NSW DEPARTMENT OF
PRIMARY INDUSTRIES

SOILpak – cotton growers - Readers' Note

This document is part of a larger publication. The remaining parts and full version of the publication can be found at:

http://www.dpi.nsw.gov.au/agriculture/resources/soils/guides/soilpak/cotton

Updated versions of this document can also be found at the above web address.

PART C. DIAGNOSING SOIL CONDITION

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C1. Soil pit digging: where, how and when?

PURPOSE OF THIS CHAPTER

This chapter explains where, how and when to dig an observation pit to examine the soil profile. It should be read before using the SOILpak soil description sheets for existing and new cotton developments (Chapter C2, Appendix 6).

CHAPTER OVERVIEW

This chapter covers the following points:

- how to ensure that the pit or group of pits represent the field
- how to dig the pit using a backhoe
- preparing a backhoe pit for examination
- using spades and other alternatives to backhoe pits
- suitable times of year to examine the soil profile.

WHERE TO DIG

When you decide to assess the suitability of your soil for crop production by examining a soil profile, you can use clues such as yield differences, aerial photos or soil colour as a basis for deciding where to dig your observation pit. It is useful to look at a site with no apparent problems to appreciate the degree of compaction in poor areas. Digging inspection pits in nearby areas that have never been farmed also provides a useful comparison.

For post-harvest soil assessments, aim to include the best-yielding, average and worst-yielding sections of a field in the soil sampling program. If, however, a field is known to be very uniform in terms of crop performance, one sampling site may be enough.

Choose an area away from the ends of the field where machines turn. Walk in at least 15 m across the direction of water flow. If hills or wide beds are in place, count as you go, so that you can find a guess-row (the row at the outside edge of the cultivation equipment). From the guess-row count to a main wheel track.

Dig the pit across the rows and include at least one ‘tractor row’ and one ‘picker row’ (see below).

For new developments or redevelopments, dig pits on a grid pattern with a spacing of approximately 150 m. Research is required to fine-tune this recommendation. For comparison, Australian wine industry managers engage consultants to dig soil inspection pits on a grid with a spacing of between 50 and 100 m.

After you have landformed a field, pit inspections at about three of the pre-development inspection sites should be adequate.

CHOOSING THE LOCATION OF PITS USING GPS EQUIPMENT

Recently developed Global Positioning System (GPS) instruments can be used to locate your position in a field. This allows you to record your sampling site location (for example, where you have dug a pit) and easily return to it for a follow-up soil examination. The accuracy of GPS units varies with cost; a hand-held unit with no correctional capabilities (costing a few hundred dollars) may have errors of ± 100 m, whereas a less portable unit (costing several thousand dollars) may have errors of only ± 10–20 mm.

You can use positioning systems, in conjunction with yield maps, to locate and examine the soil at sites of (for example) high yield, average yield and low yield. Basic yield maps can be made by hand harvesting at key sites. The development of yield sensors to be used in conjunction with cotton harvesting equipment is being researched.

The availability and use of yield sensors and positioning systems is likely to increase. The use of positioning systems, with the subsequent mapping of yield and other soil factors, provides the basis for increasing the efficiency of farming operations. Using these systems will allow soil in a paddock to be treated according to its needs, rather than as a single homogeneous block. This approach is referred to as precision agriculture or site-specific farming.

More information on positioning systems associated with precision agriculture can be obtained from the Australian Centre for Precision Agriculture, based at The University of Sydney. They have a web site, located at http://www.usyd.edu.au/su/agric/acpa.

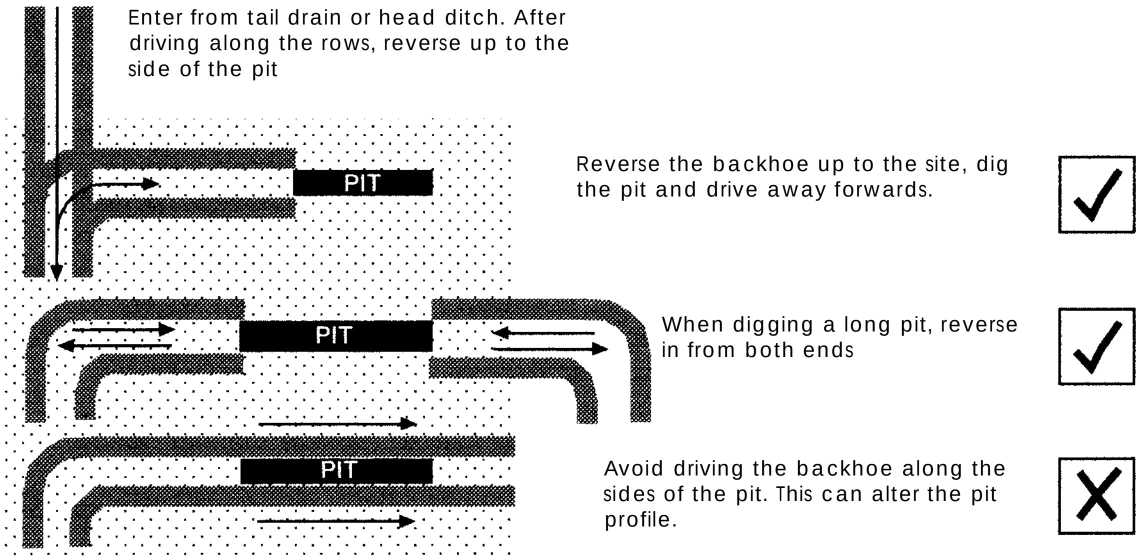
HOW TO DIG A BACKHOE PIT

A backhoe pit provides a good overview of the entire root zone of a cotton crop. It allows easy sampling of the subsoil and sub-surface.

It is important that you have not changed what you will see in the pit by driving the backhoe over the area where the pit will be.

Before driving into the field, decide exactly where you want the pit. Reverse the backhoe up to the spot so that you can dig in undisturbed ground (see Figure C1-1). Avoid digging pits exactly on top of the sites of previous backhoe pit investigations. Position the pit to include plant lines under a 'tractor row' and a 'picker row' (Figure

Figure C1-1. Moving a backhoe to and from a pit.



C1-2).

Keep the sides of the pit vertical. Vertical sides make a better profile (depth is easier to measure) and minimise the amount of sideways heave as the backhoe bucket moves in and out of the hole (heave disturbs the soil profile). Because plant roots often extend well below 1 m, you will need to dig about 1.2 to 1.5 m deep with the backhoe. A little extra depth allows you to examine the whole profile in comfort, and to allow room for the soil you will be removing from the walls. The recommended dimensions for an inspection pit are shown in Figure C1-3. A width of 1 m is shown, although sometimes it may be more convenient to make the pit 0.5 m wide. For particularly important pits that need to be photographed, a secondary pit can be dug at right-angles to the main pit to provide extra width. If you are digging a pit that is longer than recommended, back in from each end to prevent compaction from the backhoe wheels (Figure C1-1). If you need to compare different parts of a wide-rig cultivation system, dig two pits: one across the wheel tracks and one (away from the backhoe trail) near a guess-row.

Important warnings

- Check on the location of underground cables and pipes before digging a backhoe pit. Striking such objects during excavation endangers the backhoe operator, and the cost of repairing damage may be great (Figure C1-4).
- Keep the backhoe boom well clear of overhead power lines.

Figure C1-2. Locating the inspection pit in relation to the wheel tracks of cotton farming equipment.

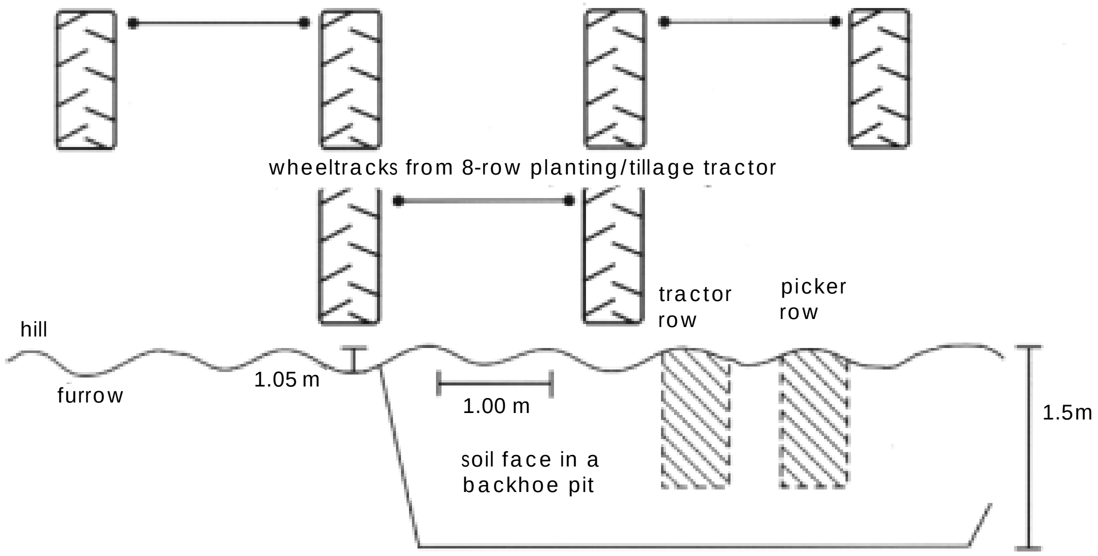
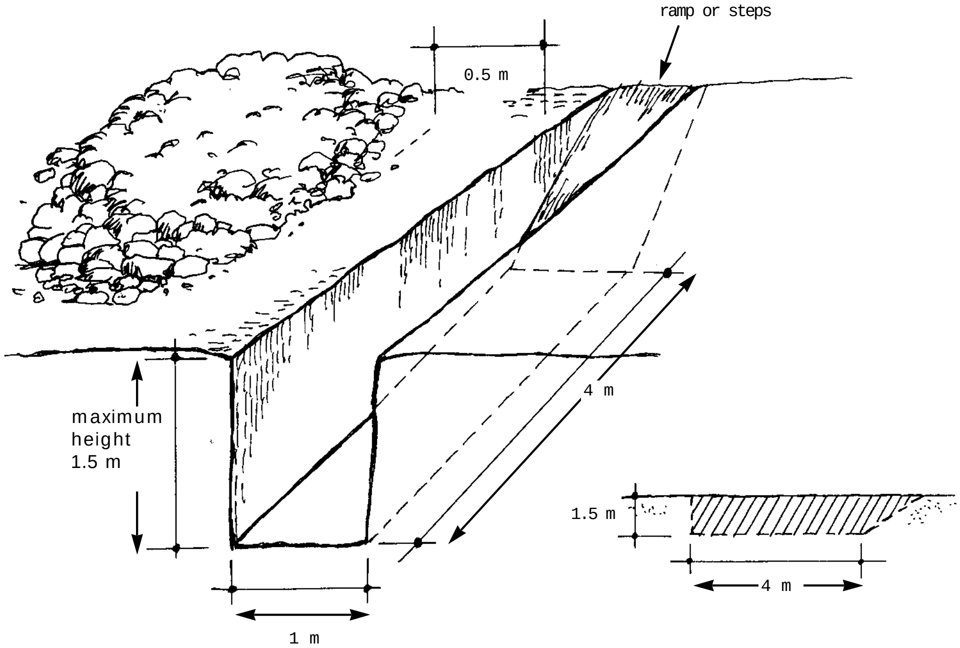
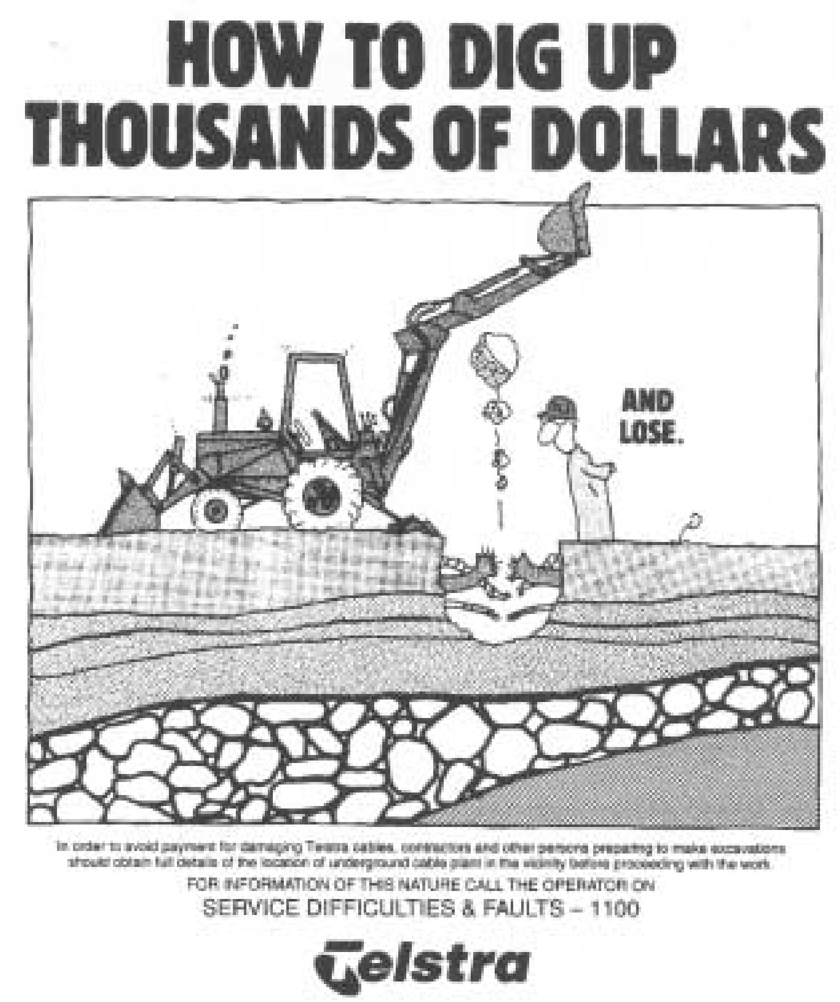


Figure C1-2. The recommended dimensions for a soil pit



- In New South Wales, the maximum allowable depth for backhoe pits without benching (see Figure C1-5) or special support is 1.5 m. WorkCover has stipulated that it is illegal for people to get into pits that are any deeper, because of the danger of wall collapse. The danger of collapse is reduced if the excavated soil is dumped well clear of the pit (see Figure C1-3). In Queensland, rural industry is exempt from regulations dealing with the excavation of soil to a depth of at least 1.5 m. However, a rural employer is obliged to provide a healthy and safe workplace—this involves undertaking a risk assessment, and implementing the findings of that assessment.
- Clean excavating equipment carefully to prevent the spread of serious soil-borne cotton diseases such as fusarium and black root rot, and of weeds such as nutgrass. For disease suppression, equipment should be washed to get rid of large lumps of soil

Figure C1-4. Without good planning, digging a backhoe pit can be hazardous!



