia matrella
Zoysia japonica
Paspalum vaginatum
Stenotaphrum secundatum
Digitaria didactyla
Axonopus compressus
Eremochloa ophiuroides
Axonopus sp. 'Pearlgrass'

LOW

Fig 40. Drought tolerance of turfgrasses.

3.6 DISEASE AND INSECT TOLERANCE

Disease and insect problems are minimised when using turfgrasses adapted to Singapore. For example, rarely is disease or insect damage seen on *Zoysia matrella*, which is native to S.E. Asia. However, disease and insect damage are often seen on *Paspalum vaginatum*, native to South America (Fig 41).

Fig 41. Sclerotinia (dollar spot) fungus on *Paspalum vaginatum.*

The most important prevention measure is to use resistant turfgrasses (Fig 42). Proper management is also important, including maintaining well drained rootzones. If disease symptoms occur, maintain optimum fertility levels, raise mowing height, and reduce traffic. If symptoms advance, utilising a fungicide or insecticide specific to the pest may be necessary.

Zoysiagrasses	HIGH
Axonopus compressus	
Axonopus sp. 'Pearlgrass'	
Digitaria didactyla	
Stenotaphrum secundatum	
Eremochloa ophiuroides	
Cynodon spp.	
Paspalum vaginatum	LOW

Fig 42. Disease and insect resistance of turfgrasses in Singapore. Species at top have greater resistance.

3.7 FERTILITY REQUIREMENT

Turfgrasses differ in their fertility needs, primarily due to differences in nitrogen requirement (Fig 43). For fertility requirements and fertilisation management, ref. Sect. 6 Turfgrass Management – Fertilisation.

Cynodon spp.	HIGH
Paspalum vaginatum	
Zoysiagrasses	
Stenotaphrum secundatum	
Digitaria didactyla	
Axonopus compressus	
Eremochloa ophiuroides	
Axonopus	LOW

Fig 43. Fertility requirement of turfgrasses.

3.8 MOWING HEIGHT

Turfgrasses differ in optimum mowing height for maximising density (Fig 44). Mowing heights, frequencies, and mowers are discussed in Sect. 5 Turfgrass Management – Mowing.

Stenotaphrum secundatum	HIGH ↑
Eremochloa ophiuroides	
Axonopus compressus	
Axonopus sp. 'Pearlgrass'	
Zoysia japonica	
Paspalum vaginatum	
Cynodon spp.	
Zoysia matrella	
Zoysia pacifica	↓ LOW

Fig 44. Mowing height of turfgrasses.

SECTION 4 TURFGRASS PLANTING

- Tropical turfgrasses are generally vegetatively planted, though a few species have seed available.
- Vegetative methods include sodding, close turfing, stolonising, sprigging, plugging, and Spot turfing.
- Prior to planting, seedbed should be prepared by grading, and smoothing by raking.
- Fertiliser should be incorporated into the seedbed, following soil test recommendations.
- Mowing should commence when turf height is approximately twice that of desired height. Delaying mowing will stress seedlings, resulting in thinning of stand.

4.1 SODDING

- Sodding generally consists of laying turf sheets or rolls end to end (Fig 45).
- Sodding results in instant turf. However, if turf is to be used for sports or heavy foot traffic, an establishment time of several weeks should be allowed for initial rooting or "pegging".
- Sodding is the most expensive form of planting, typically costing 5 to 7 times that of seeded turf.
- Quality sod is:
  - Fresh – cut sod must be planted within 24 hours unless refrigerated.
  - Pure cultivar – no off species or weeds, and absolutely no perennial grass weeds or nutsedges.
  - Maturity – sod should be mature and well knitted, but not old. There should not be a thick thatch layer present (Fig 46).
  - Soil layer:
    - Soil layer should not be too thick. Less than 20 mm is ideal.
    - Soil layer should be of the same type (same soil texture class) as onsite rootzone, otherwise drainage problems associated with layering will occur. If soil is markedly different, use washed sod.

Fig 45. Sodding turfgrass.

Fig 46. Turf sod of proper thickness and maturity.

Fig 47. Sodded turf was not rolled, resulting in dieback.

- After sodding, lightly roll for good soil contact, then thoroughly water. Failure to roll will result in dieback of areas lacking good soil contact (Fig 47).
- Water 1x/day until roots begin to grow into soil, then reduce watering to once every 2 days for another week, followed by once every 3 days until established.
- Two weeks after planting, fertilise with a complete fertiliser to apply a rate of 0.5 kg N/100 square metres.
- A form of sodding, termed "close turfing", is often used, where irregularly shaped, generally small, turf pieces are used in planting (Fig 48). Though turf pieces are laid touching one another, an irregular surface results, as pieces vary in soil thickness, and contact between pieces is not uniform (Fig 49). If close turfing is used, sequential topdressings will be necessary to gradually level the soil surface.

Fig 48. Planting by close turfing.

Fig 49. Close turfing results in an irregular turf surface.

4.2 STOLONISING

- Stolonising consists of broadcasting rhizome or stolon pieces over the soil surface.
- Stolonising and sprigging are faster in establishing than seeding, but slower than sodding.
- Rhizomes or stolons should contain at least 3 nodes (growing points).
- Spread 3–5 cubic metres of stolons per 1000 square metre area. Higher rate will result in more rapid establishment.
- After broadcasting stolons, topdress with rootzone mix 6 mm thick, then roll, and water in.
- To avoid stolon dessication, stolonise by section of lawn, followed by topdressing and light watering.
- Following planting, irrigate lightly 3 times per day to keep stolons moist. After rooting occurs, decrease to 2 times per day for one week, followed by 1 time per day until establishment.
- Every two weeks after planting, fertilise with a complete fertiliser to apply a rate of 0.25 kg N/100 square metres until established.
- Hydrosprigging is a rapid, efficient method in which stolons are mixed as a slurry with a cellulose or other mulch, together with starter fertiliser and perhaps a tackifying (sticking) agent. Slurry is then applied with a hydroseeder, modified to prevent stolon damage (slower agitation, lower pressure). As mulch is applied during hydrosprigging, no topdressing or rolling are required. (Fig 50).

Fig 50. Planting with hydrospringging.

4.3 SPRIGGING

- Sprigging consists of partially burying stolons in rows 15–30 cm apart. Sprigging can be done by hand, or by specialised sprigging machines.
- Stolon rate may be less than stolonising (typically half).
- Establishment rate may be a bit slower than stolonising.
- Following planting, irrigate lightly 3 times per day to keep stolons moist. After rooting occurs, decrease to 2 times per day for one week, followed by 1 time per day until establishment.
- Every two weeks after planting, fertilise with a complete fertiliser to apply a rate of 0.25 kg N/100 square metres until established.

4.4 PLUGGING

- Plugging involves planting of 50–70 mm diameter plugs (rooted turf pieces with soil) into holes (Fig 51).
- Planting is on a grid, with plugs approximately 300 mm apart.
- Lightly topdress, and roll weekly until establishment.
- Following planting, irrigate lightly 2 times per day to keep plugs moist. After rooting occurs, decrease to 1 time per day until establishment.
- Every two weeks after planting, fertilise with a complete fertiliser to apply a rate of 0.25 kg N/1000 square metres until established.

Fig 51. An individual plug.

4.5 SPOT TURFING

- Spot turfing is similar to plugging, however irregular, nonrooted turf pieces are used rather than rooted plugs, resulting in an irregular, nonuniform surface and poor establishment (Fig 52). Therefore, spot turfing is not recommended as a method of turf planting.


Fig 52. Spot turfing.

4.6 SEEDING

- Only a few tropical turf species produce seed, and therefore can be seeded. Seeding rates for these species are shown in Fig 53.

Turfgrass	Seeding Rate (Kg/100 sq metres)	Germination Rate (Days)
Cynodon spp.	0.5–0.8	7–15
Eremochloa ophiuroides	2.0–3.0	7–14
Zoysia japonica	1.0–1.5	10– 4
Paspalum vaginatum (if available)	0.4–0.7	10–14
Digitaria didactyla (if available)	0.2–0.8	7–14

Fig 53. Seeding rates for tropical turfgrasses.

