Soil matters

Monitoring soil water and nutrients in dryland farming

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Foreword

The cliché—'Farming is no longer a way of life; it's a business'—takes on more meaning as prices for produce become more competitive while our soil resource is becoming depleted. Today, farming is indeed a business of producing crops, pastures, and livestock from limited resources. It involves complex interactions between labour, capital and land on the one hand and the variable inputs of production on the other. Efficiencies have to be sought at all stages.

The greatest efficiency to be gained is in the use of water—the most scarce resource in the production capacity of our land. Next would be the use of plant nutrients obtained from the soil. Our rural industry is moving from resource exploitation to resource maintenance—words such as 'sustainability' become more prominent in our farming vocabulary.

With this backdrop, it is highly appropriate that the APSRU team should produce *Soil Matters* for the northern cropping region of New South Wales and Queensland.

Soil Matters describes 'best practice' for those monitoring soils for water and nutrients. It should be used by farmers and consultants in the field, and is especially relevant to those wishing to apply their data to the APSIM crop simulation program. The use of APSIM can revolutionise the way farmers think about efficiencies in water and nutrient use and in strategies for risk management. Like any other computer simulation model, the output of APSIM depends greatly on the quality of information being applied.

Soil Matters provides clear and well illustrated instructions on how to achieve the high-quality data needed.

This manual is a starting point for the linkage between applied research and the needs of industry to make better use of our soil resources. Adoption of its methods and the subsequent use of the results by farmers will represent a great advance in soil monitoring and cropping potential. It should result in a much better understanding of what is happening in their soil and plant environment, of their opportunities and risks, and should lead to better resource management.

Jim Hitchener
IAMA Limited, Toowoomba

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These supporters helped us to recognise the value that they saw in improved soil monitoring and the impact that it could have on their farming enterprises. This initial support led to expanded interest and acceptance from the wider farming community for both the direct benefits of soil monitoring and for its role in simulation of crop and pasture production relevant to an individual paddock or farm.

Thanks to our colleagues at APSRU, the researchers who provided advice and input into the content of the manual, and to those who assisted in the preparation of the manuscript—particularly Lisette Ackhurst, Dean Hargreaves and Mackey Vogler. Special thanks to Lisette for the preparation of the many diagrams and figures.

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Neal Dalgliesh

Mike Foale

APSRU, Toowoomba

November 1998

Frequently asked questions

Quick answers are given to some of the questions that farmers frequently ask about soil. More detailed information is available in the suggested modules.

Soil type

What soil types do I have? Brief descriptions of the major soils of the Darling Downs and soil water characteristics for a wide range of soils of the northern grain region are given in Module 5. A soil map of the central Darling Downs is enclosed. Detailed descriptions of soil types for your district can be found in *Land Management Manuals* from the Queensland Department of Natural Resources. Southern users should contact their local agronomist.

Module 5

Appendix 5

Soil sampling

How many cores do I need to take to check water and nutrients in a paddock? A 40 ha paddock of reasonably uniform soil requires 8 cores, bulked together, to get within 20% of the true nitrogen level. Water content is less variable, requiring only 5 cores.

Module 2

Where in the paddock do I sample to get the best estimate of water and nutrients? In a fallow, cores may be located randomly or in set patterns. In-crop or post-harvest sampling may need a more set pattern to represent both inherent variability and that caused by unequal extraction of water and nutrients across the row.

Module 2

How deep do I need to sample to check the soil water and nitrogen available to a crop? Sample to the full depth of the root zone, being aware that this depth may vary across the paddock and is likely to be deeper than many of us expect.

Module 2

How deep can crop roots go? Cereal crops and cotton have the potential to grow beyond 1 metre depth, while grain legumes can grow to 120 cm. Rooting depth may be limited by soil type, acidity at depth, salinity, shallow soil profile, and also the lack of deep soil water.

Module 1, 2, 5

How can I check the depth of rooting in my crops? Take a soil core and check for roots as you break off pieces along its length. A hand lens is useful for identifying roots.

Module 2

What depth intervals should I use? Depth interval depends on the reason for sampling. Shorter intervals are used at the surface for nutrients such as phosphorus and zinc. Intervals of 30 cm or greater are generally used at depth. Shorter intervals give more detail about the location of water and nutrients.

Module 2

What if I damage the tube or the core jams during sampling? Tubes with a formed cutting tip are easily heated and re-formed if damaged. Jammed cores can be removed by first using a wood auger, and then inverting the tube and bumping it on a solid wooden block to remove residue.

Where do I get information on fabrication or sourcing of soil sampling equipment? Several Darling Downs companies make sampling rigs and coring tubes. Plans for fabrication of tubes are presented.

Appendix 1, 2

Soil properties

Module
1, 2, 3, 4, 5

Why is bulk density (BD) important? BD is needed to calculate soil water (as mm/100 mm of soil depth) and nutrient content (in kg/ha). A low BD indicates high pore space and greater potential to store water. Roots extend more readily through a soil of low BD.

Module
1

What are salinity and sodicity? Salinity is an accumulation of dissolved salts in a soil layer; these can restrict rooting depth and prevent the roots taking up water. Many clay soils are saline at depth, preventing access to deep water and nutrients. Sodicity is an accumulation of sodium ions.

Module
1

How does sodicity affect the soil? Sodicity in the soil induces lack of cohesion between the fine soil particles. Instead of remaining as cohesive peds, the particles disperse when wet, filling pore space between larger soil particles, and preventing penetration by roots and reducing capacity to hold water. Sodic soil has a very high Bulk Density.

Soil water

Module
1, 3, 4, 5

What is plant available water capacity? Plant available water capacity (PAWC) is a measure of how much water a soil can supply to a crop. It is calculated as the difference between the amount of water that a fully-wet soil can hold and the amount left after a crop has matured under severe water stress.

Module
4, 5

Do I need to calculate PAWC for my soil? First check Module 5 to see if your soil type has already been measured. If it has not, follow the instructions in Module 4, or enlist the aid of a consultant.

Module
2, 3

Can I calculate the water available to my crop and check how efficiently it is being used? Soil water status can be calculated by measuring soil water content at sowing. After allowing for in-crop rainfall and run-off, and deducting remaining soil water at maturity, water use efficiency is calculated by dividing yield (kg) by water used (mm).

Soil nitrogen

Module
1, 3

How can I calculate how much nitrogen to apply? Application rates are calculated from the nitrogen needed for the expected yield and protein content less the amount already available in the soil at sowing.

Module
1, 3

How do I calculate the nitrogen available in the soil? Multiply the mg/kg value (from soil analysis) by bulk density and the thickness of each layer of soil analysed, and add these values for all depth layers.

Module
1, 2

What causes a nitrogen bulge in the soil? Mineral N from near the surface moves down freely with water entering the profile. Unused N from one season can be carried to depth and, if not used by following crops, will accumulate in the lower profile.

Module
2, 3

How do I know if there is a nitrogen bulge? This can be detected by deep sampling; it may be expected if you have applied fertiliser during periods of low crop yield or in land recently brought into crop production.

Introduction

The north-eastern cropping region of Australia lies in a subtropical environment of extreme rainfall variability. Successful crop production depends upon the buffering influence of stored soil water to sustain growth during the prolonged periods between significant falls of rain.

The greatest challenge for farmers in this region is to cope with this high level of uncertainty of the weather and the associated uncertainty about the accumulation of water in the soil. This climate variability and nitrogen availability are the most critical determinants in crop production. Most farmers would like to replace their gut feel about the state of these two variables with reliable measurements.

Farmers have, for many years, monitored the soil using practical methods such as the push probe to determine the depth of wet soil, and the appearance of a crop and the protein content of its grain as measures of fertility.

This manual describes those techniques but also provides alternatives to improve both the quality and quantity of the information. This is especially valuable for crops such as dry-land cotton because of the high investment that is at risk.

Confidence in soil management

Farmers have to adopt all cost-effective means to reduce uncertainty in the production system. If the amount of soil water and available N have been measured directly, or estimated from suitable rainfall and soil information, the farmer can make more confident decisions. These include when, or even whether, to plant a crop, the expected yield, and the profitability of an investment in fertiliser nitrogen.

Nitrogen is especially important because it is the one plant nutrient whose availability may fluctuate between sufficiency and almost total absence in the course of a single cropping season.

Farmers and their advisers have requested a simple explanation of the key soil processes to better understand this resource and practical guidance to making relevant soil measurements. Our experience in APSRU with on-farm collaborative research has highlighted many issues for which a ready source of reference would be valuable.

This handbook is intended to fill these basic needs whilst pointing to sources of more detailed information on many technical aspects of soil properties and behaviour.

Exploring your soil

The APSRU booklet – *Exploring the soil on your farm* (Foale et al. 1993) – provided an introduction to the use of soil coring as a crop management tool. However, the widespread interest in soil monitoring techniques has shown the need for further guidance to best practice.

This manual provides details of the basic soil properties and processes, and is a comprehensive guide to soil sampling, analysis, synthesis of information, and the practical application of results.

The scope of this manual

This manual comprises a set of modules that provide background information on, and describe the best practice in, soil monitoring. The simple explanation of soil and plant processes enables the results of soil monitoring to be used with confidence to achieve more profitable and sustainable crop management.

Five modules

All modules and the appendices are bound in the main book. The database of Module 5 is a separate booklet to allow for updating of data.

1. Understanding your soils

Module 1 explains the formation of the soil, and the physical, chemical and biological properties relevant to a dry-land crop production system. There is particular emphasis on soil properties that impact dryland cropping systems.

2. A guide to soil sampling

Module 2 is a comprehensive guide to soil sampling. It includes sections on when, where, how deep and how often to sample; what tools to use; and how to process, store and transport the samples. This is useful for the farmer who wants to perform his own sampling, but is particularly aimed at commercial operators seeking to provide a high-quality soil sampling service along with relevant advice.

3. Calculating water and N

Module 3 shows how to convert the results of the analyses for water and nitrogen content into values useful in management. It describes how to apply these values to management decisions prior to planting, or to gain insight into efficiency of water use by previous crops.

4. Determining Plant Available Water Capacity

Module 4 outlines the field procedures for characterising the soil with respect to storage of soil water and its uptake by different crops. Characterisation is a specialised task, undertaken for each soil type of interest and is generally carried out collaboratively by the farmer and consultant. The module describes measurement of variables to calculate plant available water capacity—information of crucial value in the use of simulation as a tool to add value to soil monitoring data.

5. Soil characterisation data

Module 5 contains a description of soils of the northern grain region; this should be used, where appropriate, in conjunction with the enclosed soil map and key. A database of information that includes the plant available water capacity for a range of common soil types and crops is provided in a separate booklet, allowing updated and new data to be included.

Appendices

The appendices provide supplementary information for those wishing to source or manufacture soil sampling equipment or to read more about the topics covered in the manual.

Appendix 6 contains proforma calculation sheets for soil water and soil nitrogen. These should be photocopied for all field workings.

1. Understanding your soil

Soil formation

The soil, and the vegetation it supports, make up the life-supporting transition zone that lies between the underlying rocks and sediments of the earth and the atmosphere. Within the soil, there is a complex interaction of natural processes. These sustain an environment in which plants germinate and develop roots which have access to water and nutrients held in the soil. Soil forms and evolves on a time-scale of thousands of years.

The combined influences of the weather, the vegetation and animals, and chemical, physical, and biological processes generate soil.

A soil profile builds up on a foundation of parent material comprising raw rocks of enormous diversity, ancient weathered landscapes, or sediments deposited by wind and water. The upper slopes lose soil to the lower slopes through erosion by water, while more soil is added to the flats along creeks and rivers by flooding. In arid environments, wind moves soil around the landscape.

The least obvious influence on soil formation is the passage of time. Soils that range in age from a few years (on recent alluvium) to a few thousand years, all the way up to many millions of years are found in the farmlands of Australia.

The role of parent material

The physical and chemical properties of the parent material strongly influence the type of soil that is formed. This applies especially to the mix of sand, silt and clay—and the concentration of key nutrients such as phosphorus (P), potassium (K) and calcium (Ca).

Parent material that is rich in quartz (granite, coarse alluvium, ancient deeply-weathered landscape) gives rise to sandy or loamy soil low in P, while most basalt and many other fine-grained sediments (alluvium, silt-stone, shale) form soil of medium to high clay content associated with a medium to high level of P.

Clay that is young on a geological time-scale is usually of the cracking, or shrinking-swelling type (called smectite), which is made up of two parts silica to one part alumina. Clay that is more weathered becomes transformed; two forms of this type of clay are called koalinite and illite.

Soil loss exceeds soil formation

Although soil may be lost from the land surface through erosion by wind or water, new soil develops as the weathering processes extend below the present soil depth, converting parent rock into soil. The influence of water and transported soil chemicals, and of exploring plant roots, soil microbes and fungi, converts parent material at the lower extreme of a soil profile into living soil. The rate of soil formation at the interface with parent rock is only a few millimetres per century, and is much too slow to compensate for the accelerated rate of soil loss from the surface due to farming. This loss lowers potential productivity; for example, an average annual soil loss of only 2 t/ha, taken uniformly over a paddock, will result in a loss in soil depth of 20 mm after 100 years.

Soil physical properties

Structure and texture

The soil medium or matrix consists of a mix of air, water, and fine to coarse particles of weathered minerals, especially silica and silicates of aluminium. Particle sizes range from below 2 microns (0.002 mm) to above 2 mm. The fraction above 2 mm is classed as gravel and is considered to be of little significance in the agricultural soils of the northern grain belt.

The relative proportion of the three particle size categories, sand, silt and clay, determines the texture of the soil. This term refers to the behaviour of the soil when wet. Different textures are distinguished, based on feel (rough or smooth particles), cohesiveness—the length of a ribbon of wet (but not sticky) soil formed by squeezing out between the fore-finger and thumb—and capacity to retain water (see Module 5 – *Determining soil texture*).

The structure of the soil refers to the degree of development in the soil profile of aggregations of peds (the basic small units of structure, often just a few cubic mm in volume), and the strength of surface aggregates (crumb-like clusters of peds and organic particles). The opposite condition to aggregation is dispersion which causes a compacted layer to form, resulting in slowed movement of soil water. Well developed aggregates in turn are assembled into large 'building blocks' which generally are easily broken down in the hand or by cultivation into progressively smaller component units. Water and growing roots generally move freely in between the aggregates of a well-structured soil.

Structure also refers to the degree of development of layers in the profile, recognisable due to change in colour and/or texture.

Soil water

The amount of water that a crop can take up from a fully wet soil is referred to as the plant available water capacity (PAWC). When a clay soil is very wet but not saturated, practically all of the air space (pores) is filled with water. In a sandy soil (illustrated in Figure 1.1 on page 6), a much lower proportion of the pore space remains filled with water because water drains out of the large pore spaces between the particles (see Module 4).

Clay particles are extremely fine and packed closely together; a high proportion of the water held by a clay soil, within its peds, clings tightly to these particles. There is little drainage, but there is also limited uptake by the root. Usually less than half of the total water that is held in soil with high clay content can actually be taken up by roots.

Apart from particle size affecting the physical behaviour of water, and causing different degrees of drainage, crop types differ in their ability to take up water from the soil. This is due to differences in depth and density of roots, differences in the duration of the growing season and differences in the 'sucking power' of the crop when it experiences water deficit (See Figure 1.2. and Module 4).

Soil water analysis

The next section helps to explain the results of soil water measurement through a brief presentation of some basic soil science.

The analysis sheet shown on the next page is output from the APSoil computer program. APSoil has been developed to link field information with appropriate soil characterisation data and to output information on water and nitrogen in a form appropriate to farmers.

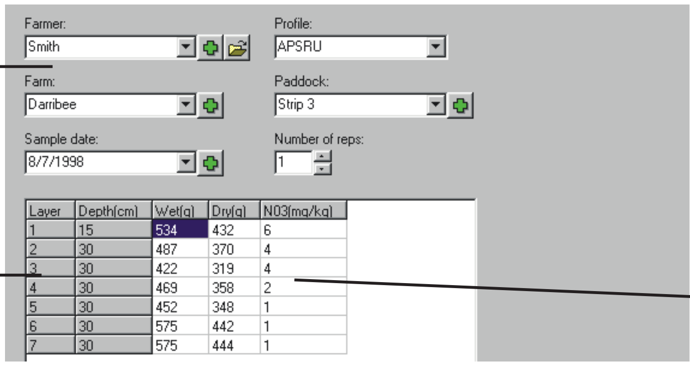
Methods for obtaining the soil data required as input for APSoil are described in Module 2; methods of calculating Plant Available Water Capacity are described in Module 4.

Soil water measurement

– an example of paddock reports from APSoil

Details of farmer, paddock and sampling visit.

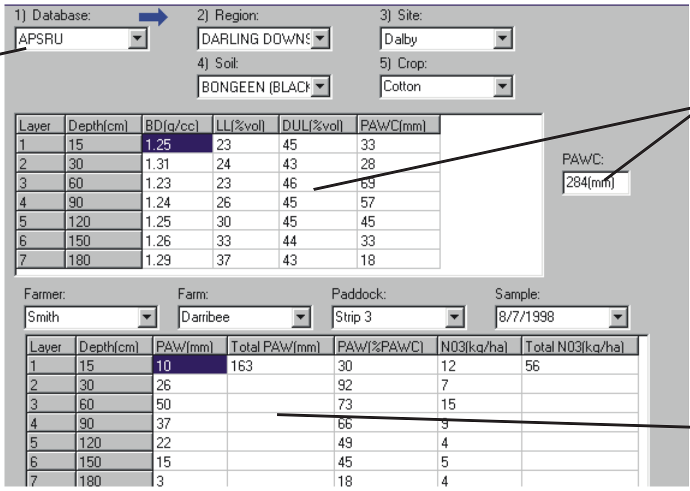
Series of depth intervals or layers that were sampled (Module 2).



Layer	Depth(cm)	Wet(g)	Dry(g)	NO3(mg/kg)
1	15	534	432	6
2	30	487	370	4
3	30	422	319	4
4	30	469	358	2
5	30	452	348	1
6	30	575	442	1
7	30	575	444	1

Wet and dry weight and nitrogen concentration of samples are inserted by farmer or consultant (Module 2)

Soil type, site and crop details from database (Module 5), or locally generated



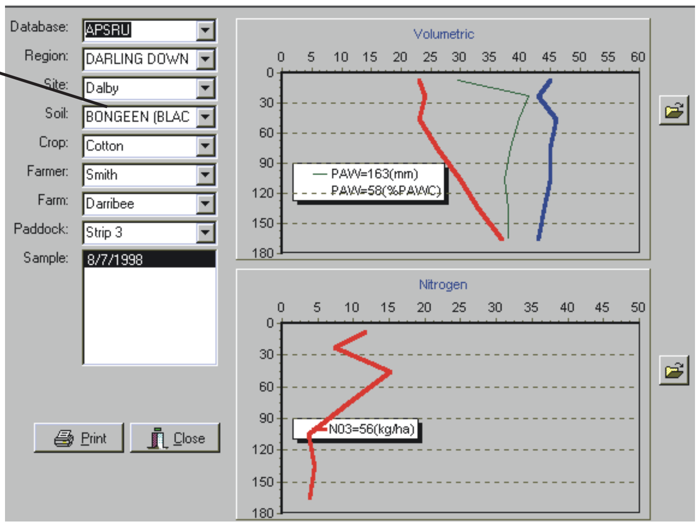
Layer	Depth(cm)	BD(g/cc)	LL(%vol)	DUL(%vol)	PAWC(mm)
1	15	1.25	23	45	33
2	30	1.31	24	43	28
3	60	1.23	23	46	69
4	90	1.24	26	45	57
5	120	1.25	30	45	45
6	150	1.26	33	44	33
7	180	1.29	37	43	18

Layer	Depth(cm)	PAW(mm)	Total PAW(mm)	PAW(%PAWC)	NO3(kg/ha)	Total NO3(kg/ha)
1	15	10	163	30	12	56
2	30	26		92	7	
3	60	50		73	15	
4	90	37		66	9	
5	120	22		49	4	
6	150	15		45	5	
7	180	3		18	4	

Bulk Density and PAWC of soil x crop combination for each layer and the whole profile (Module 4)

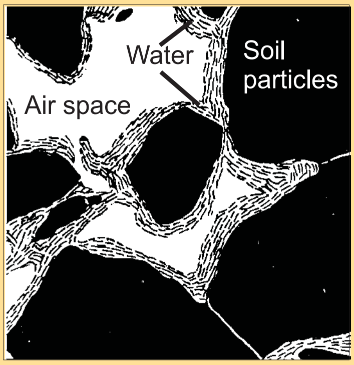
Water and available N calculation, based on soil physical characteristics, for each layer and the whole profile (Module 3)

Details of farmer, paddock and sampling



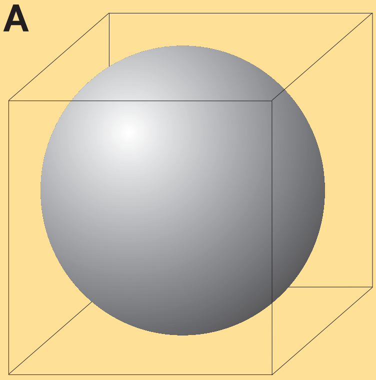
Results of available water and nitrogen presented graphically.
Data from a series of sampling dates can be compared on a single graph.

Water, air and soil particles



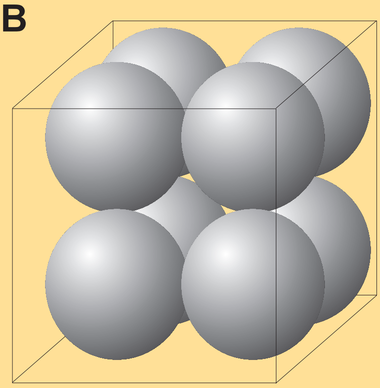
Water clings to the surface of soil particles, but drains out of large pore spaces. Plant roots can draw off only the 'available' part of the clinging water layer. Small particles that occupy the same soil volume as large particles have a greater surface area to which water can cling and smaller pore spaces. Water retention is related to the combined surface area of all the particles in a soil sample and the amount of fine pore space between them.

A



Sphere A represents a soil particle that occupies the same volume as the 8 particles of half its diameter in B.

B



The volume and weight of the 8 spheres in B are the same as the large one in A, but their combined surfaces have twice the area. More of the 'pore space' between the small spheres will be occupied by water than between large spheres as less water will drain.

Clay particles have a diameter that is less than one tenth that of fine sand. The particles in a given mass of clay have a surface area at least 100 times greater than the same mass of fine sand. Thus clay has a higher capacity to hold water than does sand, but it releases to the root system a smaller proportion of the water it holds. Shrink-swell clays 'make room' for water to move in, and out from, between particles. As water is lost, this clay shrinks back to its 'dry' state.

(Top illlustration after Jenny, 1980)

Figure 1.1. Water, air and soil particle size

Plant available water capacity (PAWC)

The amount of water extracted by a plant depends on the soil's physical and chemical properties, and on root density, rooting depth, crop demand and the duration of crop growth.
The blue and red areas represent the plant available water capacity (PAWC) for two crops which differ in their ability to extract water. Water stored in the red surface area is prone to evaporation and may not be available to the plant.

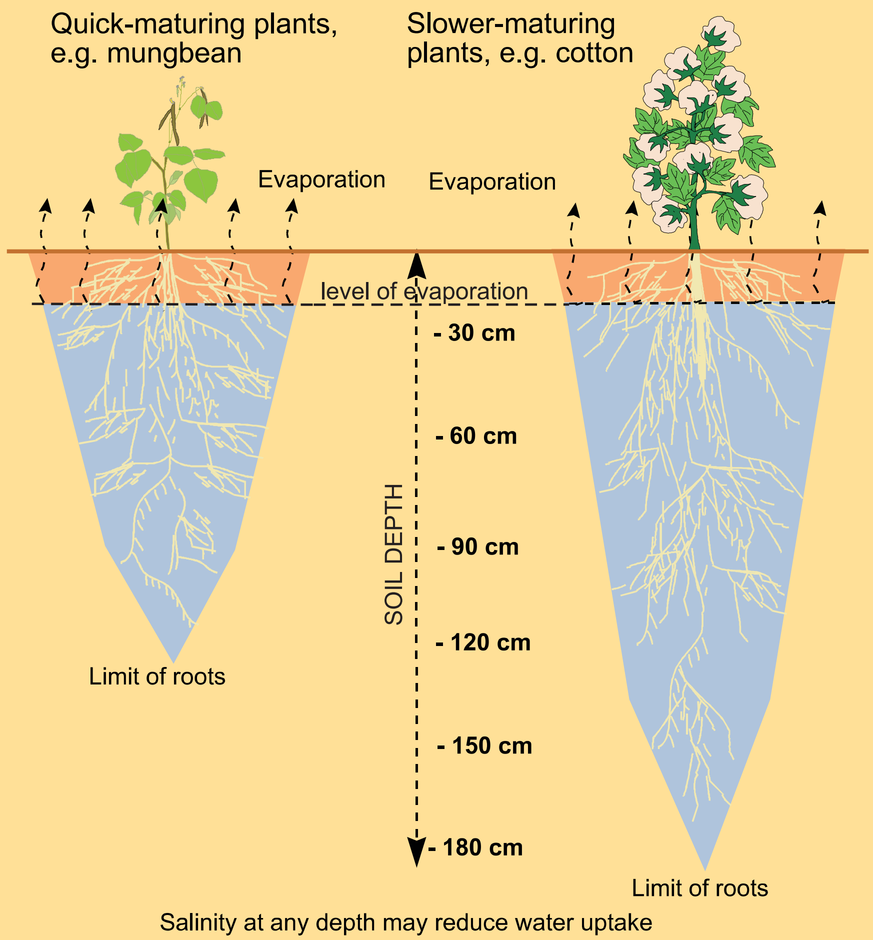


Figure 1.2. Plant available water capacity for two differing crops, represented as water 'buckets'.

Water storage

In cracking clay, the aggregates of particles (peds) swell as water moves into the space between the plate-shaped particles (less than .002 mm diameter). Upon drying, the aggregates shrink as water moves out from between the particles, and large cracks open in the soil between large clusters of peds. These shrink-swell soils are able to store more water than lighter-textured soils or rigid types formed from less reactive clays. This increased storage provides a more reliable water supply to crops between rainfall events, making cracking clay soils the preferred choice of farmers in the northern grain belt (see Module 4).

Sandy soils store the least water. They are not suited to cropping in the semi-arid subtropics because the amount that can be stored would rarely be sufficient to enable a crop to survive the frequent long periods between rainfall events.

Soil structure and cover affect water infiltration

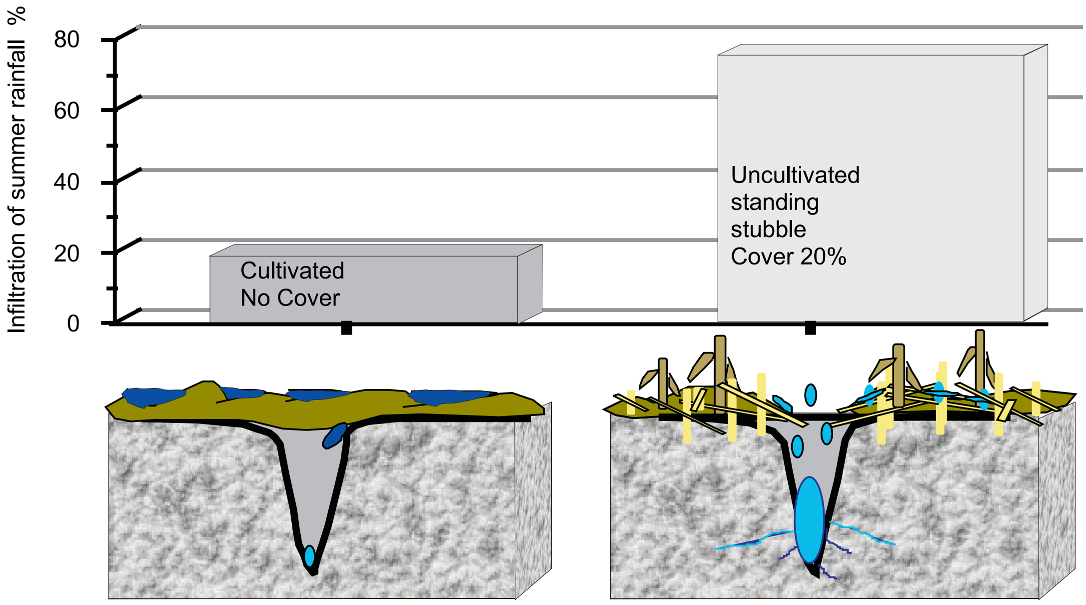
Apart from the capacity of the soil to store water, the rate of entry of water into the soil during rainfall is also crucial to successful farming.

Infiltration of water into a dry cracking clay soil is initially rapid through the large open cracks, but water entry slows, as firstly the surface clay aggregates and then the large blocks of soil peds beneath the surface are wetted up and swell. Water from high intensity rainfall, or irrigation, will enter a dry cracked soil very rapidly through the open cracks; the water will then soak "sideways" into the large blocks of soil peds from the water-filled cracks.

The stability of aggregates and fine peds, and of the gaps between them, determines the rate of infiltration into a wet soil. Swelling will cause the peds to press together. However, if the peds are highly stable and internally cohesive, the gaps between them will remain sufficiently wide and sufficiently connected to allow significant downward flow of water. Infiltration when the surface soil is wet is also improved by the presence of residue (Figure1.3), the absence of compaction—which accompanies cultivation—and by a high concentration of soil organic matter. Cultivation imposes a risk of damage to fine peds causing blockage of the gaps between peds and aggregates upon which water flow depends.

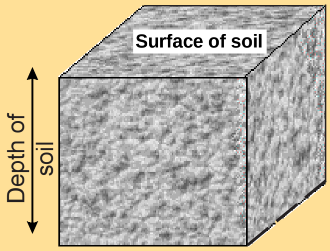
Some soil shows hard-setting behaviour, in which particles become packed tightly together, showing little shrinkage upon drying. In these soils cultivation has a role in creating roughness at the surface, which generally improves infiltration of water, at least during the next rainfall event. Hard-setting may develop again, following a substantial fall of rain, on a soil that disperses rather than forming aggregates.

Figure 1.3. Rainfall infiltration over a summer fallow: an example of a cultivated paddock with no cover compared with an uncultivated paddock with 20% cover provided by standing stubble (Freebairn and Wockner 1996).

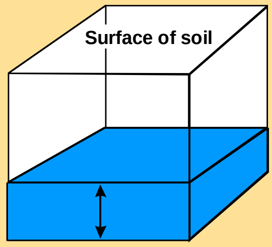


Connecting soil water and rainfall

Soil water can be considered in the same terms as rainfall, i.e. as millimetres of water, in the soil profile. The weight of water in a soil sample (called the gravimetric water content and expressed as a percentage of the dry soil weight) must be converted to millimetres of water. This can be explained by visualising a block of soil which contains an amount of water. If this water flowed into a single layer after removing the soil particles, this Volumetric Water Content can be seen as depth of water (in millimetres).



Water distributed throughout soil

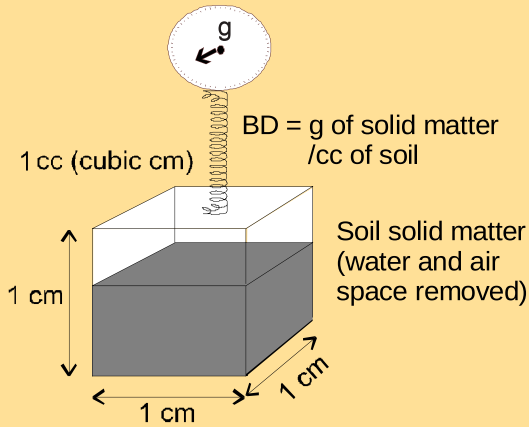


Equivalent depth of water after soil is 'removed'

To calculate this depth of water when we know the weight of water in a certain weight of soil—the gravimetric water %—we need to know the weight of soil solid matter in the block—its Bulk Density.

Bulk Density (BD)

Bulk density (g/cc) of soil solid matter is the weight of solid particles in 1 cubic centimetre of soil.



Once the bulk density is known, the weight of water per gram of soil can be converted to water volume per cc of soil volume, which is equivalent to the mm depth of water per cm soil depth. We can relate this directly to rainfall in mm.

For example:
Calculating mm of water in a soil layer that has a gravimetric water content of 40% and a BD of 1.3g/cc.

Volumetric water content = 40% x 1.3 g/cc
= 52% or 52 mm of water per 100 mm depth of soil

This calculation uses data from soil sampling procedures outlined in Module 2, and is integrated in Module 3 to estimate available water for the whole profile (Table 3.3). The measurement of PAWC, including BD, is explained in Module 4.