(Figure C1-6), then rinsed with a 1% bleach solution. Sampling equipment, footwear and vehicles also require this treatment, preferably on a concrete pad, before leaving a farm.

- If you are investigating unfarmed areas, and pits are to be left unattended, consider putting a temporary fence around each pit to avoid injury to livestock.

Figure C1-5. Benching allows for pit inspections deeper than 1.5 m.

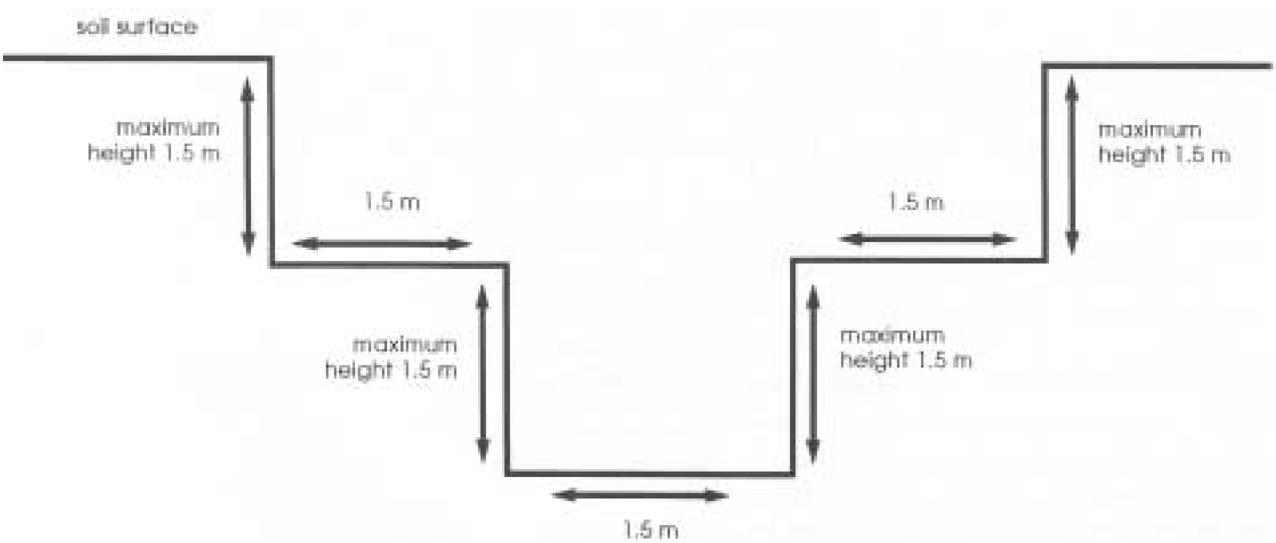
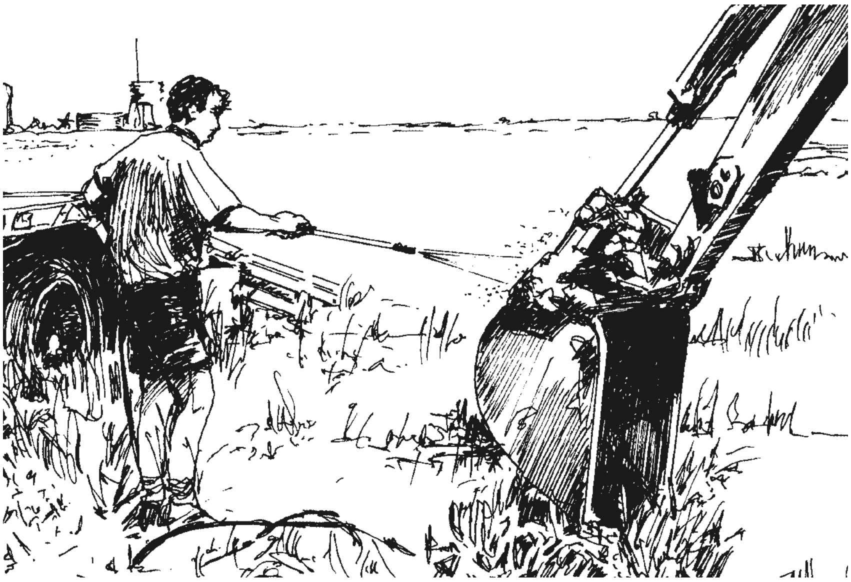


Figure C1-6. Excavation equipment must be disinfected to avoid the spread of cotton disease.



If possible, pile the excavated soil on the uphill side of the pit. Then, if it rains heavily, the pile will stop some run-off getting into the pit. Cover the pit face with a plastic sheet if rain is imminent.

Fill in the pit soon after inspecting it to allow the soil to settle before planting the next crop. Subsided pits may be a hazard to light, fast-moving field traffic (for example, spray rigs), so mark them with clearly visible and flexible plastic pegs.

PREPARING A BACKHOE PIT FOR EXAMINATION

Clear away any soil spilt on the surface above the face you wish to examine. This is important, as it allows you to locate the original surface as a reference for the depth of features.

Pick back an area on the face of the pit to remove soil compacted/smeared by the backhoe bucket. This will reveal the natural structure and colour. Use a tool such as a chisel, screwdriver, asparagus-cutting knife or pocket-knife.

Work across the pit face and then from top to bottom, prising out the damaged exterior of the pit face. This systematic trimming will enable you to remove most of the marks left by your knife. If the profile is to be photographed, ensure that the lighting is as even as possible – shadows over part of the soil will obscure important details in the photographs.

INSPECTION HOLE ALTERNATIVES - SPADE, CORER, AUGER

There are a number of alternative and supplementary methods to the backhoe pit for assessing soil structure. These include the use of a spade, a coring tube, or an auger. Information gained with these alternative methods can be recorded on the description sheets outlined in Chapter C2.

These methods are useful if it is impractical to dig a back-hoe pit for some reason, such as lack of machinery or wet conditions. Some of the methods can be used quickly to confirm, over an entire field, the diagnosis of soil structure from a small number of backhoe pits.

Alternatively, the methods can help to select a representative site in which to dig a backhoe pit for a more detailed evaluation.

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See Chapter C4 for further information on assessing soil structure.

Spades

Several soil experts prefer to use a spade when examining soil structure, due to its simplicity, portability and low cost. Some users have found that it is easier to sample the subsoil if the spade blade is cut to a width of about 15 cm at the cutting edge.

A great advantage of this technique is that the spade can be carried with you at all times and will be available if questions arise about the current soil structure.

Start by pushing the spade in at approximately 25 cm intervals, parallel to the direction of traffic (see Figure C1-7). Note how deeply you can push the spade to get an idea of where hard or compacted zones may lie. In very dry soil you may need your foot for leverage, whereas in wet soil you will probably get better feedback by just pushing the spade in by hand. Continue across a number of rows, including the wheeled row.

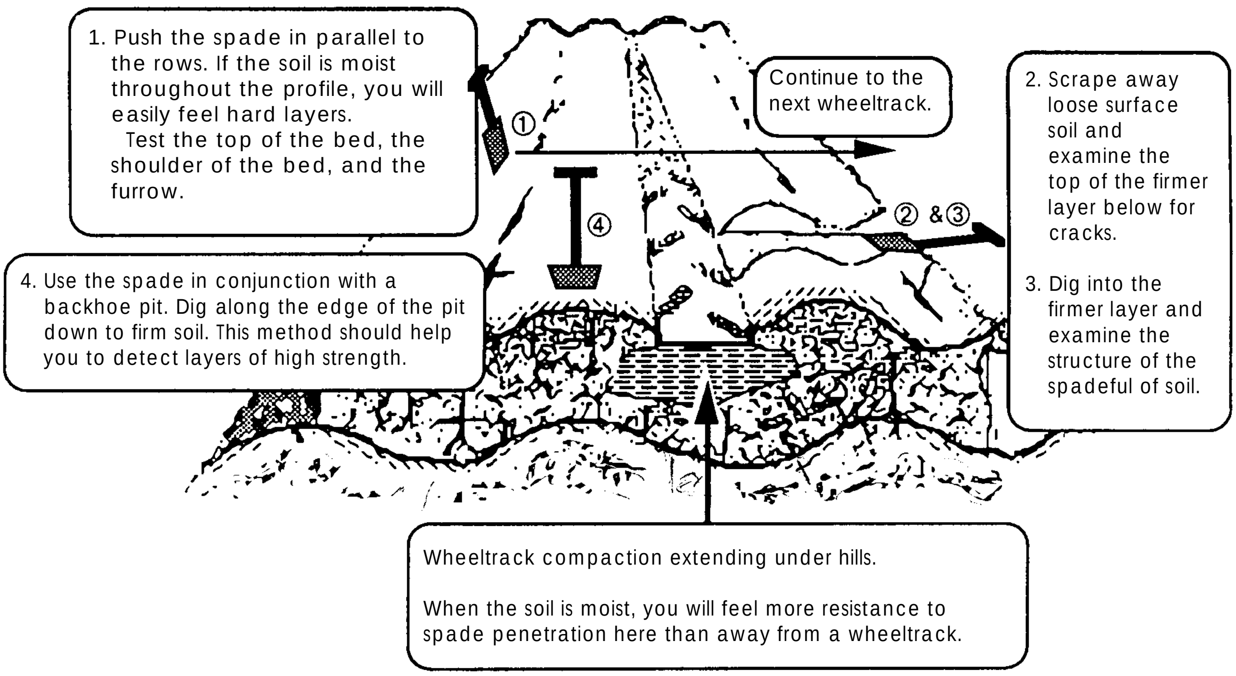
If you find hard zones under the beds, examine the soil in more detail. Use the spade to scrape away loose soil (moisture will affect how easily the loose soil can be removed) and note the depth and condition of the loose soil.

Look at the top of the hard layer that you have uncovered—you can use your hand to lightly scrape away very loose soil. Take particular notice of the amount of cracking (if the soil is dry) and the number of biopores (old root channels, tunnels created by ants and earthworms).

With the top of the firm layer now exposed (note that this firmness is not necessarily compaction) dig out a spadeful of soil. Keep the soil on the blade of the spade and note the orientation and the depth from which it came. Look for natural, platy or massive structures within the spadeful of soil that are associated with vehicle compaction. Where the soil is hardset, pore spaces are poorly connected and often have a honeycomb-like appearance.

In a spadeful of soil dug as described, natural crack-lines may be expanded, making them easier to see than when they are undisturbed in the face of a backhoe pit.

Figure C1-7. Using a spade to help in soil structural diagnosis.



When you are examining soil structure to depth, it will be easier if you dig a small hole first, then take a slice of soil from the side of the hole for examination.

A spade is particularly useful quickly to assess the impact, either good or bad, of a tillage operation.

You can use a spade in conjunction with a backhoe pit. Dig down parallel to the edge of the pit until the soil feels firm. Throw the spadeful of loose soil into the pit. Repeat the process along the top edge of the pit. If there is a hard layer it can be more obvious when using this technique than by just looking at the vertical face of the pit.

Information collected using the spade method should be drawn on to SOILpak description sheets for interpretation and later reference.

Advantages

- Simplicity
- Accessibility
- Speed—more, but smaller, replicates than with a backhoe
- Feel—the feel of the soil as you are digging can provide detailed information about the structure
- May make it easier to see natural crack lines
- A good technique to use when the soil is very moist.

Cautions

- Difficulty assessing the subsoil
- The cross-sectional view of the soil will not be as good as with a backhoe pit
- Moisture can greatly alter the feel of the soil when digging; dry soil is harder than moist soil even when it is in good structural condition.

Coring tubes

Coring tubes can be useful if it is not possible to dig a pit. Generally the force required is too great to insert a coring tube by hand. A tractor with a hydraulic ram is effective.

Soil cores are particularly useful if you are sampling the soil before cotton field development or redevelopment, where the emphasis is on soil chemical properties rather than severity of soil compaction.

Figure C1-8 shows three designs for coring tubes made from steel tube of 1.6 mm wall thickness. Exhaust pipe (50 mm diameter) may be used; larger tubes (75 or 100 mm diameter) give better cores. The shape of the cutting tip should force excess soil outside the tube (Designs A and B), leaving the core relatively undisturbed. Design C is unsuitable for examining soil structure; it is better suited to creating a relatively undisturbed hole (for example, for neutron probe access tubes at the expense of remoulding the core.

Lightly smear the inside and outside of the tube with a non-contaminating lubricant (for example, mould release oil) to prevent the soil from sticking.

Often the success of soil coring will depend upon the moisture conditions. Good samples are difficult to obtain from loose, wet profiles (the core may stick to the soil tube), or extremely dry profiles (the core tends to crack and fall apart as it is removed). Severely deformed cores should be rejected.

Expose the soil structure within the core by picking off the smeared outer layer. (A boot knife is a convenient tool.) Often the soil structure will become more obvious as the soil dries and the cracking pattern becomes conspicuous.

A convenient way to store cores for later reference is in split PVC pipe.

See Chapter C3 for more information on soil moisture sampling.