- Always follow recommended seeding rates. High rates result in weak seedlings and damping off fungal disease.
- Correct seeding rate by calculating pure live seed (% PLS), where % PLS = % purity X % germination. Both % purity and % germination should be listed on seed label.
- Buy only quality, certified seed.
- Prior to planting, seedbed should be prepared by grading, and smoothing by raking.
- Fertiliser should be incorporated into the seedbed, following soil test recommendations.
- Following planting, lightly rake seed.
- Mulch with straw or similar mulch at a rate of approximately 490 kg/1000 square metres. Coverage of soil should be approximately 75% when looking down onto surface.
- Following planting, irrigate lightly 3 times per day to keep seed moist. After shallow rooting occurs, decrease to 2 times per day for one week, then decrease to once per day until establishment.
- Every two weeks after planting, fertilise with a complete fertiliser to apply a rate of 0.25 kg N/1000 square metres until established.
- Mow with a sharpened rotary mower, not a reel mower. Reel mower will pull out young seedlings. Do not use a backpack mower.

4.7 THE PLAYING SURFACE

Event lawns and other high use areas receiving sports related activities must have a safe playable turf surface. Surface must be even, without gaps in the turf. Essential qualities of a good playing surface are listed below:

- Turf coverage
  - To avoid player injury, turf coverage must be even and uniform, not patchy or undulating.
  - Rootzone must be properly graded, following guidelines (ref. Sect. 2.1 Grading).
  - Uniform, pure cultivar turf sod sheets must be installed. Close turfing using irregular sod pieces will result in unacceptable turf surface unless subsequent topdressing and rolling is utilised.
  - Lightly roll turf after installation, and at least once more at 2–3 week intervals to achieve uniform surface. Topdress prior to rolling to fill in depressions, using identical rootzone soil mix.
- Surface hardness
  - Excessive hardness will result in player injury.
  - Surface hardness should be between 70 to 130 GMAX (gravity maximums), as measured by a Clegg Turf Impact Hammer.
  - Surface hardness indicates compaction. To avoid compaction, ref. Sect. 2.3.3 Maintenance of Soil Structure and Macroporosity.
  - During dry periods, turf may require irrigation to minimise surface hardness.

SECTION 5 TURFGRASS MANAGEMENT – MOWING

5.1 MOWING HEIGHT AND FREQUENCY

Though mowing is the most expensive management practice in terms of man hours and fuel costs, it is also the most important. Proper mowing technique, particularly mowing height and frequency, is critical to achieve quality turf.

Mowing encourages lateral branching, thereby increasing turf shoot density (number of shoots per unit ground area). Decreasing the mowing height will generally stimulate more lateral branching, increasing turf density and quality. However, mowing also decreases total leaf area, resulting in less photosynthesis and reduced rooting (Fig 54). Each turfgrass species has a minimum mowing height, beyond which the turf begins to starve due to lack of leaf area, resulting in turf thinning (reduced density) and dieback (Fig 55).

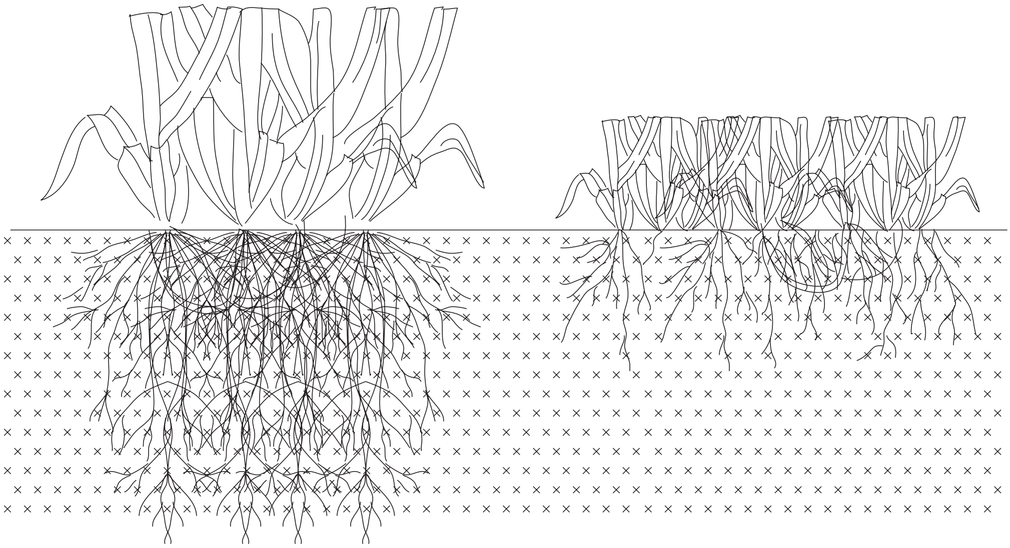


Fig 54. Effect of reducing mowing height on shoot density and rooting depth.

Fig 55. Mowing below the minimum mowing height for a species results in thinning and dieback.

Scalping occurs when too much leaf area is removed at a given mowing. This stresses the turf, causing it to rapidly use up foodstores, again causing starvation, thinning and dieback (Fig 56). No more than 35-40% of the total leaf area should be removed at a given mowing. This is known as the "1/3 rule" (Fig 57). Therefore, as mowing height is lowered, mowing frequency must increase to stay within the 1/3 rule.

Fig 56. Scalping results when more than 40% of total leaf area is mowed.

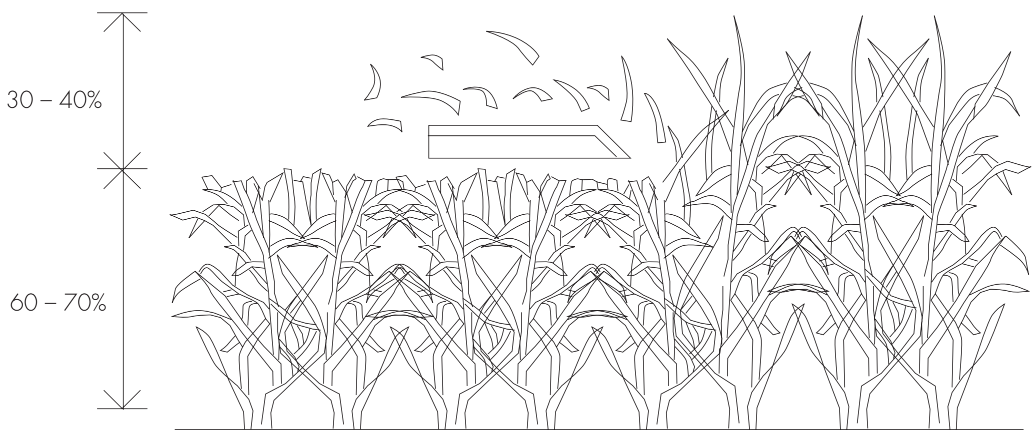


Fig 57. The "1/3 rule" for mowing turfgrasses.

Optimum mowing heights, and mowing frequencies, vary depending on turf species (Fig 58).

Turfgrass	Mowing Height (mm)	Mowing Frequency (days)
Hybrid *Cynodon* spp.	2–20	1–3.5
Paspalum vaginatum	4–25	2–7
Zoysia matrella	5–25	3–7
Zoysia pacifica	5–25	3–7
Digitaria didactyla	6–25	3–7
Zoysia japonica	20–35	4–8
Cynodon spp.	20–35	4–8
Axonopus compressus	25–40	6–9
Axonopus sp. 'Pearlgrass'	25–40	6–9
Eremochloa ophiuroides	35–60	6–9
Stenotaphrum secundatum	45–75	6–9

Fig 58. Optimum mowing heights and frequencies of tropical turfgrass species.

Turfgrasses which can be mowed at lower heights generally have finer leaf texture, higher shoot density, and therefore higher quality. However, these high quality turfgrasses may require higher management levels, including more frequent mowing. Care must be taken to choose the turfgrass species based on level of quality required, and maintenance budget available.

5.2 MOWER TYPES

5.2.1 Rotary

Rotary mowers are the most flexible in terms of mowing height, are inexpensive to operate, and provide vastly improved cutting quality over backpack mowers. They are ideal for moderately maintained parks, streetscapes, and lawn turf. Mower consists of a rotating (spinning) bar with a sharpened front edge (Fig 59). Clippings may be collected, or can be allowed to fall back into cut turf (preferable).

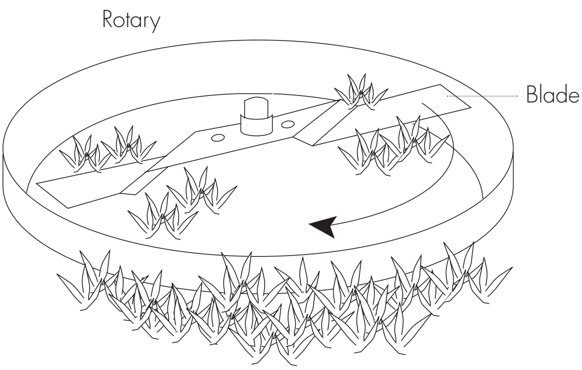


Fig 59. Rotary mower consists of a horizontally spinning blade.