Organic matter, roots, and micro-organisms

Both long fallow and cultivation of the soil reduce soil organic matter, by reducing the rate of addition of residue; they also increase the surface area of particles of residue and organic matter exposed to soil organisms that consume organic residue.

This reduction of soil organic matter can be slowed, and possibly reversed, by management that increases the proportion of total rainfall that crops use. The practice of minimum or zero tillage generally improves rainfall capture (Figure 1.3 and Module 3) which in turn helps to increase both the crop yield and the amount of residue. If soil water storage is adequate, planting an 'opportunity crop' will use in-crop rainfall which might well run off from a fallow.

An opportunity crop makes use of the soil water while its canopy shades the soil surface, reducing evaporation.

Recovery of water from the soil depends upon adequate root development. Soil compacted by machinery, or affected by sodicity, (see following section on Chemical factors) resists the penetration of roots.

Cracking soil, however, provides 'freeways' for the rapid extension of roots deep into a profile. When the soil is wet and cracks are closed, roots still experience less resistance to their extension in these crack pathways. Even when the soil is depleted of plant available water, root extension at depth may continue. Although little water remains to be extracted, the moist atmosphere, deep in the soil, enables roots to continue to extend downwards. If there happens to be some deeper extractable water these exploring roots will gain access to it.

The physical properties of the soil surface, especially the stability of soil peds, are influenced by the amount of organic matter, and by the level of microbial and faunal (small soil animals) activity. Soil that is high in phosphorus sustains high microbial and faunal activity, which is indicated by good crumb structure, tunnels that have been burrowed out by worms and insects, and an absence of surface crust. Soil that has a high calcium status generally has a robust and stable ped structure.

Summarising soil physical properties

- Soil texture is determined by the relative mix of fine and coarse particles.
- Soil structure reflects change in texture, mix of different clay minerals, and capacity for particle aggregation into peds and clusters of peds.
- Potential soil water storage depends on texture, and on the type of clay minerals present.
- Plant available water is highest in cracking clay soil.
- High phosphorus sustains microbes and microfauna which improve soil structure.
- High calcium imparts stability to peds, improving structure; sodicity causes dispersal of aggregates and hard-setting.
- Roots can extend rapidly down the 'freeways' provided by deep soil cracks.

Soil chemical properties

A soil laboratory analysis sheet provides information on the chemical characteristics of the soil.

This sort of analysis information has been available from commercial laboratories for many years (Figure 1.4).

Organic Carbon - a measure of organic matter reserves which are an indicator of cropping history, and of the potential for nutrient release. Values between 1 and 2 are common in clay soil.

Nitrogen - available to the crop; moves through the soil profile with the water; may accumulate at depth. (Modules 2 and 3)

Sulphur - available to the crop; may move through the soil and accumulate at depth.

Phosphorus - The BSES test which is used in acid soils, may overestimate available P in alkaline clay soils.

The Colwell test is used in alkaline clay soils.

Chloride - indicator of the level of salinity.

Elec Conductivity - gauges salinity by indirect measurement. A measure of all salts in the soil solution.

Calcium/Magnesium Ratio - variation is associated with different levels of soil dispersion. Values below 0.1 indicate high dispersion and poor infiltration.

Cation Exchange Capacity - indicates potential capacity of soil to store nutrients, e.g calcium, potassium.

Sodium % - indicates a possible sodic effect.

Elec Conductivity (SE) - alternative value for conductivity adjusted for soil texture.

RESULTS OF ANALYSIS*

* Values given indicate an adequate or favourable level.

Date of Sampling..............
Soil colour (Munsell).........
Soil Texture.......................
pH (1:5 water)...................

Organic Carbon % C.....
Nitrate nitrogen mg/kg.........
Sulphur mg/kg.....................
Phosphorus (BSES) mg/kg...
Phosphorus (Colwell) mg/kg

Potassium meq/100g..........
Calcium meq/100g..............
Magnesium meq/100g.........
Sodium meq/100g...............

Chloride mg/kg..................
Elec. Conduct. dS/m...........
Copper mg/kg.....................
Zinc mg/kg.........................

CALCULATIONS
Calcium/Magnesium ratio....
Cation Exchange capacity meq/100g
Sodium % of cations..............
Elec. Conduct. (s.e.) ds/m.......

Texture - a rough guide to water storage capacity (higher in cracking clays and clay loams). (Module 5)

pH - above 7.0 alkaline; possible sodicity above 8.4; acid below 7.0; possible plant toxicity below 5.0

The three major cations - essential for plant growth. Exert great influence on soil structure, colour, and aggregate stability.

Sodium - a high level disperses aggregates, reducing pore space and infiltration rate.

Importance of trace elements depends on land use; these cations less available where pH is above 7.5.

Zinc - low levels often limit growth on clay soil. VAM increases uptake of zinc.

Figure 1.4. Explanatory notes for a sample laboratory analysis sheet.

Plant nutrients

All the nutrients needed for plant growth are found in the soil. The other major inputs to growth are water taken up from the soil and carbon dioxide from the atmosphere.

A major contributor to plant nutrient reserves in the soil is the residue from the breakdown of plants, small and large animals and soil flora (Figure 1.5).

Plants take up nutrients almost exclusively in mineral form in solution, after the organic molecules, comprising mostly carbon, hydrogen, oxygen and nitrogen, have been broken down.

Nitrogen, phosphorus and sulphur are available to plants in soluble 'mineral' form, as nitrate (NO_3^-), phosphate (PO_4^{---}) and sulphate (SO_4^{--}). Nitrate and sulphate move freely in the soil solution and are carried down the profile by infiltrating water.

The general behaviour of phosphorus moving between different levels of availability is illustrated in Figure 1.6. Phosphate can be fixed by attachment to certain soil compounds, particularly aluminium and iron oxide, becoming unavailable for uptake by roots or soil organisms. This is a particular problem in red acid soils rich in iron and aluminium oxides. In highly acid soils, the sulphate anion can also become fixed and unavailable.

Most other nutrients are attached by electric charge to clay or organic particles as positively charged cations (single atoms such as potassium, magnesium and zinc), unattached to other elements though com-

Figure 1.5. The cycle of soil organic matter and nutrients

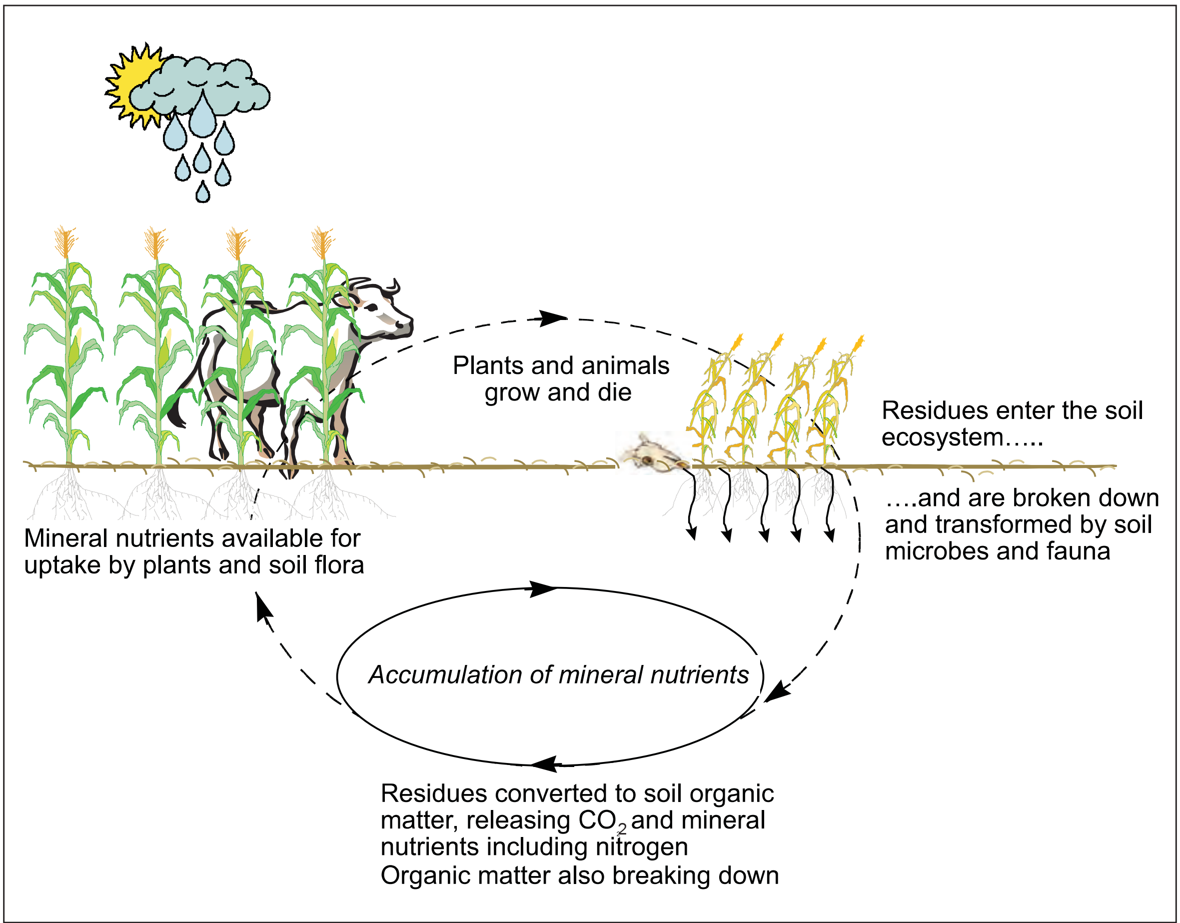
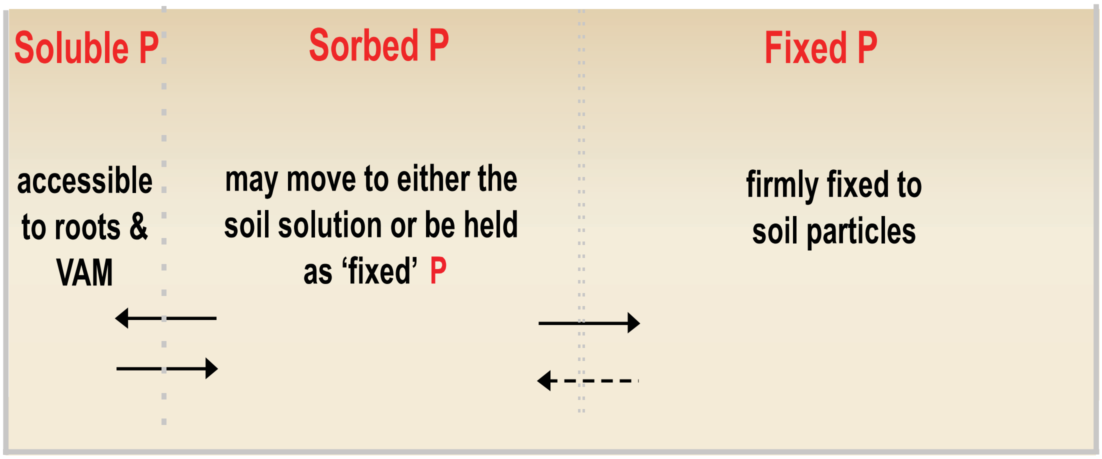


Figure 1.6. Soil phosphorus—the relationship between soluble (available) P and other forms



- This tank model is used to illustrate the two-way flow between P in solution, sorbed P held loosely, and fixed P held tightly, on soil particles. Soil tests measure P in solution and some sorbed P.
- The relative size of the three compartments differs with soil type and cropping history.
- Fertiliser P will mostly expand the soluble compartment, but in some soils some can move through the buffer reserve and become fixed. As fixed P is released only slowly, the soluble compartment will shrink as P is taken up by plants. Even though P is taken from the soil in products, change in concentration shown in tests might not reflect that loss, due to release of sorbed P.
- VAM fungi in the soil gain access to some of the P in solution which roots cannot access directly. A VAM filament can enter gaps between soil aggregates that are half as narrow as those that the root hair can enter.

plemented by anions located in the vicinity. Through an electrical exchange process, the plant root captures both cations and anions from the surface of soil particles or from the soil solution. The concentration of these nutrients in the soil can be determined by laboratory analysis. This analytical information is used by farmers to assist in making fertiliser decisions (see Figure 1.4).

pH affects nutrient availability

pH is an expression of acidity-alkalinity on a scale of 1–10. The chemical environment of the soil can be acid, neutral or alkaline. The ideal state is neutral which is the status of pure water, but generally there are influences which generate acidity (e.g. the movement through the soil of strong acid ions such as sulphate or nitrate) or alkalinity due to the accumulation of strongly basic ions (such as calcium and sodium)

The term pH was derived from the method of measurement of the concentration of hydrogen ions in a solution. This concentration is indicated by the electrical **p**otential in the solution between two **H**ydrogen electrodes. The lower the pH number, the higher the concentration of hydrogen ions; a drop of 1 unit of pH represents a ten-fold increase in the concentration of hydrogen (acid) ions.

The pH scale provides a useful indicator of some aspects of chemical properties and behaviour of the soil that affect plant growth. Alkaline clays generally contain a majority of ions of the bases calcium, magnesium, potassium and sodium.

Both extremely high and extremely low pH soils are unfavourable to plant growth. A high degree of acidity (below pH 5.5) may trigger the release in a toxic form of aluminium or manganese, while strong alkalinity (above pH 8.0) impairs uptake by the root of scarce trace element cations, such as copper, iron, manganese and zinc.

Converting laboratory analyses from mg/kg to kg/ha

Results of analyses for some nutrients are reported as weight of nutrient per unit weight of soil, i.e. mg/kg (equivalent to the old 'parts per million' or ppm).

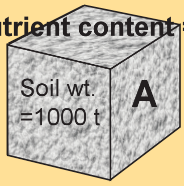
Understanding the conversion from mg/kg to kg/ha

A 10 cm layer of soil over 1 ha has a volume of 1000 cubic metres; the weight of soil will depend on its Bulk Density (BD) (see page 9).

The weights of 1000 cubic metres of two soils of different BD (A and B) are illustrated below. If the nutrient concentration is 10 mg/kg:

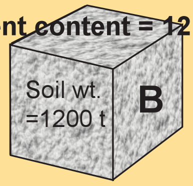
Soil A with BD of 1.0 g/cc will have a nutrient content of 10 kg/ha (10 x 1.0)
Soil B with BD of 1.2 g/cc will have a nutrient content of 12 kg/ha (10 x 1.2).

Nutrient content = 10 kg/ha



There is more nutrient in Soil B on an area basis because of its greater weight of soil on an area basis.

Nutrient content = 12 kg/ha



Salinity

High concentration of salts (mostly sodium chloride but also other soluble mineral salts) can cause a problem to crop production. A highly saline soil solution impairs the uptake of water because the dissolved salts lower the potential of water molecules to pass through the cell membrane into the root. The plant experiences a chemical drought. Excessive salinity commonly affects the lower profile in clay soils and may prevent roots from entering that layer.

Laboratory and field measurements of salinity are expressed as Electrical Conductivity. The critical values of EC vary between crops, but Table 1.1 is a guide. Local advice should be sought for crop-specific values.

Table 1.1. Plant response to salinity[a]

Conductivity (dS/m)[b]	Depression in yield
below 0.2	very low
0.2 to 0.5	low
0.5 to 0.7	medium
above 0.7	high

[a] measured on 1 part soil to 5 parts water
[b] deciSiemen per metre (= milliSiemen per cm)

Sodicity

Sodicity can affect the physical properties of a soil.

When clay particles have a high proportion of their electric charges linked to sodium ions, they lose their normal tendency to cling together, and are inclined to disperse. Sodicity is shown by excessive swelling of the clay and dispersal of the fine particles that make up soil aggregates.

The mobilised fine particles block the larger pore spaces in the soil structure forming a 'hard-setting' or 'massive' layer of high bulk density. This reduction of pore space impedes the entry and storage of water in the soil mass, and interferes with root growth as few pores remain that are suitable for the entry of root hairs (greater than 14 microns diameter*). A high proportion of magnesium relative to calcium amplifies sodicity. Application of gypsum (calcium sulphate) will displace some of the sodium ions but this may be very expensive if deep layers of soil are affected.

[*1 micron is 1 thousandth of 1millimetre]

Summarising plant nutrients and chemicals

- Plant nutrients are recycled through the decomposition of organic matter.
- The mineral composition of the parent rock influences the level of soil nutrients such as phosphorus and the cations (calcium, potassium, magnesium, etc).
- Extremely high or low soil pH may impede uptake of some trace elements; low pH may cause toxicity to roots.
- Salinity affects water uptake resulting in a chemical drought at high EC.
- Excess sodium (sodicity) disperses fine particles into pore spaces reducing water infiltration and blocking root access.

Soil biological properties

Organic matter

The powerhouse of biological activity is the soil organic matter, ranging from fresh plant and animal residue and excreta to highly processed humus.

Analysis for organic carbon (% C) generally indicates the level of organic matter, although the presence of inert charcoal may distort the figure. A factor of 1.7 is used to convert % C to % organic matter.

Under undisturbed vegetation, organic carbon ranges from 2-3% C under brigalow forest to about 1% C under grasslands such as Queensland bluegrass or Mitchell grass. After continuous cultivation for 30–50 years, organic carbon levels drop well below 1% C, accompanied by a loss of soil structure. The level of organic matter in a soil is an equilibrium between incorporation of new material and the rate of oxidation, which is dependent on soil temperature and moisture. The return of plant material to the soil under cropping is reduced because of removal of harvested yield or from loss through burning or baling residues; cultivation also exposes a larger surface area of soil particles to the atmosphere, increasing the rate of oxidation.

The ratio of carbon to nitrogen is important. Incorporating a large amount of inert plant material (e.g. straw) may increase the physical organic matter but will not improve the level of vital or labile humus. Bacteria trying to digest (decompose) the straw will need to obtain their nitrogen from the small pool of available soil nitrogen, and this may make it unavailable to a succeeding crop.

Restoring organic matter and soil structure

The cracking clays do not suffer as great a loss of structure as other soil types because their shrinking and swelling nature maintains their ped structure.

Restoration of orgainc matter and structure in other soils can be advanced substantially only by reverting to grassland for a number of years. The fine fibrous roots of a pasture grass place its organic matter in intimate contact with soil particles in a totally different way to that of incorporating plant residues by mechanical means. Pasture leys of pure legumes (medic or lucerne in the southern regions or lablab, cowpea or butterfly pea in the subtropics) will raise soil nitrogen levels quickly but the plant residues break down too quickly to provide a lasting organic carbon increase.

However, a pasture solely of grass has limited potential because its total dry matter production, and depth of rooting, are restricted by low available nitrogen. Thus, restoration of fertility (organic matter and nitrogen) requires a mixed pasture of grass and legume.

Farming and soil biology

Soil biology is much affected by farming activity.

The plant residues that accumulate under mono-cropping are the specific food source for parasitic insects and diseases such as crown rot and root lesion nematode in wheat. Crop diversity encourages populations of competing organisms and reduces the build-up of specific pests and diseases.

Clean cultivation between crops incorporates residues causing rapid loss of soil organic matter, whereas biological activity is slower under zero tillage. Although nutrients are recycled more rapidly under cultivation, the favourable effects of surface residue and preserved organic matter on physical properties are reduced.

Maintaining a high soil nutrient status (especially of phosphorus) favours not only improved crop growth but also rejuvenates the population of beneficial soil micro-organisms and invertebrates.

Where or when soil water is adequate, opportunity cropping can improve rainfall use efficiency (i.e. the amount of plant material that grows for every mm of rain that falls. See Module 3). The residue from an opportunity crop improves the quantity of residue entering the organic cycle and so allows better capture of water in the next fallow. High productivity arising from good water and nitrogen management therefore improves organic matter.

VAM

If biological activity in the soil is greatly reduced by a long (10 to 18 month) fallow, necessitated by drought, the next crop may show symptoms of phosphorus and zinc deficiency. This is because of reduced activity of VAM (vesicular arbuscular mycorrhiza) fungi. These VAM fungi become attached to the plant roots, thereby greatly increasing the surface area of the root system. A crop with a strong VAM association has a greatly enhanced capacity to forage for zinc, phosphorus and also potassium.

VAM fungi take 2 to 3 months to become fully active after a long break between host crops, especially if the fallow has been free of weeds.

Summarising biological properties and organic matter

- Organic matter provides energy and nutrients to soil organisms, and replenishes the reserve of plant-available nutrients in the soil.
- Diversity of soil organisms depends on a supply of residue from diverse plants.
- Active and diverse soil organisms improve the physical and nutrient-supplying properties of the soil, and reduce the activity of soil-borne pathogens.
- VAM fungi assist roots to take up scarce phosphorus and zinc, and require careful management to remain active.
- Cropping, and especially baling or burning, limit the flow of crop residues into the soil due to export or loss of product from the paddock.
- Changed farming methods can reverse soil degradation by halting the run-down of organic matter.
- Organic matter is best replenished by the fine root system of a medium-term ley grass–legume pasture.

2. A guide to soil sampling

This module is a guide to best practice in soil sampling for the measurement of soil water and analysis of nutrients. It contains information on the equipment needed, strategies and methods of sampling, and practical tips for speedy and efficient operation.

Why sample soils?

Taking and analysing samples increases our knowledge of the state of the soil. This can help a farmer make better and more profitable decisions in the management of a crop.

The most suitable method of sampling and the level of intensity will depend on the type of information needed, how much value the farmer places on that information and on the equipment available. As the complexity and scope of the information increases, so does the cost of obtaining it.

Matching soil sampling method to information needs

Push probe
- fast assessment of depth of wet soil to length of probe
- minimal equipment
- cheap and portable

but
- no soil removed for nutrient analysis
- unknown soil water at greater depth or below dry layer
- errors with deep cracks
- relies on experience

Hand coring
- soil available for observation and analysis of water and nutrients
- can sample entire root zone
- useful for small number of samples
- cheap ($150) and portable

but
- labour intensive and slow
- needs skill to operate

Mechanical coring
- efficient operation for broadscale use
- encourages more comprehensive sampling and higher precision

but
- higher capital cost ($3000–5000)
- needs skill and experience.

Increasing information ↓

Increasing cost ↓

Reasons for soil sampling

- Guide to farmer's decisions.
- Determine initial conditions for computer simulation of crop or fallow.

Surface sampling

- Chemical analysis to guide phosphorus and zinc fertilisation.

Deep sampling

- Water and/or nitrogen and other nutrients in the root zone
- Soil depth
- Rooting depth
- Other inhibiting factors such as extreme pH or salinity.

Sampling strategies

Handling paddock variability – sampling intensity

Paddock with a single soil type

The amount of water and the concentration of nutrients may vary considerably within a paddock, associated with localised variation in soil, topography and past cropping history.

Even in a paddock of apparently low variability, taking more cores will provide a more accurate description of the water and nutrient status. However, the intensity of sampling must be balanced against the level of accuracy required for the particular decision, and the time and costs associated with the sampling.

Table 2.1 demonstrates the trade-off between accuracy and the number of samples when these are bulked to make a composite sample for analysis. The table shows information for two levels of accuracy and for three levels of confidence—2 times in 3 or 66%; 4 times out of 5 or 80%; 9 times out of 10 or 90% (see box on Accuracy and Confidence, page 19).

At a given combination of accuracy and confidence, more cores are needed to assess nitrate N concentration than for gravimetric water because N is more vari-

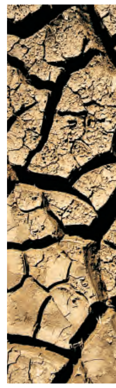
Table 2.1. Number of cores needed for different levels of accuracy in paddocks of low variability.

Confidence level	Number of cores needed for	
Medium level of accuracy		
	nitrate N±20% of mean	Water ± 2% water
66%	3	2
80%	5	3
90%	8	5
Higher level of accuracy		
	Nitrate N ±10% of mean	Water ±1% water
66%	10	7
80%	18	12
90%	29	20

Understanding accuracy and confidence

Accuracy – refers to the amount of deviation on either side of the mean for the paddock. For example, if the true value for nitrate N in a paddock is 10 mg/kg, an accuracy of plus or minus 20% means that the mean of the sample values lies between 8 and 12 mg/kg.

Confidence – as the number of cores changes, the chance that their mean will fall within certain limits of accuracy also changes. Even with a large number of cores, there is a chance that the mean value could fall outside the range of accuracy desired. For example, for a 90% confidence level, using ten sets of samples, one of the mean N values would probably fall outside the desired accuracy limits while the other nine would be inside the limits.



able (Jones 1994). Thus, to be within 10% of the mean value of nitrate N, 66% of times, 10 cores would be needed, whereas to be within 2 units of the percent water content, 90% of times, 5 cores would be needed.

Table 2.1 was formulated using information from some of the less variable soils in the region. Towards the west of the region, topography, soil type and depth and crop growth are more variable. There are presently no recommendations for sampling intensity for these areas, but those in Table 2.1 should be considered the minimum. Obviously the results will be more reliable when more cores are taken.

Paddock with multiple soil types

If the variation in soil within a paddock affects crop performance, the individual areas should be sampled. This variation may be determined by observation of soil type or yield or through the use of technologies such as yield mapping using a Global Positioning System (GPS) and harvester-mounted monitors. Table 2.1 should be used to determine the number of cores needed for each individual area. Fertiliser and crop management strategies may then be modified to suit the variation.

If the paddock is to be treated as one management unit, decisions may be based on information taken from the dominant soil type, from specific problem areas, or from a selected *average* area.

Sampling in a large paddock

The largest paddock used in formulating Table 2.1 was 40 ha. Many farm paddocks are larger than this, and will need a different approach to sampling. There will often be sufficient variation to warrant sampling of individual soils. In this case, the recommendations made in the preceding section can be used.

If a large paddock of apparently uniform soil is to be treated as one management unit, options include:

- increasing the sampling intensity, possibly with less bulking of cores in the initial sampling (Figure 2.2). This will provide an insight into variability on which to base future sampling strategies.
- selecting a transect or strip across the paddock on which all subsequent sampling is undertaken (Figure 2.1). This allows future results to be compared against a known benchmark.

These methods will provide an average of the water and nutrient status of the paddock. In the case of nitrogen, this will result in some areas of the paddock being over-fertilised, others under-fertilised. Further advances in yield monitoring and fertiliser application will lead to variable application of nutrients based on soil type, and water and nutrient status.

In both large paddocks and those with multiple soil types, the sampling strategy depends on whether the paddock is being fallowed or cropped at the time of sampling. When, for example, a row crop is growing, it will be difficult to sample for individual soils or on a diagonal transect. However, as most sampling is done before or after a crop, this should not be a constraint. Sampling patterns are discussed in *Handling paddock variability – sampling patterns* (page 22).

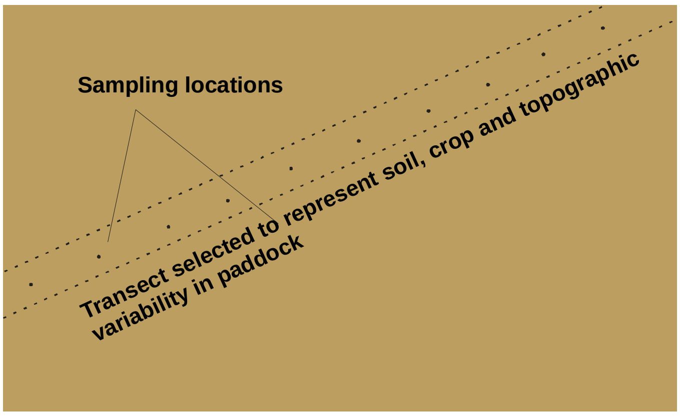


Figure 2.1. A sampling transect across a large paddock selected to represent paddock variability.

Bulking samples

The level of bulking of samples will vary with the task and the budget, but increased bulking results in less information on the variability of the paddock.

Bulked samples must be representative of all the cores sampled. They must be thoroughly mixed and sub-sampled (see *Processing samples in the field, p.35*) since the laboratory may carry out analysis on as little as 5 grams of soil.

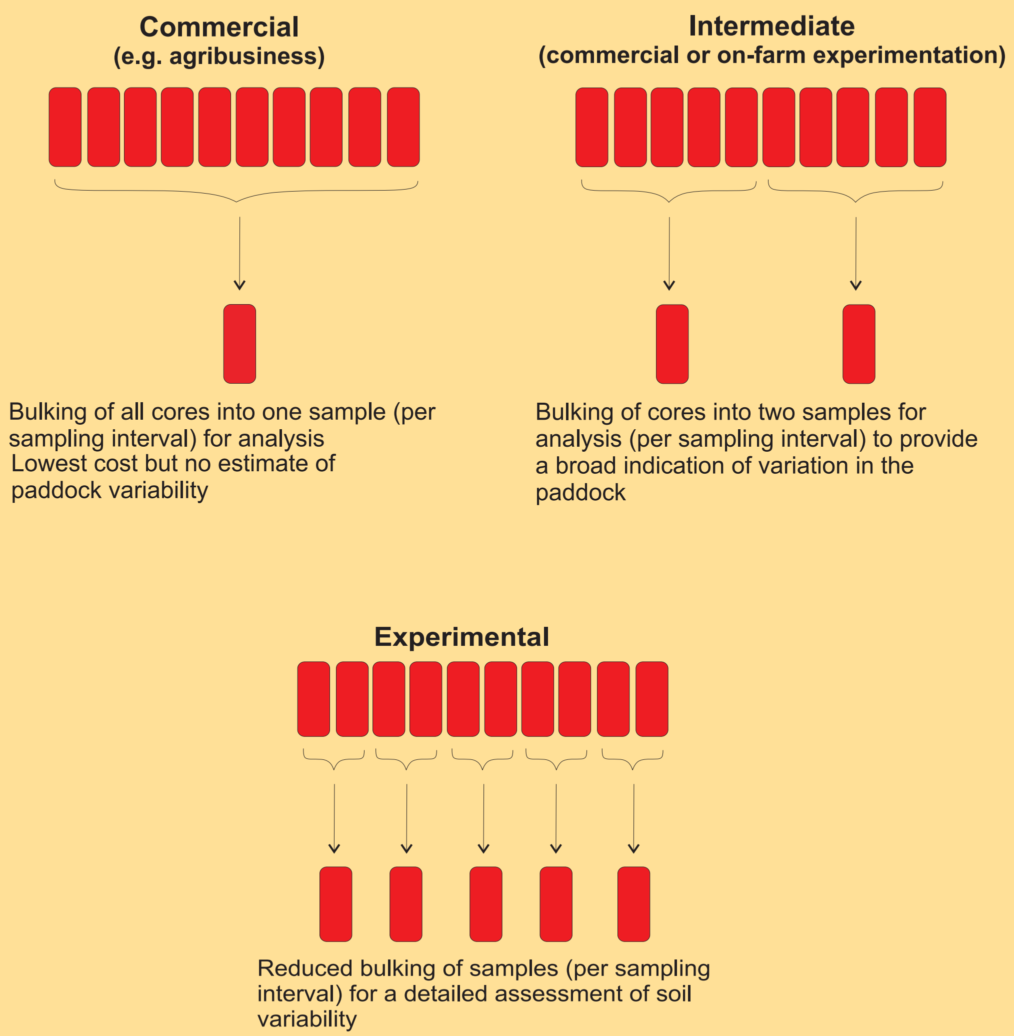


Figure 2.2. Bulking of soil cores according to the sampling task. Increased bulking reduces cost of analysis but provides less information on paddock variability.

Handling paddock variability – sampling patterns

Sampling pattern is influenced by the crop that is about to be planted or has been recently harvested and spatial variability of water and nutrients within the paddock.

Figure 2.3 describes some common sampling situations, and directs the user to the appropriate section for further information.