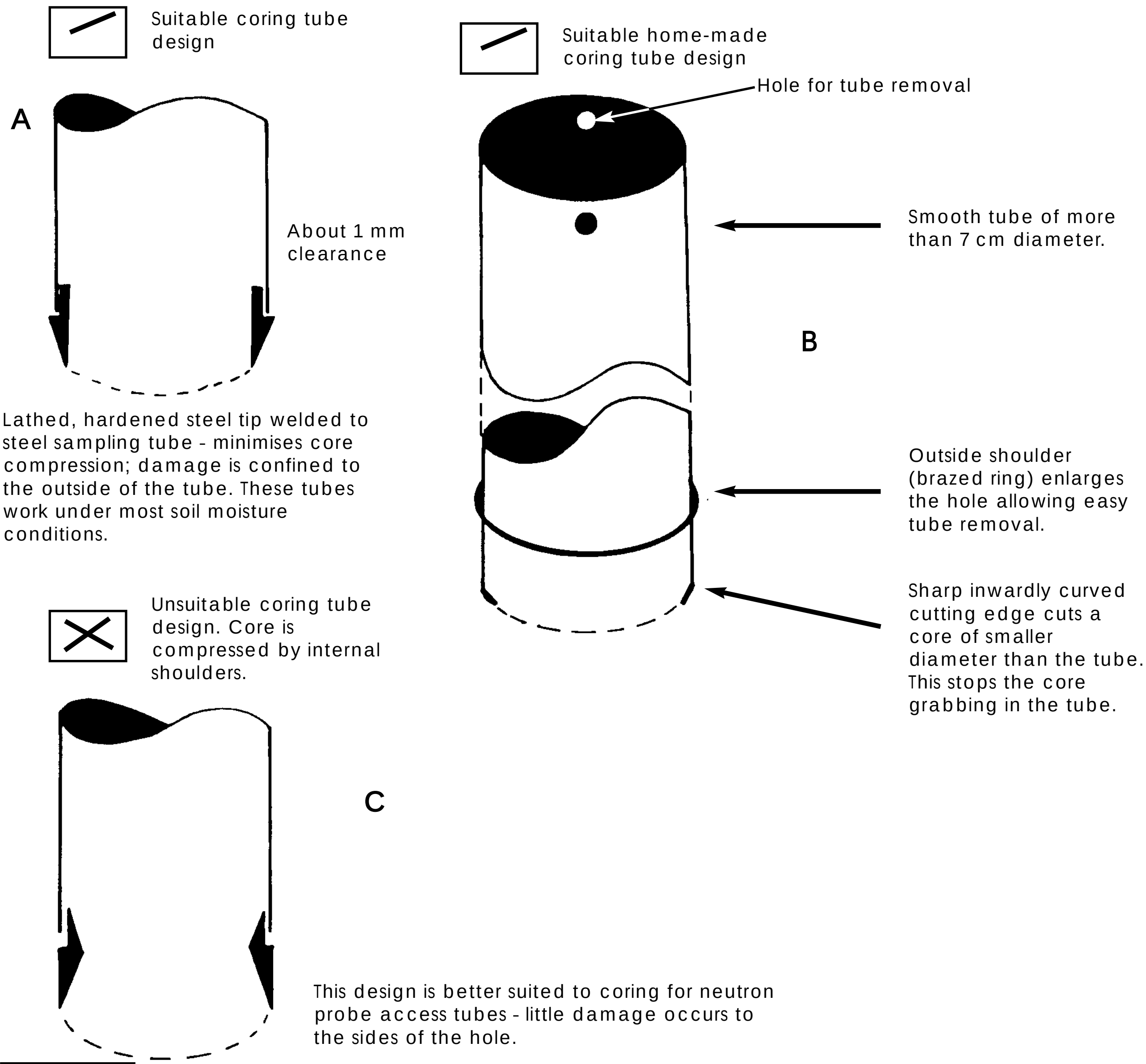
Advantages

- Cores can be kept as a record of soil types and problems.
- Deep samples can be taken more conveniently than with the spade method.
- Less disruptive than backhoe pits.

Cautions

- Slow.
- Machinery and operator required.

Figure C1-8. Cross-sectional view of three coring tube designs.



- Core can stick in tube.
- Small sample.
- Outside of core smeared.
- No guarantee that structure is completely undisturbed – moist soil may compress.

Soil augers

Soil augers greatly modify the structure of a soil sample. However, they can be used successfully to sample for soil moisture or for chemical analysis. They may also be useful for quick field examination of soil texture and colour before digging backhoe pits.

Advantage

- Simple and fast.

Caution

- Not suitable for removing soil for structural assessment.

WHEN TO DIG INSPECTION PITS

The following times are suitable for inspecting the soil using one of the above-mentioned methods:

Existing developments

- **Immediately after the cotton harvest.** While the plant rows are still in place you can easily locate wheel tracks. Look for lateral spread of wheel compaction in the furrows, and examine the structure of the beds and the subsoil. The soil structure can be related to the events during land preparation or harvest and to the last crop's performance. Examples of during-season problems are stunted plants and unusually short irrigation cycles due to poor water infiltration. You can plan your tillage and fertiliser operations for the coming season, and there is time for the soil to settle after the pit is filled in.
- **Immediately after a rotation crop,** to check whether the soil structure has improved. Deep tillage may be required to improve the soil structure further.
- **After a test run of tillage equipment,** to see if the operation was effective, and has not created more problems than it was supposed to solve. Problems include excessive cloddiness, too much dust and/or smearing at the base of the tines. Equipment may require adjusting, or it may be best to cease tillage until soil conditions improve.
- **After changes in management practice,** to determine whether a soil problem is being overcome by a new approach to crop management. The grower and adviser can see, for example, the results of changing to minimum tillage.

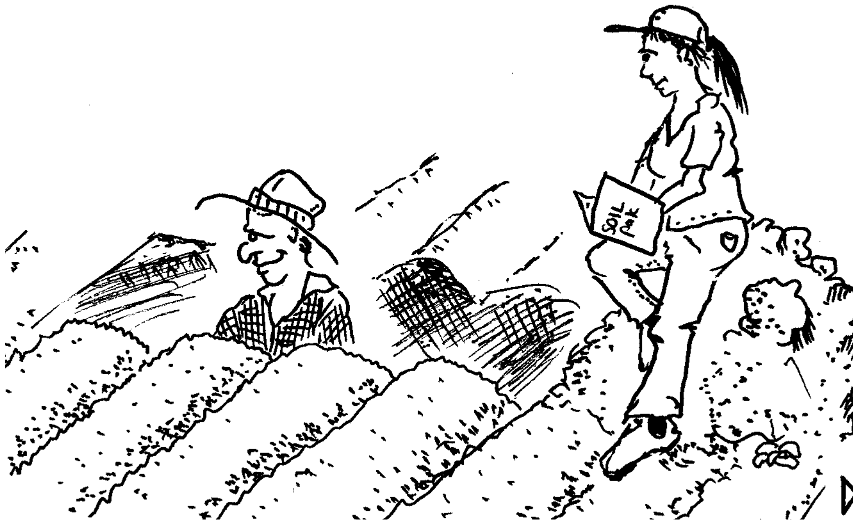
Comparisons between farmed and adjacent unfarmed (pristine) areas may be carried out at any time, but the comparison is most meaningful when all of the sites are examined at the same water content. The most suitable soil water content for soil examination is at, or just below, the plastic limit.

New developments

When developing new country, to avoid inherent problems in the soil. If soil is going to need amelioration, this can be costed into the project. Soil evaluation allows you to select the most appropriate irrigation system and fertiliser program. In this way problems in the first cropping sequence can be predicted and avoided.

After country has been developed. Pits enable you to determine if structural damage occurred during the process of landforming. Bad structural problems can result from landforming that took place when the soil was too wet. Exposed areas of subsoil may have fertility problems.

C2. Features of the description sheets



PURPOSE OF THIS CHAPTER

This chapter describes how to use the soil description sheets in Appendix 6, which provide a focus for this manual. Once soil information from the field and laboratory has been carefully measured and recorded on these sheets, informed practical decisions can be made about cotton soil management. The sheets provide a permanent record of soil condition.

CHAPTER OVERVIEW

This chapter covers the following points:

- features of the description sheets, which are presented for the following circumstances:
  - existing cotton developments (GREEN SHEET)
  - cotton field development or redevelopment (ORANGE SHEET)
  - after landforming (YELLOW SHEET).
- a brief explanation of why the various features on the sheets need to be recorded
- equipment needs.

Other chapters to refer to:

- Chapters C3 to C10: (Soil diagnosis procedures)

INTRODUCTION

Three types of soil description sheet have been supplied to deal with the following circumstances:

- existing cotton developments (post-harvest progress sheet) (GREEN SHEET)
- cotton field development or redevelopment (ORANGE SHEET)
- after landforming (YELLOW SHEET).

The numbers recorded on the sheets are compared with the critical limits described in Chapter A2, and closeness to the ideal is determined. Management options are then considered to deal with any problems that have been identified.

Over time, the recorded information can be used to show trends in soil physical and chemical fertility.

EXISTING COTTON DEVELOPMENTS– GREEN DESCRIPTION SHEET

The green 4-page description sheet for the evaluation of soil condition in existing cotton developments is in Appendix 6. It is accompanied by an example of a filled-in form.

The description sheet is usually used soon after cotton harvest. However, relevant sections of it may also be used after the harvest of a subsequent rotation crop, and to test the effectiveness of management strategies, such as deep tillage.

At first glance, the sheet may appear unnecessarily detailed and complicated. With practice, though, it soon becomes straightforward. If the evaluation is to be comprehensive, and able to be repeated over time to investigate trends in soil condition, it is not feasible to simplify the assessment procedures any further (based on existing knowledge). Financial benefits of the investigation are likely to far outweigh the costs.

Do not worry if you cannot fill out every section of the sheet the first time, but aim to achieve this goal eventually.

Reasons for including the features listed on the sheets are as follows:

1. Farm and field information

The following factors require no explanation:

- **Grower's name and address**
- **Field number/name, and area in hectares**
- **Whether or not the development is irrigated or dryland**
- **Type of irrigation system (if relevant)**
- **Water quality (if salinity is a concern) in terms of electrical conductivity (EC; dS/m), sodium adsorption ratio (SAR) and chloride concentration (Cl^-; mol/m^3)**
- **Anticipated cropping program**
- **Crop sequence for the previous 3 years**
- **Presence or absence of harvests on wet soil**
- **Width of row crop equipment**
- **Type of tillage and nitrogen application equipment**

- **Sketch of field features and pit location.** The sketch of pit location in a field allows the pit to be relocated in future.
- **Depth to watertable.** Depth to the watertable (if known) can be recorded.
- **Map/GPS grid reference of sampling point.** Pit location is made easier if you note the map grid reference. Use the 'Geocentric Datum of Australia' (GDA) system, rather than the 'Australian Geodetic Datum' (AGD), which will be phased out by 2000. An example of a grid reference is 148º 00' 04.8" E, 31º 49' 54.6" S. The position of this grid reference for the GDA system differs from the matching AGD coordinate by about 205 m. Global Positioning Systems (GPS), which record field site position via the use of satellites, provide a convenient way of determining spatial position (and, if necessary, elevation). Pit position, in relation to the high- and low-yielding parts of a field, should be noted.
- **Sampling date**
- **Sketch of pit features.** The sketch of main pit features is particularly important. After a pit face has been trimmed, the sketch provides an overview of the location of zones with poor structure and those with favourable structure. Show wheel track location and the position of plant roots. Note whether or not the soil has an attractive 'earthy' aroma.
- **Cotton crop performance.** This is evaluated by looking mainly at *lint yield* in bales per hectare (1 bale = 225 kg). This is a good starting point. However, well-run businesses also need to examine the efficiency of use of their inputs. Key factors (which can be greatly improved by high-quality soil management) are:

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See Chapter C7 for more information on deep drainage.

— **lint yield per megalitre of water** (applied as irrigation water, rainfall or stored in the soil profile at planting) used by the cotton crop. Ideally, this calculation should take into account the amount of deep drainage.

— **apparent N fertiliser recovery**, which is the proportion of N applied as fertiliser taken up by the cotton crop; to calculate this, nil-N strips will be needed close to the sampling site; N content and weight of sampled plants in the fertilised and unfertilised areas have to be measured around mid-January; N recovery is calculated using the following formula:

Apparent N fertiliser recovery (NFR, %)

$$= \frac{\text{crop N uptake (fertilised)} - \text{crop N uptake (unfertilised)} \times 100}{\text{N fertiliser applied}}$$

As the severity of soil compaction increases, the frequency of irrigation and the N application rates have to be increased to maintain yield—their efficiency of use therefore declines. Crop water use efficiency (CWUE) values >1.33 bales/ML are considered to be good. Aim for a nitrogen fertiliser recovery of > 70%. Another key factor is *lint yield per dollar spent on land preparation,* given that some growers inadvertently over-cultivate the sub-surface and subsoil of their fields.

— **total input of salts.** Where irrigated cotton is being grown, record the total input of salts for the previous cotton-growing season. Use the equation shown in Chapter C7.

— **bent roots.** If the taproots of plants from the previous cotton crop were deformed (for example, in a right-angled deflection), the frequency and extent of this problem should be reported. Root deformation is often a sign of soil structural problems.

— **the internode length pattern of a representative plant.** This provides a record of stress experienced during the last season (for example, stress caused by waterlogging and/or moisture deficiency).
— **soil problems highlighted by moisture probes.** Note evidence of soil problems from neutron or capacitance probe readings.
— **disease symptoms.** Record any disease symptoms seen in the previous cotton crop.

2. Surface features of hills/beds

- **Surface cover.** Consider the surface features within a radius of about 20 m from the pit. Where a crop other than cotton has been grown recently, use the QDPI 'stubble cover photo-standards' (Appendix 7) to describe the percentage cover of organic mulch. Also, provide an overview of weed infestation.
- **Bed height and width.** The height (above the base of the furrow) and width of the hill/bed is an important feature that needs to be noted.
- **Bed shoulder compaction.** Also note the severity of compaction of the hill/bed shoulder.
- **Field slope, and the possible presence of gilgais** ('melon holes'), are important features that should be measured using surveying equipment.
- Any signs of the following are worth recording:
  — **crusting**
  — **hardsetting or dispersion of the soil surface**
  — **water and wind erosion.**

3. First visual impressions of soil suitability for root growth and water intake

Before carrying out a thorough assessment of soil structure under the plant lines (see sides 3 and 4 of the description sheet), quickly make a note of your visual impressions of soil suitability for cotton root growth, and for water intake at the soil surface. When looking at a soil profile and deciding upon the future soil management, consider three things:

- **the past**—previous tillage, crop rotations, land levelling, fertiliser application and climatic conditions
- **the present**—what are you currently observing in the pit?
- **the future**—what is your estimation of the behaviour of the soil to various management options, given that only certain types of farming machinery are available at this site for the next crop, and that future weather conditions are difficult to predict?

After several months of practice, this judgement should be accurate enough to allow rapid assessment of soil condition.

4. Profile tests

Layers are defined as follows:
— topsoil, 0–10 cm
— sub-surface, 10–30 cm
— upper subsoil, 30–60 cm
— mid subsoil, 60–90 cm
— lower subsoil, 90–120 cm.

To ensure consistency of measurement, do the soil assessment within the following depth intervals in each layer:
— topsoil (0–10 cm)
— sub-surface (15–25 cm)
— upper subsoil (40–50 cm)
— mid subsoil (70–80 cm)
— lower subsoil (100–110 cm) (optional).
Separate evaluations should be carried out in the two zones shown in Figure C1-2:

- Under plant lines adjacent to one of the main (during-season) wheel tracks (*Tractor Row*)
- Under plant lines adjacent to a furrow wheeled only by cotton pickers (*Picker Row*).