Advantages

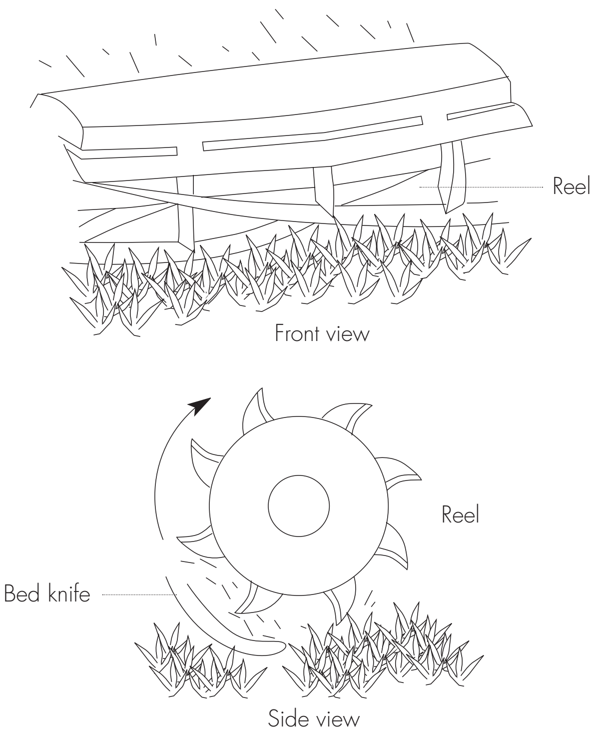
- Allow cutting heights from 25–75 mm.
- Inexpensive to operate and maintain: only engine servicing and periodic blade sharpening with grinder is required.
- Debris and surface irregularities will not damage mower.
- Cuts tall grass, weeds, and tough seedstalks.

Disadvantages

- Quality of cut will suffer, due to shredded leaf blades if blade is not kept sharp.
- Mower can cause flying debris that is a hazard to operator and people nearby.
- Difficulty in mowing steep slopes or small irregular areas.

5.2.2 Reel

Reel mowers provide the highest quality of cut obtainable, and are the only mowers able to cut at less than 25 mm height. Therefore, they are used for high quality turfgrasses grown for golf courses, sports fields, and high quality lawns. Mower consists of a rotating drum containing a series of curved blades, which cut against a horizontal cutting bar at bottom (Fig 60).



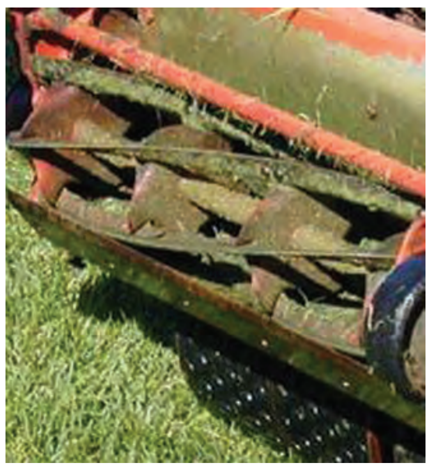


Fig 60. Reel mower consists of a rotating drum having a series of blades. Grass is cut against the cutting bar.

Advantages

- Provides the highest quality of cut obtainable, cleanly cutting grass blades.
- Can mow at less than 25 mm height.

Disadvantages

- Quality of cut is reduced at mowing heights greater than 25 mm.
- Irregular ground surfaces and debris will damage mower.
- High maintenance costs, including frequent backlapping, cutting bar grinding, and adjusting, requiring skill and experience.

5.2.3 Flail

Flail mowers are similar to rotary mowers in cutting height. They can cut very tall grasses and even tree saplings, and can cut over irregular, debris strewn terrain without damaging the mower. However, their quality of cut is typically lower than a rotary mower, though newer models offer improved cuts. Flail consists of a series of small T-shaped blades attached by swing bolts to a spinning shaft. Debris causes the individual blades to deflect back, not damaging the mower (Fig 61).

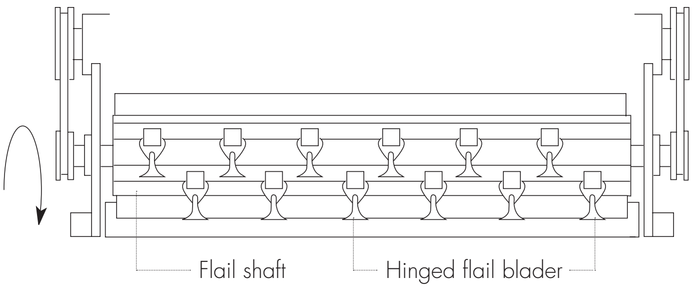


Fig 61. Flail mower consists of small, hinged T-shaped flail blades mounted on a spinning shaft (flail shaft).

Advantages

- Can cut very high grass, weeds, even saplings.
- Uneven terrain and debris will not damage mower.
- Mower requires low maintenance.

Disadvantages

- Generally provides lower quality cut than rotary mower.
- High power requirement.

5.2.4 Backpack

Backpacks are inexpensive and require no maintenance. The spinning filament or blade can cut tall or short turf, even tall weeds, though they will not cut tough seedstalks (Fig 62). However, they provide a very uneven, low quality cut, tearing the blades, and scalping the turf. They also frequently damage young trees by girdling. Therefore they are not recommended, except in uneven, cramped or steep terrain where regular mowers cannot go.

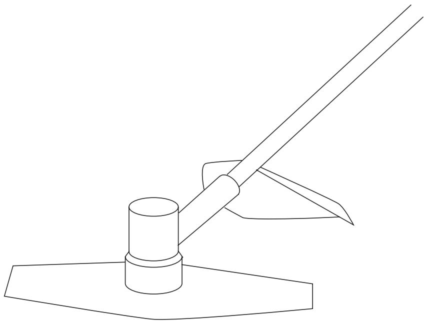


Fig 62. Backpacks cut with a rapidly spinning nylon filament or small blade.

Advantages

- Can cut very high grass or weeds.
- Uneven terrain and debris will not damage mower.
- Mower requires no maintenance.

Disadvantages

- Provides very low quality cut (Fig 63), resulting from:
  - Tearing of leaf blades
  - Scalping due to lack of control of mowing height, and
  - Failure to cut grass seedheads
- Scalping damages turf, resulting in thinning (Fig 63b).
- Frequent girdling of young trees (Fig 63d).
- Very inefficient due to slow coverage of area.

Fig 63. Backpacks provide very low quality cut, due to (a) tearing of leaf blades, (b) scalping due to lack of control of mowing height, and (c) failure to cut grass seedstalks. They also can damage tree trunks, resulting in girdling (d).

SECTION 6 TURFGRASS MANAGEMENT – FERTILISATION

- Optimum fertility is essential for:
  - Turfgrass quality, including shoot density, colour, and uniform weed-free turf
  - Traffic tolerance – recovery from traffic injury
  - Disease and insect resistance
- Nutrient additions include:
  - Fertilisation
  - Returning turf clippings
  - Use of nutrient laden waters, including recycled urban waste waters
- Nutrient removals include:
  - Removal of clippings
  - Water leaching through soil profile and water runoff
- Nutrient needs should be determined by periodic soil testing (see Sect. 2.3.4.1 Soil Testing).
- Fertiliser ratios are given as a – b – c, where a = % by weight N, b = % by weight P_2O_5, and c = % by weight K_20. To convert P_2O_5 to P multiply by 0.44, and to convert K_20 to K multiply by 0.83.
- Compared to other landscape plants, turfgrass requires a higher proportion (ratio) of nitrogen (N), relative to phosphorus (P) and potassium (K). To optimise turfgrass growth, fertilisers should be used having a higher ratio of N relative to P and K, for example 4-1-2.

6.1 ESSENTIAL NUTRIENTS

- Macronutrients are required in largest amounts. They are generally deficient, requiring periodic fertilisation. These include:
  - Nitrogen (N, as nitrate – NO_3 or ammonium – NH_4)
  - Phosphorous (P, as phosphate – PO_4)
  - Potassium (K)
- Secondary nutrients are required in smaller amounts. They may be deficient, depending on the soil and climate. These include:
  - Calcium (Ca)
  - Magnesium (Mg)
  - Sulfur (S, as sulfate – SO_4)
- Micronutrients are required in very small amounts. They are generally not deficient, not requiring fertiliser additions. Exceptions include iron and manganese deficiencies in alkaline soils. Micronutrients include:
  - Iron (Fe)
  - Manganese (Mn)
  - Boron (B, as borate – BO_3)
  - Copper (Cu)

- Zinc (Zn)
- Molybdenum (Mn, as molybdate – MoO_3)
- Chlorine (Cl)

- Nutrients which are typically deficient on turfgrass in tropical climates, requiring fertilisation, are discussed below.