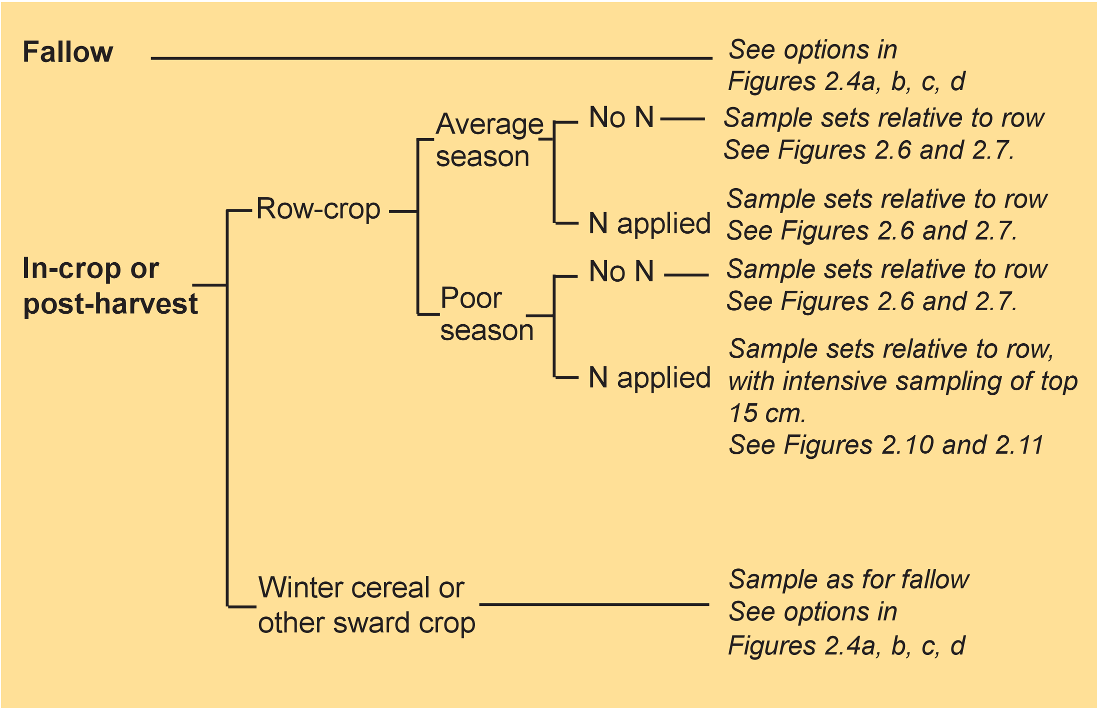
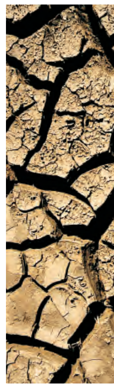


Figure 2.3. Deciding on the appropriate sampling strategy for the given cropping x fertiliser regime

A stirrup sampler—a useful tool for surface sampling for P and Zn.

Sampling a fallow

Fallows are commonly sampled to check or confirm water and nutrient levels before planting a crop. Sampling is easy because of the unrestricted access to the whole paddock and because it is assumed variation caused by previous crops has evened out during the fallow. This permits simple sampling patterns, with various options shown in Figures 2.4 a, b, c and d.



Sampling a fallow

Diagonal

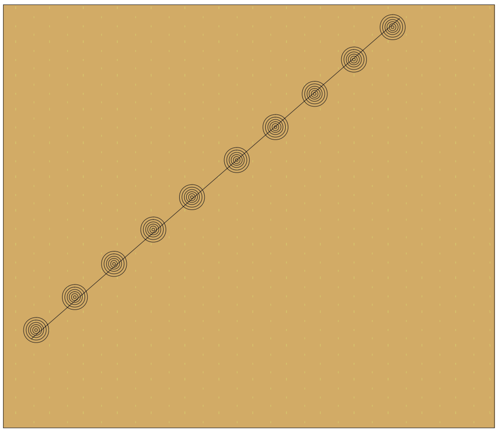


Figure 2.4a. Pattern for sampling a paddock that has a single soil type—diagonal.

Set a line across the diagonal of the paddock and take cores at equal points along the line. This pattern allows a subsequent identification of the location of the coring line, which may help in the interpretation of results (where samples are being bulked into two or more sets for analysis).

If the paddock has been ploughed with a one-way disc plough over a number of years, avoid sampling in areas affected by the action of the plough (particularly the corners and centre of the paddock).

Circular

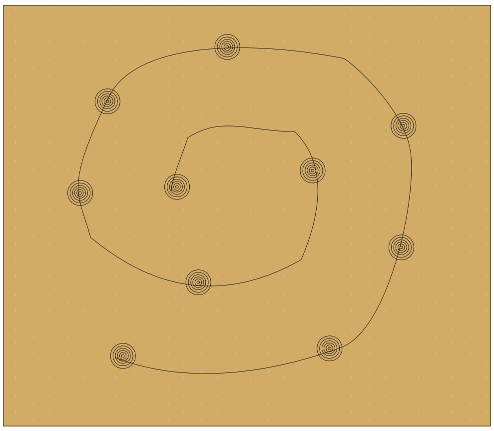


Figure 2.4b. Pattern for sampling with a single soil type - circular/spiral.

A circular pattern (Figure 2.4b), may cover paddock variability more effectively than the diagonal line. However, it may be more difficult to later identify those areas within the paddock from which individual sets of bulked samples were taken. It is more useful in large paddocks than in a strip -cropping layout.

Lines

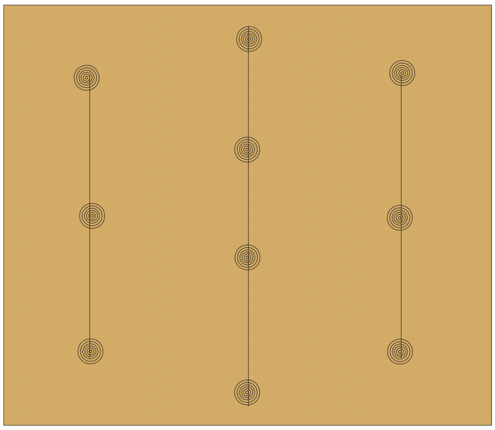


Figure 2.4c. Pattern for sampling with a single soil type - parallel lines.

This pattern (Figure 2.4c) enables two or more sets of bulked samples to be taken and the location of sampling lines readily identified for later reference.

Random

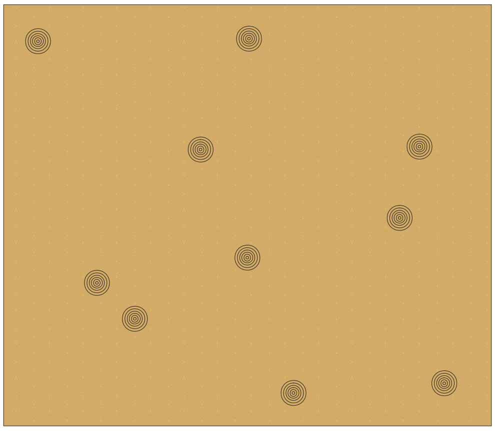


Figure 2.4d. Pattern for sampling with a single soil type—random.

Random sampling (Figure 2.4d) across the paddock adequately covers variability but it is difficult to later define where individual samples were taken.

Sampling in-crop or after harvest

Row crops with nitrogen applied

–during or after a season of at least average production

In a year with reasonable rainfall and crop production, it is assumed that most of the applied nitrogen has moved from the application band into the root zone where it is used by the crop (Figure 2.5).

However, residual nitrogen and water often remain at the end of the season, particularly at depth and in the inter-row. The sampling strategy must account for this potential variation.

Suggested sampling strategy

To minimise sampling bias, take cores in specific locations representing the full width of the zone influenced by an individual row of the crop (Fig.2.6a and 2.7a). A core-locating board can be used to determine sampling locations.

A core-locating board ensures that a set of samples is taken in pre-determined locations relative to the row.

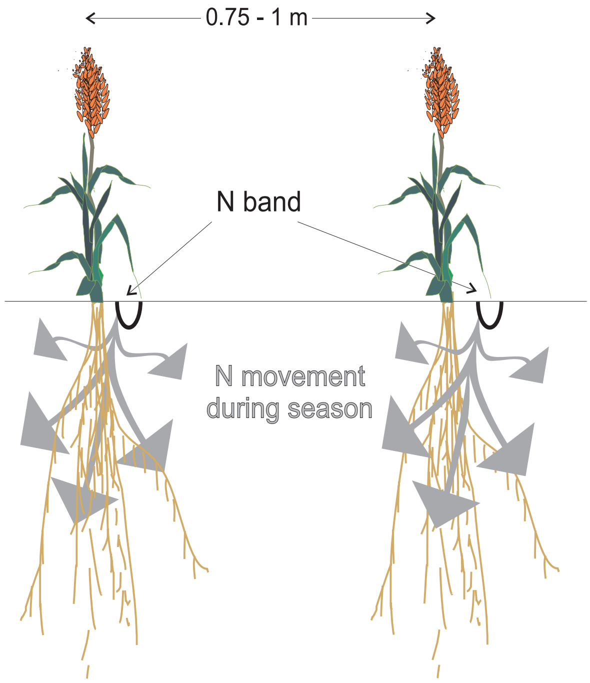


Figure 2.5. Typical movement of nitrate N from banded fertiliser under a sorghum crop which experienced substantial in-crop rainfall.

Take at least two sets of cores in each paddock (the number of cores per set depending on the desired level of accuracy determined from Table 2.1), taking each set from the area influenced by an individual crop row (Figures 2.6a; 2.7a). Cores should be spaced along the full length of the paddock (Figures 2.6b; 2.7b).

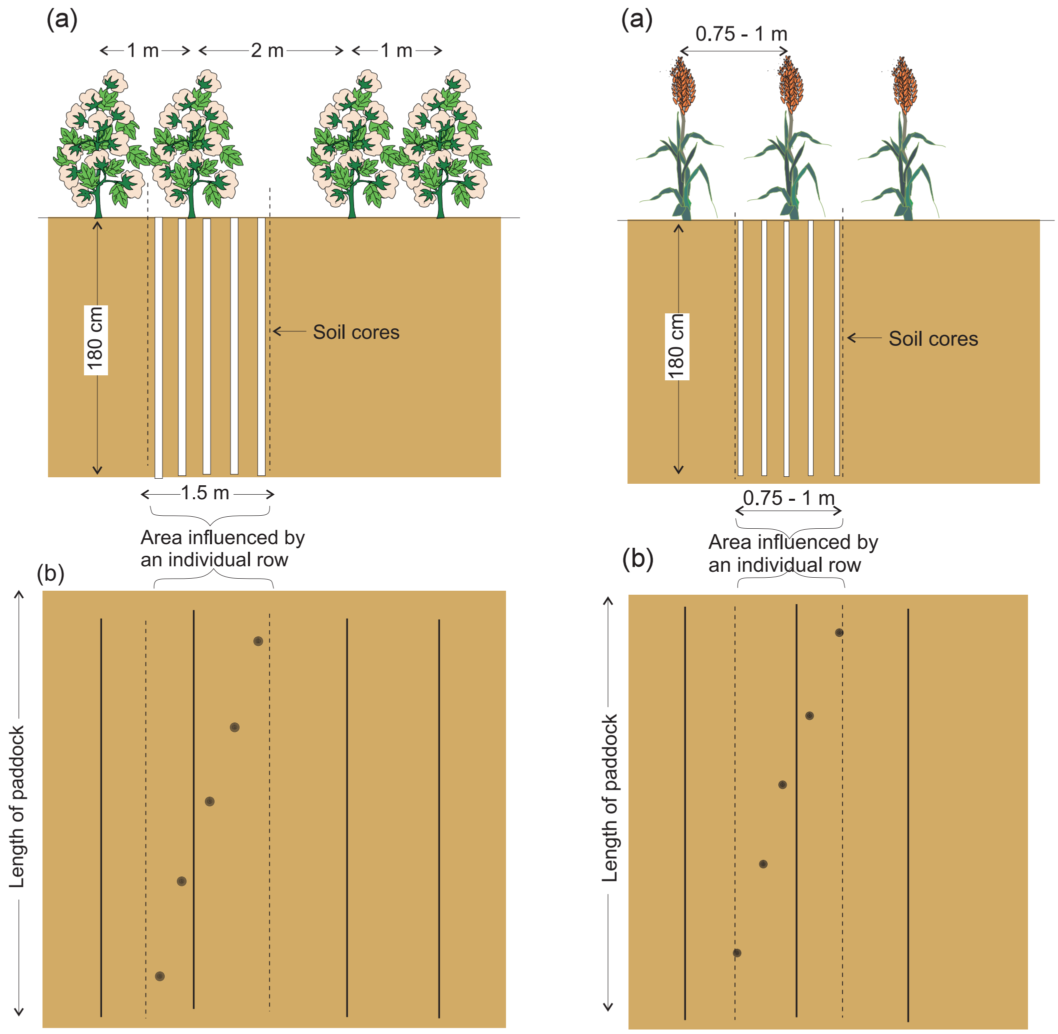


Figure 2.6 (left): (a) Vertical section of the soil under single-skip-row cotton showing the location of cores needed to capture variation across a row. (b) Plan view showing the location of individual cores in relation to the row of cotton and the length of the paddock.
Figure 2.7 (right): (a) Vertical section of the soil under an evenly spaced sorghum crop. (b) Plan view for a row of sorghum along the length of the paddock.

If the crop has been harvested and slashed, and it is easy to move between rows, samples should be taken adjacent to a number of rows (Figure 2.8). This will minimise the risk of bias caused by, for example, uneven application of nitrogen along one row.

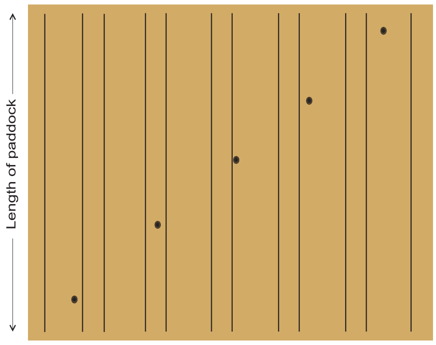


Figure 2.8. Plan view of paddock showing the location of sampling points when it is possible to move across rows after harvest or slashing. Note that cores are still taken in set locations relevant to the nearest row.

Row crops with nitrogen applied – during or after a season of below average crop production

In a poor year, the nitrogen may not have moved far from the initial application band (Figure 2.9). A small number of inappropriately placed cores may miss the narrow band of residual nitrogen altogether, or hit it too frequently.

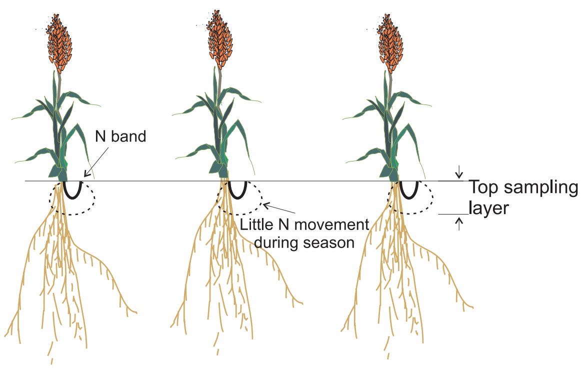


Figure 2.9. Likely movement of nitrate N from banded fertiliser under a sorghum crop after limited in-crop rainfall.

Sampling strategy

Sample as for a good season but increase the sampling intensity in the top 15 cm (or appropriate depth) to cover the expected increased variability in this zone (Figures 2.10 and 2.11). Take soil to the appropriate depth from the total width of the row zone using a narrow spade. Mix the sample thoroughly before sub-sampling.

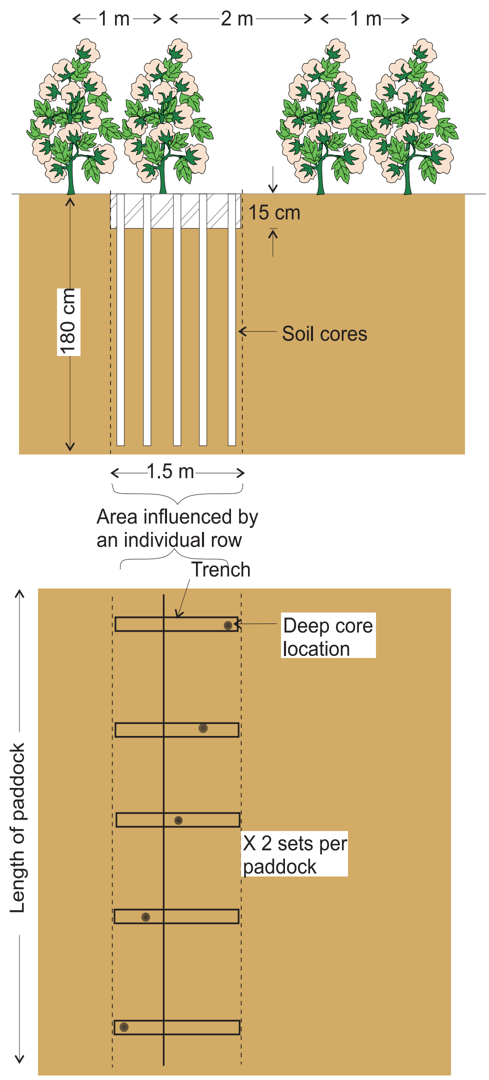


Figure 2.10(a). Vertical section of the soil profile under single-skip-row cotton showing additional near-surface sampling to capture concentrated residual N. (b) Plan view showing the location of individual cores and surface samples in relation to the row of cotton and the length of the paddock.

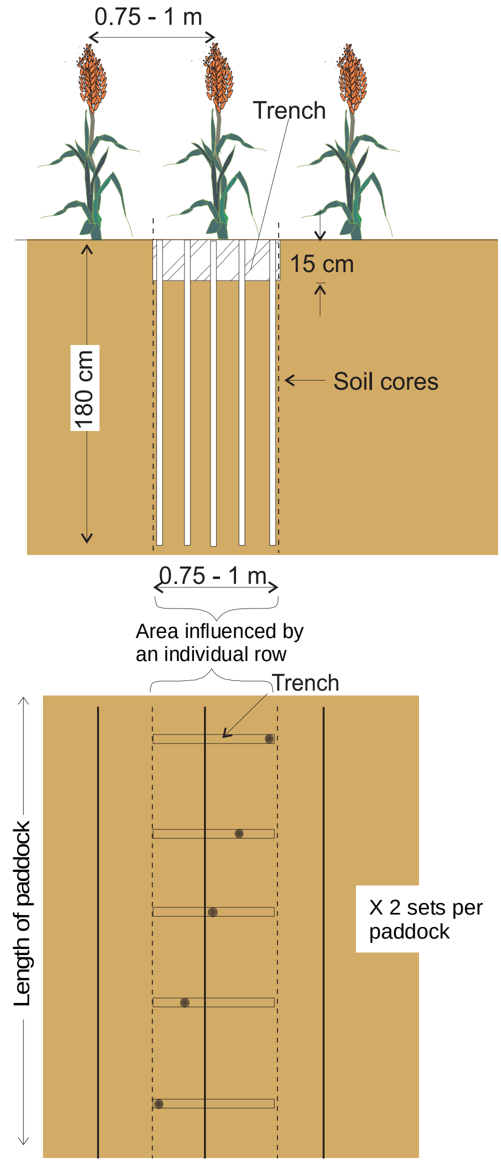


Figure 2.11(a). Vertical section of the soil profile under an evenly-spaced sorghum row showing near-surface sampling to capture concentrated residual nitrate N.
(b) Plan view showing the location of individual cores and surface samples in relation to the row and the length of the paddock.

Use a spade to take a trench surface sample across the width of the row zone—after a below-average cropping season when banded fertiliser N may not have moved far.

Row crops — no nitrogen applied

Although no nitrogen has been applied, the levels of nitrogen and water are still likely to vary between the row and inter-row areas due to variation in pre-plant levels and extraction patterns during the season. Choose the sampling strategy described above for *the season of at least average production.*

Winter cereals and other sward crops — with and without nitrogen applied

Because nitrogen application bands are closer in winter cereals, early rains should disperse nitrogen applied pre-season through the soil (Fig. 2.12). This, along with in-season rainfall and uptake of water and nitrogen by the crop, makes it unnecessary to sample particular points in the row zone. Sample as for a fallow. Use the same system for crops grown without applied nitrogen or if nitrogen has been broadcast.

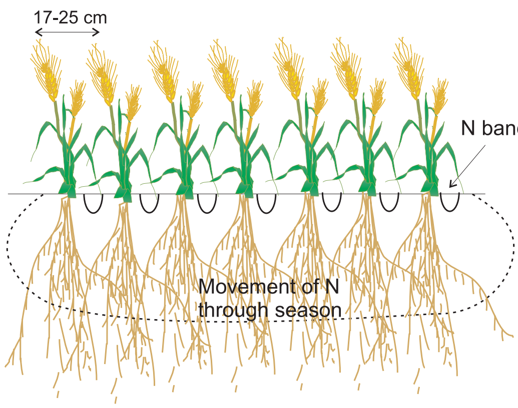


Figure 2.12. Banded application of fertilizer on a sward crop such as wheat. As even limited planting and in-crop rainfall will usually merge adjacent bands, no special coring in relation to location of the bands is needed.

Depth of sampling

How deep to sample will depend on the reasons for sampling, the soil type and the crop to be grown. If information is needed on the total amount of stored water and nitrogen available to a crop, depth will be different to when diagnosing only for phosphate fertiliser needs.

To relate supplies of water and nitrogen to potential yield, sampling should extend to the potential depth of rooting of the crop. Even though water and nitrogen in the deeper layers of the soil profile may not be used in all years, these resources are potentially available. Unfortunately, because of the high cost of nutrient analysis, sampling is not always done to potential rooting depth. The information presented in Table 2.2 and Figure 2.13, particularly in relation to nitrogen, is a compromise between the ideal and the practical, with the understanding that there is a good chance that some resources available to a crop will not be detected.

Queensland recommendations for sampling depth are shown in Figure 2.13. New South Wales recommendations vary slightly for surface sampling (Table 2.2.)

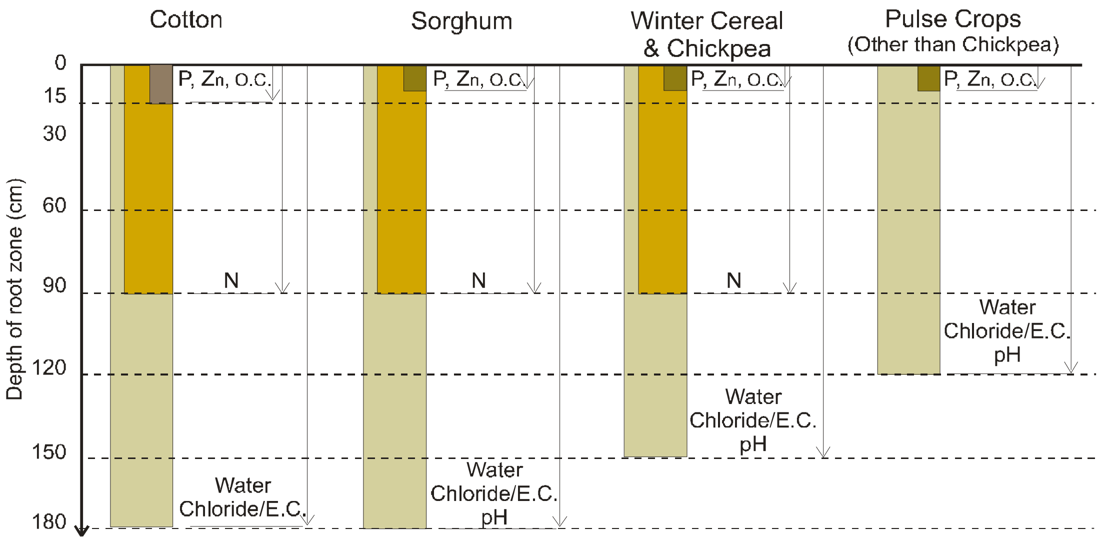


Figure 2.13. Depth of sampling for crops with different rooting depth

Table 2.2. Depth of sampling for crops with different rooting depth (Qld and NSW)

Crop	Depth of rooting (cm)	Water, chloride, E.C., pH	Nitrogen	P, Zn, Organic carbon Qld	NSW
Cotton	180	180	90	15	30
Sorghum	180	180	90	10	15
Winter cereal. chickpea	150	150	90	10	15
Other pulse crops	120	120		10	
Pastures	150	150	150	10	10

Nitrogen bulges

Nitrate nitrogen is soluble in water, and is carried down through the soil with each wetting front. This nitrogen can accumulate, as a bulge, at a depth where it may be available to crops with a deeper rooting habit.

Knowing where the bulge is located may save on fertiliser application and may influence crop choice.

Options could be:

- to grow a deeper rooted crop able to access the nitrogen (for example, wheat may be able to access deep N at flowering)
- not to grow a certain crop because of the adverse effects of too much nitrogen at a particular stage of its growth (for example, in cotton, the combination of deep N and a wet finish to the season may encourage excess bush growth, causing problems with pests and harvest).

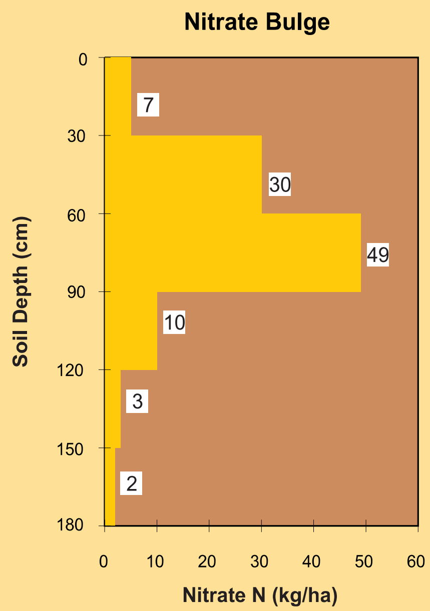


Figure 2.14. A nitrogen bulge at depth.

When the results will be used for crop simulation, sampling must be deep enough to account for all the critical resources that are potentially available to the crop. In these cases, the sampling depth for nitrogen should be increased to the potential rooting depth of the crop and for organic carbon to 60 cm.

Although the frequency, depth and number of layers of sampling may be reduced as experience and knowledge increases, sampling for the first time should be to full depth of rooting. This enables assessment of the total soil profile for nitrogen bulges (Figure 2.14.), salt concentration, pH and other factors that influence the interaction of plant and soil. This may assist in future decisions on sampling depth and interpretation of sampling results and crop performance.

Depth of sampling

The depth to which to sample depends on the soil type, the crop being grown and the reason for sampling:

- for **water** – sample to the potential rooting depth.
- for **nitrogen** – most nitrogen is found in the top 90 cm. When more nitrogen has been applied than the crop can use, it may accumulate at depth as a ‘bulge’. Initial sampling to rooting depth will show this, and will also allow analysis for pH and salt. Sample to rooting depth if data is to be used in simulation.
- for **immobile nutrients** (P, Zn) – sample surface only.

With experience, sampling depth may be modified to suit the local conditions.

Sampling intervals

Before a sampling program is started, the sampling intervals (the lengths into which the core is to be cut for processing) must be decided.

The intervals commonly used for crops of the region are shown in Figure 2.15 while Figure 2.16 compares the information available as the sampling interval increases.

The benefits of more specific information through the use of shorter intervals must be balanced against the extra cost.

In soils with clearly defined horizons, such as duplex soils, the interval should be tailored to the natural boundaries between soil horizons.

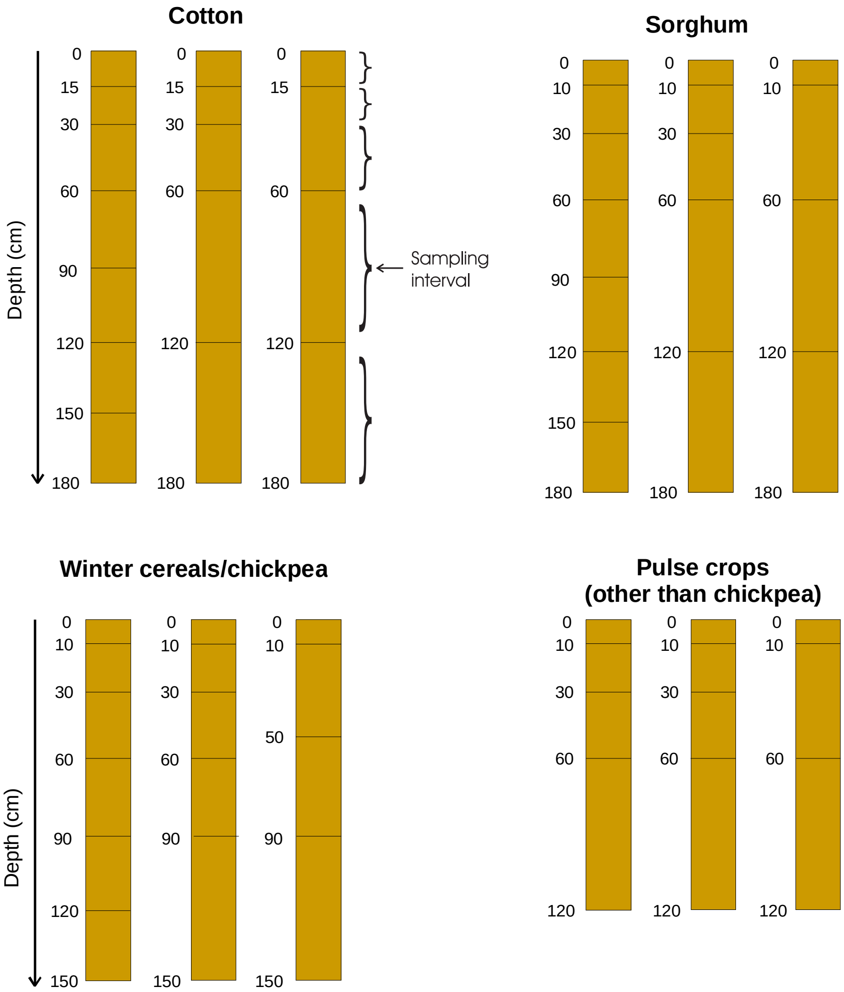


Figure 2.15. Depth interval combinations for measurement of water content depending on the detail required. For cereals and cotton, nitrate N would be measured in all layers to 90 cm or the nearest deeper layer.

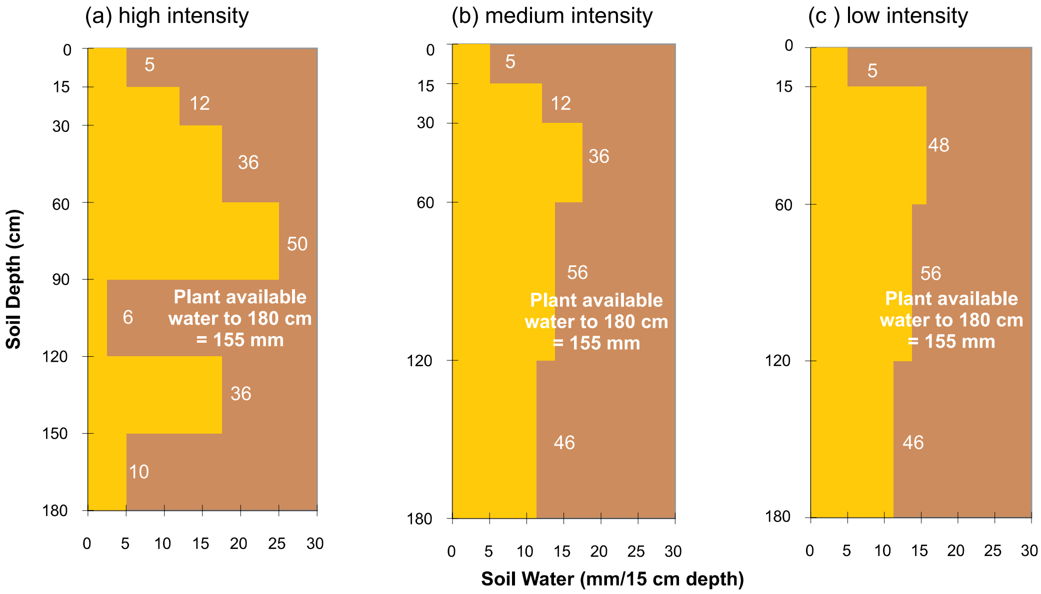
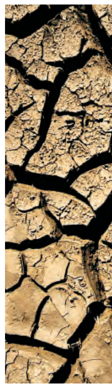


Figure 2.16. Sampling for soil water using the three sets of recommended depth intervals for cotton described in Figure 2.15. Longer sampling intervals (b, c) may miss important detail such as the dry layer between 90 and 120 cm (a).



Surface samples

When monitoring the immobile nutrients, phosphorus and zinc, analyses are made on surface samples of 10 or 15 cm length depending on the crop. Sampling protocols (based on local calibration) developed for particular crops in Queensland and New South Wales are shown in Table 2.2. Fertiliser recommendations from the major fertiliser companies are based on these protocols.

If levels of P and Zn in a paddock are to be monitored over a number of seasons in crops with different recommended surface sample intervals, it is possible to standardise on a particular interval to allow comparisons. However, it will be difficult to make fertiliser recommendations in the years where the non-standard interval is used.

Intervals for simulation models

While interval length is not critical in simulation, intervals used to describe the water and nutrient status should be the same for both measurements, and sampling should be deep enough to account for all resources which the plant may use.

Sampling intervals

- Choose interval lengths according to the purpose of sampling.
- Conform with local protocols and conventions where possible.
- Longer sampling intervals give less precise detail about where the water and nutrients are located.
- Standardising on common intervals will aid longer-term interpretation.

Gathering field information

Push probing

The push probe, a steel rod (80-150 cm in length) with a tapered cone welded to its tip, is pushed into the soil by hand.