4a. Profile tests in the pit, under the plant lines

- **Biopores** made by earthworms, ants and old root channels are easily recognised—their presence or absence should be noted.
- **Texture and moisture determination** in the field are described in Chapter C3. Texture relates to the proportions of sand, silt and clay in a soil sample. Soil moisture assessment indicates closeness to the plastic limit, the point at which soil changes from being brittle to plastic. When soil is plastic, it is easily damaged by tillage operations.
- **Mottling** is soil marked with spots or blotches of different colour or shades of colour. It is often associated with temporary waterlogging. Note its presence or absence.

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See Chapter C3 for more information on texture and soil moisture assessment.

- **Soil pH (water)** is a measure of soil acidity/alkalinity. A first approximation can be obtained in the field by using a Raupach test kit. However, ensure that the indicator solution is not beyond its expiry date—old indicator solution is likely to give misleading pH results.
- **Slaking** is a process whereby clods of soil collapse in water to form microaggregates. If the clods are strongly bound by organic matter, they will remain intact. Otherwise they will noticeably fall apart within seconds. Record whether or not this process occurs in a dish of distilled water or rainwater.
- **Dispersion** is the separation of slaked microaggregates into clay, sand and silt particles. It is assessed over a period of 2–4 hours using the ASWAT test (see below). However, observation of the degree of dispersion after 10 minutes (indicated by cloudiness around clods in the distilled water) provides a useful first approximation of the severity of this problem.
- **Lime (calcium carbonate) nodules and/or gypsum,** when present, usually indicate the presence of alkaline conditions, and may be associated with poorly-drained, sodic conditions. Lime nodules fizz when acid is poured over them, while naturally-occurring gypsum is characterised by its sparkling, crystalline form.
- **Hard, dark nodules of manganese oxide** indicate the presence of waterlogged conditions for at least part of the time—they fizz when hydrogen peroxide is poured over them.

- **The SOILpak score** is a measure of how compact the soil is. In loamy soil (clay content less than 35%), some of the factors listed do not allow clear distinction of soil condition over a range of water contents, so they are not assessed.

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See Chapter C4 for more information on the SOILpak scoring procedure, and the ASWAT test.

4b. Profile tests at home and in the laboratory

- **The Aggregate Stability in Water (ASWAT) Test** takes between two and four hours to carry out. It is a measure of the degree of dispersion (that is, the degree of collapse of soil microaggregates into the component sand, silt and clay). The ASWAT test is a modification of the well known 'Loveday and Pyle' dispersion test. As the soil becomes more dispersive, it becomes more prone to waterlogging when wet, and sets hard when dry. Because hill position is unlikely to greatly affect soil dispersibility, testing should be done only under the plant line adjacent to the main wheel track.
- **Laboratory tests:**

  — pH
  — electrical conductivity (EC)
  — chloride content
  — cation exchange capacity (CEC)
  — exchangeable sodium percentage (ESP)
  — electrochemical stability index (ESI)
  — ratio of exchangeable calcium to exchangeable magnesium (Ca/Mg)
  — calcium carbonate ($CaCO_3$) content
  — organic matter
  — available water
  — nutrient content.

  These tests should be done only by laboratories accredited by National Association of Testing Authorities (NATA). Otherwise, inconsistencies may occur. Note which laboratory you are sending your samples to.

  Soil dispersibility: Of the above, measurements of the following help to explain why a soil is or is not dispersive:
  — ESP
  — ratio of exchangeable calcium to exchangeable magnesium
  — $CaCO_3$ content
  — organic matter content
  — EC
  — pH.
  ESI (EC ÷ ESP) is a particularly useful index of soil dispersibility.

  Salinity: Electrical conductivity data also are used to indicate how saline a soil is. A first approximation of soil electrical conductivity can be obtained using a field meter. However, laboratory results are more accurate.

  Alkalinity: Apart from adversely affecting soil stability in water, alkalinity (high pH) makes many soil nutrients poorly available.

  Soil structural resilience: Cation exchange capacity; CEC (the sum of exchangeable cations) is a measure of the *structural resilience* of soil—that is, its ability to decompact by shrinking and swelling.

Available water testing is an optional extra. It is recommended for use in areas where soil texture and perhaps colour obviously vary from one part of a field to another.

Soil nutrient testing: Refer to NUTRIpak for more information.

5. Conclusions

For each of the three main depth intervals under the two plant-line positions (use mean values for the subsoil), make conclusions about:

- **Severity of compaction** (as measured by the SOILpak score)
- **Suitability of soil moisture for tillage**
- **Natural regeneration potential,** which takes into account soil CEC (a measure of soil shrink/swell potential)
- **Soil stability in water** (as measured by the ASWAT test)
- **Salinity hazard**
- **pH.**

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See Chapter A2 for more information on critical limits.

If possible, the subsoil infiltration rate should be estimated (for example, by the chloride balance method), to assess the risk of deep drainage losses. Critical limits for deep drainage will vary according to the hydrogeology, and the intensity of groundwater pumping, within each district.

6. Recommendations

Based on the conclusions made about soil condition on the description sheet, management options are suggested to improve soil condition for cotton production. Details of the options are presented in the following chapters:

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See Chapter C7 for more information on estimating the subsoil infiltration rate.

- **Add biopores** to dry/cracked soil, with a rotation crop (Chapter D2)
- **Deep till** soon to reduce compaction (Chapter D2)
- **Increase surface cover** (Chapter D1)
- **Apply gypsum/lime** (Chapter D2)
- **Alter hill/bed height** (Chapter D1)
- **Modify bed shoulder compaction** (Chapter D1)
- **Change field slope** (Chapter D1)
- **Apply extra nitrogen,** and use **more-frequent irrigation** for the next cotton crop (Chapter D3)
- **Reduce or increase the pH** (Chapter D8).

It also is important to consider the following points:

- If you find you do not need deep tillage, record the tillage implements to be used for the control of Heliothis pupae.
- If you have observed serious compaction, consider the precautions you can take to stop it happening again; for example, use narrower tyres or tracks.
- If a salinity/watertable problem is identified or suspected, refer to your regional water table information and seek further advice.

COTTON FIELD DEVELOPMENT OR REDEVELOPMENT- ORANGE DESCRIPTION SHEET

The orange 4-page description sheet for the evaluation of soil condition in new cotton developments and redevelopments is in Appendix 6.

Do not worry if you cannot fill out every section, but try to achieve this goal.

You do not need to work out the SOILpak score in this evaluation, because the soil is likely to be compacted by landforming in the near future. Nevertheless, the score is a useful guide to the potential physical fertility of the site.

Irrigation engineers will be able to use information about soil stability in water and pH to help them make decisions about field layout and the extent of cutting and filling.

Data about texture and available water can be used to locate soil types that have similar hydrological properties within the same management unit.

If contrasting units of soil cannot be separated easily into relatively uniform furrow irrigation zones, consider using drip irrigation. Dripper output within small management sub-units can be matched with the water-holding capacity and infiltration characteristics of each sub-unit.

It is best to measure soil water-holding capacity in the laboratory, but it can be estimated crudely using information about soil texture.

If possible, the subsoil infiltration rate should be estimated—for example by the chloride balance method—to assess the risk of deep drainage losses.

Uniformity of structure management within a field is made much easier if soil with similar natural regeneration potential (as measured by soil cation exchange capacity) is included within its boundaries.

If a soil is wetter than the lower plastic limit, particularly in the subsurface or subsoil, the site should be dried with a well-fertilised crop such as wheat before development, to make the site more resistant to compaction.

If the soil is silty (that is, the clay content is less than 35%), avoid working it at water contents substantially less than the plastic limit, so that dust production is minimised.

The likelihood of exposing sodic subsoil can be predicted, allowing you to make plans to apply ameliorants such as gypsum. You can also make notes about the need to modify the field slope at the assessment site.

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See Chapter C3 for more information on estimating the soil water-holding capacity.

☞

See Chapter C7 for more information on estimating the subsoil infiltration rate.

☞

See Chapter C3 for more information on plastic limits.

AFTER LANDFORMING- YELLOW DESCRIPTION SHEET

The yellow 4-page recording sheet for the evaluation of soil condition after landforming is in Appendix 6.

Do not worry if you cannot fill out every section, but try to achieve this goal.

The measurements are similar to those used for existing cotton developments (post-harvest); the main difference is that no hills or beds are in place to guide the sampling.

EQUIPMENT NEEDS

Equipment needs for soil assessment are outlined in Table C2-1.

CONCLUDING COMMENTS

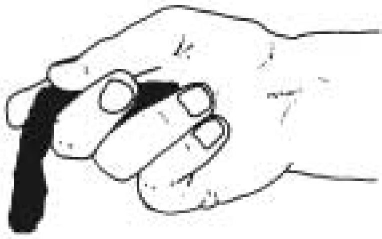
The following checklist is a quick reminder of things to do when digging a soil pit and filling in a SOILpak description sheet:

1. Start filling in section 1 of the description sheet (field history, etc.).
2. Decide where to dig the inspection pit(s). (Take into account wheel tracks, plant growth and crop yield.)
3. Dig pit. Keep sides straight and unheaved by the digging implement.
4. Pick back the pit face to remove smears and reveal undisturbed soil.
5. Feel the soil—make a mental note of how the soil feels as you clean the face of the pit.
6. Sketch the soil profile and the location of the pit in the field, and finish section 1 of the description sheet.
7. Observe the surface features (section 2).
8. Give your first impressions of soil suitability for the growth of cotton roots and water entry (and, in the case of new developments, risk of deep drainage losses).
9. Work through section 4 of the soil description sheet, and pay special attention to determining SOILpak scores under the plant lines.
10. Collect soil samples where the SOILpak scoring was carried out.
11. Carry out the ASWAT ‘soil stability in water’ test on these soil samples.
12. Send away some of the soil to a NATA-certified testing laboratory.
13. When the results are sent back by the laboratory, complete section 4 of the description sheet.
14. Fill in the conclusions (section 5) to summarise the results.
15. Make recommendations (section 6) and develop management strategies based on your findings.

Table C2-1. Items to have on hand before starting soil assessment in the field

Item	Use
Spade	For moisture probing, for examining features close to the surface over more of an area than just the pit, and for removing loose soil at the edge of the soil pit
Pry bar	For use in very hard dry soil
Auger	Quick soil moisture probing
Strong knife / spatula / screwdriver / trowel / chisel / asparagus knife (depending on preference)	For cleaning the face of the pit from smear marks and to remove clods for examination
Small pointed knife	To expose structural features
SOILpak soil description sheets, clip-board and pens	For recording observations
Tape measure or ruler	For depth recording
Several litres of distilled water or rainwater	Texture and dispersion tests
Steel frame (20 cm x 20 cm x 10 cm), white acrylic paint, diluted and transported in 4 L fuel cans	Highlighting of continuous vertical macropores
Hand lens	To examine microstructure
Petri dishes	For carrying out dispersion and lime tests
Dilute hydrochloric acid	To test white nodules for lime
Hydrogen peroxide	To test black nodules for the presence of manganese (Mn)
Towel	For cleaning gear
Plastic bags, labels and rubber bands	For collecting soil samples
Munsell colour chart (not essential)	For determining soil colour
Camera (not essential)	Permanent recording of features

C3. Soil moisture (before tillage), soil texture and available water



PURPOSE OF THIS CHAPTER

This chapter explains how to estimate soil moisture before tillage, soil texture and available water.

CHAPTER OVERVIEW

This chapter deals with the following points:

- why you should determine soil moisture status before tillage
- ways of estimating soil water content in the field :
  —plant symptoms and weather
  —moulding in the hand
  —moisture probe
- how to estimate soil texture by hand
- how to determine available soil water.

SOIL MOISTURE AND TILLAGE

As the moisture content of a soil changes, the soil's consistency goes through a series of different states (Figure C3-1).

Dry soil is friable (crumbly if loose, or brittle if compacted). At such a moisture content, tillage fractures and loosens the soil. Dry tillage benefits cracking clays (but not some silt-dominated soil).

The *plastic limit* (PL) is the water content above which a soil becomes plastic (can be compacted and remoulded). In cracking clays, the PL often is about midway between field capacity and permanent wilting point. Plastic soil is good for making roads, earth dams and earthenware pots—but not seedbeds in clay soil.

The *liquid limit* is the moisture content above which the soil starts to flow like a liquid. Liquid soil is called slurry.

A moisture content drier than the plastic limit is best for tilling cracking clays. That is not to say you should never till a cracking clay that is wetter than the plastic limit, but you should disturb that soil as little as possible.

The deeper you till, the more important it is for the soil to be dry through the full depth of tillage (and deeper). Use the following methods to determine soil moisture when you are considering tillage operations.

WAYS OF DETERMINING SOIL WATER BEFORE TILLING THE SOIL

Plant symptoms and weather

If your previous crop was at or near the permanent wilting point at harvest and there hasn't been any subsequent rain, your soil should be at or below the plastic limit (see Figure C3-1). Most crops, including cotton and wheat, will dry the soil (where the roots are active) to a similar soil water content. The depth to which the different species can extract moisture does vary.

If the soil has a high clay content, deep cracking in the soil should be noticeable at this stage.

On sodic clay soil (soil with high contents of exchangeable sodium), plant symptoms such as wilting may indicate that the soil is dry. However, soil moisture may still be in the moderately moist range even though the moisture is not available to plants. Hence such a soil is moist enough to smear if tilled.

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See Chapter D2 for more information on the moisture-extracting capacity of different crops.