6.1.1 Nitrogen (N)

- Nitrogen is the nutrient needed in largest quantity. Turfgrass leaf N contents are typically 3–4% by dry weight. Therefore leaf clippings are high in nutrients, and should be left on the turf after mowing (exceptions are golf and bowling greens and tees).
- Nitrogen is needed for synthesis of proteins, nucleic acids (ex. DNA), and chlorophyll.
- Nearly all soil N is bound within soil organic matter (humus).
  - Most Singapore soils are low in organic matter, and thus are typically N deficient. Practices which increase soil organic matter are beneficial, including returning clippings, encouraging deep root growth, etc.
  - Plants absorb N in inorganic form only, as either nitrate or ammonium.
  - As organic matter decomposes, it releases N as ammonium. Therefore, organic matter is the soil's N store, slowly releasing N for plant uptake.
- Soil testing can determine the amount of soil organic matter, but cannot tell you the amount of N immediately available to the plant. Therefore, soil testing cannot give you precise recommendations on the amount of N fertiliser needed. Turf managers rely on visual signs to determine when fertilisation is needed. Fertilisation should commence as growth begins to slow (i.e. clipping yield declines), but before yellowing or more advanced symptoms occur. N deficiency symptoms include (Fig 64):
  - Slow growth, and lack of recovery from traffic injury.
  - A uniform yellowing of older (lower leaves).
  - Loss of shoot density.
  - Increased susceptibility to Schlerotinia fungus (dollar spot).

Fig 64. Nitrogen deficiency on turfgrass.

- However, excess N may result in:
  - Fungal diseases, particularly Pythium and Rhizoctonium.
  - Loss of rooting and stress (particularly drought) tolerance.
- Ammonium released by decomposing organic matter is rapidly converted to nitrate by soil microorganisms. Nitrate is not held by soils, but readily leached, particularly in high rainfall environments. Therefore, frequent N fertilisation is needed in the tropics, with frequencies up to double that of temperate environments.
- Fertilisation rate of turfgrasses is largely a function of N requirement. Fertilisation requirements are shown in Fig 43. In the tropics, N requirements vary widely, depending on species (Fig 65).

Turfgrass	N Requirement (kg N/100 sq m/yr)
Cynodon spp.	4–7
Paspalum vaginatum	4–6
Zoysiagrasses	4–5
Stenotaphrum secundatum	3–4
Digitaria didactyla	3–4
Axonopus compressus	3–4
Eremochloa ophiuroides	2–4
Axonopus sp. 'Pearlgrass'	2–4

Fig 65. Nitrogen requirements of turfgrasses in the tropics.

- Waterlogged soils are anaerobic, stimulating anaerobic soil bacteria to break down nitrate into gas, a process named denitrification. In wet soils up to 50% of total soil N can be lost in this way.
- N fertilisers are available in fast release and slow release forms.
  - Fast Release
    - Inorganic salts of nitrate or ammonium (ex. ammonium sulfate, potassium nitrate), exception being urea, a fast release organic.
    - The least expensive per unit N. On a cost per unit N, slow release fertilisers are several times more expensive than fast release (SCU = 2–3x, UF and IBDU = 3–4x, compost = 5–6x).
    - Can be applied in solid or liquid form, or dissolved in irrigation as fertigation.
    - Give a quick response, but are readily leached, requiring more frequent application. After application, growth rate increases to maximum within 7 days of application; fertilisers are exhausted within 3–4 weeks.
    - As salts, they can readily burn turf at high application rates. Maximum application should not exceed 0.5 kg N/100

square metres. Notice this is not the weight of the fertiliser, but instead the weight of elemental N.

- High rates followed by exhaustion result in wide growth swings, depleting turfgrass of carbohydrates, reducing root growth, increasing susceptibility to diseases and pests, and ultimately thinning the turf. Therefore, if fast release fertilisers are used they should be applied at least on a monthly basis, following the rate recommended for the turf species (Fig 65).

– Slow Release
  - Compost can be considered a slow release N fertiliser if it is maturely composted to a humus. It typically contains 3–6% N. It has the advantage of organic matter additions to the soil.
  - Urea-formaldehyde (UF), the longest lasting slow release, varies in release rate, depending on temperature, moisture, and formulation, which affects solubility. In temperate regions, UF residual can last more than one year, but that may be reduced by half in the tropics.
  - Sulfur or polymer coated urea (SCU) provide varying rates of release, depending on thickness of coating, and whether the coating is coated with wax or microbial inhibitors. Generally they are faster releasing than UF.
  - Isobutylidene diurea (IBDU), having a faster release, does not carry over from year to year. Release rate is dependent on temperature, soil moisture, and pH. Release is too rapid in wet, warm soils to be considered a slow release, and this is also true for acidic soils of pH < 5.

6.1.2 Phosphorous (P)

- Phosphorous is needed in moderate amounts, with leaf concentrations ranging from 0.2–0.4%.
- P is generally unavailable in soils, being tied up in insoluble forms:
  - Under acidic conditions (pH < 5.6), iron and aluminum form insoluble complexes with P.
  - Under basic conditions (pH > 7.4), calcium forms insoluble complexes with P.
- P is needed for plant energy conversion, cell membrane function, and nucleic acids (DNA).
- P deficiencies result in:
  - Purpling of older (lower) leaf margins (Fig 66).
  - Slow turf establishment, as young turf plants have minimal root systems,
  - Thinning turf.

Fig 66. Phosphorous deficiency shows up as purpling along margins of older leaves.

- P is immoble in soils. It is critical to incorporate P throughout the rootzone prior to establishing turf, and P deficiency is often seen at this time. Subsequent fertilisations will benefit by applying after coring to allow more thorough incorporation into the rootzone.
- P is provided by using a complete N-P-K fertiliser. Deficiencies can be treated by fertilising with superphospnate or treble superphosphate.
- If pH is outside ideal range (5.8–7.3), apply either sulfur or lime at soil tested recommended rates. Incorporate by applying after coring.

6.1.3 Potassium (K)

Healthy turf leaf K concentrations range from 1.8–2.2%. Therefore, removal of clippings rapidly depletes soil of K.

- K is needed for enzyme functions in metabolism, osmotic adjustment and stomata function, and for drought, traffic, and disease tolerance.
- K deficiencies result in:
  - Browning of older (lower) leaf margins,
  - Shallow rooting.
  - Loss of environmental stress tolerance.
- K has a moderately high leaching potential, so regular fertilisation is needed in the tropics.
- K needs can be provided in full by fertilising with a complete fertiliser, i.e. one that contains N, P, and K.

6.1.4 Calcium (Ca)

- Calcium is an intermediate nutrient, present in turf leaves at concentrations of 0.25–0.5%.
- Ca is generally deficient in acid tropical soils, having been leached out of the rootzone. If soil pH is below 5.5, Ca and often magnesium additions are needed in the form of lime (calcium carbonate) or dolomite (calcium carbonate + magnesium carbonate). Apply lime or dolomite at soil test recommended rates (ref. Fig 28).
- Ca deficiencies result in:
  - Dieback of young leaf tips.
  - Loss of salinity tolerance.
  - Poor nutrient uptake and regulation.
- Ca is immobile in soils. Incorporate Ca throughout rootzone prior to establishing turf, according to soil test recommendations. Subsequent fertilisations should follow coring to allow incorporation.

6.2 FERTILISER APPLICATION

It is not enough to know fertiliser requirements from a soil test. One must also apply the correct rate, using a properly calibrated fertiliser spreader, and to apply using proper technique. Applying by hand tossing should not be used, as this results in a very uneven application (Fig 67). A simple and inexpensive hand held spin spreader will result in much higher uniformity (ref. Fig 69). Similarly, misapplying using a drop or centrifugal (spin) spreader will result in uneven application.

Fig 67. Hand tossing fertiliser will result in uneven turfgrass growth, colour and quality.