The presence of water is gauged by the operator through the feel *of the probe as it moves through the soil. The soil is generally described as* being wet to a depth of …… cm. *Other probe designs include the use of a spring and pointer system to provide a visual indication of change in soil resistance and hence a possible change in soil moisture (Fawcett 1969; Fawcett* et al. *1974).*

Taking a sample

Hand coring

The hand sampling kit includes a driver, soil tubes and a jack for extracting the tubes. The driver has a hardwood head and is of sufficient weight (9-12 kg) to drive a 38 mm diameter tube (1.6 mm wall thickness) to a depth of 90 cm. This should take about 15 blows in moist soil.

If sampling below this depth, insert a 1.8 m tube of a smaller diameter (generally 32 mm) down the existing hole and drive further. Tube design is similar for both hand and hydraulic sampling systems.

Use the driver to insert a tube. The wooden head minimises damage to the tube collar.

Insert a smaller diameter tube down the existing hole to sample to a greater depth.

Use the jack to remove the tube. Locate the jack so that the chain is vertically above the tube to maximise leverage and minimise the risk of bending the tube.

Mechanical coring

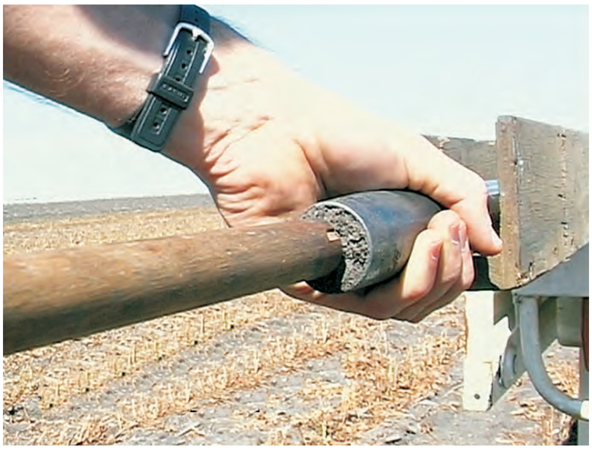
A hydraulic sampler attached to a tractor, road vehicle or trailer enables quick and efficient sampling.

Units are driven by a hydraulic pump, powered from the vehicle PTO or a 12 volt electric motor.
Tubes of 32, 38 or 50 mm diameter can be inserted to a depth of 1.5–1.8 m.
Extra loading of the vehicle may be needed when inserting large diameter tubes while a jack hammer may be needed in hard or rocky soils.

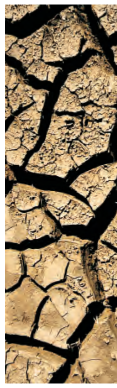
Controlling insertion using a remote switch. The coring tube is attached to the ram by a pin for quick attachment and removal

Processing samples in the field

1. Removing core from sampling tube



Use a push rod (25 mm wooden dowel) to remove the core from the tube.
The core is pushed into a cutting tray for partitioning.



A cutting tray may be made from wood, or 75 mm diameter PVC or steel pipe cut in half length-wise; it is marked with the appropriate depth intervals.

2. Dividing the core into sampling intervals

Cutting the core into sampling depth intervals.

3. Placing cores into mixing containers and sub-sampling

After the core is cut into the appropriate sample lengths, the individual sections are placed in separate storage containers (one for each depth interval) until all cores in the particular sampling run have been completed.

The sample is then broken up, mixed, sub-sampled and bagged for transport and processing. The number of sub-samples required per depth interval will depend on which analyses are required and the specifications of the lab. It is common to take two sub-samples, one for soil water estimation and the other for nutrient analysis.

Place soil from each sampling interval (bulked from all cores taken) into a separate container until the sampling run has been completed. Keep containers shaded during sampling to minimise evaporation.

Break up the soil into small evenly-sized fragments to allow thorough mixing.

Mix and sub-sample

by either (a) splitting the sample by pouring evenly into two containers.

or (b) using a splitting board. Mix the sample into 6 equal-sized heaps. Bulk alternate heaps and bag them.

4. Storing samples

Options for storing

1. Disposable paper bags reduce the time spent in sample preparation, but samples for water determination must be weighed immediately after bagging. Samples may be dried without being removed from the bag (and without the need to open the bag). If bags are used for moisture determination only, they can be discarded after dry weighing.

2. Plastic bags are essential when weighing is delayed or when samples may be contaminated by other samples or the environment. They are also used when samples are analysed wet. The use of plastic bags is more labour intensive as they have to be opened before drying (or the samples have to be removed from the bags and placed on trays). Samples being dried slowly in plastic bags (e.g. at 40^{0} C for nitrate analysis) may continue to incubate and release additional nitrate nitrogen.

3. Sealable tins or plastic bottles are useful for storing samples for wet analysis but, like plastic bags, have some drawbacks. Lids have to be removed before drying and tins need to be cleaned and lids replaced after drying. If the weights of the tins vary, the individual tare weights have to be recorded for calculation of moisture content.

Sample Storage

Commercial laboratories have requirements for the storage of samples and procedures for speedy dispatch; they often provide standard sample bags.

If you are doing your own analysis (for example for water content), store samples in sealable plastic bags, tins (tobacco or paint) or wet-strength paper bags. Paper bags must be weighed immediately in the field before water loss, but their use reduces drying times and speeds up handling of samples.

Sampling Hygiene

During all sampling operations, but particularly when sampling for trace elements, hygiene is of the utmost importance. Common sources of contamination include cigarette ash or galvanising from power lines or bucket handles when sampling for zinc. Coring tubes should be lubricated with silicone-based oils when sampling for organic carbon.

5. Weighing samples in the field

If paper bags are used for storing soil water samples, weigh them immediately after bagging.

If the samples are placed in sealed containers, they may be weighed in the field or the lab.

A battery-powered electronic balance used in the field for weighing samples for soil water determination.
The minimum accuracy required for weighing soil samples of more than 200 g is a resolution of one gram.

How much soil is required for analysis?

Sub-sampling in the field reduces the quantity of soil taken to the laboratory and the associated costs of handling, drying and grinding. Follow the recommendations from the analytical laboratory on procedures and sample size. A typical sample size for water and nutrients is 300 g.

6. Recording data in the field

Commercial analysis providers generally supply data sheets to record the sample information.

If these are not available, start your own system of recording the sampling details, including farmer and paddock identity, date, and depth and timing of sampling.

Information on the depth of observed rooting, incidence of dry layers and details of any soil changes since previous sampling may help later in interpreting data.

Record sampling information and observations on the soil condition at the time of sampling.

7. Transporting samples

Samples must be handled carefully between the field and analytical laboratory so that the results of analyses are not jeopardised.

If the soil is to be analysed for nitrate N or ammonium N, poor treatment of the samples can cause serious errors. Problems occur under conditions that allow chemical change to continue in the sample.

Samples should be stored in a cool box and transported quickly to the lab for immediate analysis. If this is not possible, strategies include:

- placing samples into prepared bottles of extractant (potassium chloride) in the field.

or for nitrate N analysis

- air drying samples in the field on a tarpaulin or black plastic sheet
- speedy transport of samples back to base for oven drying and storage. Refrigerate (or freeze) if a wet sample is needed.
- storing samples in a local cold room, e.g. at a hotel, until return to base. Some mineralisation may continue.

Options for handling and processing samples for particular analyses are described in more detail in Table 2.4.

Keep samples cool during transport.

Drying samples in the sun — useful if drying facilities cannot be reached for several days.

Beware of contamination from dust, fertiliser residues or galvanised tools and buckets.

Post-field processing of the samples

– for commercial analysis

If samples are being sent to a commercial lab for analysis, follow the stated requirements. This will normally include placing the sample in a standard container and rapid transport of the wet sample to the lab.

Immediate delivery is important, especially if the soil is to be analysed for ammonium nitrogen or nitrate nitrogen, as nitrification and mineralisation may continue during storage under warm conditions.

– prepared by the farmer or consultant

Water

The most common determination done by the consultant or farmer is for water. Samples need to be weighed wet, dried to a constant weight (by air drying or in a conventional or microwave oven) and the weight recorded. The type of container in which the sample is stored will affect the way that the samples are handled (Table 2.3).

Table 2.3. Temperature and duration of drying for soil water determination

Container	Temp. °C	Drying time	Comments
paper bag	105°C	1-2 days	– quick drying – less sample preparation • don't need to open bags for effective drying • can discard sample and bag after drying • use dried bag as standard tare weight
paper bag	microwave oven	30-40 mins, check wts.*	– quick drying – less sample preparation – don't need to open bags for effective drying – can discard sample and bag after drying – limited oven space (*NB: a container of water must be placed with the samples to protect the oven element*)
plastic bag	105°C	2 days, check wts.*	– slower drying than paper bags – increased sample preparation • open bags before placing in oven (or put sample on tray) NB. First confirm bags will not melt!
sealed tin or bottle	105°C	1-2 days, check wts.*	– quick drying – increased sample preparation • open tins before drying • empty and clean tins after use • record of tin tare weights needed for multiple use

* Check wts. : Check weight during drying until constant.

Nutrients

Generally, samples for nutrient analysis are forwarded to the lab promptly after sampling, and the consultant or farmer is not concerned with preparing samples for analysis.

The following section is primarily designed for use by those who have access to an in-house lab and have to prepare the samples.

Table 2.4. Temperature and duration of drying for soil chemical analyses

Nutrient	Handling of soil	Container	Drying temp.	Drying time	Comments
Nitrate N (NO_3)[a]	placed in extractant in field	glass or plastic bottle			logistics difficult
	returned to lab for immediate extraction	plastic bag			good results, but difficult with many samples
	returned to lab for drying	paper bag	air dry or 40°C	2 days, check wts.	efficient drying and sample handling
		plastic bag	air dry or 40°C	2-4 days, check wts.	slow drying, inefficient sample handling
		tin	air dry or 40°C	2 days, check wts.	efficient drying, increased sample preparation open tins before drying, empty after drying.
	refrigerate	plastic bag			analyse within 1-2 days
	freeze	plastic bag			long-term storage
Ammonium N (NH_4)[b]	placed in extractant in field	glass or plastic bottle			logistics difficult
	returned to lab for immediate extraction	plastic bag			good results, but difficult with many samples
Phosphorus, Zinc, Organic C., pH, EC, Chloride	drying	paper bag	air dry or 40°C	2 days, check wts.	
		plastic bag	air dry or 40°C	2-4 days, check wts.	
		aluminium container	air dry or 40°C	2 days, check wts.	

Notes

[a]Nitrate N. - some variation in results is likely between the various methods of preparation; placing samples in extractant solution in field or immediate extraction on return to lab will give the best results. Balance the costs of preparation and timeliness against the required level of accuracy.

[b]Ammonium N. - do not use dried samples for ammonium analysis. Do not store moist samples because ammonium N. may continue to accumulate during storage

Drying samples in a microwave oven

A small number of samples can be dried quickly in a domestic microwave oven. Samples can either be laid out in a microwave-proof dish or, if stored in paper bags, placed directly into the oven.

The number of samples that can be dried at any one time depends on the type of container being used, the size of the samples and the physical size and power rating of the microwave. Five or six samples can often be dried at the same time if in paper bags.

Drying time is dependent on the size of the samples, the initial moisture content and the power of the oven, but should be no more than 30-40 minutes per set.

Protect the element of the oven by including a (non-metallic) container of water with the samples. This should be re-filled with cool water when the water begins to boil.

After 15–20 minutes, the samples should be check weighed. This should then be repeated every five minutes until the samples reach a constant weight.

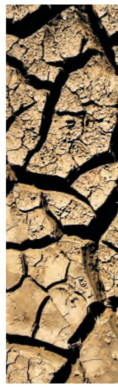
Do not dry samples that contain iron-stone or manganese nodules in a micro-wave oven.

Drying for other analyses

Although the microwave oven is normally used to dry samples for the determination of soil water, we have also used it for preparing samples for nitrate N analysis (the basis of the procedure outlined on the following page). Drying temperatures are much higher than those generally recommended, but no adverse effect has been noted in the analysis results. However, it is not recommended for samples for the analysis of ammonium N, phosphorus, zinc or other trace elements.

Placing samples in a domestic microwave for drying. Note the bowl of water— essential to avoid damage to the element of the oven.

Important note:
Always consult the manager of the kitchen before using the household microwave oven.



A suggested sampling procedure

This procedure is used for the on-farm monitoring of water and nitrate N by APSRU. It has given good speed and quality control where many samples are collected daily. It is not recommended for sampling ammonium N, P or trace elements, or if small changes in water or nitrate N are being sought (e.g. in small-plot experimentation).

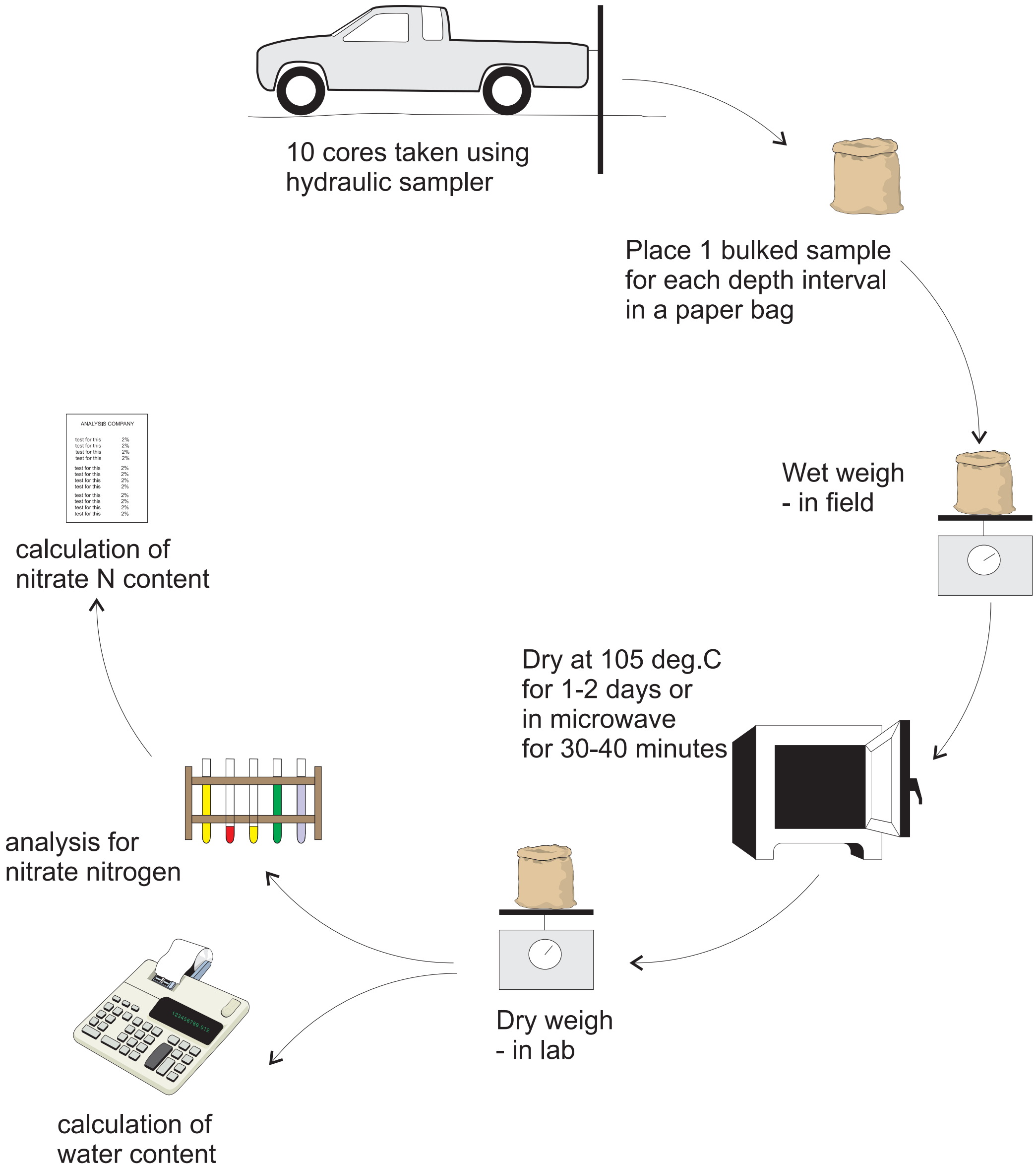


Figure 2.17. A sequence of operations for on-farm monitoring of soil water and nitrate.

Calculating and interpreting the results of soil monitoring

The resulting data for soil water (wet and dry soil weights) or nitrate nitrogen (in mg/kg) must now be converted to useable information.

Module 3 of the manual describes the calculation and use of these data:

- to estimate yield prospects for the coming season based on soil water and expected rainfall.
- to look at the efficiency of storage of water and its use by a subsequent crop.
- to estimate the nitrogen requirements of a crop based on crop yield and available nitrate nitrogen.

APSoil

APSoil is a computer program designed to convert field-sampling information into a form suitable for interpretation by the consultant or farmer.

APSoil combines the analytical results received from the lab with the characteristics for the particular soil type (as shown in Module 5), and presents the results in graphical or tabular form.

Examples of output from APSoil are shown in Module 1.

Additional information on APSoil is available in Appendix 3.

Operational hints and techniques

Careful storage and regular maintenance of equipment will minimise downtime during sampling. When things go wrong, make sure you have the skills and equipment to solve the problem. During a prolonged sampling operation, spare coring tubes reduce time wasted cleaning or repairing blocked tubes.

In-field maintenance of equipment

Tube lubrication equipment

Mould oil	To lubricate internal and external surfaces of soil-coring tubes. Can contaminate samples for organic carbon.
Silicone-based oil	Lubrication as above, but without risk of contamination of samples for organic carbon.
Waste rags	To apply lubricant to tube.
Oil bath	To lubricate internal and external surfaces of soil tube.
Pull-through	Routine lubrication of inside of soil tube.

Use an oil bath to lubricate a tube inside and outside. Excess oil left on tube may contaminate the soil sample.

A pull-through made of an oily rag attached to a weight with a rope will lubricate the inside of the tube without leaving excess oil.

Tube maintenance

Oil outside of tube	Frequency depends on soil type and moisture conditions (more frequent in very wet or very dry soil). Use waste rag to apply oil.
Oil inside of tube	Frequency depends on soil type and moisture conditions; a pull-through lubricates the tube without leaving excess oil.
Check for internal obstructions	Use half-round file to remove burred tube edges and clean up the cutting tip Use wire brush and pull-through to remove soil sticking to inside of tube.

When things go wrong!

Equipment for clearing tube blockages and repairing tube tips

Wood auger	To remove compacted soil from a blocked tube
Round wire brush	To remove soil sticking to inside of tube.
Extension handle	Threaded to attach auger or brush
Rubber mallet	To tap tube to dislodge a jammed core.
Wooden block	Strike inverted tube onto block to dislodge jammed core.
Half-round file	To sharpen tip damaged by rocks.
Tip-forming die	To reshape or to change offset of tip
Drift	To reshape inside of damaged tip

Left: Tools for removing blockages.
Middle: Die to reshape external dimensions of tip.
Right: Drift to reshape internal dimensions of tip.

Problem: coring tube will not push into the soil

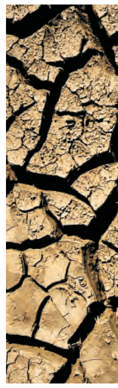
Reason	Solution
Soil too dry	Re-oil outside of tube to reduce friction Use a smaller diameter coring tube Make sure tube is directly under sampling rig to maximise weight advantage of vehicle Add weight to the tray of the vehicle, for example a 200 litre drum of water.
Soil too wet	Re-oil outside of tube to reduce friction.
Excessive tip offset	Reduce offset so that less soil is displaced by the cutting tip.

Problem: Core jams in the tube during sampling

Reason	Solution
Tube rusty	Store tubes in purpose-built diesel oil bath, or oil tubes before storing. Oil tubes both internally and externally before use. Polish tube both internally and externally with steel wool or wire brush.
Insufficient tip off-set (taper)	Re-heat tube tip and increase offset by hammering into die (where formed tip being used) or replace current turned tip with one that has more offset. Oil tip after re-setting.
Soil too wet	Wait until soil surface dries before sampling. Sample in two pushes, the first to 20-30 cm and the second deeper, using the same core hole. Oil tubes both internally and externally prior to use.
Loose, dry soil surface	Scrape dry layer from soil surface prior to sampling. Take a hand sample of loose dry surface soil.

Problem: core jams while being removed from tube

Reason	Solution
Obstruction/ loose soil in tube	Check interior of tube for obstructions and file clear; generally associated with a dent or a burred edge around the top of the tube. If the core is jammed, do not force with push rod; auger out or invert tube, tap top of tube against wooden block and allow loose soil and core to slide out.



Removing a jammed core

Most cores jam when the surface soil is very wet. Blockages occur in the first 20-30 cm of the tube—after this is removed, cleaning generally progresses quickly.

Remove the bulk of jammed soil with a wood-auger (25 mm diameter) screwed into the steel extension handle.

Use a knife to scrape remaining soil adhering to the inside wall of the tube.

Tap the tube with a rubber mallet to dislodge a core which has jammed further up the tube. Do not use a steel hammer which may dent the tube.

Removing a jammed core (continued)

Invert the tube and strike it down onto the wooden block

Use a wooden push rod (25 mm dowel) to remove dislodged material from the tube. If a gentle force on the rod fails to remove the core, assume that it is still jammed and try another method, such as the wood auger. Forcing the rod may result in a more serious jam.

Thoroughly clean the inside walls with a steel boiler brush dipped in mould oil. All soil must be scoured from the tube wall to avoid further blockages.

The pull-through will remove soil dislodged by the wire brush and apply oil to the internal wall of the tube.

Problem: Core slides out the bottom of tube as it is extracted from soil

Reason	Solution
Suction caused by the seal between the wall of the core hole and the tube as it is withdrawn	Drill 2-3 mm hole in face of tube tip to allow air pressure to equalise as tube is withdrawn (see tube fabrication in Appendix 1). Extract tube slowly from the ground to allow time for pressure to equalise. 
The weight of the column of soil causes it to slide back through the cutting tip	Slide 2 or 3 paper clips over the cutting edge of the tip to roughen core surface as it moves through cutting tip during insertion. If the problem persists in particular soils or moisture conditions, increase offset on tube tip.

A core sliding back into the core hole as the tube is removed from the soil .

Paper clips will roughen the surface of the core as the tube is inserted. This increases friction between soil and tube tip and may also allow equalisation of air pressure, stopping cores from sliding back during extraction.

3. Calculating water and N

Calculating water and nitrogen shows how data obtained using techniques described in Module 2 are turned into information for crop management. The data can be used to calculate the requirements of a crop for water and nitrogen, or used as input for simulation models such as APSIM.

Module 3 contains the following sections:

Soil water calculations

1. Checking *Past paddock performance* to convert rainfall to yield, using an estimate of fallow efficiency.
2. Estimating *Yield prospects for the coming season* based on the water available in the soil and forecasts of rainfall.
3. Checking *What happened in the past season* to determine actual water use efficiency.
4. Checking *What happened in the fallow* to determine actual fallow efficiency.

Nitrogen calculations

5. Calculating *Crop nitrogen requirements*.
6. Calculating *Available soil nitrogen and fertiliser requirements*.
7. 'Ready reckoner' tables of nitrogen requirements based on grain yield and protein percentage.

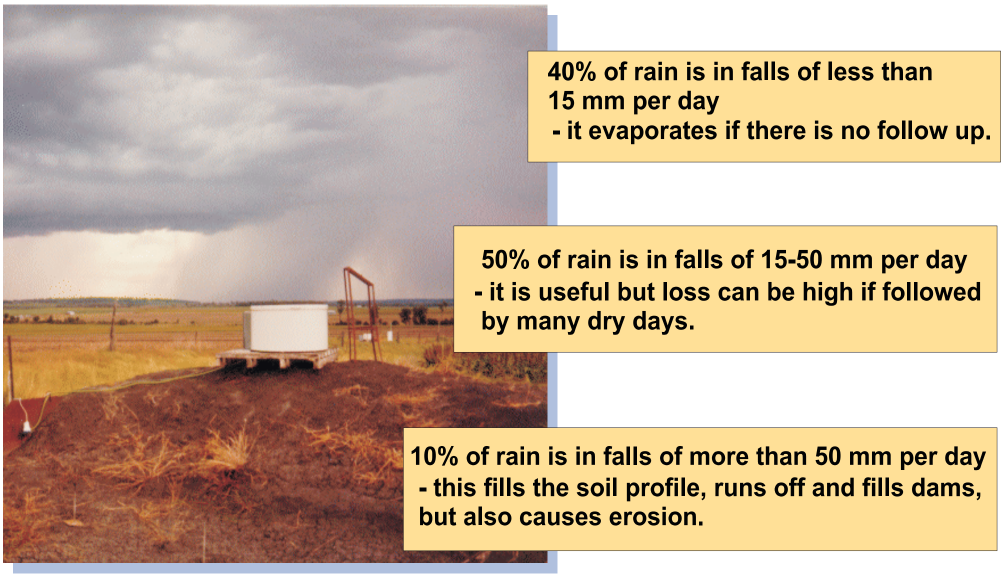


Figure 3.1. How useful is your rain? – its effectiveness in the northern cropping zone depends on the intensity, quantity and duration of rainfall events.

Soil water calculations

1. Past paddock performance – converting rainfall to yield using an estimate of fallow efficiency

An estimate of the proportion of rainfall stored during the fallow (*fallow efficiency*), plus the rain that falls during crop growth, can be related to crop yield. The efficiency of conversion of water to yield is called *Water Use Efficiency* (WUE). Although a more accurate indication of WUE is obtained when fallow water is measured (by probing or coring), WUE based on an estimate of fallow efficiency will provide a useful rule of thumb for assessing future yield potential. Sections 2, 3 and 4 provide the tools necessary to determine WUE based on in-field measurements.

In Section 1, we will use Calculation Sheet: Water 1 to calculate:

1.1 Rainfall stored during the fallow

1.2 Water available from fallowing and in-crop rainfall

1.3 Yield produced from each mm of water (Water Use Efficiency)

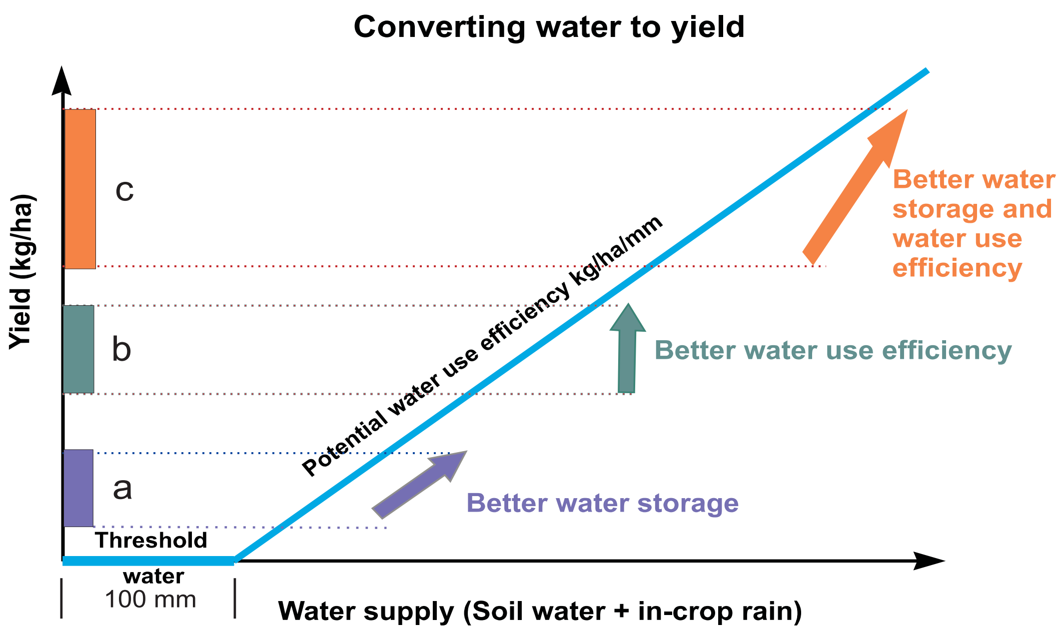


Figure 3.2. Diagram of the Water Use Efficiency model showing a general relationship between rainfall and yield. (a) shows yield increases associated with better water storage, (b) when the same amount of water is converted to more yield—higher water use efficiency, and (c) where both water storage and water use efficiency are increased. Note the threshold of 100 mm to account for run-off, evaporation and growth of plant before grain production (after French and Schulz 1984).

1.1. Rainfall stored during the fallow

Typical fallows in southern Queensland and northern NSW lose 60–80% of rainfall as run-off and evaporation, leaving 20-40% water in the soil available for crop growth (Figures 3.1 and 3.3, Table 3.1).

The proportion of rainfall stored varies each season, but tends to be higher in the eastern areas than the drier western districts.

Good management practices, such as maintaining stubble and controlling weeds early, can increase fallow moisture storage (Figure 3.3).

Table 3.1. The percentage of rain stored during a typical fallow (Freebairn 1992)

Region	% of rain stored		
	range	average	good
East[1]	0–40	20	25
West[2]	0–40	17	22

[1] Darling Downs and east of Newell/ Leichhardt Highways
[2] Western Downs, Maranoa

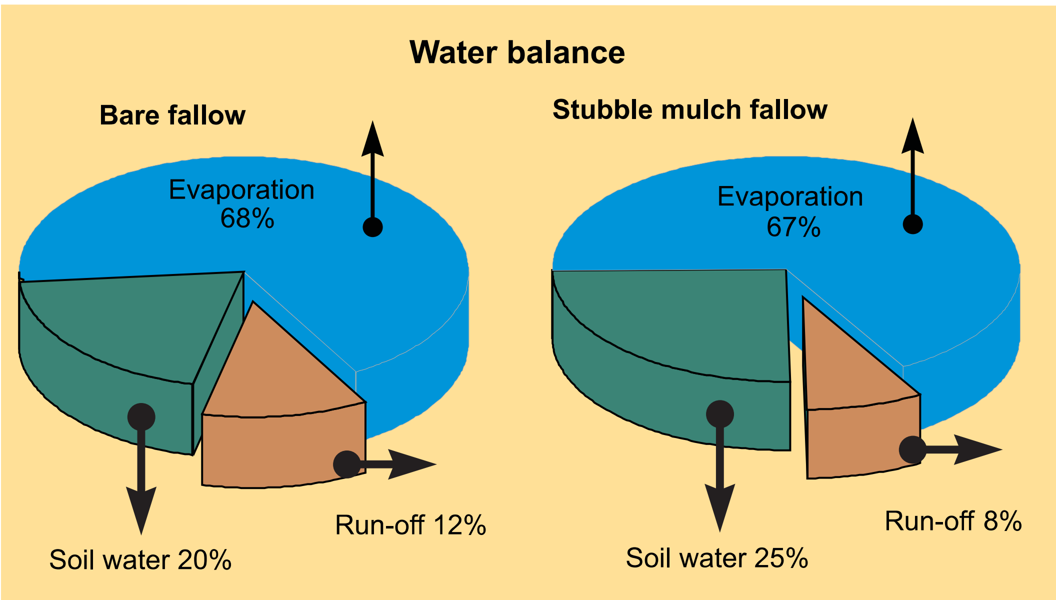


Figure 3.3. The effect of stubble cover on water storage on the eastern Darling Downs (Freebairn and Wockner 1996).

1.2. Water available from fallowing and in-crop rainfall

The total water supply for the crop is the fallow water storage plus any in-crop rain falling between planting and physiological maturity, i.e. when the crop *turns*—rainfall after this is of little benefit to the crop.

1.3. Yield produced from each mm of water (WUE)

The performance of a crop can be described in terms of kilograms of yield for each millimetre of water supplied to the crop—its Water Use Efficiency (Figure 3.2 and 3.4).

Water Use Efficiency (WUE) is useful for comparing yields across paddocks and seasons. However, it is a simplified method that does not take into consideration the varying value of rainfall at different stages in the growth of a crop.

In one version of the calculation of WUE, the total water supply is reduced by a threshold value of 100 mm to account for:

- the water needed to grow crop biomass (leaves and stems) before it can start to produce grain
- in-crop run-off and evaporation
- water not used and left over at harvest.

While a threshold of water of 100 mm is suggested, other values can be used based on local experience. However, a consistent value must be used if comparisons are to be valid.

A low crop WUE suggests that yield has been reduced by either adverse weather, for example frost or the nature and timing of rain, or by adverse management, for example, low rates of nitrogen fertiliser or weeds, or a late sowing.

Farmers can increase crop yield and return by improving fallow management and the plant available water, and by improving in-crop management.