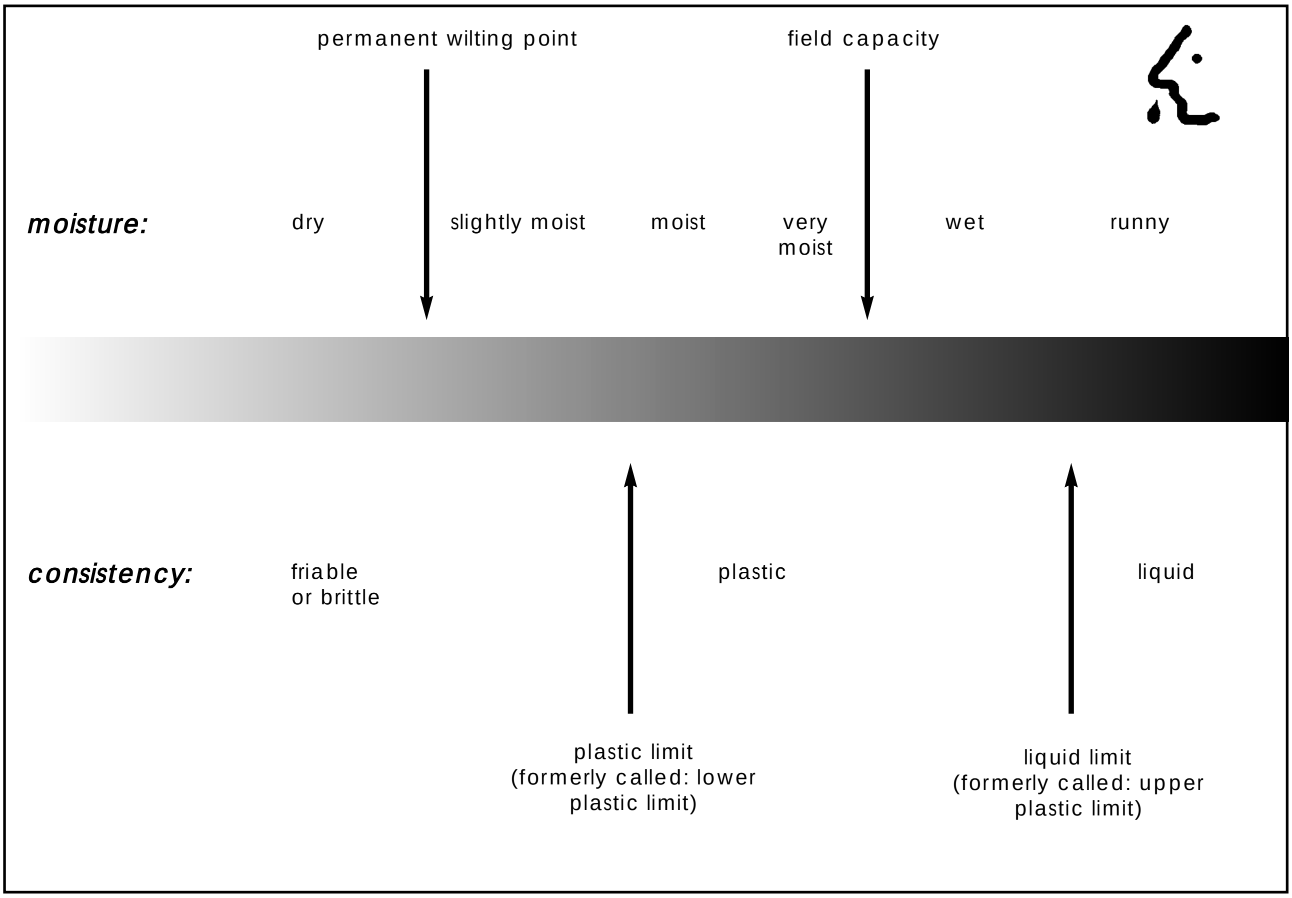
Moulding of soil samples in the hand

Moulding freshly collected soil from the various sampling depths into a ball in your hand will allow you to estimate how close the soil water content is to the plastic limit. Attempt to roll it into rods with a diameter of 3 mm (see Figure C3-2). Roll it out on a flat surface (for example, a smooth plastic folder) using a firm pressure, and try to shape it into a rod. Do not work the soil in your hands too long, as the heat of your hands will dry it and it will no longer be at the field water content.

The soil's water content is classified as either dry, or at the plastic limit (PL), or wet. It gives only a rough guide to soil consistency and suitability for tillage.

- Dry soil does not make a ball when it is squeezed in the hand, and it fragments into powder or smaller fragments (at or drier than wilting point—nil available water). Rods cannot be formed.

Figure C3-1. Soil moisture and consistency



- At the plastic limit, clay soil forms a crumbly ball but just fails to make a 3 mm rod.
- Moist soil forms a ball on squeezing in the hand, but does not ribbon unless high in clay. It can be rolled into a rod thinner than 3 mm. Wet soil feels sticky and leaves a wet outline on the hand when squeezed.

Table C3-1 can be used to assess soil moisture.

Figure C3-2. 'Closeness to plastic limit' determination using the rod test

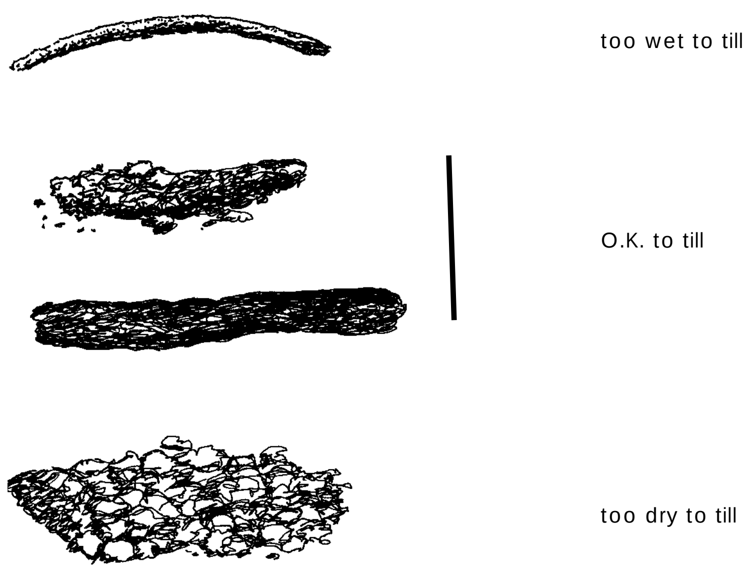


Table C3-1. Guide to assessing soil moisture

Soil moisture status	Sand, sandy loam	Loam	Clay loam, clay
Dry or slightly moist	Will flow through fingers or fragments will powder.	Will not ball when squeezed in hand. Fragments will powder.	Will not ball when squeezed in hand. Fragments will break to smaller fragments or peds.
Plastic limit	–	–	Will ball. Will not ribbon. Just fails to make 3 mm rod.
Moist	Appears dry. Ball will not hold together.	Forms crumbly ball on squeezing in hand	Will ball. Will not ribbon. Will rod to 3 mm.
Very moist	Forms weak ball but breaks easily.	Will ball. Will not ribbon.	Will ball. Will ribbon easily.
Wet	Ball leaves wet outline on hand when squeezed, or is wetter.	Ball leaves wet outline on hand when squeezed, or is wetter. Sticky.	Ball leaves wet outline on hand when squeezed, or is wetter. Sticky.

Adapted from: R.C. McDonald *et. al.* 1990, *Australian soil and land survey field handbook*, Inkata Press, Melbourne.

The potential of clay-rich soil to be damaged through compaction and/or remoulding is high when the soil is wetter than the plastic limit, and low when the soil is drier than the plastic limit. Loam soil can be damaged when tilled at water contents drier than the plastic limit, because of dust formation.

Moisture probes

Neutron probes are widely used for irrigation scheduling. They can also be used to predict the suitability of the soil water content for tillage.

As a guide, on heavy clay soil, the point below which tillage is safe is approximately 30% of total available moisture, depending on soil compaction (see Figure C3-3). Compaction will lower this value.

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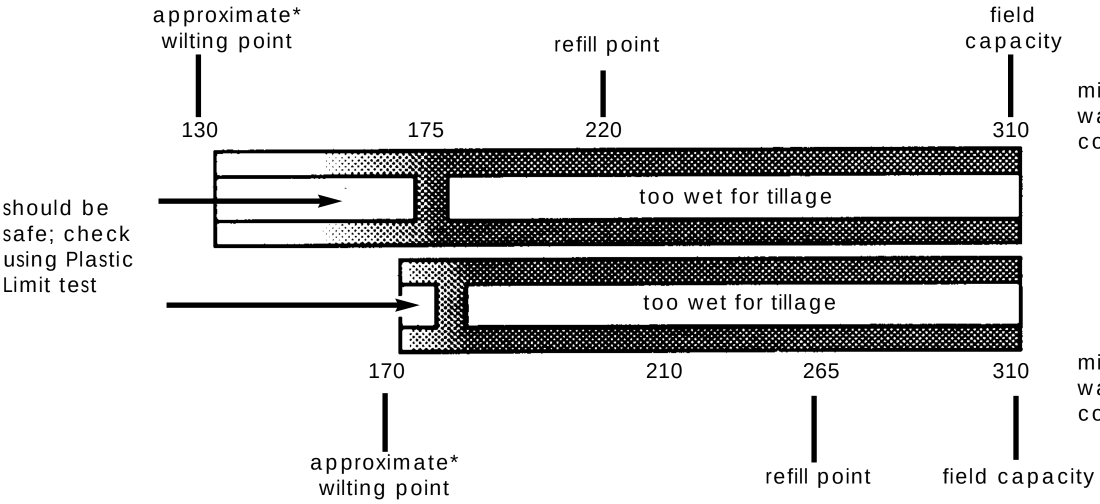
See Chapter C9 for more information on neutron and capacitance probes.

DETERMINING SOIL TEXTURE

Field texture is a measure of the proportions of gravel, coarse sand, fine sand, silt and clay in the soil. This test need be done only once at a particular sampling point after landforming, because it is a soil property that changes only very slowly over time.

Texture of the soil surface will strongly influence the structure of the surface layers. This will affect seedling emergence, water infiltration, trafficability and ease of tillage. Texture also affects soil water-holding capacity, and the behaviour of some herbicides. In relation to loams, clays tend to be less prone to hardsetting (which causes water infiltration and seedling emergence problems), and hold

Figure C3-3. Examples of moisture contents for safe deep tillage of compacted and non-compacted cracking clay soil (0-70 cm). The amount of water between the refill point (the point at which a crop requires irrigation to avoid stress) and the field capacity is referred to as 'readily available water'.



*The amount of moisture where the plant is wilted for most of the day.

more nutrients. However, clays are more likely to have poor aeration, a slow rate of warming after irrigation, and poor workability and trafficability after rain. Take a sample of soil sufficient to fit comfortably into the palm of the hand. Moisten soil with water, a little at a time, and work it until it just fails to stick to your fingers. This is when its water content is approximately 'field capacity'.

Continue moistening and working until there is no apparent change in the feel of the ball of soil (usually 1 to 2 minutes). The behaviour of the worked soil and the ribbon produced by pressing the soil out between thumb and forefinger (see Figure C3-4) characterises the texture (Table C3-2).

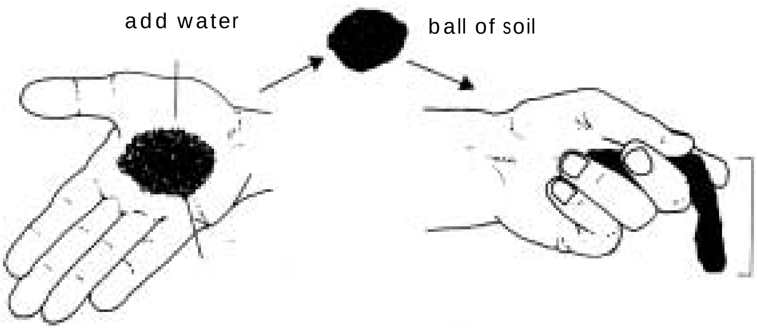
Table C3-2. Behaviour of moist bolus (ball) for contrasting types of cotton soil.

Sandy clay loam (SCL)	Strongly coherent bolus, sandy to touch; medium size sand grains visible in finer matrix; will form a ribbon of 2.5–3.8 cm.
Clay loam (CL)	Coherent plastic bolus; smooth to manipulate; will form a ribbon of 3.8–5 cm.
Silty clay loam (SiCL)	Coherent smooth bolus, plastic and silky to the touch; will form ribbon of 3.8–5 cm.
Fine sandy clay loam (FSCL)	Coherent bolus, fine sand can be felt and heard when the bolus is manipulated; will form a ribbon of 3.8–5 cm.
Sandy clay (SC)	Plastic bolus, fine to medium sands can be seen, felt or heard in clayey matrix; will form a ribbon of 5–7.5 cm.
Silty clay (SiC)	Plastic bolus; smooth and silky to manipulate; will form a ribbon of 5–7.5 cm.
Light clay (LC)	Plastic bolus; smooth to touch; slight resistance to shearing between thumb and forefinger; will form a ribbon of 5–7.5 cm.
Light medium clay (LMC)	Plastic bolus; smooth to touch, slightly greater resistance to ribboning shear than light clay; will form a ribbon of about 7.5 cm.
Medium clay (MC)	Smooth plastic bolus, handles like plasticine and can be moulded into rods without fracture; has some resistance to ribboning shear; will form a ribbon of 7.5 cm or more.
Heavy clay (HC)	Smooth plastic bolus; handles like stiff plasticine; can be moulded into rods without fracture; has firm resistance to ribboning shear; will form a ribbon of 7.5 cm or more.

Reference: Northcote, K.H. 1979, *A factual key for the recognition of Australian soils,* 4th ed, Rellim, Adelaide, S.A.

Moisture of the sample will influence the length of the ribbon formed. Be careful not to knead the ball for too long, as it will dry out. Re-wet the ball if it reaches this point.

Figure C3-4. Field texture analysis



Decisions to be made from texture observations

Structure and salinity assessment

Texture measurements are used to separate loams (less than 35% clay) from clays (more than 35% clay) in structure assessment.

They allow $EC_{1:5}$ data to be converted to EC_e in salinity investigations.

In general terms, the higher the clay content, the lower the amount of water that drains through the soil. However, good soil structure will overcome the potentially poor internal drainage of a clay soil.

Available water

The texture of the soil will also affect the water-holding capacity and internal drainage of the soil. Thus texture can influence irrigation scheduling.

There are three categories of stored soil water:

- ‘readily available water’ (water held between ‘field capacity’ and ‘refill point’, the point at which plants begin to have problems extracting soil water)
- ‘plant available water’ (water held between ‘field capacity’ and ‘permanent wilting point’)
- ‘unavailable water’ (water stored in very small soil pores that cannot be extracted by plant roots). The amount of ‘unavailable water’ in the soil tends to become greater as clay content increases.

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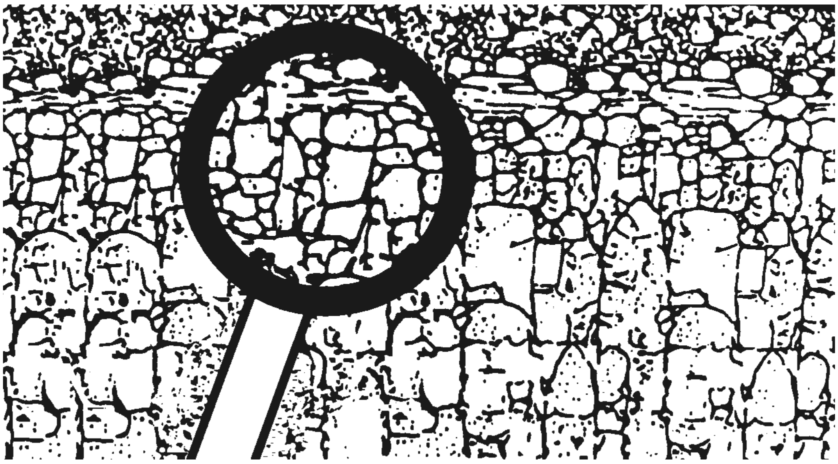
See Chapter C9 for more information on calculating available water.