6.2.1 Fertiliser Applicators

6.2.1.1 Sprayers – liquid

- Advantages:
  - Most accurate application, given proper calibration and spraying technique.
  - Best uniformity.
  - Liquid fertilisers are least expensive.
  - Convenience of co-applying pesticides.
  - Foliar uptake of micronutrients.
- Disadvantages:
  - Only fast release fertilisers can be applied.
  - Fertiliser burn is possible unless washed into soil.
- High volume liquid fertilisation uses sufficient volume (12–20 litres/100 square metres) to wash liquid into the soil.
- Foliar feeding liquid fertilisation uses small volumes (2 litres/100 square metres) that only wet leaves, suitable for micronutrient applications where foliar absorption occurs.

6.2.1.2 Drop Spreaders – solid

- Advantages:
  - Accurate – uniform distribution across hopper (Fig 68)
  - Can apply blended fertilisers (having different granules) uniformly
  - Can apply fertiliser uniformly to small, irregular areas
- Disadvantages:
  - Slow coverage
  - Care is needed to prevent striping

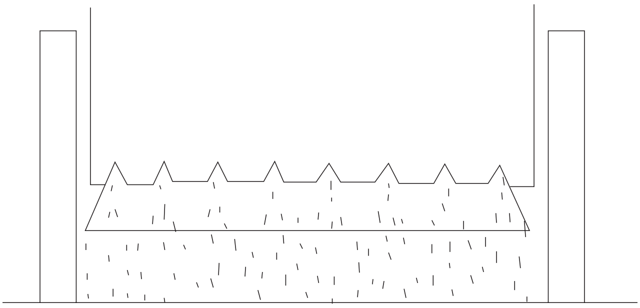


Fig 68. Drop spreader.

6.2.1.3 Centrifugal (spin) Spreaders – solid

- Advantages:
  - Fast coverage for large areas (Fig 69)
  - Inexpensive
- Disadvantages:
  - Less accurate – lens shaped distribution makes overlap necessary
  - Cannot apply blended fertiliser, as different sized granules will fly different distances.

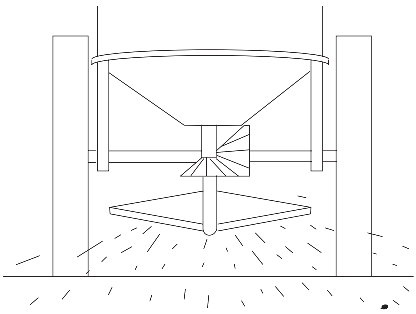


Fig 69. Centrifugal (spin) spreader.

6.2.2 Calibration

- Applicators must be properly calibrated to achieve the correct application rate of either fertiliser, pesticide, or growth regulator.
- For calibration of a liquid sprayer, one must know:
  - Boom width (distance between passes of the sprayer, usually the length of the boom)
  - Sprayer output (litres/100 square metres)
  - Tractor or walking speed

- Tank volume
- Concentration of nutrient in fertiliser
- For calibration example, ref. Fig 70
- Nozzles
  - Use flat fan nozzles only
  - Boom pressure must match nozzle specifications
  - Nozzles must be uniform in output and pattern. Check output uniformity often. Output (ml/sec) must be within 10% of boom average, otherwise replace nozzle.
  - Nozzles must be properly placed and oriented on boom.
  - Flat fans are designed for 40 degree overlap. Therefore, spray height must be maintained at level recommended, depending on a) angle of spray, and b) distance between nozzles (Fig 71)

Data:

- Fertiliser formulation = 0.14 kg N/litre
- Desired rate = 0.1 kg N/100 square metres
- Sprayer output = 8.2 litres/100 square metres
- Tank volume = 379 litres
- Total treatment area = 100 square metres

How much liquid fertiliser is required for this application?

- 1 litre fertiliser/0.14 kg N = x liter fertiliser/0.1 kg N
- **0.7 litre fertiliser/100 square metres**

How much fertiliser should be poured into a full tank?

- 0.7 litre fertiliser/8.2 litres tank mix = x litre fertiliser/379 litres tank
- **32.4 litres fertiliser**

Fig 70. Calibration example for a liquid sprayer.

Nozzle Spacing (cm)

Spray Angle (degrees)	50.8	76.2
65	55.9 – 61.0	–
73	50.8 – 55.9	73.7 – 78.7
80	43.2 – 48.3	66.0 – 71.1
110	25.4 – 30.5	35.6 – 43.2

Fig 71. Spray height (boom height from ground) depends on a) nozzle angle, and b) distance between nozzles on boom.

- For calibration of a dry spreader, one must know:
  - Swath width – swath width is the distance between passes of the spreader
    - For drop spreader, swath width is the width of the hopper
    - For centrifugal spreader, swath width is generally 70% of total throw area (overlap 30%)
  - Tractor or walking speed
  - Weight of granules dropped per unit area
    - Multiply swath width by distance traveled
  - Concentration of nutrient in fertiliser
  - For calibration example, see Fig 72

Steps:

- Select collection area = swath width x distance traveled
- At constant speed, collect granules applied over collection area, using 3 progressively increasing spreader settings
- Convert weight of granules on collection area to weight granules / 100 square metres
- Draw calibration curve
- Select spreader setting to apply desired fertiliser rate

Collection area = 1 metre swath width x 7 metres traveled = 7 square metres

Required rate = 1.5 kg fertiliser / 100 square metres

Run spreader at three settings, and weigh granules:

- Setting 1 output = 0.7 kg
- Setting 2 output = 1.4 kg
- Setting 3 output = 2.3 kg

Draw calibration curve, and select spreader setting that will give you the correct fertiliser output. In this case, Setting 2 will give you the correct fertiliser application rate.

Fig 72. Calibration example for a dry spreader.

SECTION 7 TURFGRASS MANAGEMENT – CULTIVATION

7.1 IMPORTANCE OF CULTIVATION

- Turfgrass cultivation operations include:
  - Vertical mowing (verticutting)
  - Slicing/spiking
  - Coring
    - Hollow tine
    - Solid tine
    - Deep tine
  - Reasons for cultivation:
    - Reduce soil compaction
    - Improve soil aeration and rooting
    - Improve water infiltration and drainage
    - Improve fertiliser and soil amendment incorporation
    - Reduce thatch
- Thatch:
  - Layer of undecomposed, waxy organic material above soil surface, but below living turf shoots, consisting largely of undecomposed stems, stolons, and rhizomes (Fig 73).

Fig 73. Thatch layer on *Cynodon* spp.

- Stoloniferous and rhizomatous turfgrasses are most susceptible to thatch.
- Thatch may be waxy and hydrophobic, repelling water, resulting in dry areas in turf.
- The turfgrass root system will grow into the thatch layer, resulting in drought prone, weakened turfgrass, which is susceptible to scalping.
- Thatch harbours insect pests and diseases
- Thatch adsorbs pesticides, reducing their effectiveness
- Thatch accumulation is due to growth-decomposition imbalance, resulting from:
    - Excess nitrogen fertiliser use
    - Limited soil microorganism activity, due to:
        - Unfavourable pH
        - Anaerobic conditions

7.2 VERTICAL MOWING (VERTICUTTING)

- Vertical mowers consist of vertical spinning knives mounted on a horizontal shaft (Fig 74).

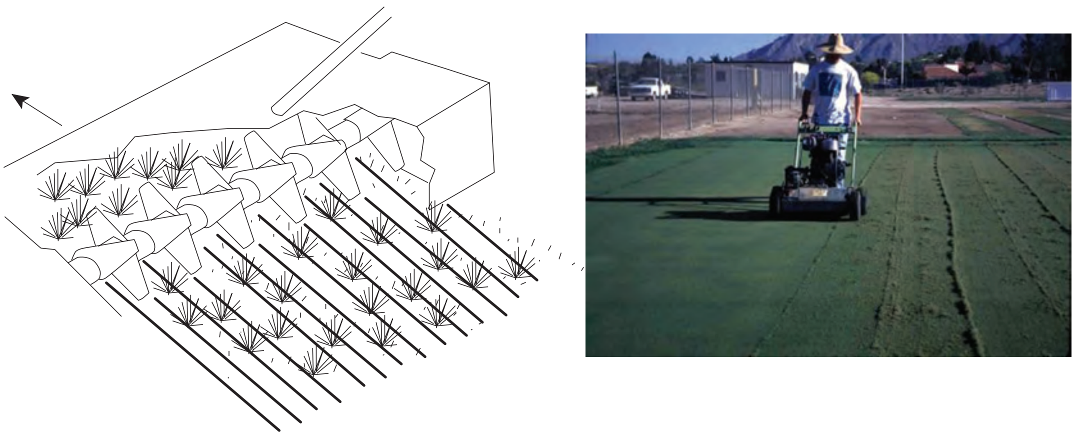


Fig 74. Vertical mower consists of vertical spinning knives.