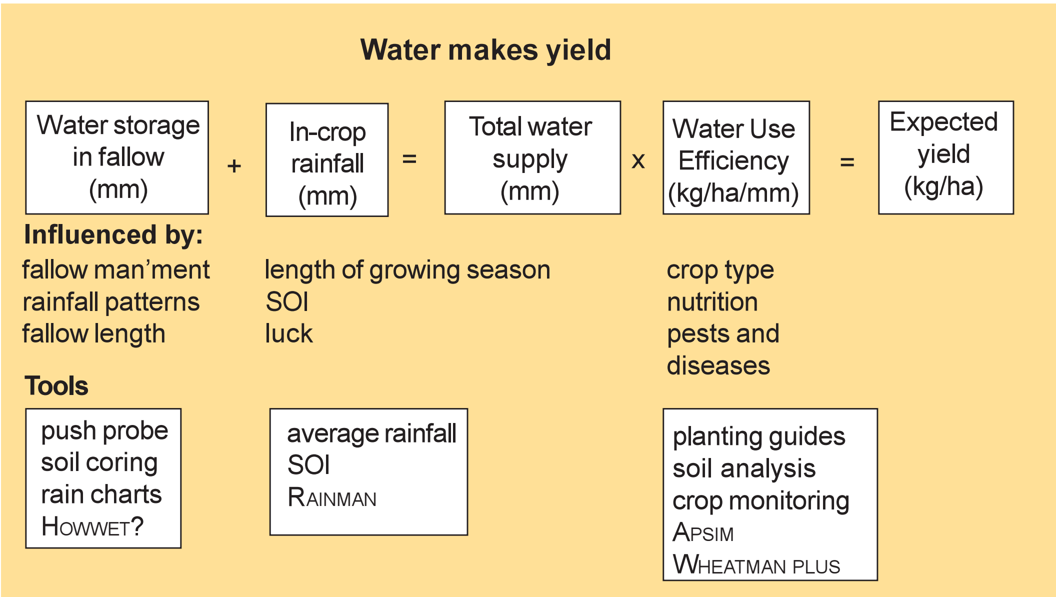


Figure 3.4. Converting water supply to yield and the tools available to improve management. (Freebairn and Wockner 1996)

Calculation Sheet: Water 1 – Past crop performance

Enter rainfall for your site (available from own records or Australian Rainman)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
wettest 20%*												
average												
driest 20%⁺												

* the wettest one season in five (20% of seasons) or *in 20% of years rainfall will exceed ……….?*

⁺ the driest one season in five (20% of seasons) or *in 80% of years rainfall will exceed ……….?*

1.1. Rainfall stored during fallow

When does the fallow normally start and finish?

Month the fallow starts: ____________________

Month the fallow ends: ____________________

Total fallow rainfall = ______ mm

Water stored over the fallow = Fallow rainfall x % of rainfall stored (suggest 20%, see Table 3.1)

= ______ mm x ______%

= ______ mm

1.2. Water supply from in-crop rainfall

When do you normally plant and harvest?

Month of planting: ____________________

Month of turning*: ____________________

Total in-crop rainfall = _____ mm

Total water supply = Water stored over fallow + in-crop rain

= _____ mm + _____ mm

= _____ mm

1.3. Yield produced from each mm of water (WUE)

Water use efficiency = $\frac{\text{Crop yield (kg/ha)}}{\text{(Total water supply – 100)}}$

= $\frac{\text{\_\_\_\_\_\_ kg/ha}}{\text{mm – 100}}$

= ____________ kg of yield/ha/mm of water

* Turning = physiological maturity — when the crop stops accumulating more yield.

Note: Proforma copies of calculation sheets are provided in Appendix 6.

2. Estimating yield prospects for this season using available soil water and rainfall forecasts

This section describes how to calculate the amount of water likely to be available for the crop about to be planted.

Water presently stored in the soil and the expected rainfall are used to estimate the total water available for the crop. An estimated Water Use Efficiency is then used to calculate yield.

In Section 2, we will calculate:

2.1 Available fallow moisture – using: **a)** results of push probing (see Calculation Sheet: Water 2); **b)** soil coring (see Calculation Sheet: Water 3); **c)** percentage of rainfall stored over fallow (see Calculation Sheet: Water 1; or HOWWET (see page 61).

2.2 Rainfall expected while the crop is growing.

2.3 Total water supply expected for the crop.

2.4 Yield expected this season.

(Use Calculation Sheet: Water 4 for 2.2, 2.3 and 2.4)

2.1. Estimating available moisture at planting

a)– using a push probe

The amount of water that has accumulated during a fallow is often determined by using a push probe to measure the depth of wet soil. However, how much of this water a crop can obtain depends on both the depth of wet soil and on the soil type.

Heavy clay soils usually hold more water than lighter, sandy soils (Table 3.2). Knowing the depth of wet soil and the amount of water that a soil can potentially hold enables the calculation of water available for plant growth (Calculation Sheet: Water 2). Probing can over-estimate available water as the soil, although moist, may not be fully wet. However, an experienced prober knows how the soil feels, i.e. the probe has a 'sucking' feel when withdrawn from 'fully wet' soil while it has granular feel when pushed into a 'half full' soil.

Calculation Sheet: Water 2 – Estimating available fallow moisture – using a push probe

Water available to plants = Depth of wet soil x water available/cm of wet soil* (see Table 3.2)

(Plant Available Water) = ______ cm x _______ mm of water/cm of soil depth

Available stored water = ________ mm of water

* this is described as the Plant Available Water Capacity. PAWC values for some soils are listed in Table 3.2

Examples using information in Table 3.2.

1. Cotton to be grown on a Waco soil; probing indicates 60 cm depth of moist soil.

Waco soil has 2.6 mm of available water for **each** centimetre of depth to 60 cm.

Thus total water available to 60 cm is 2.6 x 60 = 156 mm

2. Wheat to be grown on a Brigalow soil at Chinchilla; probing indicates 80 cm depth of moist soil.

Calculate to next deepest layer shown in Table 3.2; for **each** cm of soil to 90 cm, 1.6 mm of water is available to the crop.

Thus total water available to 80 cm is 1.6 x 80 = 128 mm

Table 3.2. Water available to plants when typical northern grain region soils are fully wet (at *drained upper limit* or Plant Available Water Capacity). To calculate total water, identify depth of wet soil (cm) and multiply this by the mm/cm in the relevant column (see Calculation sheet: Water 2, p.56)

Soil Type (location)	Crop	Water available to plants when the soil is fully wet (mm of water/cm of wet soil) to 30* cm	to 60 cm	to 90 cm	to 180 cm	
Darling Downs and east of Newell Highway						
Waco	cotton	2.7	2.6	2.5	1.9	
(Bongeen)	sorghum	2.3	2.2	1.9	1.5	
(black vertosol)	wheat	2.3	2.2	1.9	1.5	
Brigalow	cotton	2.0	1.9	1.8	1.3	
(Kupunn)	chickpea	1.8	1.7	1.7	1.1	
(grey clay)	wheat	1.7	1.6	1.5	1.1	
Brigalow	cotton	1.9	1.8	1.7	1.6	
(Croppa Creek)	wheat	1.8	1.8	1.7	1.6	
(grey clay)						
Belah	cotton	1.8	1.7	1.6	1.2	
(Moree)	wheat	1.2	1.4	1.4	1.1	
(grey clay)						
Cecilvale or Box	cotton	2.2	1.9	1.7	1.2	
(Dalby)	sorghum	1.6	1.5	1.4	1.0	
(grey clay)	barley	1.7	1.6	1.4	1.0	
Mywybilla	cotton	2.7	2.3	2.0	1.6	
(Bongeen)	sorghum	2.4	2.0	1.9	1.6	
(black vertosol)						
Western Downs, Maranoa and west of Newell H'way						
[1]grey clay (Nindigully)	1500 KPa	1.9	1.3	1.0	0.8	to150 cm
[1]grey clay-solodic (Nindigully)	1500 KPa	1.2	1.1	0.9	0.8	to120 cm
[1]red-brown earth-duplex (St George)	1500 KPa	1.1	1.0	0.9	0.9	to150 cm
Brigalow	wheat	1.9	1.7	1.6	1.1	
(Chinchilla)	cotton	2.1	2.1	2.0	1.5	
(grey clay)						

* water in the top 30 cm of the soil is prone to evaporation and may be lost to the crop soon after the rainfall event

[1]data provided by N Christodoulu, DPI, St George

NB: Determination of PAWC is detailed in Module 4, while Module 5 provides a more comprehensive range of PAWC data for the soils of the region.

or b) – using a soil corer

Moisture accumulated during the fallow is more accurately estimated using soil cores. Data from soil cores, along with information about the soil and crop type, give a much more reliable measure of available water than can be obtained with a push probe (Table 3.3 and Calculation Sheet: Water 3).

or c) – using percentage of rainfall stored over the fallow

The percentage of rainfall stored can be used to quickly estimate fallow water storage. The percentage will vary, but is generally between 20 and 40% (Table 3.1). Calculation Sheet: Water 1 can be used for this calculation.

Table 3.3. Example of calculating available fallow moisture using a soil corer

Depth interval (cm)	Layer thickness (cm)	Bulk[1] density (g/cm^3)	Crop[1] lower limit (%)	Wet weight [2] (g)	Dry weight[2] (g)	Gravimetric water [3] (%)	Volumetric water (%)	Available water (mm)
	a	b	c	d	e	f (d-e)/e x100	g f x b	h (g-c) x a/10
0-15	15	1.20	25	201	165	22	26	2
15-30	15	1.22	26	195	150	30	37	17
30-60	30	1.31	28	350	280	25	33	15
60-90	30	1.35	31	370	291	27	37	18
90-120	30	1.40	33	377	291	30	41	24
120-150	30	1.45	35	400	301	33	48	39
150-180	30	1.50	38	380	285	33	50	36
						Total available water		151

[1] Input from Module 5 for specific soil type and location - lower limit is in volumetric measure
[2] Input from field data
[3] Calculate using (d-e)/e if d and e are net weights; use (d-e)/(e-tare) if gross weights

Calculation sheet: Water 3 – Estimating available fallow moisture – using a soil corer

Depth interval (cm)	Layer thickness (cm)	Bulk[1] density (g/cm^3)	Crop[1] lower limit (%)	Wet weight [2] (g)	Dry weight[2] (g)	Gravimetric water[3] (%)	Volumetric water (%)	Available water (mm)
	a	b	c	d	e	f (d-e)/e x100	g f x b	h (g-c) x a/10
							Total available water	

[1] Input from Module 5 for specific soil type and location - lower limit is in volumetric measure
[2] Input from field data
[3] Calculate from (d-e)/e if d and e are net weights; use (d-e)/(e-tare) if gross weights

or d) using HOWWET?

The computer program HOWWET? calculates fallow water storage from local rainfall. HOWWET? is described on page 61.

The most suitable method of gauging water will depend on the farmer's attitude to the value of the information. Some may consider that the push probe or HOWWET? provide enough information to make decisions, whereas others may prefer the more detailed information available only from coring. Coring also allows analyses for nutrients to be done on the samples.

2.2. Rainfall expected while the crop is growing

As we cannot forecast exactly how much rain will fall on a crop, planting decisions have to be based on expected rainfall.

Expected in-crop rainfall may be estimated from monthly rainfall totals for average, wet and dry seasons, or it may be based on seasonal forecasts (see below).

In-crop rainfall refers only to the rain that falls between planting and physiological maturity (i.e. when the crop stops using water) —later rain is of no benefit to crop yield.

2.3. Total water supply expected for the crop

Total available water is calculated by adding the water available at planting (2.1) and the expected in-crop rainfall (2.2).

2.4. Yield expected this season

Since water is the major limiting factor to crop growth in the northern grain region, the yield potential for a crop can be estimated from the expected total available water supply.

The performance of past crops shows how efficiently they have been able to convert available water into yield. This knowledge provides the link between the current available water and potential yield.

The calculation of WUE from an estimate of fallow efficiency and rainfall is shown in Section 1. Sections 3 and 4 provide the means to calculate WUE based on the farmer's own experience using soil and crop information and rainfall, measured in the field.

The range of WUE for some crops grown in the region is shown in Table 3.4.

Table 3.4. Typical Water Use Efficiencies

Crop	Water use efficiency (kg/ha/mm) range	good crops
Winter		
wheat	5–20	12 (10–15)
barley	5–20	12 (10–15)
chickpea	3–10	6–7
Summer		
sorghum	5–20	12–15
sunflower	2–8	
mungbean	2–6	
cotton	2.2 kg lint/ha/mm*	

*(Ridge 1994)

Seasonal forecasting

Seasonal rainfall forecasts are available from a number of sources. These include sites on the Net, through fax and the printed media.

The Long Paddock:	www.dnr.qld.gov.au/longpdk (Qld DNR/DPI)
SOI Fax Hotline:	Fax no. 1902 935301 (QCCA)
Farmfax:	Fax no. 07 3222 2996 (Qld DPI)
Seasonal Climate Outlook:	published monthly by the Bureau of Meteorology National Climate Centre

Calculation sheet: Water 4 – Calculating expected yield from available soil water and forecast rainfall

2.2. Rainfall expected while crop is growing

(Enter rainfall for your site from own records or Australian Rainman)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
wettest 20%*												
average												
driest 20%+												

* the wettest one season in five (20% of seasons) or *in 20% of years rainfall will exceed ………..?*

+ the driest one season in five (20% of seasons) or *in 80% of years rainfall will exceed ………..?*

Period of crop water use

month of planting = ______________

month of turning = ______________

(physiological maturity or when the crop stops accumulating more yield)

Estimated in-crop rainfall for period

= ______ mm

2.3. Total water supply expected for the crop

Available water = Soil water at planting* + Expected in-crop rain

= _______ mm + _____ mm

= _______ mm

*from Calculation Sheet: Water 2 or 3

This calculation can be repeated for average, wet and dry years.

2.4. Yield expected this season

Expected Yield = Water Use Efficiency x (water supply – 100)

(WUE from Table 3.4 or from your own calculation of past paddock performance)

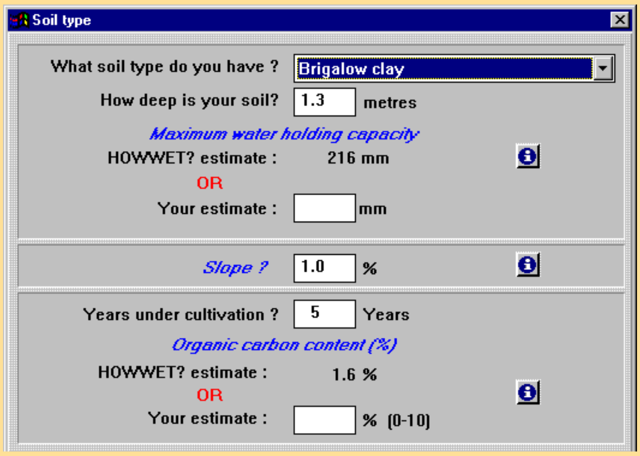
= ________ kg/ha/mm x ______mm

= ________ kg/ha ÷ 1000

Expected yield = ______ t/ha

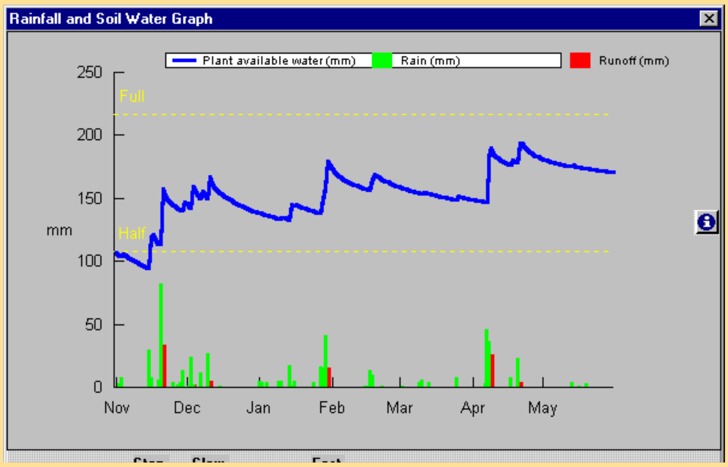
HOWWET?

A computer program to estimate the storage of water and nitrate nitrogen in soil using rainfall records

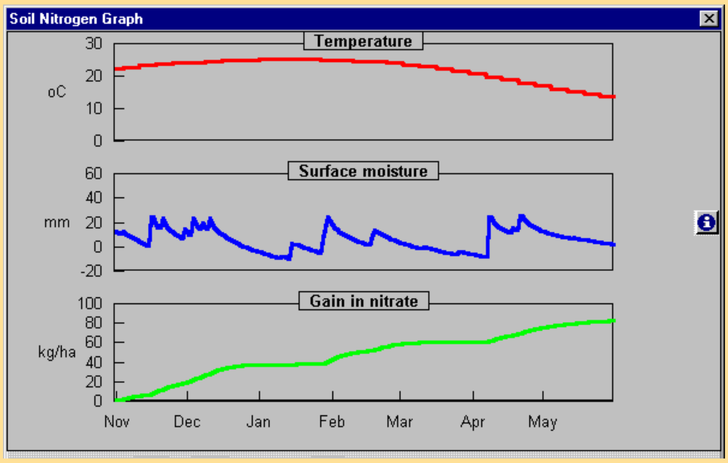


Enter the details of your soil—what type, how deep, the PAWC, what slope, number of years under cultivation, what level of organic carbon.

Enter the daily rainfall over the fallow period, how full of water was the soil profile at the start of the fallow, what was the percentage soil cover at the start and end of the fallow.



HOWWET? calculates the progressive water balance based on rainfall, evaporation and run-off from the daily falls of rain.



HOWWET? calculates the gain in nitrate nitrogen in the soil from the daily soil moisture levels and daily temperature.

3. What happened in the past season? – determining actual Water Use Efficiency

In this section, we determine the actual WUE from the crop yield and from information gained through probing or coring before and after the crop, and rainfall records.

3.1. How much water did the crop use?

Not all the water available to crops is used every year—moist soil at depth after harvest indicates residual water. Residual water is best assessed by coring, as it is difficult to push a probe through the upper layers of hard dry soil.

The amount of water used by a crop can be determined from the water available at planting, the measured in-crop rainfall and the available water remaining at harvest.

3.2. How efficiently did the crop use water?

Water Use Efficiency can be confirmed using the information obtained at this time. WUE reflects the impact of management (weeds, disease, nutrition, planting time) and the nature and timing of rain, which will vary between seasons. Calculating the WUE over a number of seasons will set the range for a particular farm.

Calculation sheet: Water 5 – What happened this season?

3.1. How much water did the crop use?

Plant available water (PAW) at planting (from Section 2)

$PAW_{planting}$ = _____ mm

Rain while the crop was growing (from your own records)

In-crop rainfall = _____ mm

Plant available water (PAW) at harvest

$PAW_{at\ harvest}$ = _____ mm

Amount of water used by the crop

Water used by the crop = $PAW_{planting}$ + In-crop rain – $PAW_{harvest}$

= _____ mm + ____ mm – _____ mm

= _____ mm

NB: In seasons where it can be assumed that little water remains in the profile after harvest, there is no need to core to determine residual water. Set $PAW_{harvest}$ = 0.

3.2. How efficiently did the crop use water?

WUE_{actual} = Actual crop yield (kg/ha) ÷ (Water used – 100)

= ______ kg/ha ÷ (_____ mm – 100)

= ______ kg/ha ÷ ______ mm

= ________ kg/ha/mm

4. What happened in the fallow? –determining actual fallow efficiency

In this section, we use information gained at the start and at the end of the fallow to determine how efficient the fallow was at storing water.

This information can be used to compare fallow management systems (for example, was the conventional fallow as efficient as one using zero-till and herbicides?)

Calculation sheet: Water 6 – How much rain was stored during the fallow?

a. Estimation by push probe (See also Calculation Sheet: Water 2)

Plant Available Water (PAW_{start}) at start of the fallow

PAW_{start} * = Depth of wet soil at start x PAW Capacity (See Table 3.2)

= ________ cm x ______ mm/cm

= ________ mm

Plant Available Water (PAW_{end}) at end of the fallow

PAW_{end} = Depth of wet soil at end x PAWC (Table 3.2)

= ________ cm x ________ mm/cm

= ________ mm

or b. Estimation by coring (at start and at end of fallow, using Sheet: Water 3)

PAW_{start}* = ______ mm

PAW_{end} = ______ mm

Fallow rainfall = ______ mm (from own records)

How efficient was the fallow?

Fallow efficiency = (PAW stored during fallow ÷ Fallow rainfall) x 100

$$= \frac{(PAW_{end} - PAW_{start})}{\text{Fallow rainfall}} \times 100$$

$$= \frac{(\_\_\_\text{ mm} - \_\_\_\text{ mm})}{\_\_\_\text{ mm}} \times 100$$

$$= \frac{\_\_\_\text{ mm}}{\_\_\_\text{ mm}} \times 100$$

Fallow efficiency = ________%

*In seasons when it can be assumed that little water remains in the profile after harvest of the previous crop, there is no need to determine PAW at the start of the fallow. Set PAW_{start} at 0.

or c. Using HOWWET? (see page 61)

or d. Use daily rainfall records (see Figure 3.1 – daily falls less than 15 mm are discounted unless there is follow-up rain; falls 15 to 50 mm useful unless followed by high evaporation; falls over 50 mm beneficial if soil is dry and cracked but not if soil is wet.)

Nitrogen calculations

Nitrogen strategies, such as rate of N fertiliser, should be altered in line with yield expectations based on available soil moisture, seasonal forecasts of rainfall and time of planting.

Nitrogen calculations works through the calculations required to determine a nitrogen fertiliser rate based on soil analysis, the requirement of the prospective crop and rate of mineralisation of soil N.

5. Calculating crop N requirements

In Section 5, we will determine:

5.1 Target yield
5.2 Nitrogen removed in the harvested grain
5.3 Nitrogen needed to grow the crop
(Use Calculation sheet: Nitrogen 1)

5.1. Target yield

The target yield is based on the availability of the main limiting factor—water. Calculation of the total water available for the crop, using soil moisture, seasonal forecasts and HOWWET? has been described in the previous sections. Other ways of determining yield range from past experience and district yield averages to complex decision support packages and models.

Past experience and average yield

Average yield from a paddock or district indicates possible future yield. Estimates may take into account rainfall and water storage during the fallow and prospects for in-crop rainfall, but are generally conservative and may not reflect yield potential.

Wheatman Plus

Wheatman plus is a computer program that estimates the likelihood of good, average or poor yield for winter crops, based on soil moisture and historical weather records; this provides the basis for nitrogen decisions. WHEATMAN PLUS also helps decide the best fertiliser rate for existing seasonal conditions.

APSIM simulation model

The APSIM model can simulate cropping sequences for a wide range of crops. Simulated yield is based on initial soil moisture and nitrogen levels and on long-term historical weather records. Simulations can be tailored to local conditions and soil type, and enable farmers to compare fertiliser strategies based on seasons experienced in the past. Decisions can be based on the *risk level* associated with various options.

5.2. Nitrogen removed in harvested grain or cotton seed

The amount of nitrogen likely to be removed in harvested grain can be estimated from the expected yield and protein content. For cotton, a removal rate is based on bales picked.

5.3. Nitrogen needed to grow the crop

About half of the soil nitrogen taken up by cereals ends up in the harvested product; the rest remains in the roots, stems and leaves of the crop. Thus available nitrogen at planting needs to be about twice that expected to be removed in the harvested material.

Calculation sheet: Nitrogen 1 –
Calculating the nitrogen requirement of the crop

5.1. Target yield

Target yield* = ______ t/ha (or bales/ha)

The expected yield will be based on the availability of water. Calculation of the total supply of water for the crop, and what that may mean to yield, has been described in a previous section.

Target protein (wheat, barley, sorghum) = ______ % protein

5.2. Nitrogen removed in harvested grain or cotton seed

N removed depends on yield and protein content of grain

N in wheat grain = Yield (t/ha) x grain protein % x 1.75
= ______ t/ha x ______ x 1.75
= ______ kg/ha

N in barley/sorghum grain = Yield (t/ha) x grain protein % x 1.60
= ______ t/ha x ______ x 1.60
= ______ kg/ha

N in cotton seed = Yield (bales/ha) x 11 kg[1]
= ______ bales/ha x 11 kg
= ______ kg/ha

Nitrogen removed in harvest = ______ kg/ha

[1](Ridge 1994)

5.3. Nitrogen needed to grow the crop

Only about half of the available soil N ends up in harvested grain or cotton

N needed = 2 x N removed in grain or cotton seed

= 2 x ______ kg/ha

= ______ kg/ha

*Once target yield and protein levels have been set for wheat, barley or sorghum, the nitrogen needed to grow the crop may be read off Tables 3.7 or 3.8. This avoids the need for calculations 5.2 and 5.3. (Note that figures in Tables 3.7 and 3.8 have been rounded off to nearest 5 kg.)

6. Calculating available soil N and fertiliser requirements

In Section 6, we will use Calculation Sheet: Nitrogen 2 to calculate:

6.1 Nitrogen available in the soil
6.2 Nitrogen mineralisation
6.3 Extra nitrogen needed to achieve the expected yield.

6.1. Nitrogen available in the soil

A soil test measures how much mineral nitrogen is available for the crop. Analysis results, in milligrams per kilogram, can be converted to available nitrogen as kg/ha (See Table 3.5.) Available N is calculated from the bulk density of the soil and the N concentration for each depth interval. These are added to provide total available N; its location within the soil profile can be seen by plotting a graph as in Table 3.5.

6.2. Nitrogen mineralisation

Soil nitrate is a product of the biological breakdown of organic nitrogen tied up in the soil organic matter. Available nitrogen is released when the soil microbes are active—in moist and warm conditions (Turpin et al. 1997). (See Figure 3.5)

However, the rate of N release also depends on the stockpile of organic N. A newly cleared brigalow soil may have levels as high as 2% organic carbon and 0.2% organic N. These levels decline under continuous cropping as soil organic matter is oxidised, and nitrogen is removed in crops.

Although we can never forecast the coming season with complete accuracy, we need to estimate, at the time of fertiliser application, what extra release (mineralisation) of nitrogen we can expect between applying fertiliser and crop maturity.

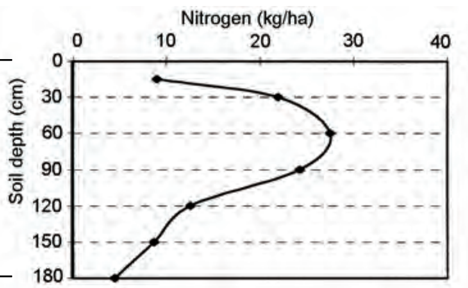
Table 3.6 provides estimates of the total mineralisation during a fallow for a number of soil types and ages of cultivation. During crop growth, the rate of mineralisation slows as the soil dries.

6.3. Extra N needed to achieve the expected yield

The extra nitrogen needed is the difference between what is required to produce the expected crop yield and what is available from the soil.

Table 3.5. Sample set of data showing calculation of total available nitrogen, with graph of nitrogen distribution in profile.

Depth interval (cm)	Layer thickness (cm)	Bulk Density (g/cm^3)	N conc. (mg/kg)	Available N (kg/ha)
	a	b	c	d (cxb) x a/10
0-15	15	1.20	5	9
15-30	15	1.22	12	22
30-60	30	1.31	7	28
60-90	30	1.35	6	24
90-120	30	1.40	3	13
120-150	30	1.45	2	9
150-180	30	1.50	1	5
		Total available N		110



Calculation sheet: Nitrogen 2 – Fertiliser requirement

6.1. Soil N available (from soil tests) (Use Table 3.5 as an example)

Depth interval (cm)	Layer thickness (cm)	Bulk Density# (g/cm^3)	N conc.* (mg/kg)	Available N (kg/ha)
	a	b	c	d (cxb) x a/10
			Total available N	

Bulk Density data for specific soils and locations are available from Module 5 database

* Nitrogen concentration input from results of analysis.

6.2. Nitrogen mineralisation

N mineralised in-crop = ______ kg/ha

. In-crop mineralisation may be estimated from Table 3.6

6.3. Extra nitrogen needed to achieve expected yield

The amount of extra nitrogen needed to achieve the expected yield is the difference between that required to produce the expected crop yield and what is available from the soil.

Extra N needed = N to grow crop – (Total N available + N mineralised in-crop)

= ______ kg/ha – (_____ kg/ha + _____ kg/ha)

= ______ kg/ha

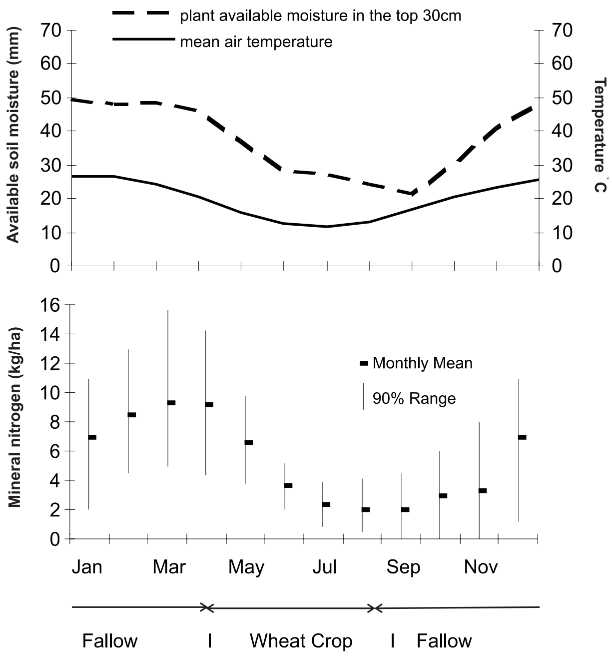
A positive result means extra N is needed.
A negative result means extra N is not needed from fertiliser or legume rotation. In this case, there is a surplus of nitrogen for the expected yield.

Table 3.6. Rate of mineralisation (kg/ha of mineralised N per season) during fallow for soil type x age of cultivation. Rates are reduced by 50% under a crop (Cahill and Dimes 1997).

		In-crop nitrogen mineralisation per season * (kg/ha of N) Number of years under cultivation									
		0 to 10		10 to 20		20 to 30		30 to 50		50+	
Region	Soil type	Winter	Summer	W	S	W	S	W	S	W	S
Darling Downs	Heavy alluvial (Anchorfield)	45	80	30	50	25	40	20	40	20	40
	Light alluvial (Waco)	45	80	30	50	25	40	20	40	20	40
	Brigalow clay	50	90	35	60	30	50	25	50	25	45
	Light box clay	40	70	25	50	25	45	25	45	25	45
	Soft wood brigalow (Uplands)	40	70	25	45	25	40	20	40	20	40
	Red brown and red earths	20	35	15	30	10	25	10	20	10	20
Dawson-Callide Central Highlands	H'vy alluvial flooded brigalow or Yellow wood	60	90	40	60	35	50	30	50	30	45
	Deep open downs	50	75	35	50	30	50	25	35	25	35
	Light Callide alluvial	40	90	30	50	30	40	30	45	30	45
	Brigalow-softwood scrub	60	90	40	60	35	50	30	50	30	45
	Brigalow-Dawson Gum duplex	60	90	40	60	35	50	30	50	30	45
	Shallow open downs	50	75	35	50	30	50	25	35	25	35
South Burnett	Red scrub	30	75	25	55	20	45	20	40	15	30
	Red forest	30	75	25	55	20	45	20	40	15	30
	Brown forest	35	80	20	50	20	45	20	40	20	40
	Black forest	35	80	20	50	20	45	20	40	20	40
	Brigalow	40	100	30	65	24	55	20	50	20	50
	Black alluvial	40	85	25	55	20	45	20	40	20	40
Western Downs	Heavy alluvial (Coolibah)	45	80	30	50	25	40	20	40	20	40
	Open downs - Mitchell grass	50	75	35	50	30	50	25	35	25	35
	Deep/h'vy brigalow-belah	50	90	35	60	30	50	25	50	25	45
	Shallow/light brigalow or Box	40	70	25	50	25	45	25	45	25	45
	clay	50	90	40	70	30	55	20	40	15	20
	Shallow/light belah or Box clay	20	25	15	20	10	15	10	15	10	15
	Red brown or Red earths										

* Winter (W) - April to September; Summer (S) - October to March

Figure 3.5. Temperature and soil moisture determine the mean rate and range of monthly mineralisation under a wheat/fallow rotation (Turpin et al. 1997. Dalby data).



7. Nitrogen fertiliser rates

'Best-bet' fertiliser rates can be set for an expected yield and expected protein. The following tables provide 'ready-reckoners' for the available nitrogen needed by the crop to achieve the expected yield and grain protein.

The tables assume a nitrogen use efficiency of 50% (i.e. 50% of the N ends up in the grain). For wheat and barley, this applies only when protein levels are between 7% and 14% as it is not certain how much nitrogen is left un-used in the soil if the protein level is above 14%. Sorghum often has a nitrogen use efficiency of around 60% so its nitrogen requirements may be less than those specified below. Because of these assumptions and the probabilistic estimate of future rainfall, nitrogen requirements shown are rounded off to the nearest 5 kg.