Texture assessment will give you a crude estimate of soil water-holding capacity. Loams (sometimes with more than 180 mm ‘plant available water’ per metre of soil) tend to have more ‘plant available water’ than clay-rich soil (120–180 mm/m; sometimes greater in self-mulching clay) and sandy soil (< 120 mm/m). To obtain accurate data about available soil water, it is necessary to measure soil water-holding capacity in a laboratory equipped with pressure plates. Calculation of ‘readily available water’ requires field measurements with a moisture probe.

To provide a check on the accuracy of the field estimates of soil texture, some of the samples should be sent to an accredited Soil Physical Testing Laboratory for a more precise particle size analysis (PSA).

C4. Structural condition



PURPOSE OF THIS CHAPTER

This chapter explains how to assess and interpret soil structural condition using information from the field and laboratory. The three distinct aspects of soil structure are considered:

- degree of compaction/remoulding (structural form)
- stability of the soil in water (structural stability)
- regeneration potential of a soil after it has been compacted (structural resilience).

The focus is on soil suitability for the growth of cotton roots.

CHAPTER OVERVIEW

This chapter covers the following points:

- field observations and laboratory tests
- making a decision about soil physical fertility
- conclusions and management recommendations.

Associated chapters that you may need to refer to are:

- Chapter C1: ‘Soil pit digging: where, how and when?’
- Chapter C2: ‘Features of the description sheets’.

INTRODUCTION

The aim of this chapter is to explain how to assess soil structure in a pit (dug with a back-hoe or spade) and with laboratory data. Three distinct aspects of soil structure are considered:

- degree of compaction/remoulding (structural form)
- stability of the soil in water (structural stability)
- regeneration potential of a soil after it has been compacted (structural resilience).

This chapter focuses on soil suitability for the growth of cotton roots.

Soil stability under the influence of compactive forces (resistance to compaction and remoulding) is discussed briefly. Record your 'root growth suitability' observations on the soil description sheets (Appendix 6) introduced in Chapter C2.

Then compare your results with the given 'critical limits', and make land management decisions for the next stage of your farming operation.

DEGREE OF COMPACTION/REMOULDING

Compaction of a soil causes its bulk density to increase. Remoulding involves rearrangement of soil pores without an increase in bulk density of the soil. Both processes have the potential to restrict the root growth of cotton by increasing soil strength when it is dry and by reducing aeration when the soil is wet.

Field signs

Surface condition

Surface condition may give broad clues about soil structural condition and associated factors.

When drawing the sketch of the main pit features, record any soil surface features that indicate soil structure problems:

- large clods (diameter greater than 2 cm)
- deep wheel tracks
- wheel tracks over beds.

Where relevant, note the coverage and type of surface mulch and the degree of crusting/hardsetting/dispersion, in Section 2 of the description sheets.

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See Chapter C6 for more information on surface mulch.

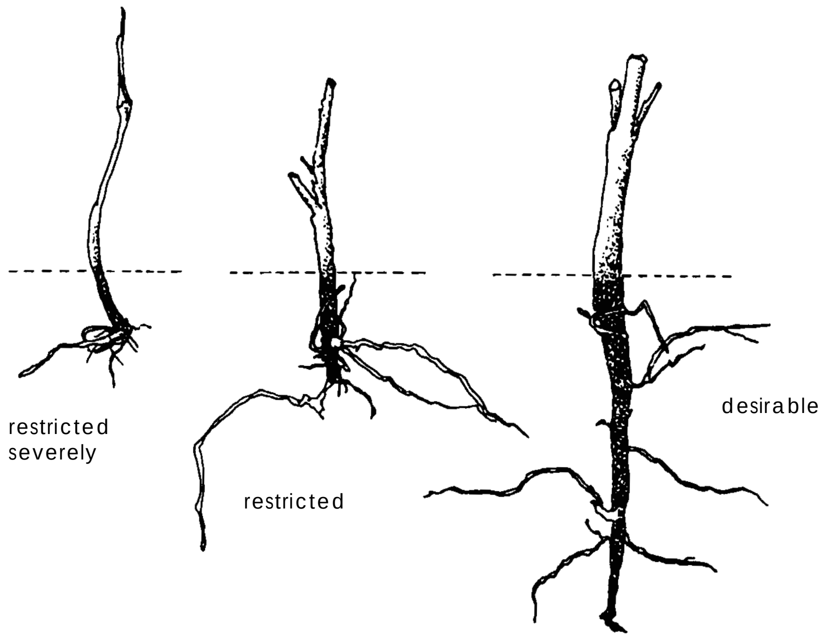
Root shape

To assess soil suitability for root growth, pull up 10 cotton plants (or tap-rooted weeds) per row next to and away from the main wheel tracks, and determine the proportion of malformed roots (See Figure C4-1). Also examine root growth in the pit in relation to soil structure.

Bent or branching roots do not automatically indicate a hard layer. Roots may deviate or branch in response to nutrients and water availability, or to avoid waterlogged zones (possibly due to the application of too much water).

During very wet seasons, moisture is readily available in the surface layers and the plants have little need to develop deep roots. Crops grown under drip irrigation often show roots bending towards the drip line in response to nutrient and water availability.

Figure C4-1. Cotton root symptoms following compaction.



Bending of roots by compaction in one season does not necessarily mean that compaction will be present or will be bad in the following season. The crop with the bent roots may have partly restored soil structure.

Nevertheless, deformed roots may indicate soil compaction. If bent roots are present, be especially careful to look for evidence of soil compaction or remoulding in the root zone.

Internode length, and pattern

Observe internode length at the end of the season. It will give you a historical record of the stresses encountered by the growing crop.

Look at a number of randomly selected plants and record the length of the internodes on the main stem. Record if there are many internodes shorter than 5 cm, especially towards the centre of the plant.

As a guide, internodes in the centre of the plant should be longer than 5 cm. Shorter internodes indicate moisture stress, possibly caused by compacted soil (See Chapter C9, especially Figure C9-5).

Plant growth hormones such as Pix™ will shorten internode length. Stress caused by infrequent irrigation as well as insufficient nitrogen will also shorten internode length.

Like root shape, internode length can aid in the diagnosis of compaction. A combination of the two (bent roots and short internodes) should point you towards careful inspection of the SOILpak compaction scores.

SOILpak 'degree of compaction/remoulding' score

Determine the SOILpak score at depths of:

- 0–10 cm (topsoil)
- 15–25 cm (sub-surface)
- 40–50 cm (upper subsoil)
- 70–80 cm (mid subsoil)
- 100–110 cm (lower subsoil)

in the following positions:

- under the plant lines next to the main wheel track (tractor row—TR)
- at the same point one hill across towards the 'guess row' (adjacent to picker wheel track, that is, picker row—PR).

Do this by carefully excavating a representative piece of soil with dimensions about 7 cm high, 7 cm wide and 7 cm deep. Scoring is on a scale of 0.0 to 2.0. Beginners can give each soil sample one of five SOILpak scores: 0.0, 0.5, 1.0, 1.5 or 2.0. More advanced users may subdivide the scores further (as many as 20 sub-divisions). The meaning of the scores, in simple terms, is as follows:

- 0.0 = terrible
- 0.5 = poor, but could be worse
- 1.0 = moderate
- 1.5 = good, but could be better
- 2.0 = excellent.

If the soil is firm, refer to Table C4-1. Where the soil is loose, refer to Table C4-2. Examples of damaged and undamaged clods are shown in Figures C4-2 to C4-5.

On the description sheets, record the score for each of the listed soil factors, then calculate their average. In most cases, the scores for a particular sample match up well and a mean value is easily calculated. Note that three of the listed factors are disregarded if the estimated clay content is less than 35%.

If one of the values used in calculating the SOILpak score deviates greatly (by more than 0.3) from the other component scores, use the equation shown after the tables to determine the 'average component value'. The equation contains 'weighting factors', which indicate the relative importance of each factor. This 'average component value' is adjusted, if necessary, according to the presence or absence of the following 'over-ride factors':

- inter-connected pores from the soil surface
- thin smeared layers
- abrupt texture change within layer
- excessive dust (loams)

Figure C4-4. Plant roots growing around, rather than through, a compact clod.

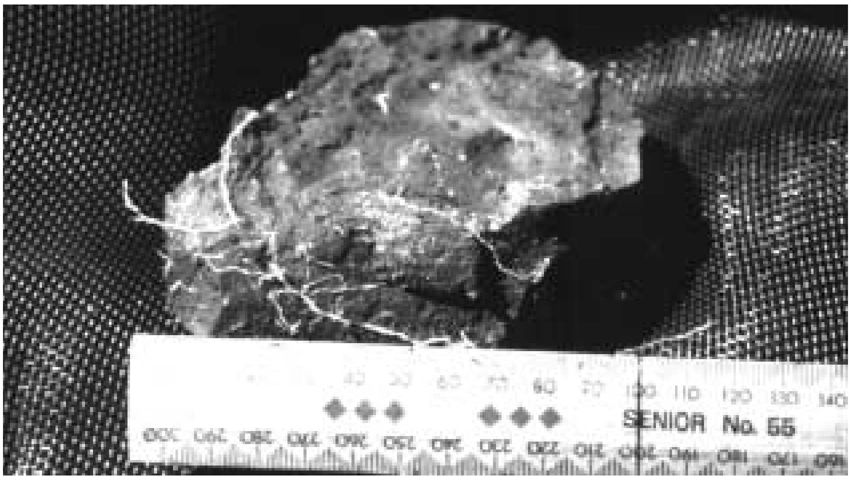
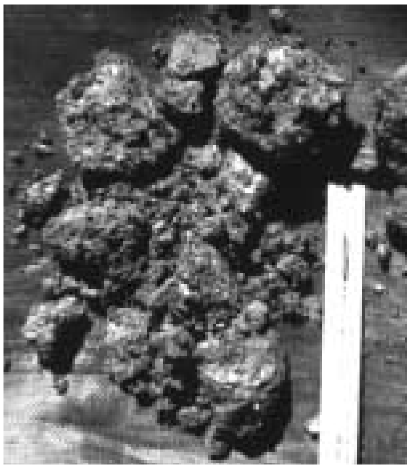


Figure C4-2. Large compact clod from under a hill that was accidentally placed on top of an old wheel track (SOILpak score = 0.2).

Figure C4-3. Clod with 'conchoidal' structure.

Figure C4-5. Well-structured clods that are associated with vigorous root growth (SOILpak score =

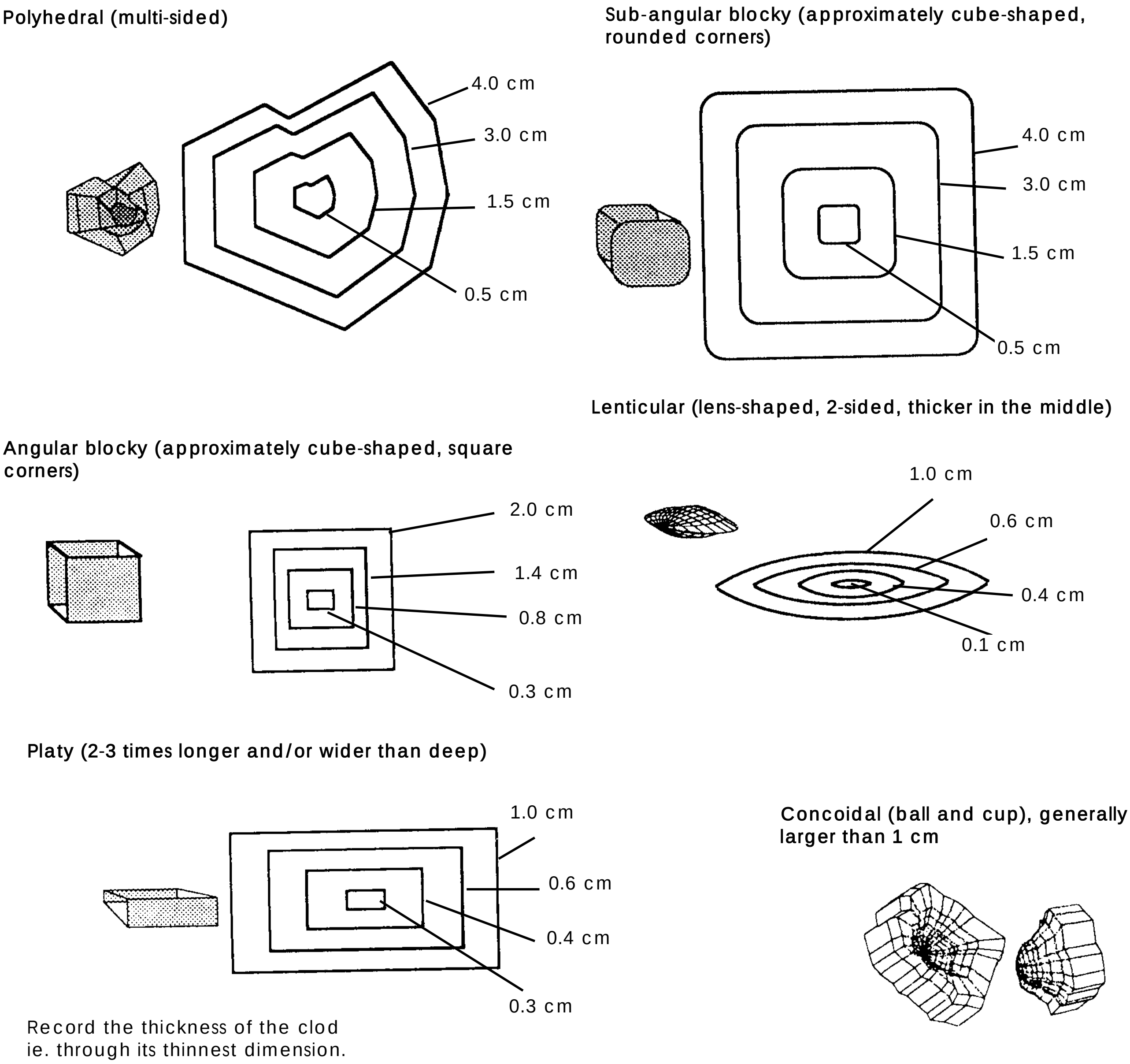


- surface crusting/hardsetting
- furrow encroachment.

These factors are described in more detail later in this chapter.