- Vertical mowers are primarily for reducing thatch. Thatch-prone tropical turfgrasses include:
    - *Cynodon* spp. (bermudagrass)
    - *Paspalum vaginatum* (seashore paspalum)
    - *Zoysia* sp. (zoysiagrasses)
- Vertical mowing is necessary when thatch layer becomes thicker than 25 mm. Frequency may vary from twice per year to once every 2 or 3 years.

- Vertical mowing is disruptive to turf, causing some injury. Therefore, it should be done only when turf is actively growing. Do not do when turf is stressed. Fertilise soon after vertical mowing to stimulate new growth.
- Vertical mowing should be done twice, in opposite directions. Rake and remove thatch debris afterwards.

7.3 SPIKING/SLICING

- Spiking and slicing are basically the same, consisting of making small diameter holes (spiking) or narrow slices (slicing) through the turf surface and into the soil (Fig 75).

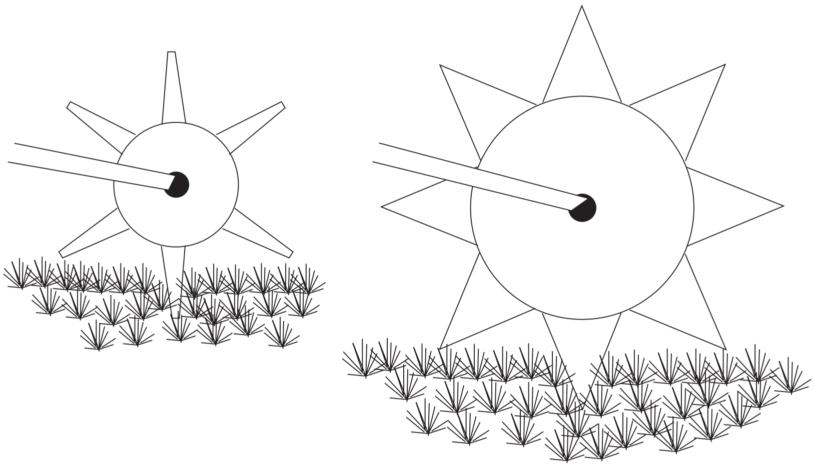


Fig 75. Slicing/spiking consists of poking or cutting holes through the turf (a). Unit in photograph can be converted from corer to slicer by changing tines (b).

- Spiking and slicing provide water and air passages into the soil, improving water infiltration and aeration, while reducing surface compaction.
- Spiking and slicing have no effect on thatch.

7.4 CORING

- Coring results in larger, deeper holes into the turf soil, and therefore is more disruptive than spiking/slicing. Coring should be done only when the turf is actively growing, and not during drought periods. Fertilise immediately after coring to stimulate recovery.
- To aid in deeper penetration, coring should be done when soil is moist, but not wet, to avoid compaction.
- Coring improves water infiltration and drainage, aeration and rooting, better than spiking/slicing.

- Coring machines are of two types:
  - Rotating drum – tines are attached to a rotating drum or wheels. This method is faster and cheaper, but penetration is more shallow (3–5 cm), and holes are not as clean (Fig 76).

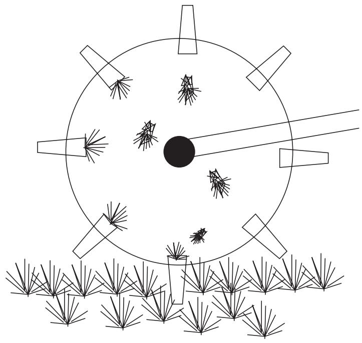



Fig 76. Rotating wheel or drum aerator.

  - Vertical overhead tines (VOHT) – tines move directly up and down in a piston-like motion (Fig 77). This allows for cleaner, deeper holes, but is slower, normally requiring about 10 minutes to cover 100 square metres.

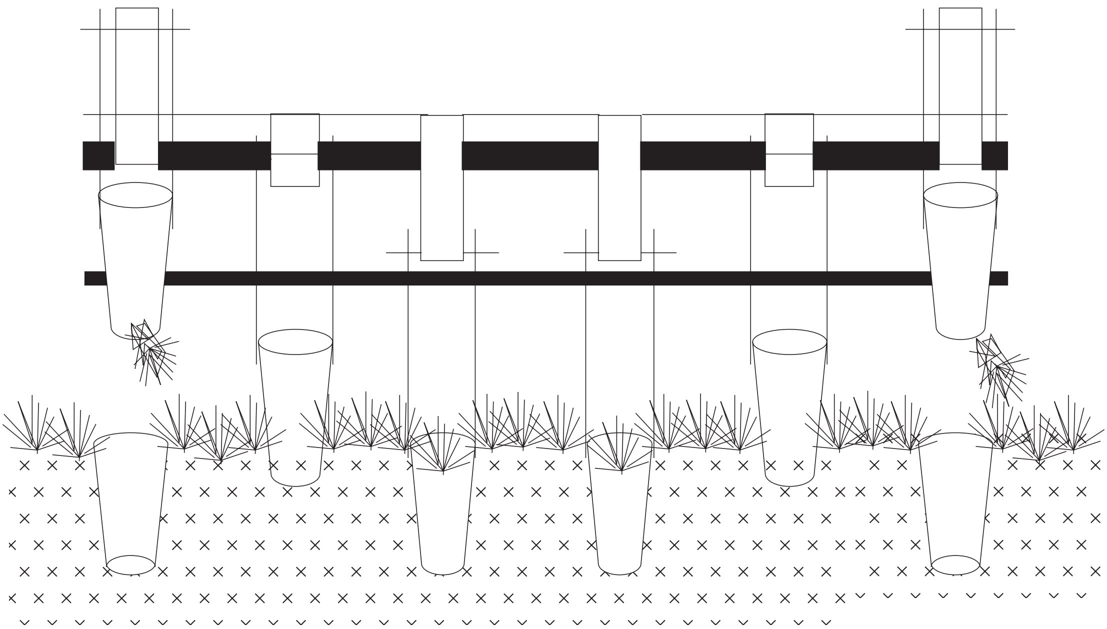


Fig 77. Pulling cores by hollow tining.

7.4.1 Hollow Tining

- Hollow tining pulls out and removes cores from the turf (Fig 78). Therefore it helps reduce thatch, especially when followed by topdressing.

Fig 78. Hollow tine cores removed from turf.

- Pulled cores should be allowed to dry, then broken up by dragging a steel mat over the turf surface. This will also aid in reincorporation. Reincorporation serves to:
  - Introduce organic matter into the soil profile, and
  - Allow soil microorganisms to break down thatch layer.
- Hollow tines can normally penetrate only 6–8 cm deep, though deep VOHT machines may penetrate to 10+ cm if soil is soft and moist.

7.4.2 Solid Tining

- Though solid tines reduce compaction, and improve aeration and drainage, benefits are not as great as with hollow tines, due to the compacting effect of solid tines.
- However, solid tines are more robust, and therefore can penetrate deeper into the soil without breaking. This allows them to break up soil compaction in deeper layers. Deep tining machines may penetrate up to 20 cm deep if conditions are right (see below).

7.4.3 Deep Tining

- Often traffic compacts only surface layers, in which case regular tining will suffice. However, uniformly deep compaction results when rootzone is improperly constructed, or when heavy soils (clay type) are used which is often the case in Singapore. In this case, deep tining can temporarily alleviate compaction and improve drainage and deep rooting.

- Deep tining machines are available, which can tine to a depth of 15–25 cm, depending on soil compactness and moisture (Fig 79).

Fig 79. Deep tining machine Vertidrain in operation

- In deep tining, only solid tines may be used.
- In some machines, tines laterally shift at depth, breaking up lower compacted layers (Fig 80).

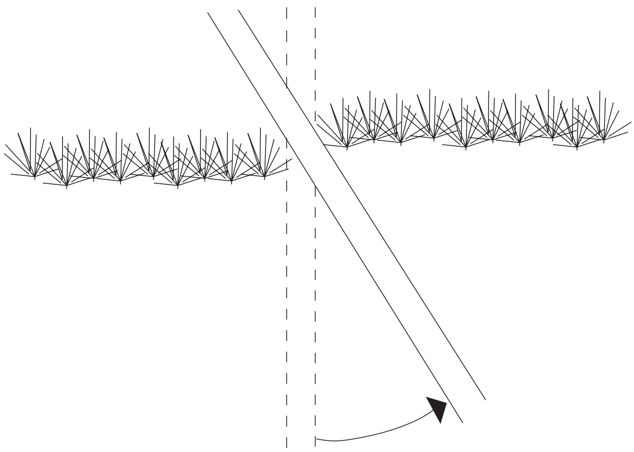


Fig 80. Deep tines twist during penetraton to break up compacted layers.