Wheat

Table 3.7. Wheat - available soil nitrogen (kg/ha) needed for expected yield and grain protein %

Yield	Wheat grain protein %							
(t/ha)	7%	8%	9%	10%	11%	12%	13%	14%
1.0	25	30	30	35	40	40	45	50
1.5	40	40	50	55	60	65	70	75
2.0	50	55	65	70	80	85	90	100
2.5	60	70	80	90	95	105	115	125
3.0	75	85	95	105	115	125	140	150
3.5	85	100	110	120	135	150	160	170
4.0	100	110	125	140	155	170	180	195
4.5	110	125	140	160	175	190	205	220
5.0	125	140	160	175	195	210	230	245

For example, a wheat yield of 3.0 t/ha with a grain protein of 13% requires 140 kg/ha of available nitrogen from a combination of soil N, in-crop mineralisation and applied fertiliser.

Barley and sorghum

Table 3.8. Barley and sorghum - available soil nitrogen (kg/ha) needed for expected yield and grain protein %.

Yield	Barley and sorghum grain protein %							
(t/ha)	7%	8%	9%	10%	11%	12%	13%	14%
1.0	20	25	30	30	35	40	40	45
1.5	35	40	45	50	55	60	60	70
2.0	45	50	60	65	70	80	85	90
2.5	55	65	70	80	90	95	105	110
3.0	70	80	85	95	105	115	125	135
3.5	80	90	100	110	125	135	145	160
4.0	90	100	115	130	140	155	165	180
4.5	100	115	130	145	160	175	190	200
5.0	110	130	145	160	175	190	210	225

For example, a barley yield of 3.0 t/ha at a grain protein of 11% requires 105 kg/ha of available nitrogen.
Sorghum – a yield of 3 t/ha at a grain protein of 10% requires 95 kg/ha of available N, assuming nitrogen use efficiency of 50%.

4. Determining Plant Available Water Capacity

Introduction

The climate and soils of the northern cropping region have determined the system of agriculture that has developed.

Dryland cropping in semi-arid climates depends heavily on water that has accumulated in the soil from rainfall during a fallow. As soils vary greatly in their capacity to store water, knowing the storage capacity of a soil helps in assessing the opportunities and risks of cropping.

Continuity of water supply to the plant depends on the storage capacity of the soil and how often more water enters the storage. Simulation of crop growth can relate yields to a water budget, but this requires accurate weather data and good characterisation of the water storage of the soil.

Plant available water capacity

A growing crop relies greatly on water that has been stored in the soil during periods of fallow or reduced cropping activity; the capacity to store this water depends on the soil's physical characteristics such as structure and depth.

The maximum water available is known as the Plant Available Water Capacity (PAWC)(Figure 4.1); it varies with soil type and crop.

PAWC is the difference between the upper water storage limit of the soil and the lower extraction limit of a crop over the depth of rooting (Godwin et al. 1984; Ratliff et al. 1983; Gardner 1985). (Formulae 1 and 2 on page 73)

In many seasons, the maximum water storage capacity is not reached for reasons including insufficient rainfall, fallow weeds, run-off and evaporation. In these cases, the actual water present is described in terms of the PAWC, that is, how full is the *bucket*.

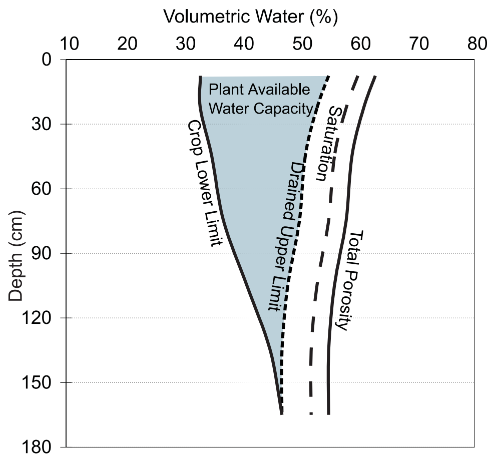


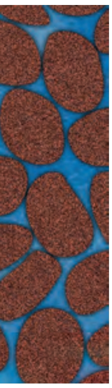
Figure 4.1. A typical storage profile for a slow-draining, heavy-textured soil showing the storage capacity of the soil, PAWC, *as defined by the* drained upper limit, crop lower limit, saturation and total porosity.

Are Modules 4 and 5 for you?

Module 4 provides an overview of the science and techniques involved in characterising a soil for plant available water capacity (PAWC).

It is designed for those who want a better understanding of the science behind the techniques or who actually go out and characterise soils.

Those who are mainly interested in using PAWC information should refer to Module 5 before deciding to start their own soil characterisation work. The Module 5 database provides PAWC data for a wide range of soils from the northern cropping region.



Defining the variables to calculate PAWC

To determine PAWC, a number of soil variables have to be measured or calculated. These include:

- soil *bulk density*
- volumetric water content at *Drained Upper Limit* (DUL)
- volumetric water content at *Crop Lower Limit* (CLL)

Two other soil variables—volumetric water content at *Saturation* (SAT) and *Total Porosity* (PO)—can also be determined. Total porosity is used to calculate saturation—an important variable when characterising a soil for crop simulation studies.

Formulae to calculate variables are shown on page 73.

Bulk Density

Bulk density is a measure of the weight of dry soil per unit volume of soil (see page 9). Bulk density is used to convert weight-based measures of soil water and nutrients to volume-based measures, e.g. from gravimetric to volumetric soil water content (Bridge 1981; Gardiner 1988). Bulk densities of soils of the northern grain belt range between 0.8 and 1.8 g/cc. (Formulae 3 and 4, p.73)

Drained Upper Limit (DUL)

Drained upper limit is defined as the amount of water that a particular soil holds after drainage has practically ceased (Gardner 1984; Godwin et al. 1984; Ratliff *et al.* 1983). It is water held against gravity, and may be removed only by plants—crops or weeds—or through direct evaporation. (Formulae 5 and 6, p.73)

Crop Lower Limit (CLL)

Crop lower limit measures the extent to which a particular crop can extract water from a particular soil type. Crops differ in their ability to extract water, determined by the length, density and osmotic potential of their roots, and the duration of their growth. (Formula 7, p. 73)

A theoretical lower limit can be measured in the laboratory equilibrating the soil at 1500 kPa (15 bar) suction (LL15). This shows differences between soil types, but does not differentiate between crops grown on one soil type. Crops can vary greatly in their ability to extract water, and may be quite different to the 1500 kPa value, especially at depth (Williams 1983) (Figure 4.2).

Measures of both LL15 and CLL are used in simulation, CLL to set PAWC for a particular soil x crop combination and LL15 to set the soil water and nutrient balance. Where LL15 has not been measured, the lowest CLL for any crop grown on the soil in question is used.

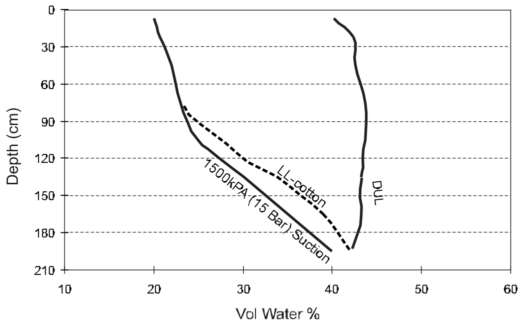


Figure 4.2. The laboratory-measured 1500 kPa suction for LL15 can over-estimate deep profile PAWC for some crops.

Saturation and Total Porosity

The water content at saturation is the maximum able to be held in the soil before drainage takes place (Godwin et al. 1984). However, even when the soil is considered to be at saturation, some pore space will contain entrapped air. The percentage entrapped air depends on the soil type, but is commonly between 2-3% for a clay and up to 7% for the lighter textured soils. Total porosity (PO) accounts for both the air space able to be filled with water and the entrapped air. (Formulae 8 and 9, p.73)

Saturation may be calculated from PO and an assumed entrapped air percentage.

Formulae used in defining PAWC and its associated variables

(1,2) Plant Available Water Capacity

PAWC (mm) for 1 depth interval = [DUL-CLL] x [depth interval (cm)/10]

PAWC for the full profile = sum of PAWC for each depth interval
(where *DUL* and *CLL* are expressed as *Volumetric Water %*)

(3) Bulk Density (BD field measured)

Bulk Density (g/cc) = dry soil wt (g)/total volume of soil (cc)

(4) Bulk Density (BD calculated)

BD (g/cc) = (1-e)/(1/AD + θ_g)
where θ_g = gravimetric water content (g/g) of wet soil
AD = absolute density of the solid matter in the soil (assumed 2.65 g/cc)
e = air filled porosity at θ_g

(5) Gravimetric water

Gravimetric Water % =
((wet wt of sample - dry wt of sample)/dry wt of sample – container tare) x 100
or use <u>net</u> weights for all weighings, i.e. ((wet wt – dry wt)/dry wt) x 100

(6) Drained upper limit (DUL)

DUL (volumetric water %) =
Gravimetric Water % (for each depth interval) x BD (g/cc)

(7) Crop Lower Limit (CLL)

CLL (volumetric water %) =
Gravimetric Water % (when crop is mature/ stressed) x BD (g/cc)

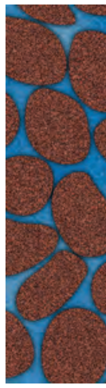
(8) Total porosity (PO)

PO (% volumetric) = (1-BD/2.65) x 100
where BD/2.65 is the fraction of the soil volume occupied by solid (sand, silt and clay) particles, based on an assumed density of 2.65 g/cc for the solid matter in the soil. A density figure of 2.65 g/cc holds for a wide range of soils, the exceptions being the organic soils (lower) and oxisols (higher).

(9) Saturation (SAT)

SAT (% volumetric) = (PO* – e) x 100
Where e = 0.03(heavy clay soils) to 0.07 (sandy soils)

*PO in this case is a decimal fraction, not %



Porosity, saturation, *drained upper limit* and *crop lower limit* are presented in this manual as *Volumetric %*.

More usually, soil water is expressed as the volumetric fraction of water, i.e. volume of water per unit volume of soil, which is equivalent to the depth of water per unit depth of soil.

For example, a *drained upper limit* value of 52% volumetric water may be expressed as 52 mm of water/100 mm of soil depth or 0.52 mm of water/mm of soil depth.

When should a soil be characterised for PAWC?

Soil characterisation for PAWC is required if detailed information on soil water and nutrient availability is needed for a commercial crop, on-farm research or for simulation. Each soil type of importance in an area, such as a catchment or district, should be characterised, but not the soil on every farm.

The soil properties (DUL, BD and SAT) need be determined only once for a particular soil type. However, if routine measurements on a farm differ from the local standard, some modifications may be needed for that location. Crop lower limit should be measured for **each crop** on **each soil** type, and should be repeated for a number of years to capture seasonal variation in water extraction.

How long does it take to characterise a soil for DUL?

The time required to characterise a soil for DUL is governed by the time taken to wet-up the soil profile. Free-draining soils through which water infiltrates quickly may be sampled after 2–3 days, but more time is needed in some soil types (Gardner 1985). In cracking clay soils where water entry is slow, wetting up may take several months.

Determining bulk density

The method used for the determination of bulk density depends on the characteristics of the soil being measured. In shrink–swell soils, bulk density may be measured in the field or calculated from the relationship between gravimetric moisture content at saturation and bulk density.

Calculation is recommended for these soils, and is discussed in the section *Water balance modelling of shrink–swell soils* (page 80). Rigid soils must be measured in the field.

Field measuring BD

If bulk density of a shrink-swell soil is measured in the field, it is done when the soil is wet, and often in conjunction with the measurement of DUL. Wetting up soils to measure DUL is described on page 83.

Although bulk density changes with moisture content in these soils, it is impractical to sample at lower moisture contents (than DUL) as it is difficult to obtain a representative sample that adequately describes the whole soil matrix—including the cracks (Berndt and Coughlan 1976).

In rigid soils, sampling may be done at any practical moisture content, as bulk density does not change with moisture content. (Figure 4.6)

Sampling for bulk density (shrink–swell and rigid soils)

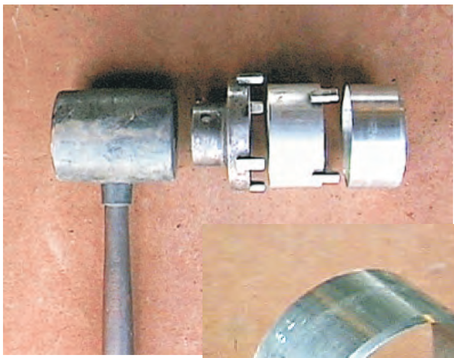
Hand sampling

Hand sampling is done with an open-ended, thin-walled (1.6 mm gauge) ring of 75-100 mm diameter and 50-100 mm length. This is hammered into the soil using a rubber mallet or a sliding hammer attached to the anvil of the driver (Talsma et al. 1976, Bridge 1981).

Access to the soil profile is generally by digging a pit and sampling horizontally into the pit wall or vertically into prepared steps. An alternative is to work from the soil surface, using a large (30 cm) diameter soil auger to access each of the depth layers in turn. Bulk density samples are taken using the sliding hammer (see page 75).

Procedure

1. Hammer the steel ring into the undisturbed soil
2. Excavate the ring without disturbing the soil within the ring
3. Carefully trim excess soil from the ends
4. Process the samples (see page 79).



Anvil, thin-walled ring and rubber mallet for sampling bulk density by hand

Close-up view of thin-walled soil sampling ring

Measuring bulk density: driving a sampling ring into the wall of a pit (Photo B. Bridge)

A sliding hammer for sampling bulk density. The removable cutting tip is placed onto the end of a removable steel ring which is inserted into the body of the sampler. After sampling, the cutting tip is removed and the ring sealed for later processing of the sample.

Mechanical sampling

Mechanical sampling is much more labour-efficient, and is recommended when a number of sites require characterisation. This method utilises the hydraulic sampling rig (mentioned in Module 2) combined with special large-diameter coring tubes as described on page 78.

Procedure

1. A thin-walled tube (60–80 cm long) is pushed into the soil using an hydraulic rig. Tubes of varying diameter (75, 100 or 125 mm) are suitable and may be used individually or in combination to sample to greater depth (Figure 4.3) (Dalgliesh 1996; Bridge 1981).
2. Carefully remove the soil core from the tube.
3. Cut the samples accurately into appropriate lengths and process (see page 79).

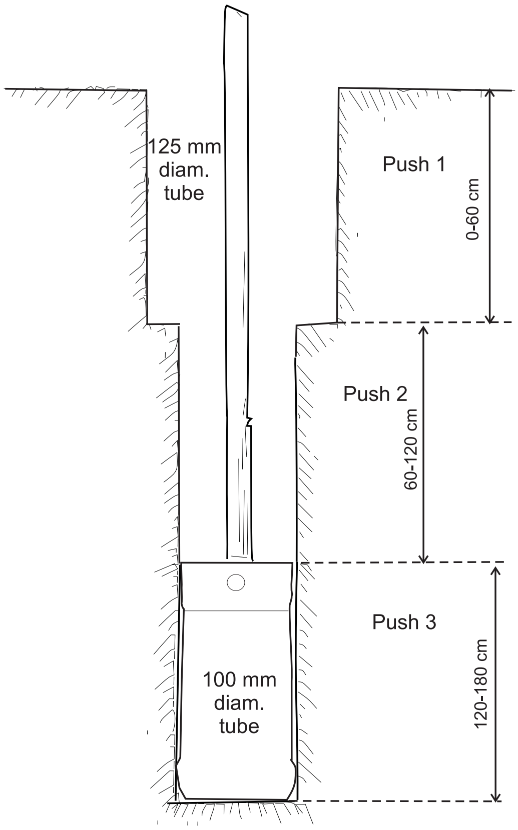


Figure 4.3. Sampling for bulk density using coring tubes of different diameters. This improves coring efficiency by minimising soil adhesion to the tube.

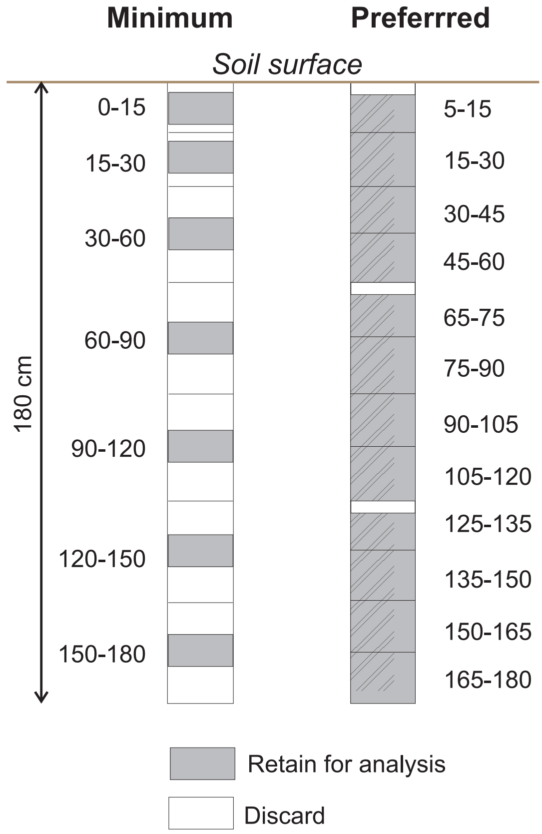


Figure 4.4. Minimal and preferred strategies for bulk density sampling. The top 5 cm of soil is always discarded.

The minimum sampling strategy for bulk density comprises sampling at the mid-point of each soil depth layer. However, with mechanical coring the preferred procedure is continuous sampling down the profile, with the results being averaged for the standard depth layers and replications. With this technique, a short section of core is discarded between each push (Figure 4.3 and 4.4) because of uneven breakage of the core as it is extracted from the soil.

Measurements of bulk density should start 5 cm below the soil surface due to potential disturbance during sampling and possible compaction, and damage to the soil surface during wetting-up.

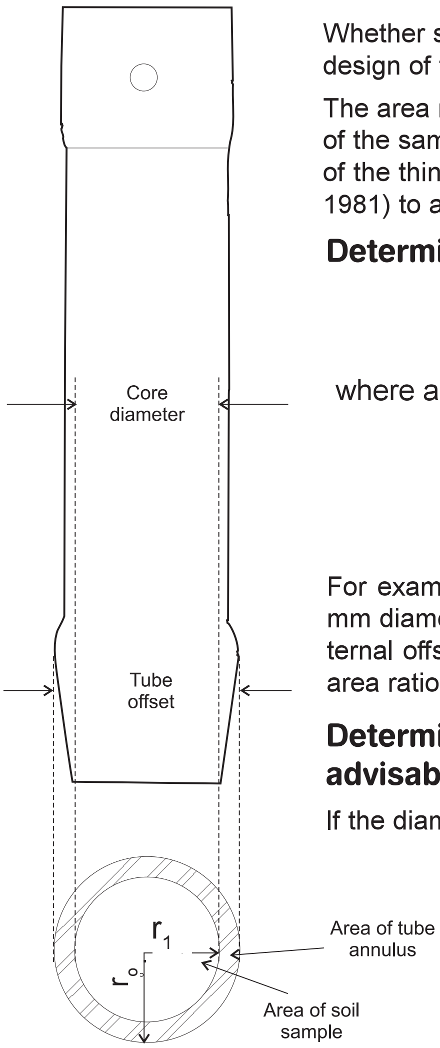
Because the calculation of bulk density requires the weight of dry soil per unit volume, sampling and handling of cores must be done carefully. The length and diameter of each sample and its position in the profile must be measured accurately.

After each core is removed, its length must be compared to the depth of the hole to adjust for core expansion or compression (Ross 1985). In most soils, compression occurs during sampling and the recovery ratio (the length of the core sample divided by the depth of the hole from which it was removed) should be greater than 0.98 for a valid mean of bulk density (Bridge 1981).

In some soils with high bulk density (greater than 1.6 g/cc) expansion may occur and the core has to be cut in proportion, particularly if the recovery ratio is greater than 1.2.

A core of less than 75 mm diameter may be compressed excessively because of the poor area ratio of small-diameter tubes (see Figure 4.5). Tubes of this diameter or smaller should be used only where larger diameter ones are not suitable or are not available. Data associated with small-diameter tubes should be treated with some reservation (Bridge 1981).

Figure 4.5.



Tube design

Whether sampling is by hand or with machine, the design of the coring tube is of critical importance.

The area ratio (that is the ratio of the area of the annulus of the sampling tube divided by the area of the soil core) of the thin-walled tube should be less than 0.1 (Bridge 1981) to avoid compressing the sample within the tube.

Determining the area ratio of the tube

$$\text{Area ratio} = \frac{\text{area of annulus}}{\text{area of soil sample}}$$

$$\text{where area of annulus } (A_{ann}) = \pi(r_o^2 - r_1^2)$$

$$\text{area of soil } (A_{soil}) = \pi r_1^2$$

$$\text{area ratio} = \frac{r_0^2 - r_1^2}{r_1^2}$$

For example, a tube that produces a core of 100 mm diameter and has a combined internal and external offset and wall thickness of 2.5 mm has an area ratio of 0.1.

Determining tube dimension for maximum advisable annulus of 0.1

If the diameter of the desired core (d_1) is known:

$$r_o^2 = 0.1 r_1^2 + r_1^2$$
$$= 1.1 r_1^2$$

$$r_o = \sqrt{1.1 r_1^2}$$
$$= 1.05 r_1$$

Mechanical sampling procedure for bulk density

Lubricate soil tubes before taking samples. Tubes are 60–80 cm long with diameters of 75, 100 and 125 mm.

Insert the tube.

Use a pusher *to slide the core from the tube onto the special cutting tray.*

Check the depth of the core hole against the length of the core to detect compression or expansion of the sample.

Confirm core length before making an accurate cut. Piano wire gives a cleaner cut and less soil adhesion than a knife.

Processing samples – for BD

Use this procedure when BD is to be measured without DUL, and hence gravimetric water content is not needed.

Procedure

1. Regularly check and record the internal diameter of the cutting edge of the sampling tube or ring during sampling.
2. Place sample in wet strength bag or in tin or plastic bag.
3. Dry at 105°C for 48 hours.
4. Record dry weight.
5. Calculate the volume of the sample – (from tube diameter and sample length).
6. Determine BD. (Formula 3, on p. 73)

– for BD and DUL

Use this procedure when both BD and DUL are needed.

Procedure

1. Regularly check and record the internal diameter of the cutting edge of tube.
2. Place sample in wet strength bag (if wet weighing in field) or in sealed tin or plastic bag (if weighing later).
3. Record wet weight of sample.
4. Dry at 105°C for 48 hours.
5. Record dry weight.
6. Calculate the volume of the sample – (from tube diameter and sample length).
7. Determine BD. (Formula 3, on p.73)
8. Determine DUL. (Formula 5 and 6, p.73)

Handle the cores carefully so that all soil from the particular depth interval is recovered.

If using paper bags,weigh samples immediately to minimise water loss.

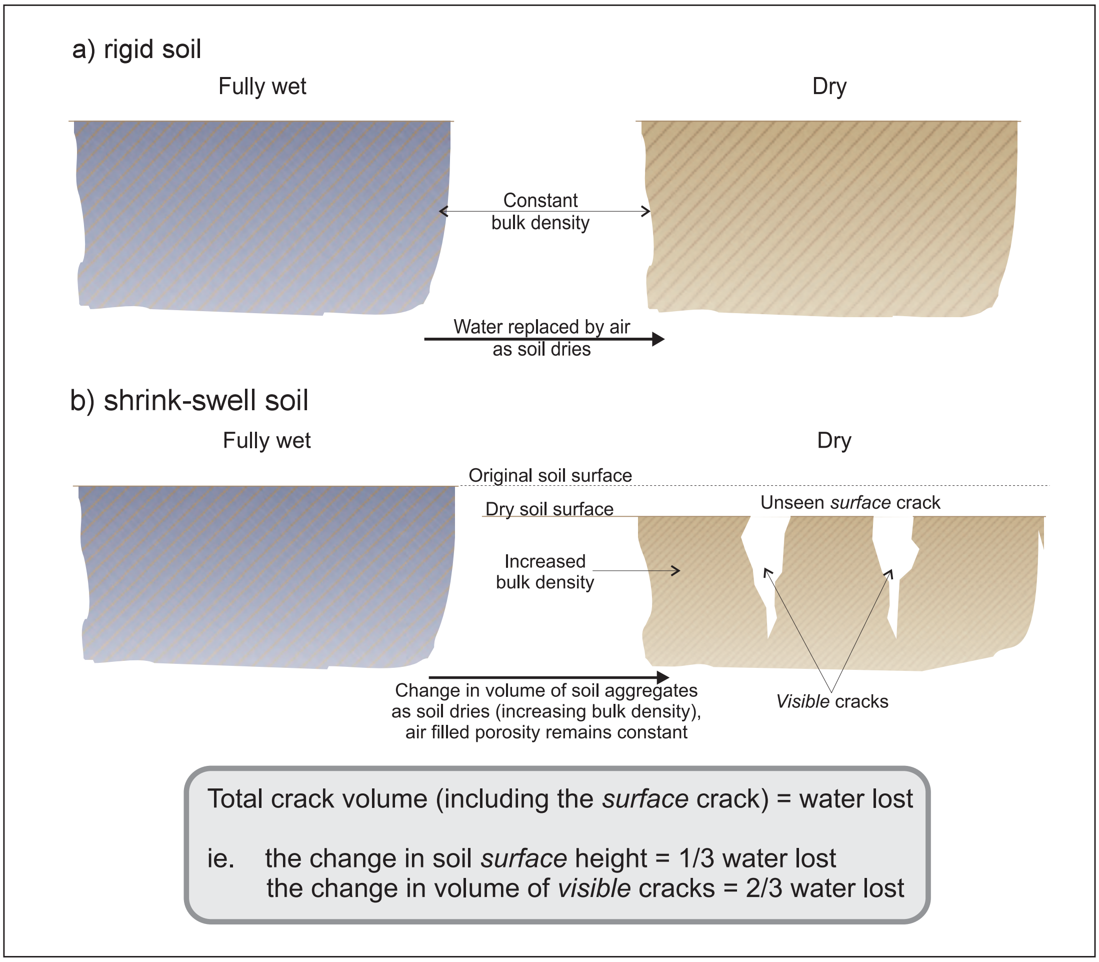
Regularly measure and record the internal diameter of the cutting edge of the tube for accurate and consistent measurement of core volume.

Water balance modelling of shrink–swell soils

The simulation of the soil water balance requires specification of the soil's water holding characteristics. For models such as the SoilWat module of APSIM, these are defined in terms of the soil's lower limit of extractable water (LL15), drained upper limit (DUL), and saturated water content (SAT) in each layer of the soil (Figures 4.1 and 4.2). Values are also required for soil bulk density (BD).

The representation of water used in SoilWat is only strictly valid for rigid soils in which BD remains constant at all water contents; as water content changes, there is a complementary change in air-filled porosity. However, this does not happen in the cracking clay soils that are wide-spread in the northern grain belt. These soils exhibit shrink-swell behaviour, which means that as the soil dries there is a change in volume of soil aggregates that is more or less equal to the volume of water lost (Figure 4.6). The air filled porosity of the aggregates remains constant and the BD changes (Bridge and Ross 1984).

Figure 4.6. The behaviour of soils under drying conditions:
a) rigid soils: as water content changes it is replaced by air; bulk density remains constant at all water contents.
b) shrink– swell soils: formation of surface *and* visible *cracks as the soil dries; air-filled porosity remains constant, density of the soil aggregates increases.*



For SoilWat to predict the behaviour of water in these soils, some assumptions are made about how DUL, SAT and BD (from which Total Porosity is determined) are defined. These assumptions enable soil water to be simulated with measurable accuracy. There are also consequences for measurement of the required soil water properties in the field, one of which is that there is no need to measure the BD of shrink–swell clay soils (as discussed on p.74).

Calculating BD in shrink -swell soils

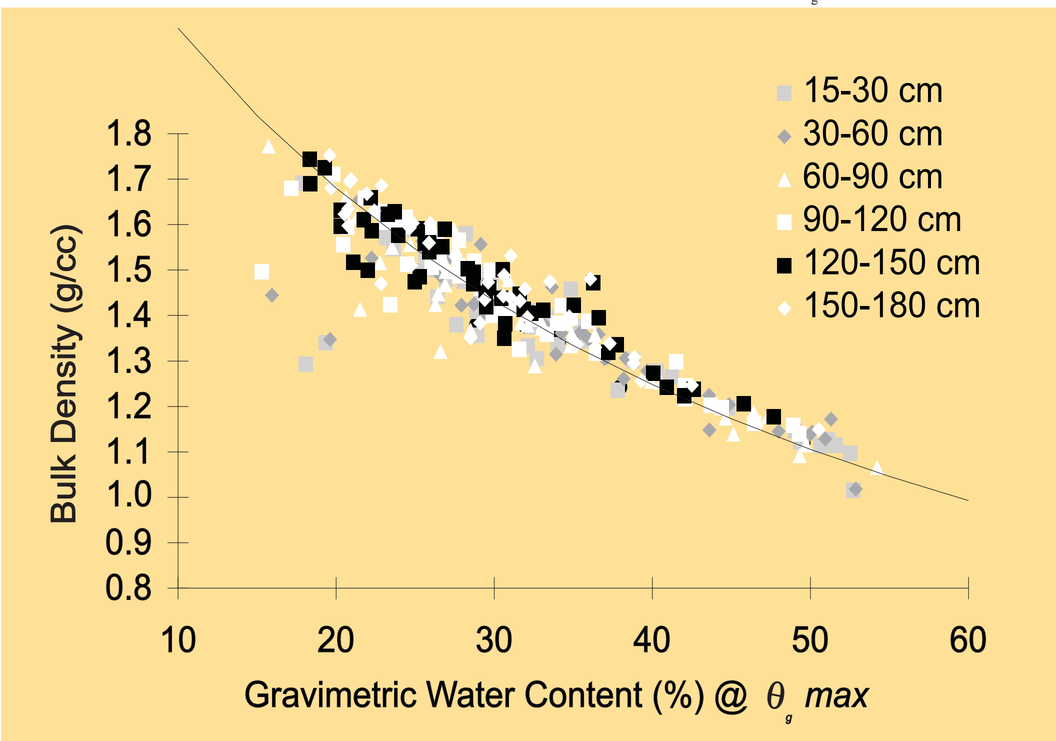
Consider the situation where a clay soil has been wet up using the methods described in the following section *Measuring Drained Upper Limit in the Field.* After a period of drainage, the soil is sampled to determine water content and bulk density. However, there is a problem in defining this water content in terms of DUL, SAT, etc. It ought to be a measure of DUL, but this is not necessarily the case in shrink-swell soils where drainage may be very slow.

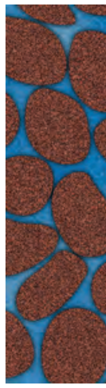
If the total porosity is calculated from the measured BD (Formula 8, p.73), the difference between this value and the volumetric water content of the soil (θ_g x BD) may be too small for the latter to be a sensible estimate of DUL. In extreme cases, estimated water content may be greater than the estimated total porosity.

Data from 50 soils of the region show a very close relation between the measured BD and the gravimetric water content of the wet soil (see Figure 4.7), corresponding to an air-filled porosity of approximately 3%. This confirms that the soils are exhibiting expected shrink-swell behaviour, thus enabling the calculation of BD (Gardner 1988).

To use this relationship in overcoming the problems associated with simulating soil water in cracking clay soils, an assumed

Figure 4.7. Relationship between measured bulk density and gravimetric moisture content of wet soil for 50 soils of the northern cropping region. Line of best fit indicates an air-filled porosity over all soil depths below the top 15 cm, of 3.2%, BD=(1–0.032)/(1/2.65+θ_g); R^2=80.8%.





BD that corresponds with the soil being absolutely filled with water (zero air-filled porosity) is used as a reference. Values are then selected for (assumed) air-filled porosity at DUL and SAT. BD at DUL is then calculated. The data tabulated in Module 5 has been calculated using an assumed air-filled porosity at SAT of 3% and SAT-DUL of 5%.

Being able to calculate bulk density for these soils from gravimetric soil water content has major implications for the characterisation of soils of the northern cropping region. Instead of having to field-measure BD, a simplified procedure requires only that the soil be wet up (as described in the following section) before cores of 50 mm diameter are taken for gravimetric soil water. These data are then used to calculate BD using (Formula 4, p.73) with *e* = 0.08.

Adjusting field-measured data for use in simulation

If BD has been measured in-field and confirmation of it meeting the above criteria is required, Table 4.1 provides an example of the calculations needed to analyse and modify the observed bulk density data. The left-hand side of the table performs the calculations on the field data for gravimetric water content and BD assuming 3% air-filled porosity at SAT. For this data set, the difference between SAT – DUL is greater than 5% in the top two soil layers, but less than 5% in the deeper. It can be inferred that, in the deeper layers, the soil was exhibiting shrink-swell behaviour. Accordingly, on the right hand side, the calculations are carried out with the appropriate assumptions to provide estimates that are consistent with the requirements of the SoilWat module.