This procedure appears complicated at first, but it soon becomes ‘second nature’ and fast. If the procedure were made any simpler, the results would not be accurate enough to allow comparisons of soil structure over time.

Figure C4-6. Common clod sizes and shapes.



Natural: polyhedral, sub-angular blocky (and lenticular and angular blocky, if small and faces are shiny).
Signs of damage: platy, concoidal, massive (and, lenticular and angular blocky, if large and faces are dull).

Table C4-1. SOILpak scoring procedure in firm soil[a].

NOTE: In loamy soil (clay content less than 35%), ignore factors 2, 5, and 8.

Factors, listed in descending order of importance	Weighting in equation	SOILpak score component Firm 0.0 (poor structure)	Firm 1.0 (mod. structure)	Firm 2.0 (good structure)
MOIST SOIL[b]				
(1) Width of primary clods produced by moderate hand pressure (see Figure C4-6)	8	mostly > 50 mm	5–50 mm	mostly < 5 mm
(2) Ease of breakage of soil sample	7	Difficult for spade or knife to penetrate; soil made up of large tight fitting clods	Moderate hand pressure needed to part the component clods	Parts readily into porouscomponent clods
(3) Behaviour of 'fresh' cotton roots (up to 3 months after cotton harvest)	6	Very few new roots	Medium number of new roots, but concentrated between clods	Prolific growth of new roots throughout the sample
(4) Shape of clods produced by moderate hand pressure (see Figure C4-6)	5	Platy or conchoidal[c]	Mixed shapes	Polyhedral, subangular blocky
(5) Features of fracture faces	4	Breakage, along the lines of force applied in any direction, into units with sharp corners; internal surfaces with no projecting sub-clods	Some natural separation planes with shiny faces, but with most fracturing taking place along the line of applied force to produce angular corners and smooth, dull internal surfaces	Natural fracture planes dominate; most of the faces are smooth and shiny, although often there are protruding, multi-faced subangular units
(6) Proportion of primary clods (within compound clods; diameter approx. 3 mm) produced by rolling the compound clods between thumb and forefinger	3	Less than 1/3 of the breakdown products are shiny faced clods	1/3–2/3 of the breakdown products are shiny faced clods	More than 2/3 of the breakdown products are shiny faced clods
(7) Internal porosity of primary clods (see Figure C4-8)	2	0.0%	0.5%	>5%
(8) Approximate colour of the interior of primary clods (use Munsell Colour chart as a guide)	1	Grey, yellowish (may be mottled)	Light grey, slightly brown	Black, dark grey, or reddish brown
EXTRA NOTES FOR DRY[b] SOIL				
		Requires a very strong blow with a heavy implement to break the compound clods, revealing smooth dull surfaces with angled corners; flinty.	As above for priority 2, but more force (hard hand pressure) required to part the compound clods.	Falls apart with light hand pressure to produce small primary clods.

a 'Firm soil' is defined as soil below the tilled layer or below the natural loose mulch; it has clods that fit together along faces, and that usually require at least gentle hand force to lever them apart; it may also be found at the surface in association with crusting.

b 'Moist' soil is defined as having a water content between 'wilting point' and 'field capacity'. 'Dry' soil is defined as having a water content less than the wilting point.

c 'Ball and socket' appearance.

Table C4-2. SOILpak scoring procedure in loose soil[a].

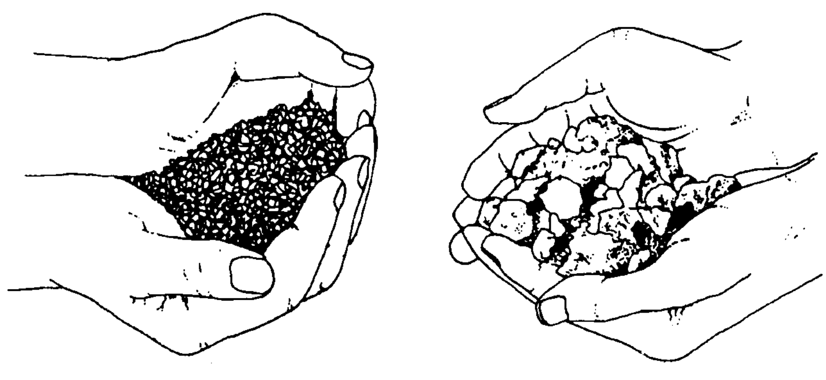
NOTE—In loamy soil (clay content less than 35%), ignore factor 2.

Factors, listed in descending order of importance	Weighting in equation	SOILpak score component		
		Loose 0 (poor structure)	Loose 1.0 (mod. structure)	Loose 2.0 (good structure)
MOIST[b] SOIL				
(1) Width of clods (see Figures C4-6 and C4-7)	5	usually > 20 mm	usually 5–20 mm	usually <5 mm
(2) Ease of breakage	4	Difficult to break	Can be parted by moderate hand pressure into smaller clods	Separates very easily into smaller clods
(3) Clod shape (see Figure C4-6)	3	Angular blocky with sharp edges, or conchoidal	Mixed shapes	Polyhedral or sub-angular blocky
(4) Proportion of primary clods (within compound clods; diameter approx. 3 mm) produced by rolling the compound clods between thumb and forefinger	2	Less than 1/3 of the breakdown products are shiny faced clods	1/3–2/3 of the breakdown products are shiny faced clods	More than 2/3 of the breakdown products are shiny faced clods
(5) Internal porosity of primary clods (see Figure C4-8)	1	Porosity rating 0%	Porosity rating 0.5%	Porosity rating >5%
EXTRA NOTES FOR DRY[b] SOIL				
		A large proportion of large, difficult to break flinty clods with sharp edges	As above, but compound clods will be firmer, some will flinty	As above

a ‘Loose soil’ is defined as loose seedbed, loose tilled layer (even if very cloddy), loose surface mulch; soil that can be removed by scraping (not digging) with the hand, a trowel or a spade; very loose soil may be found at depth in association with salinity, which promotes fine aggregation.

b ‘Moist’ soil is defined as having a water content between ‘wilting point’ and ‘field capacity’. ‘Dry’ soil is defined as having a water content less than the wilting point.

Figure C4-7. Contrasting clod size in loose surface soil.



An equation to deal with contradictory scores

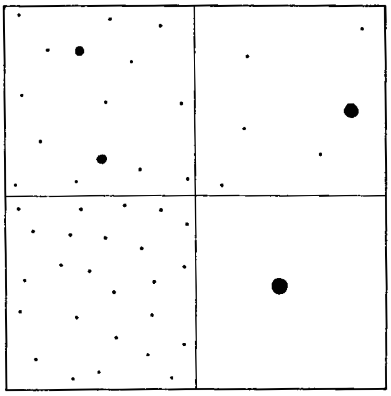
Usually there is a strong agreement between scores for each of the evaluated factors. However, sometimes the score for one factor for a particular sample of soil contradicts the score for another factor; that is, it differs by a value of more than 0.3. Under such circumstances, it is necessary to use an equation (see below) where each of the factors is given a weighting according to its priority. The weighting factors are shown in Tables C4-1 and C4-2.

The equation can still be used if one of the listed factors is unavailable at a particular site, for example where fresh cotton root behaviour cannot be included in an investigation. An example of the scoring procedure is shown in Table C4-3.

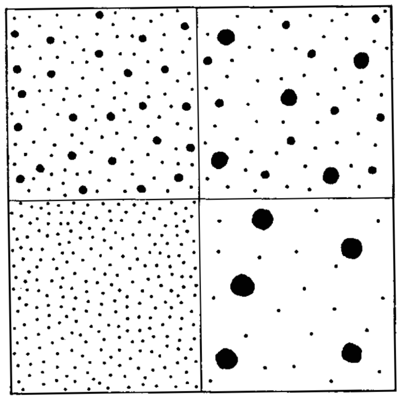
$$\text{SOILpak Score} = \frac{(S_1 \times W_1) + (S_2 \times W_2) + .. + (S_8 \times W_8)}{(W_1 + W_2 + ... + W_8)}$$

where: S = score, on a scale of 0.0 to 2.0, for each of the factors that can be considered
W = weighting allocated to each of the factors, in Table C4-1; for loose soil—see Table C4-2—a five-factor equation is used.)
The likely biological significance of each factor is presented in Table C4-4.

Figure C4-8. Clod internal porosity reference chart.



0.5%



5%

Source: Hodgson, J.M. (ed.) 1997, Soil survey field handbook, Soil Survey Technical Monograph, No. 5., Silsoe, U.K.

Table C4-3. An example of the SOILpak score scoring procedure that is used when the score for a particular sample of soil (with the dimensions 75 mm x 75 mm x 75 mm) contradicts the score for another factor (difference greater than 0.3). The soil under consideration is firm and moist.

Factor	Score	Weighting in equation (A)	Score x weighting (B)
1. Width of primary clod	0.4	8	3.2
2. Ease of breakage	0.4	7	2.8
3. 'Fresh' cotton root behaviour	– (not available)	6*	–
4. Clod shape	0.4	5	2.0
5. Features of fracture faces	0.3	4	1.2
6. Pedality of primary clods	0.5	3	1.5
7. Internal porosity of primary clods	0.0	2	0.0
8. Colour of clod interior	0.5	1	0.5
TOTALS		**30 (A)**	**11.2 (B)**
SOILpak SCORE (B÷ A)			**11.2 ÷ 30 = 0.4**

*not included in total because of missing observation

Table C4-4. Likely biological significance of the factors listed in Tables C4-1 and C4-2.

Soil morphology factor	Biological significance
Clod width	As clods become wider, taproot obliquity is likely to increase. Heliothis pupae survival increases as clod size increases.
Ease of breakage of soil sample	As clod strength increases, cotton taproots and their laterals will find it increasingly difficult to grow between, and through, the component clods because of poor aeration and/or mechanical impedance.
Clod shape	As clod platiness increases, taproots are more likely to develop a zigzag pattern as they grow downwards. Platy and conchoidal clods are usually hard and compact, without much scope for entry and exploration by root hairs.
Features of fracture faces	The incidence of clods with shiny faces appears to be associated with a decrease in the strength of inter-aggregate bonding, and with a decrease in clod size, which improves root growth and water movement. This shininess becomes more obvious as the number of shrink-swell cycles increases.
Proportion of primary clods within the compound clods (pedality), produced by rolling the compound clods between thumb and forefinger	The very narrow, but stable, fissures between small, primary clods with shiny faces should allow root hairs to enter compound clods and extract water and nutrients, unlike large, apedal clods, which do not subdivide easily into smaller components.
Internal porosity of primary clods	The presence of biopores—for example, old root and fauna channels—within primary clods should encourage soil exploration by root hairs.
Colour, degree of mottling of the interior of primary clods	Poor soil aeration caused by compaction often is associated with a bluish or yellowish tinge. Red and brown colours generally indicate an adequate supply of oxygen for root growth. However, well-structured soil can develop a bluish tinge (sometimes accompanied by manganese nodules) in the presence of a perched water table. Mottling indicates temporary waterlogging, which adversely affects the root growth of cotton.

Dealing with unusual circumstances—the use of 'over-ride factors'

- If the piece of soil under consideration has been given a SOILpak score of less than 1.5, but has at least two continuous vertical lines of weakness within a layer—for example, old crack lines or root/worm/ant channels (macropores; see example in Figure C4-9)—that could be used by cotton taproots to bypass hard and/or anaerobic layers of soil, the SOILpak score is upgraded by 0.5 units. Applying a white paint solution (see below) will highlight such features.
- If a smeared horizontal layer with a thickness greater than 5 mm is observed at any point within the layer being considered under the plant lines, downgrade the SOILpak score to 0.5 (if the score is above 0.5).
- The presence of a sharp or abrupt texture change within a layer (boundary width < 2 cm) may impede root growth and water movement; if this is evident, downgrade the SOILpak score to 1.0 (if the score is above 1.0).
- For light-textured soil (clay content <35%), downgrade the SOILpak score to 1.0 (if the score is above 1.0) if there is evidence of excessive dust (>30% powdery soil), or the presence of obvious hardsetting/crusting problems (see Figure C4-10).

- If structural damage from wheel tracks in the adjacent furrow has encroached to within 10 cm of the plant line, downgrade the SOILpak score to 1.0 (if the score is above 1.0).

Highlighting soil pores

Various types of dyes and tracers have been used to highlight soil pores. One very suitable tracer for use on cracking clays is a diluted white acrylic paint, which contrasts well with dark coloured soil. Below a technique is described, using paint, to trace interconnected pores in horizontal sections of soil. It is based on procedures developed by The University of Sydney and CSIRO Land and Water, Canberra.

1. Prepare the surface

A level area of soil is cleared at the top of the layer under consideration (usually just the soil surface). An open-ended steel frame (approx. 40 cm x 20 cm) with tall sides (approx. 10 cm) is pushed about 2 cm into the soil. The outside of the frame is then built up with loose soil to prevent leakage. When studying subsurface or subsoil layers, any smearing is removed using a simple technique of picking the surface with a shovel or knife to expose a natural ped surface. The exposed area is then carefully cleaned of loose fragments with a soft brush.

2. Add the paint

A mixture of white acrylic house paint and water is prepared (approximately 1:7 paint:water, by volume), then poured carefully into the frame (see Figure C4-11) using an object under the flowing paint to prevent direct disturbance of the soil surface. The frame is filled until the soil is ponded by several centimetres of paint (about 4 litres, depending on the infiltration rate). These frames are then left overnight, or at least long enough to enable most of the paint to infiltrate.

3. Expose the structure

Once the paint has infiltrated, the frames can be lifted out of the way. Soil at depths of 5 cm (half-way down through the topsoil) and 20 cm (half-way down through the sub-surface) is exposed by careful excavation with a mattock or hoe to observe how much paint is present. The appearance of paint in an old crack line (see Figure C4-12) or biopore provides definite proof that the macropore was connected to the soil surface.

If a permanent record is required, a thin layer of quick setting Araldite™ is then quickly mixed and spread on the prepared soil surface (approx. 20 cm x 20 cm). Once hardened, this thin layer is peeled off slowly to expose the structure of a relatively undisturbed surface of the white-paint-stained soil. It may then be photographed, under shade and next to an object of known length.

For more precise investigations, entire soil samples are impregnated with an epoxy resin containing fluorescent dye. After the resin has set hard, the impregnated soil is ground, photographed under standard ultra-violet lighting conditions, and assessed using a computer-based image analysis. Details of this SOLICON procedure are available upon request from Cooperative Research Centre for Sustainable Cotton Production, The University of Sydney. If the soil

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See Chapters B2, B4, B5 and B6 for more information about management options.