7.5 TOPDRESSING

- Topdressing consists of applying a thin layer of rootzone material over the turfgrass. Layer thickness should fill thatch layer, but not cover turf leaves.
- Topdressing material used should generally be identical to existing rootzone, otherwise layering may occur, impeding drainage.
- In some instances, particularly for highly compacted soils, sand may be topdressed into holes after tining to open up channels for drainage.
- Benefits of topdressing:
    - Apply to newly seeded turf, or overseeded turf to improve seed germination
    - Incorporate topdressing into thatch layer. This speeds decomposition and breakdown.
    - Smoothing surface following trampling injury or other surface disruption.
    - Topdressing with sand into tine holes may improve water infiltration in compacted soils.

SECTION 8 TURFGRASS WATER RELATIONS

8.1 DROUGHT TOLERANCE

- When water use is greater than root water uptake, wilting and drought stress occurs.
- Drought stress symptoms are listed below, progressing in severity:
  - Loss of springiness – footprints are left on turf for a prolonged period after traffic.
  - Turf turns off-colour, typically a bluish-gray tinge
  - Leaf curling
  - Growth reduction, resulting in clipping reduction
  - Reduced spreading and loss of recovery from trafficking damage
  - Turf thinning
- Turfgrass species differ in drought tolerance (Fig 81).

Cynodon spp.	HIGH
Zoysia japonica	
Zoysia matrella	
Paspalum vaginatum	
Zoysia pacifica	
Digitaria didactyla	
Stenotaphrum secundatum	
Eremochloa ophiuroides	
Axonopus compressus	
Axonopus sp. 'Pearlgrass'	LOW

Fig 81. Turfgrass drought tolerance.

8.2 MANAGING DROUGHT STRESS

- Manage for deep rooting – deep rooting of turfgrasses is essential for drought tolerance, as it allows turf to mine available soil moisture stores. Shallow rooted turf has been shown to lack tolerance to environmental stresses in general. To develop deep rooting:
  - Rootzone must dry down between rains or irrigation to allow oxygen exchange to the root system. Waterlogged soils result in loss of root system.
  - Provide good drainage
  - Avoid soil compaction
  - Core aerify regularly
  - Provide ample potassium fertilisation
  - Maintain mowing height at optimum for turfgrass species used
- Use a drought tolerant turfgrass. Drought tolerance is ranked in Fig 81.

8.3 IRRIGATION

- Irrigation is measured as a depth (mm), not volume. It is therefore independent of land area.
- Irrigation serves several functions:
  - Provide water to the landscape to avoid drought stress.
  - Wash fertiliser or pesticide applications into soil.
  - Flush away excess salt.
  - Syringing (lightly rinsing) turfgrass to:
    - Cool turf during heat stress
    - Wash off morning dew for disease control

8.3.1 Water Requirement and Irrigation Amount

- Turfgrass water use rate, or evapotranspiration rate (ET) is also measured as a depth (mm). As it is a rate, ET is measured per unit time, typically as mm/day or mm/week.
- Irrigation amount depends on turfgrass water use, given as ET.
- ET is influenced by:
  - Turfgrass species and cultivar (Fig 83)
  - Positive environmental factors (higher levels result in higher ET):
    - Temperature
    - Wind speed
    - Light level
    - Soil moisture
    - Fertility level
    - Mowing height
  - Negative environmental factors (lower levels result in higher ET):
    - Relative humidity
  - Plant growth regulators – plant growth regulators have been shown to reduce ET.

Paspalum vaginatum	HIGH
Stenotaphrum secundatum	↑
Axonopus compressus	
Axonopus sp. 'Pearlgrass'	
Digitaria didactyla	
Eremochloa ophiuroides	
Cynodon spp.	↓
Zoysiagrasses	LOW

Fig 83. Turfgrass species water use rate (ET).

- ET rates for Singapore typically range from 2.5–7.5 mm/day.

8.3.2 Determining When to Irrigate

- Amount of irrigation per application should be sufficient to wet the soil to the depth of the rootzone. Generally, turfgrass rootzones are approximately 20–30 cm deep.
- Soil should be allowed to dry between irrigations, allowing soil oxygen exchange to occur. Otherwise shallow rooting will result.
- Amount of irrigation per application depends on soil type. Heavier, finer textured clay soils hold more water per unit depth than coarse, sandy soils. For example, it may require up to 75 mm to wet a clay soil to rootzone depth of 30 cm. However, for a sandy soil it may require only 15–20 mm.
- If salt is present, irrigation amount should be increased 10–25% in order to push salts below rootzone.

8.3.2.1 Irrigating by ET

- To determine when to irrigate, add up daily cumulative ET until it equals soil rootzone (top 30 cm) water holding capacity, depending on soil type. Amount applied should replace cumulative ET.
- Cumulative daily ET is estimated by weather stations. Local ET estimates are available from the internet, satellite, or from on-site weather stations connected directly to the irrigation controller. Weather stations typically overestimate ET of tropical grasses by about 25%. Therefore, multiply cumulative weather station ET by 0.75 to determine actual turfgrass water use. This is termed a 'crop coefficient' or Kc.

8.3.2.2 Irrigating by Soil Moisture Status

- Irrigations can also be scheduled to coincide with soil drying. Soil should be allowed to dry to near the point of initial stress, i.e. just before colour change or wilting (leaf curl) occurs. This level will depend on the turfgrass type as well as soil type. Soil moisture status can be measured or estimated in several ways:
  - Soil moisture probes – this is the most accurate method. Recently, probes have become relatively inexpensive, and are increasingly being used by landscape managers – these include capacitance and porous block probes. Of the two, capacitance probes are the most accurate and reliable.
  - Visual – experienced turf managers can ascertain when it is time to irrigate by the appearance of the turf. Just prior to drought stress, turfgrass will:
    - Lose springiness – Footprints will remain visible on turf for a prolonged period after foot traffic occurs.
    - Initial colour change – turfgrass will go slightly off-colour, gaining a bluish-gray cast.

- Resistance – Soil dryness can be estimated by the amount of resistance felt as a thin rod (ex. screwdriver) is pushed through the soil.

8.3.3 Irrigation Rate

- Irrigation rate, termed precipitation rate (PR), is the depth of water applied by the irrigation system per unit time, expressed as mm/hour.
- Irrigation rate must be less than soil infiltration rate (IR), otherwise runoff will occur. If PR is greater than IR, irrigation cycling or pulsing may be used. For example, if PR = 20 mm/hour and IR = 15 mm/hour, PR must be reduced by 25% to avoid runoff. A solution would be to extend the irrigation cycle time by on/off pulsing. Modern irrigation controllers can program this option.
- Slope decreases soil IR (Fig 84). If slope is present, irrigation PR must be adjusted to avoid runoff.

Soil Texture	0 – 5% Slope	5 – 8% Slope	8 – 12% Slope	12%+ Slope
Sandy	50	50	38	25
Loam	25	20	15	10
Clay	5	4	3.5	2.5

Fig 84. Soil IR, and therefore maximum PR varies according to soil type and slope present. Values are in mm.

8.3.4 Irrigation System Uniformity

- Water conservation and turfgrass health depends not only on proper estimation of turfgrass water use, but also on uniform water application by the irrigation system.
- Irrigation system uniformity is dependent on:
  - Proper system design, including
    - Head spacing – heads should be of the same type, spaced head-to-head (spray of one head just touches adjacent head)
    - Pressure – pressure to all heads should be optimum for operation of the head. Pipes (mains and laterals) must be properly sized using pressure loss tables to provide correct pressure to each head in system. Heads operating at incorrect pressures will have poor application uniformity.
    - Flow rate – adequate flow in litres per hour (LPH) must be provided to heads. To ensure adequate flow to all heads, zoning is necessary. Heads should be grouped into independently operating, valved zones, each zone requiring less total flow than provided by the system.

- Proper system upkeep, including:
    - Adjustment of heads – heads must be periodically checked to ensure that they are alligned properly and level to the ground surface. Obstructions to flow, including tall unmowed turf, should be removed.
    - Head pressure – pressure to individual heads must be periodically checked to diagnose leaks, obstructions, or other problems.