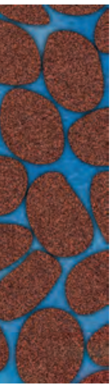


Table 4.1. Example of the calculations required to compare observed bulk density data, showing how these data can be modified to fit the criteria that SAT-DUL = 5% and air-filled porosity at SAT = 3%.

	Measured		Calculated				Recalculated for shrink-swell soils			
Depth cm	Grav g/g	BD g/cc	DUL mm/mm	PO mm/mm	SAT mm/mm	SAT-DUL mm/mm	New BD g/cc	New DUL mm/mm	New PO mm/mm	New SAT mm/mm
0-15	0.575	0.90	0.52	0.66	0.63	0.11	0.90	0.52	0.66	0.63
15-30	0.527	1.01	0.53	0.62	0.59	0.06	1.01	0.53	0.62	0.59
30-60	0.529	1.04	0.55	0.61	0.58	0.03	1.02	0.54	0.62	0.59
60-90	0.542	1.07	0.58	0.60	0.57	-0.01	1.00	0.54	0.62	0.59
90-120	0.489	1.16	0.57	0.56	0.53	-0.03	1.06	0.52	0.60	0.57
120-150	0.426	1.24	0.53	0.53	0.50	-0.03	1.15	0.49	0.57	0.54
150-180	0.373	1.34	0.50	0.49	0.46	-0.04	1.23	0.46	0.54	0.51

Calculations using measured data
DUL = Grav x BD
PO = 1- BD/2.65
SAT = PO - 0.03

Re-calculations
if measured SAT - DUL<0.05, assumes
SAT-DUL= 0.05 and PO-SAT = 0.03
New BD = (1-0.08)/(1/2.65 + Grav)
new DUL = Grav x new BD
new PO = 1- new BD/2.65
new SAT = new PO - 0.03

Measuring DUL in the field

In principle, the field measurement of drained upper limit should be a simple process of wetting up an area of soil until it has reached saturation, allowing time for drainage and then sampling for water content. In practice, the procedure can be a little more difficult and techniques have been developed suitable for the variations encountered in the soils of the region, including both rigid and shrink–swell soils.

In freely draining soils, the techniques outlined below give a good estimate of actual drained upper limit but are less suitable for the measurement of saturation due to the rapid movement of water through the profile.

In the heavy clay soils where drainage is inherently slow (Williams 1983), it may be more logical to refer to a soil being at its upper storage limit than at its drained upper limit. Some slow long-term drainage continues but, in the meantime, the water is available for plant use. In practical terms, this is the important water (Bridge 1981).

Techniques of wetting-up

Wettest soil profile

The most convenient method of measuring drained upper limit is to take samples during a wet season when the soil profile is thought to be fully re-charged. This is most effective when a dry, deeply cracked soil is exposed to intense rainfall, and water enters through the cracks.

Re-charge under these circumstances can occur quickly even in heavy clay soil; with low intensity rainfall, swelling may close surface cracks, thus reducing the rate of subsequent water entry (Williams 1983).

The limitation of this opportunistic approach is that it assumes the profile has been wet to its full capacity and to full rooting depth. This is not certain unless the water status can be checked before sampling.

A neutron moisture meter (NMM) is a convenient tool to monitor the seasonal entry and movement of water, and will indicate whether the soil is at drained upper limit to depth. If sequential observations of wetting up indicate no water movement below a particular depth, the soil below that depth has probably not reached drained upper limit. If this is suspected, or if no NMM information is available, the water potential of the soil profile should be checked before sampling. This may be done using either a filter paper technique (Fawcett and Collis-George 1967) or a tensiometer (see p.88).

When the profile is considered to be fully wet, an area of about 4 m x 4 m is covered with heavy gauge plastic sheet (100 micron builder's plastic) to minimise evaporation before sampling.

Ponded water

If drained upper limit cannot be determined from *wettest soil profile* or if the soil is already partially wetted and surface infiltration slow, an artificial wetting-up technique can be used.

The ponded method (Figure 4.8) is suitable for lighter-textured soils where entry and movement of water through the profile are rapid. However, it is not suitable for slow-draining, heavier textured soils.

Procedure for ponding

1. Select a representative site away from trees and other vegetation.
2. Insert a neutron moisture meter access tube to the potential depth of crop rooting (180 cm for most of the soils of the northern grain belt).
3. Make a circular soil bund of 1.5 m radius and about 30 cm height around the access tube.
4. Apply water regularly to the pond, monitoring with the neutron moisture meter until saturation is reached.
5. Knock down the bund.

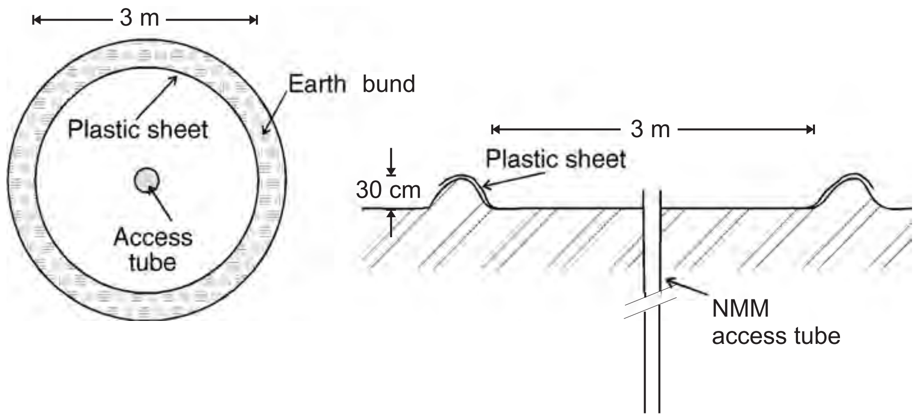


*Figure 4.8. Layout for the p*onded water technique *showing the earth bund surrounding the ponded area with the NMM access tube in the centre.*

6. Cover the area with plastic sheeting to minimise evaporation (100 micron builder's plastic).
7. Monitor the progress of drainage using the neutron moisture meter.
8. Sample when drainage has almost ceased and the soil is considered to be at drained upper limit (this may be confirmed using the tensiometer to check water potential).

Free-draining soils are usually allowed to drain for 2–3 days before sampling, but some soils should be left longer if drainage is still substantial (greater than 1 mm/day) (Gardner 1984).

Trickle irrigation

Trickle irrigation is the preferred method for shrink-swell soils where infiltration is slow (Figure 4.9). If these soils are ponded, structural instability (slaking of soil aggregates)may cause *throttles* to develop at or near the soil surface (Williams 1983); these severely reduce the rate of infiltration. The slower rate of application under trickle irrigation minimising this problem, in one case reducing the time of wetting-up from 12 weeks under ponding to three weeks.

The secret to success with trickle irrigation is not to *push* the system by applying more water than the soil can accept. To prevent the degradation of the surface structure, application should be below the rate that would cause surface ponding. An application rate, used when describing many of the soils listed in Module 5, was 200 L per week (applied to a pond area of 16 m^2).

Another method involves intermittent micro sprinkler irrigation (managed by an electronic controller) applying small amounts of water on a regular basis. The area is covered with straw mulch to minimise evaporation (Gardner E.A., pers coms).

Combined technique

On a dry, cracked, heavy-textured soil, a combination of techniques may reduce wet-up time.

High-volumes of water are applied directly into the cracks (Swartz 1966) until they close; trickle irrigation is then used to complete the process.

This system also ensures that the area surrounding the pond site is quickly wet-up, thus slowing the lateral movement of water into the drier surrounding areas.

Water should be applied down the cracks and not onto the soil surface as any surface degradation could affect later water entry during the trickle phase.

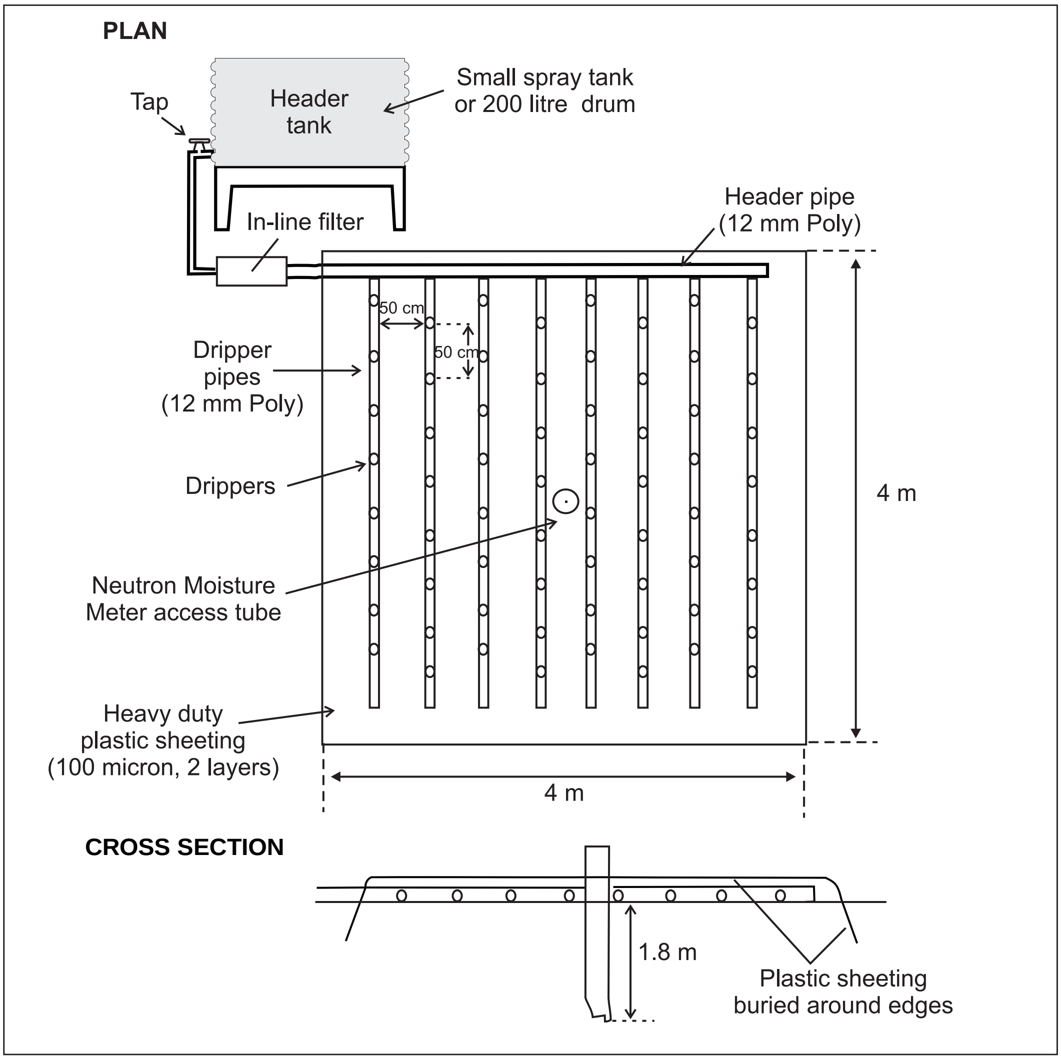


Figure 4.9. Layout for the trickle system showing the header tank supplying water to the trickle lines which are covered by plastic sheeting to stop evaporation.

Sampling for DUL

Soil moisture levels are monitored with a neutron moisture meter. Once readings indicates that drainage is minimal, soil samples are taken to determine volumetric water content at the estimated drained upper limit (Formulae 5 and 6, p. 73).

When BD is not measured in conjunction with DUL (e.g. when BD is calculated – see *Water balance modelling of shrink-swell soils,* p.80), coring may be done with a small-diameter tube. A minimum diameter of 50 mm is recommended. The tube must be able to be inserted into wet clay, and the sample removed without substantial damage.

If both BD and DUL are measured together, a single set of samples may be used. However, these samples must conform to the more exacting requirements of sampling and processing required for BD determination (see *Determining Bulk Density*, p.74).

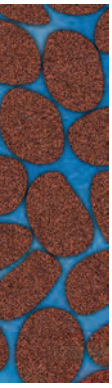
Trickle irrigation method

1. Use the hydraulic soil coring rig to insert a NMM access tube.
Insert a 50 mm soil tube to the desired depth and remove the soil from the core hole. Push the aluminium NMM access tube into the hole using the hydraulics. The tube must fit tightly in the core hole to ensure accurate and consistent readings.

2. Dig a 15 cm deep trench to bury the sheet edges to stop evaporation loss from the pond site.

3. Lay out the trickle system.

4. Lay plastic sheeting in place before back-filling the trench.



5. Attach the water reservoir to the trickle system. Note the NMM access tube in the centre of the area.

6. Monitor the progress of wetting-up *using a Neutron Moisture Meter.*

The neutron moisture meter (NMM)

A neutron moisture meter emits fast neutrons which are reflected back at slow speeds to a detector in proportion to the concentration of hydrogen atoms in the soil; this hydrogen is found predominantly in water molecules.

The detection of the neutrons is measured by the meter as a count rate. To provide a reference (to allow for instrument variability etc), the count rate is usually expressed relative to the count rate measured in water (using a drum of water with an access tube installed). The calibration enables the resulting count rate ratio to be converted to volumetric water content.

Calibrating and using the NMM in soil characterisation

A neutron moisture meter (NMM) must be calibrated to measure the actual soil water content for a particular soil type.

To calibrate the NMM, volumetric soil water values (at varying moisture contents) for a particular soil type are related to the NMM readings at the same soil depth layers. This calibration allows a regression equation to be calculated for the particular soil type.

In most cases, this information is not available when a soil is characterised for the first time; the characterisation exercise provides some of the information necessary to calibrate the neutron moisture meter.

Even so, the NNM can still indicate wetting up (or drainage) as the changes in the count rate, over time, reflect relative changes in water content. This should be started before the initial wetting up of the characterisation site so that all water movement can be tracked (as shown in Figure 4.10).

When calibrating the neutron moisture meter for a particular soil type, NMM readings and corresponding volumetric water contents should be determined when the soil profile is dry (generally at tube installation) and when wet (at final sampling drained upper limit). Additional readings and volumetric data for intermediate water contents will improve the accuracy of the calibration function. A calibration equation is then derived for that particular soil type.

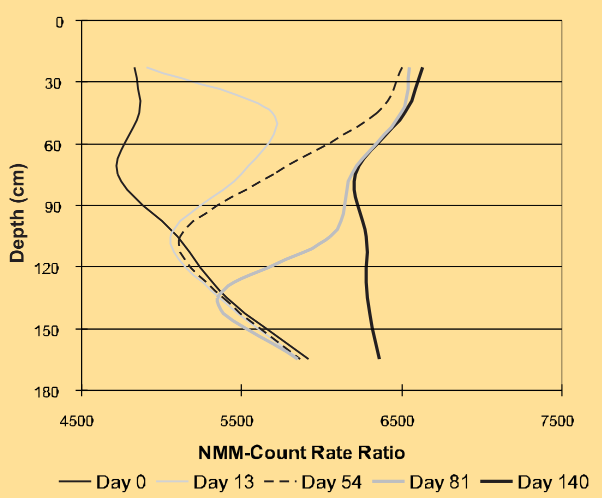
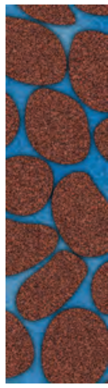


Figure 4.10. The sequential wetting-up of a heavy clay soil monitored by neutron moisture meter. The wetting front moves progressively deeper into the profile of a heavy-textured clay soil under water ponded for an extended period; in a lighter-textured soil, or where trickle irrigation is used, wetting-up would normally occur more quickly.



Field use of portable tensiometers

A portable tensiometer is useful in determining water potential in soil cores when confirmation of water status is needed before sampling for drained upper limit.

Field kit

Portable tensiometer with probe and reader (see Appendix 2 for list of suppliers); plastic sheeting for wrapping cores, bucket, probe support, 4 mm drill bit, tissues and de-ionised water.

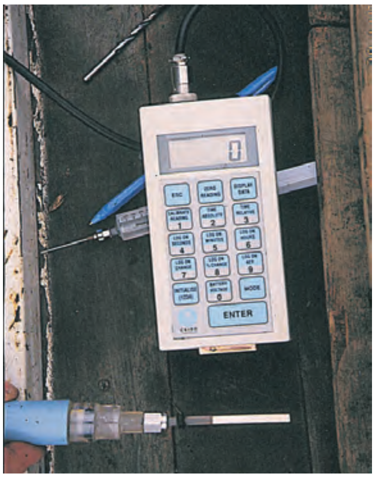
Procedure for measuring water potential

1. Assemble pre-wetted tensiometer tip on probe as in instruction manual.
2. Wet tip in a bucket of water, hold horizontally in a shaded place and check reading is zero.
3. Take a soil core (50 mm diameter) to the required depth, remove core from tube and roll in plastic sheeting to reduce evaporation.
4. Drill a hole with 4 mm bit, through the plastic, to thickness of core at the mid-point of each standard sampling depth. Extract only a small amount of soil at a time, cleaning drill regularly.
5. Push in probe tip carefully; do not use force or the tip may break. If core cracks, press it together gently.
6. Watch readings—it may take 2–5 minutes for equilibration as water movement in clay soils is very slow, and may be retarded if the drill smears the hole. The probe may need support while it is equilibrating.
7. After reading the meter, gently extract the probe, wash it with a very wet tissue to remove soil, then rinse and leave the probe in a bucket of water until the next reading.
8. Drill the next hole, and repeat steps 5–7.
9. After completing all measurements, clean the equipment and dry the tips before storing.

Note: The theoretical drained upper limit for a clay soil is 10 kPa (0.1 bar) suction, equivalent to a reading of 1000 on the portable tensiometer. A range of 900–1100 is considered to be at DUL. Soil is wetter than DUL if read-out is less than 1000, and drier than DUL if greater than 1000.

(Notes from B. Bridge, CSIRO Land and Water)

Measuring water potential with a tensiometer



Hold tensiometer probe horizontal and level with the reader to check calibration.

Drill a 4 mm diameter hole into the soil core for the probe (the protective plastic sheeting has been removed for the photograph).

Carefully insert the probe into the pre-drilled hole to avoid damage to the ceramic tip or cracking the soil core.

Allow 2–5 minutes for equilibration of the water potential.

Clean the probe after extraction using a very wet paper tissue.

Measuring crop lower limit in the field

Opportunistic approach

Volumetric water content (Formulae 5 and 7, page 73) is determined for a crop showing signs of water stress. This sampling will provide the crop lower limit for the particular crop x soil type (Ratliff et al. 1983). Whilst this is the most expedient way to determine crop lower limit, the technique has some drawbacks:

- unless fresh roots are visible, it is not known to what depth current crop roots explored and extracted water.
- where water is available to the crop in the near surface layers (particularly from in-crop rainfall), the crop may not fully exploit water deeper in the profile.
- the crop may be poor performing (due to nitrogen or other stress) and thus not represent potential extraction of the crop.
- late rain at the end of the season may re-wet the profile and prevent useful data being obtained.

The 'rain-out' shelter

Wilting can be induced by excluding rain from a vigorously growing crop. A rain-exclusion tent (see next page) is generally erected at around the time of crop flowering and remains in place until the crop has matured. The lower limit of crop water extraction is then determined.

Procedure

At flowering:

1. Take soil samples to determine the soil water profile.
2. Erect a rain-exclusion tent over the site.

At crop maturity:

3. Take at least three cores per site and determine volumetric soil water content (Formulae 5 and 7, p.73) averaged over the data sets.

Compare soil water levels at flowering and at crop maturity to determine depth and extent of recent water extraction and use data only to the depth where extraction is shown to have taken place.

In the top one or two sampling intervals (in the top 30 cm), evaporation may dry the soil to below crop lower limit. It is best to modify the volumetric soil water for these layers to the value found in the next deepest layer to ensure that plant available water is not over-estimated in the soil surface (Table 4.2).

Because of the seasonal variation in depth of soil wetting, evaporative demand and rooting depth of a particular crop type, CLL should be measured over a number of seasons, and the data modified with time.

Table 4.2. Crop Lower Limit Measurements - Volumetric Soil Water (%)

Soil sample depth (cm)	Core 1	Core 2	Core 3	CLL mean	CLL modified
0-15	16.9	18.5	17.9	17.8	21.8
15-30	20.0	20.7	19.8	20.2	21.8
30-60	21.9	22.1	21.5	21.8	21.8
60-90	23.1	23.0	22.3	22.8	22.8
90-120	24.0	23.5	23.5	23.7	23.7
120-150	25.7	24.9	25.0	25.2	25.2
150-180	26.1	25.7	25.9	25.9	25.9

A 'rain-out' shelter

A rain exclusion tent placed in position in a cotton crop. Air vents are provided at the apex of both ends of the tent to allow flow of moist air from the tent.

A rain exclusion tent showing the rooftop perspex insert fitted to improve light to the growing crop.

Trenches across each end of the tent stop surface water entering the tent.

Soil Characterisation Database

The variables needed to determine Plant Available Water Capacity for many of the important soil types of southern and central Queensland and northern New South Wales have been, or are in the process of being, measured.

The information is provided in Module 5: **Soil Characterisation Data.** This database is updated periodically; it is available on the Internet at: http://www.farmscape.tag.csiro.au/

5. Soil characterisation data

What soil type?

Assessing the level of water and nitrogen available to grow a crop depends on selecting the right soil information. This relies on experience and knowledge of the local area and on being able to describe the physical properties of the particular soil type.

Three aids to this have been included:

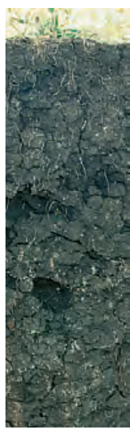
1. *Determining soil texture* describes how to define the texture of the soil.
2. *Identifying the soils of the Condamine Floodplain* is a key to identification of the major soils of the Darling Downs associated with the Condamine River. Identification is based on soil texture, structure, colour and associated native vegetation.
3. *Soil Map of the Central Downs* identifies the major soil groupings for the Darling Downs. Overlaid on these major groups is the location of each of the characterisation sites (for the Darling Downs) referred to in this module. This enables identification of the soil type and location of the nearest appropriate characterisation site. The map is published by the Queensland Department of Natural Resources.

If your area is not covered by the key or map, you should contact local consultants, DPI, DNR or Agriculture Department staff to help you with soil identification.

APSoil

APSoil is a computer program which allows you to input the analytical results received from the lab and to select soil characterisation information for a particular soil type (based on the information in this module). APSoil then calculates the quantity of water and nitrogen available to a particular crop. The results can be presented as graphs or tables.

An example of APSoil output is given in Module 1 (p.5). APSoil software can be downloaded at: http://www.farmscape.tag.csiro.au



1. Determining soil texture

(*adapted from* Soil Check, *Forge, 1995*)

Texture is a measure of the relative proportions of sand, silt and clay in the soil. It can be estimated from observing the changes in a small handful of soil when moistened with water, worked into a ball and pressed between your thumb and forefinger. Topsoil and subsoil textures are always determined separately.

The soil's texture can tell a lot about how the soil interacts with plants in an agricultural system. Texture is important because it affects movement, retention and availability of water and nutrients in the soil, and the soil's behaviour when cultivated.

Texture also affects other aspects of the soil, such as structural behaviour and susceptibility to erosion. The clay component is very important because it holds most of the water and nutrients. On the other hand, soils with a high clay content can have drainage problems. Structure (the arrangement of particles in peds and larger aggregations) also influences drainage.

You will need:

- rainwater or clean water
- soil samples
- a sieve (if there is gravel in the soil).

Five easy steps to soil texture

Note: if a soil corer has been used, look over the length of the core first. Generally, sandy and loamy soil breaks up easily, while a layer that is high in clay will be highly cohesive.

Repeat the following steps on each part of the soil to be tested.

1. Take enough soil to fit into the palm of your hand. Remove any large stones, twigs or stubble.
2. Moisten the soil with water, a little at a time, and knead until the ball of soil just fails to stick to your fingers. Add more water to get it to this *sticky* point (this is the soil's Drained Upper Limit).
3. Work the soil in this manner for one to two minutes, noting its behaviour (See Table 5.1). Inspect the sample to see if sand is visible. If not, it may still be felt or heard as the sample is working.

A soil with a high proportion of:

- sand – will feel gritty
- silt – will feel silky
- clay – will feel sticky

4. Press and slide the ball out between thumb and forefinger to form a ribbon. Note the length of self-supporting ribbon that can be formed.
5. Use Table 5.1 to classify the soil.

Remember that soil texture can change as you go down the soil profile and this variation is described by the following terms:

- *Uniform* – the texture is the same throughout the profile.
- *Duplex* – the texture changes significantly at a certain depth; there is often about 150 mm of loam over a dense clay subsoil. (These are also called texture-contrast soils.)
- *Gradational* – the texture changes gradually down the profile. Many soils vary from a loamy surface to a clay loam and then to clay.

(adapted from Chapman and Murphy, 1991)

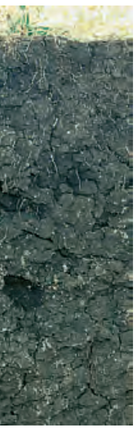
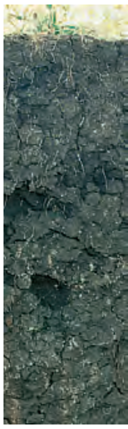


Table 5.1. How to determine soil texture

Ball	Ribbon (cm)	Feel	Texture
Will not form a ball	0.5	single grains of sand stick to fingers	sand (S)
Ball just holds together	1.3-2.5	feels very sandy, visible sand grains	loamy sand (LS)
Ball holds together	1.3-2.5	fine sand can be felt	fine sandy loam (FSL)
Ball holds together	2.5	spongy, smooth, not gritty or silky	loam (L)
Ball holds together	2.5	slightly spongy, fine sand can be felt	loamy fine sand (LFS)
Ball holds together	2.5	very smooth to silky	silt loam (SL)
Ball holds together strongly	2.5-4	sandy to touch, medium sand grains visible	sandy clay loam (SCL)
Ball holds together	4-5	plastic, smooth to manipulate	clay loam (CL)
Ball holds together strongly	5-7.5	plastic, smooth, slight resistance to shearing between thumb and forefinger	light clay (LC)
Ball holds together strongly	>7.5	plastic, smooth, handles like Plasticine, can be moulded into rods without fracture, moderate shearing resistance	medium clay (ML)
Ball holds together strongly	>7.5	plastic and smooth, handles like stiff Plasticine, can be moulded into rods without fracture, very firm shearing resistance	heavy clay (HC)



2. Identifying the soils of the Condamine Floodplain

This key will help in identification of soils on the Condamine floodplain.

It should be used in conjunction with the section on determining soil texture (Table 5.1) and with Table 5.2 which provides information on some of the characteristics of the major soils of the Darling Downs.

Key to the soils of the Condamine Floodplain

1.	Soil profile is a uniform clay texture throughout	2
1.	Soil profile exhibits a texture contrast (between the surface and the subsoil)	3
2.	Soil surface is very fine (powdery), and soil depth is <1.0 m	4
2.	Soil surface is fine to coarse, and soil depth is >1.0 m	5
3.	Soil profile is red-brown or red in colour	6
3.	Soil profile is predominantly brown or black in colour	7
4.	Subsoil is dominated by hard calcareous material (and within 50 cm of the surface)	*Edgecombe*
4.	Subsoil is dominated by >50% soft calcareous material (and within 50 cm of the surface)	*Yargullen*
5.	Soil surface exhibits moderate to severe cracking	8
5.	Soil surface exhibits minor cracking, subsoil brown LC-MC*	*Anchorfield*
6.	Soil surface texture is FSL to FSCL, A horizon is <30cm deep, hard-setting, vegetation is poplar box	*Oakey*
6.	Soil surface texture is <FSL, A horizon is >30cm deep, crusting to hard-setting	*Formartin*
7.	Subsoil is black (dark), surface hard-setting	*Haslemere*
7.	Subsoil is brown, surface hard-setting	*Dalmeny*
8.	Soil surface is grey, with visible fine sand, often crusting/hard-setting texture LC, vegetation is poplar box	*Cecilvale*
8.	Soil surface is self-mulching	9
9.	Sand (usually coarse) visible throughout the profile, found in close proximity to major streams, commonly flooded, usually growing river red gum	*Condamine*
9.	Little or no sand visible in the profile	10
10.	Surface structure coarse	*Mywybilla*
10.	Surface structure fine to moderate	11
11.	Surface structure is fine	12
11.	Surface structure moderate, found in depressions amongst Waco	*Waverly*
12.	High phosphorus levels	*Waco*
12.	Occurs between *Waco* and *Mywybilla*, low phosphorus levels	*Norillee*

Soil texture abbreviations are detailed in Table 5.1.

(*Information from A. Biggs, DNR, Toowoomba*)

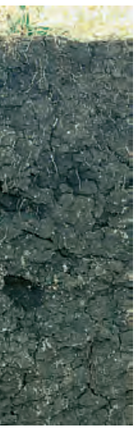
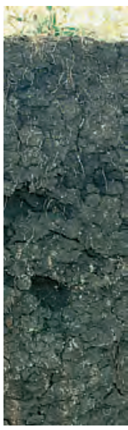


Table 5.2. Characteristics of Darling Downs soils

Soil name	Waco	Cecilvale	Anchorfield
Origin	Basaltic, alluvium, on active, low gradient fans	Alluvial fan derived from Walloon sandstone & basalt	Condamine River alluvium, basaltic source
Great soil group	Black Earth Ug5.15	Grey clay Ug5.4	Black Earth Ug5.15
Natural vegetation	Plain dominated by *Themeda* and medics	Poplar Box	Broad low banks on plain
Colour	Surface - very dark brown (10yr 2/2 - 7.5yr 2/2) At depth - dark brown (at 1.5 m, 10yr 2/3, at 1.8m, 7.5yr 4/3)	Surface - grey (not brown)(10yr 3/1) At depth - yellow/ olive (2.5yr 4/2, 5/3)	Surface - very dark brown (10yr 2/2-7.5yr 2/2) At depth - brown and yellow/ brown (7.5 yr 3/3 - 4/2, 10yr 5/4)
Clay %	70-75	35-50	50 at surface 32 at depth
Structure/ cracking	Structure - very fine surface tilth; no sand in surface, aggregates break down to microscopic level on slickensides good emergence Cracking - severe, related to clay % and type (smectite clay prone to cracking)	Structure - coarse surface; sandy particularly after rain, prone to crusting/ slaking; poor emergence Cracking - moderate	Structure - coarser than Waco but finer than Condamine; quartz sand at surface; sub-soil very fine sand in sedimentary layers (no structure) Cracking - minor
Phosphorus (mg/kg) **(soil in natural state)**	Total 1000-2000 BSES* 800-1400	Total 200-300 BSES* 7-10	Total 1700 BSES* 900-1400
Calcium carbonate	Diffuse with nodules (through profile)+ soft areas at depth (surface effervesces with H_2SO_4 or HCl)	nodules at depth	nodules at depth
Comments	very soft soil easy to push spade into full depth Boron may be deficient	Sandy hard setting surface, prone to crusting	Subdued gilgai, small mounds 1-2m across, <5cm above general level

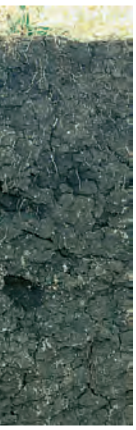
*BSES – extraction with dilute H_2SO_4



Soil matters

Soil name	Norillee	Mywybilla	Condamine	Irving
Origin	Alluvium origin, is either distal end of Waco fan or older fan; of similar age to C/vale but from different parent material (more sandstone)	Condamine River alluvium, same age as Cecilvale	Condamine River alluvium (mixed origin), present flood plain	Basaltic, colluvium
Great soil group	Black Earth Ug5.16	Black Earth Ug5.16	Black Earth Ug5.15 or 5.16	Black Earth Ug5.15
Natural vegetation	Open grass plain	Open grass plain, no medics in natural state	Blue gum woodland	Woodland
Colour	Surface - greyer than Waco, similar to cultivated C/vale (10yr 3/1) At depth - not as brown as Waco, olive/brown (2.5yr 3/2) to light brownish grey (10yr 5/1), some yellowish mottle	Surface - greyer than Norillee (10yr 3/1) At depth - olive/ brown (2.5yr 3/2 to 10yr 5/1) usually with faint yellowish mottle	Surface - very dark grey brown (10yr 2.5/1.5) At depth - dark grey/brown (10yr 3.5/2)	Surface - 10yr 2/2-3 to 7.5yr 2/2, 2/3 At depth - reddish brown (5yr 4/3)
Clay %	65-70	60-70	58-80	68-70
Structure/ cracking	Structure - physically similar to Waco (fine surface structure), no sand in surface; chemically similar to Mywybilla (related to it) Cracking - severe	Structure - tight, coarse, blocky structure (hard to break apart), abrasive, some sand in surface; poor emergence Cracking - severe	Structure - medium to coarse, tight, blocky, sand through profile Cracking - severe	Structure - fine to medium Cracking - moderate
Phosphorus (mg/kg) (soil in natural state)	Total <400 BSES* 70-90	Total low, <400 BSES* 5-20	Total 800-1600 BSES* 340-700	Total1000-1400 BSES* 500-700
Calcium carbonate	diffused with nodules through profile (surface effervesces with H_2SO_4 or HCl)	nodule form only, to within 10cm of surface in mounds	nodules at depth	nodules at depth
Comments	high salt level at depth (> 1m) may affect water uptake; fine surface tilth may be due to high % of diffuse Ca	hard to wet up but good water holding, harsh feel of cultivated aggregates, lumpy surface appearance after rain as large aggregates resist break down	Quartz grain sand evident in surface	Linear gilgai

Soil information from C. Thompson, CSIRO



Soil characterisation data

Data that characterise the soils of the northern cropping region are detailed in a separate booklet provided in the manual folder.

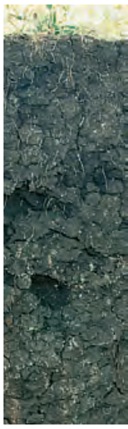
Updated versions of the booklet will be available periodically from APSRU or may be downloaded from the Internet at:

http://www.farmscape.tag.csiro.au/
or by contacting the author.

Soil characterisation data has been provided by:

M. Bange, CSIRO Cotton Research Unit, Narrabri
M. Bell, DPI, Kingaroy
I. Broad, DPI/APSRU, Toowoomba
N. Christodoulu, DPI, St George
J. Gray, DNR, St George
R. Connolly, DNR/APSRU, Toowoomba
C. Cole, McGregor Consulting, Croppa Creek
D. Freebairn, DNR/APSRU, Toowoomba
G. Wockner, DNR/APSRU, Toowoomba
D. Lack, DPI, Emerald
G. Thomas, DPI, Toowoomba

Characterisation data in the database which are not attributed to a source have been collected by S. Cawthray and N. Dalgliesh, CSIRO/APSRU Toowoomba.



Appendix 1.
Manufacture of soil sampling equipment

Push probe

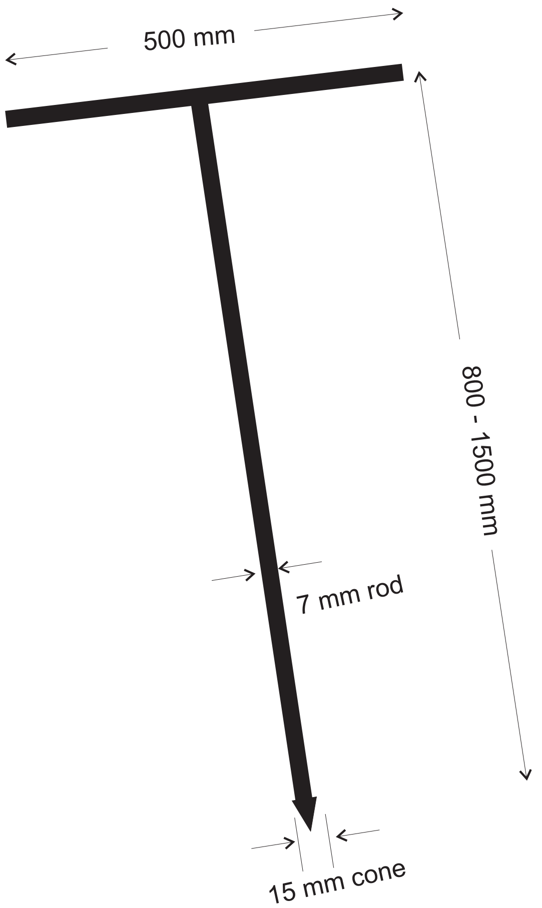


Figure 6.1. Diagram of push probe widely used by farmers to measure depth of wet soil. Other designs include the use of a spring and a pointer system to visually indicate soil resistance; these are described in the following publications (Fawcett 1969; Fawcett et al. 1974).

Wooden driver

A wooden driver is preferred to steel for driving tubes by hand or when forming cutting tips. A steel hammer will burr the collar or cause distortion below the collar, which may create difficulties in removing the soil core.

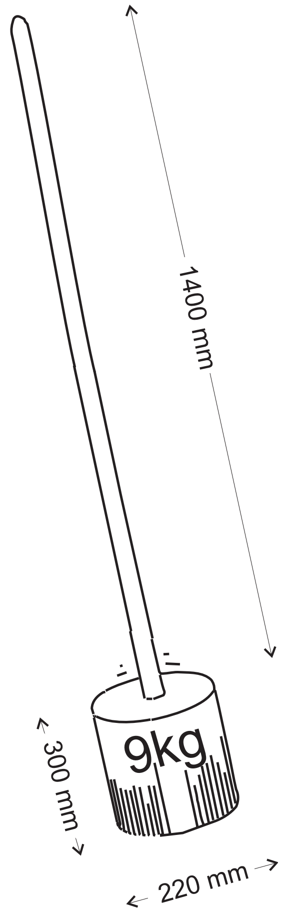


Figure 6.2. The driver *used to insert coring tubes into the soil by hand has a cylindrical head of hardwood of density 1 g/cc or higher and weighs 9–12 kg.*

Hand jack

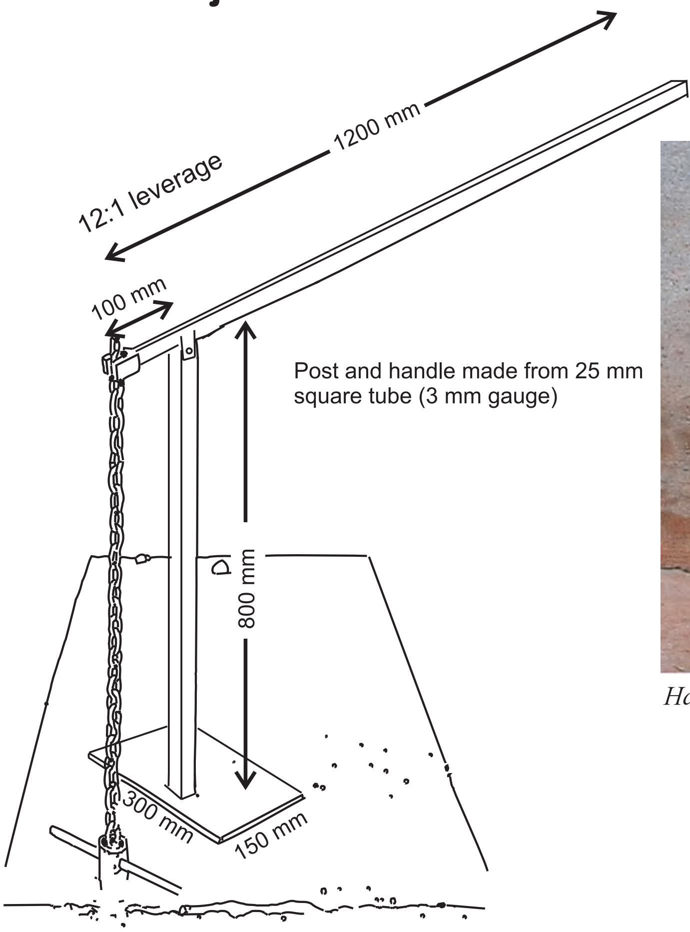


Figure 6.3. Hand jack to pull coring tube from the soil.

Hand-jack for extracting core tube

Claw for pulling chain on jack lever

Soil coring tube

The tube body is made from semi-bright steel exhaust pipe with a wall thickness of 1.6 mm (Foale 1980) (Figure 6.4). Its length relates to the depth of sampling (generally 1 to 2 metres). Tube diameter depends on the task and the type of sampling equipment available. Common tube sizes are, OD (outside diameter) 32, 38, 45 and 50 mm. Use smaller sizes for easier hand-driven sampling; use 38 or 50 mm OD tube with a hydraulic rig—38 mm is preferred in dry conditions.

The top end of the tube is reinforced with a collar of a heavier gauge steel pipe (3-4 mm wall thickness) slid over the soil tube and welded into place. To minimise weakening of the tube wall, the base of the collar is spot-welded with a full weld around the top (Figure 6.4).

The internal taper allows free movement of the soil core inside the tube; the external bulge provides clearance between the wall of the core hole and the outer wall of the tube, minimising friction as the tube is inserted and removed.

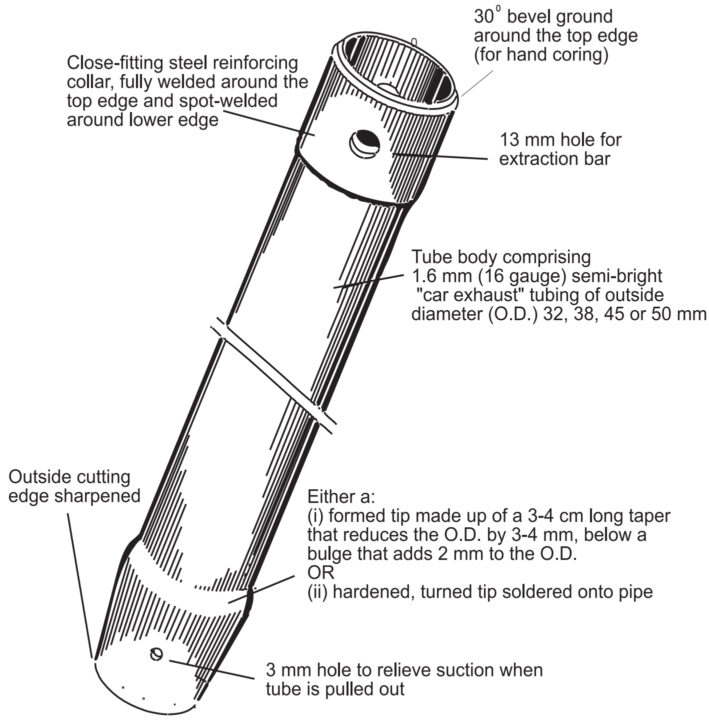


Figure 6. 4. Features of a thin-walled soil coring tube suitable for coring to a depth of 1.8 m in most soil profiles free of stony obstructions. The cutting end shown is formed from the tube using a metal die (see below).

Making the die

The cutting tip of the tube may be either turned (page 105) or formed using a die. The die is turned from Swedish hollow bar tube to have a taper of 1 mm in 10 mm (Figure 6.5). Driving a tube 40 mm into the die will reduce the diameter of the tip of the tube by 4 mm. A base plate and guide tube improve consistency in forming tips.

A die (120 mm high) with a top diameter of 40 mm and a bottom diameter of 28 mm can be used to form 32 mm and 38 mm tubes.

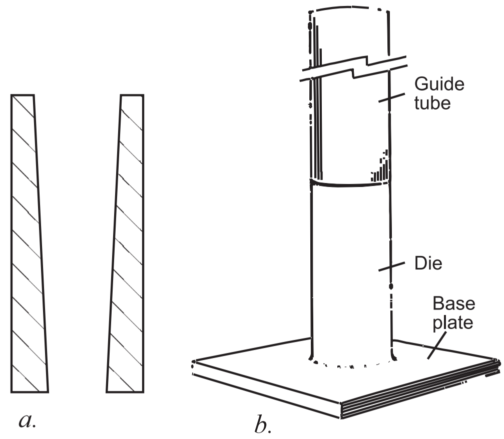


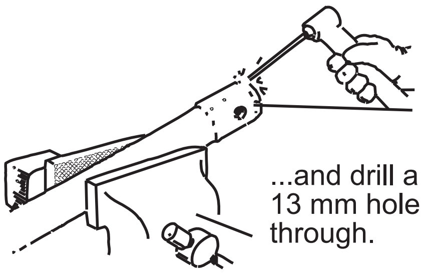
Figure 6.5a (left).Vertical section of die with inside wall machined to 3^0 incline.

Figure 6.5b (right) The die is welded to a steel base plate 150 mm square. A 400 mm length of pipe is welded to the top of the die as a guide for the coring tube.

Constructing the soil tube

① Cut a piece of exhaust tubing (semi-bright quality, 1.6 mm thickness) to the required length, i.e. 1-2 m

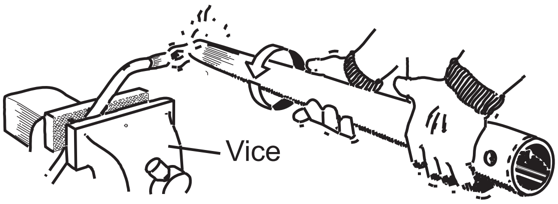
② Fit and weld a reinforcing collar to the top end of the tube...



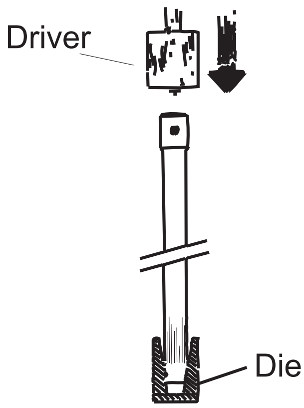
...and drill a 13 mm hole right through.

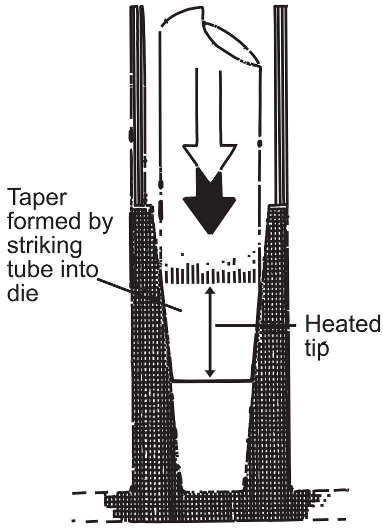
The tube collar with holes for extraction pin and spot-welds around its lower edge.

③ Hold the end of the tube in a heating flame rotating it rapidly until 3-4 cm is glowing red

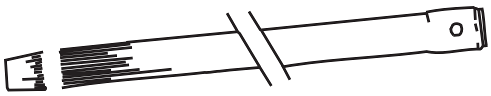


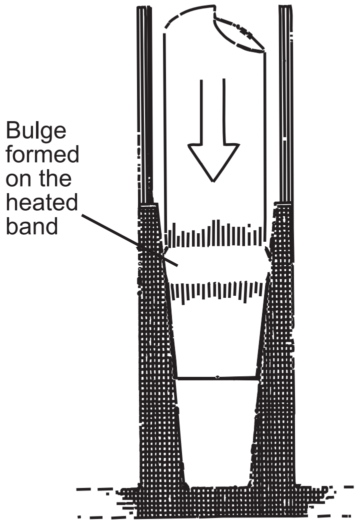
④ Quickly place the heated tip in the die, holding it vertically strike it firmly with a heavy wooden driver. Two cycles should produce a taper 3-4 cm long. Heat the die for about 30 seconds before starting to form the tube.



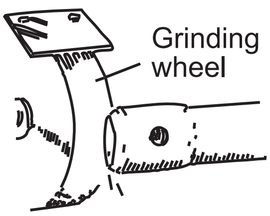


⑤ Heat a 10mm wide band around the tube, just above the taper, to red hot, place in the die and strike one firm blow to form a bulge above the taper. If the tube shows signs of folding cut off the end and start again.





⑥ If hand coring, grind a 30° bevel around the top end of the tube so that the wooden driver will always strike near the inside edge.



Drill a 3 mm airhole midway along the tapered portion of the cutting end.

Check the diameter of the offset is reduced by 3-4 mm

Remove all weld dags and burrs from the inside of the tube.

Formed or turned tip?

You can form the cutting tip of the tube in a die or use a tip turned on a lathe and silver-soldered onto the end of the tube. The formed tip is cheaper to make and easier to repair; it can be cut off when badly damaged, and a new tip formed.

A turned tip is made with more precision giving more consistent standards, but is difficult to repair. A damaged turned tip has to be replaced.

A formed tip

A hardened steel turned cutting tip

Silver solder the turned tip onto the tube.

Appendix 2. Equipment suppliers

Suppliers of soil sampling equipment and materials for the fabrication of equipment are listed. The list is not exhaustive but comprises businesses who have been able to provide equipment or services to the authors during the course of their work.

Bags

Paper bags – 133 x 70 x 235 mm satchel bag (virgin HWS brown craft), 60 gsm, PVA glued.
Plastic bags – 200 x 300 mm 100 micron code no 040415.

Garden City Wholesalers, 12 Peachy St., Toowoomba, Qld 4350
Tel: 07-46 327 622 Fax: 07-46 385 691

Coring tubes, turned cutting tips, tip-forming die

Hand and hydraulic – all diameters and lengths
Turned cutting tips – to suit 32, 38 and 50 mm tubes.
Tip-forming die to suit all tube diameters between 32 and 50 mm.

Acre Industries, 417 Boundary St., Toowoomba, Qld 4350
Tel: 07- 46 344 040 Fax: 07- 46 344 040

Hand coring equipment and push probes

Big Rig Machinery, Wambo St., (off Loudoun Rd) Dalby, Qld 4405
Tel: 07-46 623 504 Fax: 07-46 623 124

Hand coring tubes

INCITEC, Anzac Av., Toowoomba, Qld 4350
Tel: 07-46 397 400 Fax: 07-46 397 410

Hydraulic sampling rigs

– built to order
Milne Industries, PO Box 735, Dalby, Qld 4403
Tel: 07-46 621 374 Fax: 07-46 623 645

Big Rig Machinery, Wambo St., (off Loudoun Rd) Dalby, Qld 4405
Tel: 07-46 623 504 Fax: 07-46 623 124

BJ Welding Works, Southern Rd., Roma, Qld
Tel: 07-46 224 600 Fax: 07-46 224 600

Christie Engineering Pty Ltd, 123 Delaware Rd., Horsley Park, NSW 2164
Tel: 02-96 20 1208 Fax: 02-96 20 1208

Pipe for tube fabrication

– tube body - ERW steel tube, 1.6 mm wall thickness for 50 mm OD, 38 mm OD, 32 mm OD
– tube collar - heavy black pipe, 3-4 mm wall thickness, 50 mm ID, 38 mm ID, 32 mmID.

Steelmark-Eagle & Globe, 340-360 Anzac Av., Toowoomba Qld 4350
Tel: 07-46 941 133 Fax: 07-46 301 838

Portable electronic balance (battery operated)

– Wedo Accurat Digital Scales, 2 kg capacity, 1 g definition.

Downs Office Equipment, 203 James St., Toowoomba Qld 4350
Tel: 07-46 324 733 Fax: 07-46 382 177

– Arlec Digital Scales, 2 kg capacity, 1 g definition Model No DS102.
Most hardware and electronics stores.

Portable tensiometer

Hydra Sensa, Skye Instruments, Units 5/6, Dole Industrial Estate, Llandrindod Wells, Powys LD1 6DF, UK Tel: 0011-44-1597 824811 Fax: 0015-44-1597 824812

Tensiometer (Display Type) DIK-3150
Daiki Rika Kogyo Ltd, 60-3 Nishiogu 7-choma, Arakawa-ku, Tokyo, 116, Japan
Tel: 0011-81-3-3810 2181 Fax: 0015-81-3-3810 2185

Rain exclusion tent covers

– made to order.

NJ Canvas (David Green), Anzac Av., Toowoomba Qld 4350
Tel: 07-46 301 400

Rain exclusion tent frames

– made to order.

Acre Industries, 417 Boundary St., Toowoomba Qld 4350
Tel: 07-46 344 040 Fax: 07-46 344 040

Soil characterisation sampling equipment

– large diameter tubes, cutting trays and anvils.

Acre Industries, 417 Boundary St., Toowoomba Qld 4350
Tel: 07-46 344 040 Fax: 07-46 344 040

Tube lubrication oil, silicon

– 200 Dow Corning Silicon 50CS.

Ajax Chemicals, 739 Progress Rd., Wacol Qld 4076
Tel: 07-338 599 444 Fax: 07-338 599 499

INCITEC, Anzac Av., Toowoomba Qld 4350
Tel: 07-46 397 400 Fax: 07-46 397 410

Tube lubrication oil, mould oil

Major oil companies

Wire brushes

– boiler tube brushes of diameter to fit inside coring tube.

Garden City Wholesalers, 12 Peachy St., Toowoomba Qld 4350
Tel: 07-46 327 622 Fax: 07-46 385 691

Appendix 3. Software suppliers and contacts

HOWWET? and **HOWOFTEN?**
D Freebairn, APSRU, PO Box 102, Toowoomba, Qld 4350
Tel: 07-46 881 391 Fax: 07-46 881 193 Email: freebad@dpi.qld.gov.au
These programs may also be downloaded from the APSRU web site at
http://www.apsru.gov.au

Australian Rainman
Any DPI Office and Bureau of Meteorology, Melbourne and Sydney
Queensland Centre for Climate Applications, DPI, DNR, PO Box 102 Toowoomba, Qld 4350
Tel: 07-46 881 200 Fax: 07-46 881 477 Email: qcca@dpi.qld.gov.au

APSoil
Neal Dalgliesh, APSRU, PO Box 102, Toowoomba, Qld 4350
Tel: 07-46 881 376 Fax: 07-46 881 193 Email: Neal.Dalgliesh@tag.csiro.au

APSIM
Peter Carberry, APSRU, PO Box 102, Toowoomba Qld 4350
Tel: 07-46 881 377 Fax: 07-46 881 193 Email: Peter.Carberry@tag.csiro.au

Wheatman Plus
V. French, DPI, Miles Qld 4415
Tel: 07-46 271 599 Fax: 07-46 271 775

Appendix 4. Glossary of terms

bulk density	weight of solid material in a unit volume of soil (as g/cc).
bulking	mixing of soil samples from a paddock or plot to reduce the number of samples for analysis.
crop lower limit	lower limit of water extraction for a particular crop in a particular soil.
depth or sampling interval	length of a section cut from a soil core to represent a defined soil layer (eg. 30-60cm layer).
drained upper limit	upper storage limit of a soil. It is the amount of water that a soil holds after drainage has practically ceased.
hand coring kit	tools needed to take a soil core with hand power — wooden driver, jack and coring tube.
hydraulic coring rig	a hydraulic-powered rig, usually mounted on the back of a road vehicle or tractor which is used to push in and withdraw soil coring tubes.
intensity of sampling	number of cores taken to represent the soil of a particular production area.
leaching	process where soluble nutrients (such as nitrogen) are carried by water down the soil profile.
nitrogen bulge	accumulation of a significant amount of nitrate nitrogen at depth in the soil profile.
parts per million	grams of a nutrient (e.g. N, Zn, P, K) per tonne of soil (equivalent to mg/kg).
plant available water capacity	maximum water available to a crop from a particular soil type. The difference between the upper storage limit of the soil and the lower extraction limit of a crop.
rooting depth	maximum soil depth at which the roots of a particular crop have been observed over a number of seasons.
sampling strategy	combination of sample number, bulking procedure, sampling depth interval and core location devised to obtain the best representation of the water and nutrients in a particular paddock.
saturation	maximum water held in the soil before drainage takes place.
soil chemical analysis	chemical analysis of soil for key plant nutrients (nitrogen, phosphorus, sulphur etc), pH and salinity.

soil characterisation (for PAWC)	field-based investigation of the amount of plant available water that a soil can accumulate (includes the measurement or calculation of drained upper limit, crop lower limit, saturation and bulk density).
soil core	cylindrical column of soil collected with a soil corer.
soil core suck-back	a problem that arises when soil water content is high. The bulge of the cutting end of the soil tube forms a seal against the wall of the coring hole. This results in negative air pressure, in the core hole below the tube, as it is withdrawn. The soil core is sucked back out of the soil tube to relieve the pressure difference.
soil corer	steel tube driven into the soil to obtain samples.
soil monitoring	routine soil sampling over the period of a crop or sequence of crops to generate a record of water and nutrient accumulation, uptake and loss.
soil sampling	taking samples using an auger or coring device to enable visual and tactile observation, measurement of water content and chemical analysis of the soil.
total porosity	percentage of the soil volume occupied by non-solid material (i.e. air and water).

Appendix 5. References and further reading

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Cornish, P.E. and Pratley, J.E. Tillage practices in sustainable farming systems, in Dryland Farming, a Systems Approach. Eds. Squires and Tow. Sydney University Press pp 76-101.

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Appendix 6. Proforma calculation sheets (for photocopying)

Calculation Sheet: Water 1 – Past crop performance

Enter rainfall for your site (available from own records or Australian Rainman)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
wettest 20%*												
average												
driest 20%+												

* the wettest one season in five (20% of seasons) or *in 20% of years rainfall will exceed ……….?*

+ the driest one season in five (20% of seasons) or *in 80% of years rainfall will exceed ………..?*

1.1. Rainfall stored during fallow

When does the fallow normally start and finish?

Month the fallow starts: ____________________

Month the fallow ends: ____________________

Total fallow rainfall = ______ mm

Water stored over the fallow = Fallow rainfall x % of rainfall stored (suggest 20%, see Table 3.1)

= ______ mm x ______%

= ______ mm

1.2. Water supply from in-crop rainfall

When do you normally plant and harvest?

Month of planting: ___________________

Month of turning*: ___________________

Total in-crop rainfall = _____ mm

Total water supply = Water stored over fallow + in-crop rain

= _____ mm + _____ mm

= _____ mm

1.3. Yield produced from each mm of water (WUE)

Water use efficiency = $\dfrac{\text{Crop yield (kg/ha)}}{\text{(Total water supply – 100)}}$

= $\dfrac{\_\_\_\_\_\_\_\_\text{ kg/ha}}{\_\_\_\_\_\text{ mm – 100}}$

= ____________ kg of yield/ha/mm of water

* Turning = physiological maturity — when the crop stops accumulating more yield.

Calculation Sheet: Water 2 – Estimating available fallow moisture – using a push probe

Water available to plants = Depth of wet soil x water available/cm of wet soil*

(Plant Available Water) = ______ cm x _______ mm of water/cm of soil depth

Available stored water = _________ mm of water

* this is described as the Plant Available Water Capacity. PAWC values for some soils are listed in Table 3.2

Calculation sheet: Water 3 – Estimating available fallow moisture – using a soil corer

Depth interval (cm)	Layer thickness (cm)	Bulk[1] density (g/cm^3)	Crop[1] lower limit (%)	Wet weight [2] (g)	Dry weight[2] (g)	Gravimetric water[3] (%)	Volumetric water (%)	Available water (mm)
	a	b	c	d	e	f (d-e)/e x100	g f x b	h (g-c) x a/10
						Total available water		

[1] Input from Module 5 for specific soil type and location - lower limit is in volumetric measure
[2] Input from field data
[3] Calculate from (d-e)/e if d and e are net weights; use (d-e)/(e-tare) if gross weights

Calculation sheet: Water 4 – Calculating expected yield from available soil water and forecast rainfall

2.2. Rainfall expected while crop is growing

(Enter rainfall for your site from own records or Australian Rainman)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
wettest 20%*												
average												
driest 20%+												

* the wettest one season in five (20% of seasons) or *in 20% of years rainfall will exceed ……….?*

+ the driest one season in five (20% of seasons) or *in 80% of years rainfall will exceed ………..?*

Period of crop water use

month of planting = ____________

month of turning = ____________

(physiological maturity or when the crop stops accumulating more yield)

Estimated in-crop rainfall for period

= _____ mm

2.3. Total water supply expected for the crop

Available water = Soil water at planting* + Expected in-crop rain

= ______ mm + ____ mm

= ______ mm

*from Calculation Sheet: Water 2 or 3

This calculation can be repeated for average, wet and dry years.

2.4. Yield expected this season

Expected Yield = Water Use Efficiency x (water supply – 100)

(WUE from Table 3.4 or from your own calculation of past paddock performance)

= _______ kg/ha/mm x _____mm

= _______ kg/ha ÷ 1000

Expected yield = ______ t/ha

Calculation sheet: Water 5 – What happened this season?

3.1. How much water did the crop use?

Plant available water (PAW) at planting (from Section 2)

$PAW_{planting}$ = _____ mm

Rain while the crop was growing (from your own records)

In-crop rainfall = _____ mm

Plant available water (PAW) at harvest

$PAW_{at\ harvest}$ = _____ mm

Amount of water used by the crop

Water used by the crop = $PAW_{planting}$ + In-crop rain – $PAW_{harvest}$

= _____ mm + _____ mm – _____ mm

= _____ mm

NB: In seasons where it can be assumed that little water remains in the profile after harvest, there is no need to core to determine residual water. Set $PAW_{harvest}$ = 0.

3.2. How efficiently did the crop use water?

WUE_{actual} = Actual crop yield (kg/ha) ÷ (Water used – 100)

= ______ kg/ha ÷ (_____ mm – 100)

= ______ kg/ha ÷ _____ mm

= ________ kg/ha/mm

Calculation sheet: Water 6 – How much rain was stored during the fallow?

a. Estimation by push probe (See also Calculation Sheet: Water 2)

Plant Available Water (PAW_{start}) at start of the fallow

PAW_{start} * = Depth of wet soil at start x PAW Capacity (See Table 3.2)

= _______ cm x ______ mm/cm

= _______ mm

Plant Available Water (PAW_{end}) at end of the fallow

PAW_{end} = Depth of wet soil at end x PAWC (Table 3.2)

= _______ cm x _______ mm/cm

= _______ mm

or b. Estimation by coring (at start and at end of fallow, using Sheet: Water 3)

PAW_{start}* = ______ mm

PAW_{end} = ______ mm

Fallow rainfall = ______ mm (from own records)

How efficient was the fallow?

Fallow efficiency = (PAW stored during fallow ÷ Fallow rainfall) x 100

$$= \frac{(PAW_{end} - PAW_{start})}{\text{Fallow rainfall}} \times 100$$

$$= \frac{(\quad \text{mm} - \quad \text{mm})}{\text{mm}} \times 100$$

$$= \frac{\text{\_\_\_\_ mm}}{\text{mm}} \times 100$$

Fallow efficiency = ________%

*In seasons when it can be assumed that little water remains in the profile after harvest of the previous crop, there is no need to determine PAW at the start of the fallow. Set PAW_{start} at 0.

Calculation sheet: Nitrogen 1 – Calculating the nitrogen requirement of the crop

5.1. Target yield

Target yield* = ______ t/ha (or bales/ha)

The expected yield will be based on the availability of water. Calculation of the total supply of water for the crop, and what that may mean to yield, has been described in a previous section.

Target protein (wheat, barley, sorghum) = ______ % protein

5.2. Nitrogen removed in harvested grain or cotton seed

N removed depends on yield and protein content of grain

N in wheat grain = Yield (t/ha) x grain protein % x 1.75
= ______ t/ha x _____ x 1.75
= ______ kg/ha

N in barley/sorghum grain = Yield (t/ha) x grain protein % x 1.60
= ______ t/ha x _____ x 1.60
= ______ kg/ha

N in cotton seed = Yield (bales/ha) x 11 kg[1]
= _____ bales/ha x 11 kg
= _______ kg/ha

Nitrogen removed in harvest = _______ kg/ha

[1](Ridge 1994)

5.3. Nitrogen needed to grow the crop

Only about half of the available soil N ends up in harvested grain or cotton

N needed = 2 x N removed in grain or cotton seed

= 2 x _____ kg/ha

= ______ kg/ha

*Once target yield and protein levels have been set for wheat, barley or sorghum, the nitrogen needed to grow the crop may be read off Tables 3.7 or 3.8. This avoids the need for calculations 5.2 and 5.3. (Note that figures in Tables 3.7 and 3.8 have been rounded off to nearest 5 kg.)

Calculation sheet: Nitrogen 2 – Fertiliser requirement

6.1. Soil N available (from soil tests) (Use Table 3.5 as an example)

Depth interval (cm)	Layer thickness (cm)	Bulk Density# (g/cm^3)	N conc.* (mg/kg)	AvailableN (kg/ha)
	a	b	c	d (cxb) x a/10
			Total available N	

Bulk Density data for specific soils and locations are available from Module 5 database
* Nitrogen concentration input from results of analysis.

6.2. Nitrogen mineralised during crop

Total available N = ______ kg/ha

. In-crop mineralisation may be estimated from Table 3.6

6.3. Extra nitrogen needed to achieve expected yield

The amount of extra nitrogen needed to achieve the expected yield is the difference between that required to produce the expected crop yield and what is available from the soil.

Extra N needed = N to grow crop – (N available + N mineralised in-crop)

= ____ kg/ha – (___ kg/ha + ___ kg/ha)

= ______ kg/ha

A positive result means extra N is needed.
A negative result means extra N is not needed from fertiliser or legume rotation. In this case, there is a surplus of nitrogen for the expected yield.