- System uniformity should be checked on a regular basis, using the Distribution Uniformity (DU) method. Uniformity should be independantly checked for each irrigation zone. DU method is given below:
    - Catch cans with vertical walls (empty tin cans will work), of uniform size should be placed within each irrigation zone in a grid pattern. Make sure cans are level.
    - Irrigation zone should be run for a length of time sufficient to partially fill catch cans, without any overflowing. Time the run.
    - Place each can on a flat surface, and measure water depth. Record depth of each can, keeping track of where each can is within the grid.
    - Precipitation rate of irrigation system (PR) can now be calculated. Take the average depth of all cans, and divide by the run time, to obtain PR as mm/hour.
    - Calculate DU as:
      DU = (average depth of lowest 25% of cans ÷ average depth of all cans) X 100

- A Distribution Uniformity of at least 70% indicates good distribution uniformity of irrigation water across the zone.
- To correct irrigation run time to properly irrigate dry areas, divide the run time by the DU. For example, if required run time is 1 hour and DU is 70%, corrected run time will be 1 ÷ 0.75 = 1.25 hours.

8.3.5 Subsurface Irrigation

- An increasing trend in turfgrass irrigation is to utilise subsurface drip lines instead of overhead sprinklers.
- Individual drip emitters are usually imbedded within the drip lines at preset intervals (Fig 85).
- Distance between emitters and between drip lines will depend on soil type, with coarse textured soils requiring closer spacing.
- Depth of drip lines is usually set at 15 cm.
- Previously discussed sections on irrigation also directly apply to subsurface irrigation, including determining water requirement, amount and frequency of irrigation.
- There are certain advantages to subsurface irrigation, including:
  - Improved water use efficiency and water savings. There is no water loss due to evaporation of spray droplets. This loss can be substantial, especially during hot, dry weather, and in windy conditions.
  - Improved application uniformity. There is no influence of wind on uniformity. DU (ref. 8.3.4 Irrigation System Uniformity) can be 90%, provided emitters are pressure compensated, and are not clogged. Emitters differ in their resistance to root and salt clogging. To prevent root intrusion and clogging, herbicides are used, impregnated into the emitter plastic, or into filter discs at factory.
  - Lower pumping costs. Subsurface drip requires low pressure.
  - Lower component costs. However, as installation costs may be higher, the overall system cost is often similar for both.
- However, there may be disadvantages in using subsurface irrigation, depending on intended use, including:
  - Restrictions on cultivating by tining. Only shallow tining is possible.
  - Salt accumulation in rootzone or on soil surface. Dissolved salts in the irrigation will accumulate on the edge of the wetting fronts, which tend to be between irrigation tapes, and on the soil surface. This can be especially serious when irrigation water contains salts, and in low rainfall climates where natural precipitation is insufficient to leach salts to below subsurface emitters.
  - Inability to wash fertilisers and certain pesticides into the soil or rootzone. Care must be taken to prevent leaf burn when fertilising with solid fertilisers.
  - Difficulty in germinating seeds during turf establishment, or when overseeding to fill in dead spots.
  - Inability to syringe turf for cooling and rehydration during heat stress.
  - Maintenance may be difficult and costly if emitters clog.

SECTION 9 SUMMARY MATRIX

USE OR MAINTENANCE LEVEL →	LOW-MODERATE USE TURF (LOW MAINTENANCE)	MODERATE-HIGH USE TURF (MODERATE MAINTENANCE)	HIGH-VERY HIGH USE TURF (HIGH MAINTENANCE)
Construction			
a) Grading (Sect. 2.1)	Use of existing or imported topsoil or Approved Soil Mixture for rootzone.	Use of Approved Soil Mixture for rootzone.	Use of sand-based rootzone mixture (Fig 16).
b) Drainage (Sect. 2.2)	No subsurface drainage.	Subsurface drains (Fig 12). Subsurface drainage layers over drain trenches (Fig 13).	Subsurface drains (Fig 12). Subsurface drainage layers across entire field (Fig 15).
c) Initial Rootzone Soil Amendments (Sect. 2.3.4)	Add according to test recommendations for: Fertility, pH, and salinity.	Add according to test recommendations for: Fertility, pH, and salinity.	Add according to test recommendations for: Fertility, pH, and salinity.
Turfgrass Selection (Sect. 3.1)			
	All turf species may be used.	*Cynodon dactylon* *Digitaria didactyla* *Paspalum vaginatum* *Zoysia spp.*	*Cynodon dactylon* *Paspalum vaginatum* *Zoysia spp.*
Planting (Sect. 4)			
	Vegetative (sod or rhizomes): All turf species. Seeded (for rates, see Fig 53): *Axonopus compressus* (if available) *Cynodon dactylon* *Digitaria didactyla* (if available) *Eremochloa ophiuroides* *Paspalum vaginatum* (if available) *Zoysia japonica*	See "Low-Moderate maintenance turf"	See "Low-Moderate maintenance turf"

SUMMARY MATRIX (CONT'D)

USE OR MAINTENANCE LEVEL ⟶	LOW-MODERATE USE TURF (LOW MAINTENANCE)	MODERATE-HIGH USE TURF (MODERATE MAINTENANCE)	HIGH-VERY HIGH USE TURF (HIGH MAINTENANCE)
Mowing (Sect. 5)			
For mowing heights & frequencies by turf species, see Fig 58.	Rotary or flail mower. Backpack not recommended.	Rotary or reel mower.	Reel mower.
Fertilisation (Sect. 6)			
See Sect. 6 for other nutrients, pH, and applicator calibration.	N rate (kg N/100 sq. m./yr.): *Axonopus* spp. ....2 *Digitaria didactyla* ....3 *Eremochloa ophiuroides* .... 2–3 *Stenotaphrum secundatum* ....3 *Zoysia* spp. 3–4	N rate (kg N/100 sq. m./yr.): *Axonopus* spp. .... 3–4 *Cynodon dactylon* .... 4–5 *Digitaria didactyla* ....4 *Paspalum vaginatum* ....4 *Zoysia* spp. 4–5	N rate (kg N/100 sq. m./yr.): *Cynodon* hybrids.. 6–7 *Paspalum vaginatum* .... 4–6 *Zoysia* spp. 4–6
Cultivation (Sect. 7)			
	Vertical mowing – once annually or biannually: *Zoysia* spp. Slicing/spiking – none. Coring – none.	Vertical mowing – once annually or biannually: *Cynodon dactylon*, *Paspalum vaginatum*, *Zoysia* spp. Slicing/spiking – 1 or 2x/yr. Coring – 1x/yr.	Vertical mowing – once annually: *Cynodon dactylon*, *Paspalum vaginatum*, *Zoysia* spp. Slicing/spiking – 1 to 4x/yr. Coring – 1 or 2x/yr.
Irrigation (Sect. 8)			
	None, or by portable system or water truck only.	Overhead sprinkler or subsurface irrigation.	Overhead sprinkler or subsurface irrigation.

SECTION 10 FURTHER READING

Bohmont, B.L. 2006. The standard pesticide user's guide. 7th ed. Prentice Hall. 640 p.

Carrow, R.N., D.V. Waddington, and P.E. Rieke. 2002. Turfgrass soil fertility & chemical problems: Assessment & management. Wiley. 400 p.

Christians, N.E. 2007. Fundamentals of turfgrass management. 3rd ed. Wiley. 400 p.

Christians, N.E. and M.L. Agnew. 2008. The mathematics of turfgrass maintenance. 4th ed. Wiley. 176 p.

McCarty, L.B., J.W. Everest, D.W. Hall, T.R. Murphy, and F. Yelverton. 2008. Color atlas of turfgrass weeds. 2nd ed. Wiley. 432 p.

Pessarakli, M. 2008. Handbook of turfgrass management and physiology. CRC Press. 690 p.

Pira, E. 1997. A guide to golf course irrigation system design and drainage. Wiley. 434 p.

Smiley, R.W., P.H. Dernoeden, and B.B. Clark. 2005. Compendium of turfgrass diseases. 3rd ed. American Phytopathological Soc. 167 p.

Turgeon, A.J. 2007. Turfgrass management. 8th ed. Prentice Hall. 448 p.

About the National Parks Board and Centre for Urban Greenery & Ecology

The National Parks Board (NParks) is responsible for providing and enhancing greenery of the Garden City of Singapore. Beyond managing public parks, the park connector network, lush roadside greenery, nature areas and nature reserves, NParks is committed to enhance the quality of life through creating memorable recreational experiences and lifestyles.

The Centre for Urban Greenery and Ecology (CUGE) is an initiative of NParks. Through its research and training programs, NParks advances knowledge and expertise in urban greenery and ecology in the landscape and horticulture industry in Singapore. It works closely with industry partners to promote good work practices and create a thriving, creative, innovative and professional industry that will support Singapore's aspiration to be a City in a Garden.