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See Chapter C9 for more information on moisture probes.

was moister than the plastic limit when paint infiltrated (the presence of shrinkage cracks at lower water contents complicates the analysis), the rate of drop of the paint solution within the steel frame provides a rough indication of soil infiltration rate. As a guide, rates of 0–10 mm/hour for the soil surface are considered very low (lots of runoff during rain storms), and rates > 70 mm/hour are very high (runoff unlikely).

Interpretation of the SOILpak scores

Table C4-5 describes management options that should be considered (if economically viable) for the full range of SOILpak score data.

Several other procedures are available for measuring the severity of soil compaction. They are summarised in Table C4-6, together with a brief explanation of why they are not recommended for routine use by users of this manual. Information from moisture probes is very useful for compaction assessment, but remember that the rate of extraction of soil water by cotton can be affected by non-soil factors such as cool, wet weather. Careful interpretation is required.

Table C4-5. Response to the 'degree of compaction' diagnosis

SOILpak score 'critical values'	Compaction severity under the plant line	Management options to consider
0.0–0.4	serious compaction	• biological ripping and biopore production • mechanical ripping • gypsum/lime (if the soil stability tests indicate that structural collapse is at least partly due to sodicity)
0.5–1.5	moderate compaction	• biological ripping and biopore production • mechanical ripping (maybe middle-bust) • critical N and water management
1.6–2.0	negligible compaction	• minimum tillage

Figure C4-9. A large vertical macropore, created by a native earthworm in a cracking clay near Walgett.

Figure C4-10. Seedling emergence problems caused by crusting on a light-textured soil.

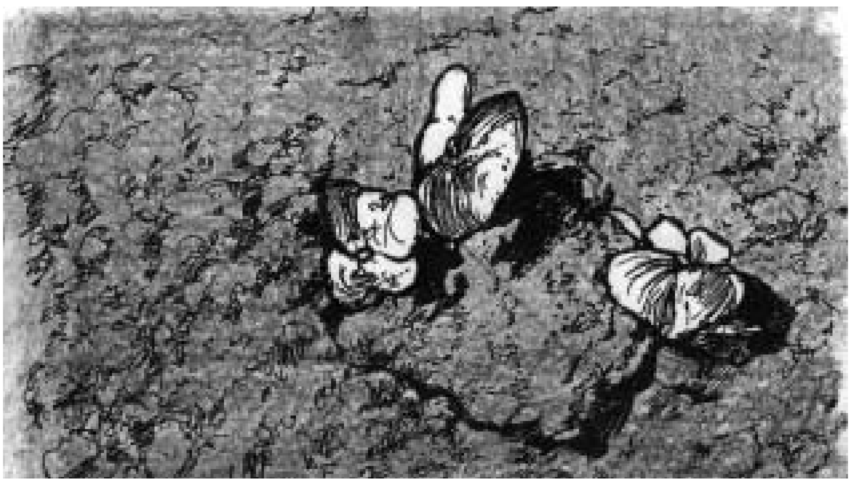
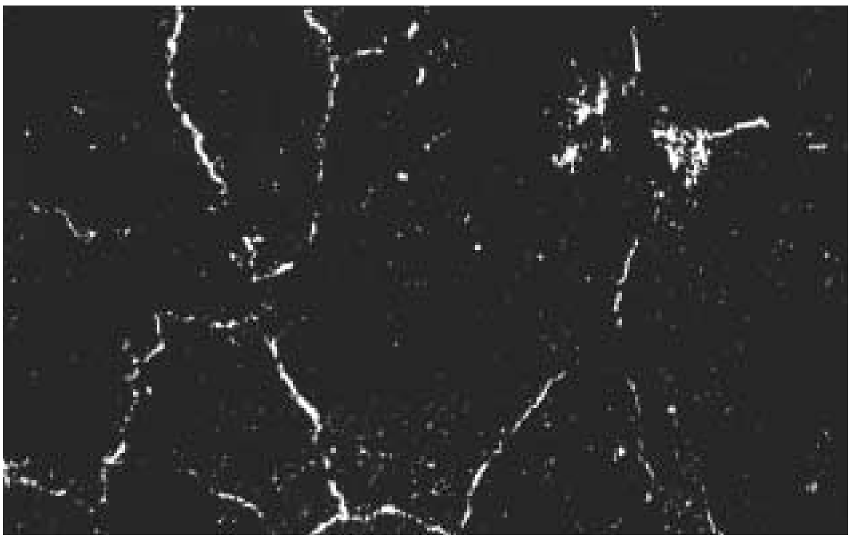


Table C4-6. Alternatives to the SOILpak 'severity of compaction/smearing' scoring procedure

Method	Situations where the method could be used when assessing structure in a cotton field	Drawbacks
1. Penetrometer	Useful if used immediately before and after a tillage operation, where the soil water content throughout the profile is around the plastic limit; penetrometers have good depth resolution.	Insensitive to differences in bulk density in sticky soil. Results need to be corrected for water content—the calibration equations vary from site to site.
2. Shear vane	Provides useful reference data at key sites —allows cross-checking of the SOILpak scores.	Results need to be corrected for water content – the calibration equations vary from site to site.
3. Bulk density cores	Provides useful reference data at key sites —allows cross-checking of the SOILpak scores, and gives information about air-filled porosity.	Time consuming. Soil water content needs to be close to the plastic limit. No information given about how well the pores are interconnected.
4. Clod shrinkage analysis	In compacted soil, can be compared easily with the large amounts of published data.	Time consuming. May be a risk of sampling bias in moderately- and well-structured soil.
5. Image analysis after resin impregnation	Provides very useful reference data at key sites —allows cross-checking of the SOILpak scores.	Time consuming and expensive. Requires specialised equipment. Soil water content needs to be close to the plastic limit.
6. Infiltration rate	Well permeameter data from the deep subsoil are useful for assessing how the structure will influence deep percolation.	Time consuming; data are often highly variable and influenced strongly by initial soil water content; potential for operator bias.
7. Calculation of non- and partly-limiting water ranges	Provides excellent information that can be related directly to crop management.	Time consuming and expensive (requires detailed strength, aeration and water content data).

Figure C4-11. Pouring a white paint solution into a soil to assess the presence of continuous vertical macropores.

Figure C4-12. White paint solution highlights old crack lines and biopores in moist clay soil (1/3 scale).



The relationship between SOILpak scores and the non- and partially-limiting water ranges is shown in Figure E6-1.

SOIL STABILITY IN WATER

There are two main types of clod collapse when water is added to soil:

- 'slaking', where large structural units disintegrate to form microaggregates
- 'dispersion', which is a more severe form of structural collapse.

For cracking clays, slaking to form microaggregates is a desirable process in terms of structural form regeneration by the process of self-mulching. Even more desirable is mellowing, a partial disintegration of aggregates during wetting that increases soil friability. However, if the microaggregates resulting from slaking disperse to produce sand, silt and clay, an undesirable massive structure may result. Water and air movement, root penetration and function, and seedling establishment are often affected adversely. In cracking clays used for irrigated cotton production, it is necessary to know the risk of soil dispersion so that preventative action can be taken.

Slaking of clods in water, and the effect of organic matter

Most clods in cotton soil collapse (slake) to form smaller aggregates when wet quickly. In cracking clays, this process apparently does not lead to serious waterlogging or soil hardness problems. In fact, it provides the benefit of breaking down excessively large clods after cultivation.

In contrast, slaking is a problem in loamy soil with poor shrink-swell potential. Slaked soil tends to set very hard when dry (particularly when accompanied by dispersion). Slaking is partially due to rapid wetting of the outer portion of clods, and subsequent swelling that is out of phase with swelling of the inner clod. The outer portion thus sloughs off the clod and breaks down into small (but not primary) units. One way of reducing slaking in loamy soil is to reduce the rate at which irrigation water is applied. Another is to add organic mulch, which increases the soil water content before water application. Organic matter also binds soil particles together, and may encourage beneficial soil organisms such as earthworms. Organic material may be applied, as well as synthetic polymers (if economically viable), to make the soil less prone to slaking in water.

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See Chapter E4 for more information on soil organic matter.

Most cotton soil is low in organic matter, especially after several years of excessive tillage.

The organic matter content of a soil is determined as follows:

Measurement of soil organic matter content

When soil test laboratories are asked to measure the organic carbon content of a soil, they generally use the Walkley-Black test. It is a crude procedure that cannot distinguish between biologically useful (labile) carbon and carbon that is inert (for example, charcoal). Much of the soil used to grow cotton in Australia contains substantial amounts of charcoal. To convert organic carbon content to organic matter content, multiply the former by a factor of 1.75. In general terms, a total soil organic matter content of below 1% is regarded as very low, 1–2% is low, 2–4% generally satisfactory, and greater than

4% is high. The test results are of limited value, but can be used to compare and rank fields, and to monitor a field over time in response to the use of a management treatment such as a winter wheat rotation.

Research workers at the University of New England have developed a procedure, based on the use of a potassium permanganate solution, to indicate the amount of carbon that is active (labile). CSIRO Land and Water in Adelaide is doing similar work. Labile carbon is a more sensitive indicator of improvements in soil organic matter status than ‘Total C’. The amount of ‘particulate organic carbon’ (organic carbon fragments larger than 0.053 mm) can also be used as a measure of ‘labile’ organic carbon in soil. In several years’ time it is likely that greatly improved procedures will be available to measure the various forms of soil organic carbon, and to provide practical interpretation of the results.

Field signs of dispersion

Separation of sand, silt and clay in the field after heavy rain (see Figure C4-13) is a reliable indicator of soil dispersion. Dispersion is usually caused by too much sodium being attached to the clay surfaces. Where sodicity occurs below the soil surface, excessive swelling and constriction of macropores (a process which, unfortunately, is difficult to detect visually) is likely to be a problem.

Figure C4-13. Dispersion causes separation of light coloured sand on the soil surface following heavy rain.

ASWAT dispersion test

Determine the ASWAT (Aggregate Stability in WATer) score at depths of 0–10 cm, 15–25 cm, 40–50 cm, 70–80 cm and 100–110 cm under the ‘tractor row’ and ‘picker row’. The procedure is as follows:

Place air-dry clods (3–5 mm diameter) in a dish containing distilled water. After 10 minutes’ and 2 hours’ immersion, a visual judgement is made of the degree of dispersion on a scale of 0 to 4.

- A score of 0 indicates no dispersion (see Figure C4-14).
- A score of 1 is slight dispersion, recognised by a slight milkiness of water adjacent to the clod.
- A score of 2 is moderate dispersion with obvious milkiness.

- A score of 3 is strong dispersion with considerable milkiness and about half the original volume dispersed outwards.
- A score of 4 is complete dispersion, leaving only sand grains in a cloud of clay (see Figure C4-15).

Add the 10-minute and 2-hour scores together, giving a range of values between 0 and 8. For those clods that scored 0, the amount of dispersion after remoulding is determined. Soil is mixed with distilled water to a plastic consistency and remoulded on a plate, using a knife, for about a minute. Small balls are formed and placed in a dish containing distilled water. The degree of dispersion of this remoulded soil is assessed as for the dispersion on wetting—the 10-minute and 2-hour scores for remoulded soil are added together.

For those air-dried clods that dispersed, 8 is added to the sum of the scores for the 10-minute and 2-hour assessments, thus giving a range of values between 9 to 16. It is assumed that the air-dry clods that disperse would show rapid and complete dispersion and score 8 when remoulded. Thus 0 indicates no dispersion and 16 indicates severe dispersion.

Because this procedure cannot be done in less than 2 hours, and requires the use of air-dry clods, it is best to do it at home or in the laboratory. The ASWAT test is a modification of the ‘Loveday and Pyle’ dispersion test.

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See Chapter D2 and Agfact AC.10: ‘Improving soil structure with gypsum and lime’ for details about management options such as gypsum and lime application.

Interpretation of the ASWAT test results

Table C4-7 describes management options that should be considered (if economically viable) for the full range of ASWAT test data.

Figure C4-14. Clods of soil that have slaked but not dispersed

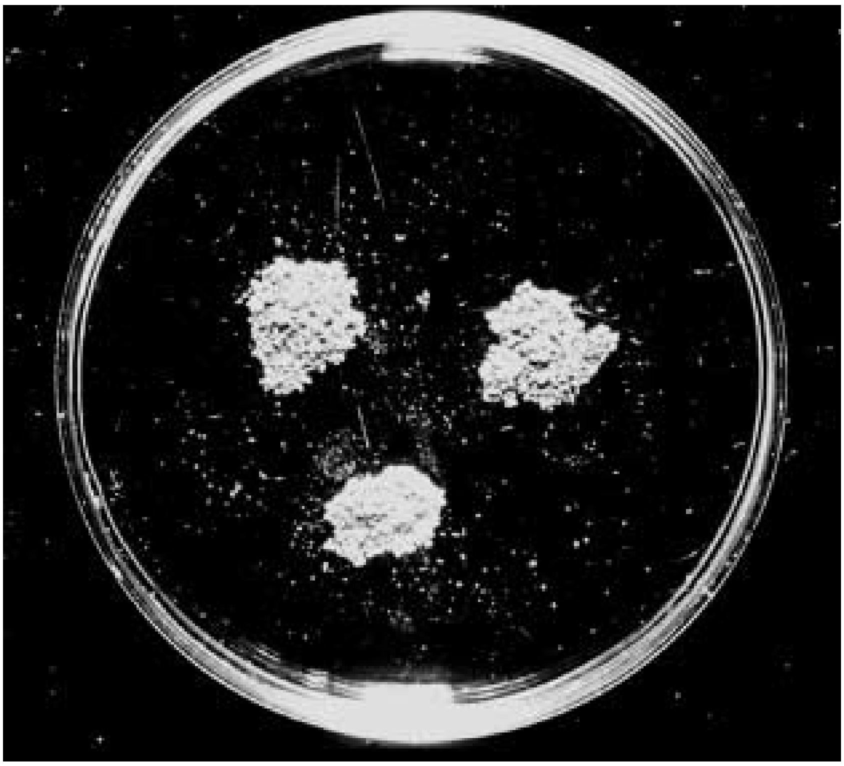


Table C4-7. Response to the soil structural stability diagnosis

ASWAT score 'critical limits'	Severity of dispersion under the plant lines	Management options to consider
7–16	serious dispersion	• Apply gypsum (and/or lime) and organic matter
2–6	moderate dispersion if the soil is remoulded	• Avoid working the soil when it is moist (also applies to the above category)
0–1	negligible dispersion	• Protection of soil from dilution by excess water (this reduces soil EC), and from the force of raindrop impact and overland flow (also applies to the above two categories)

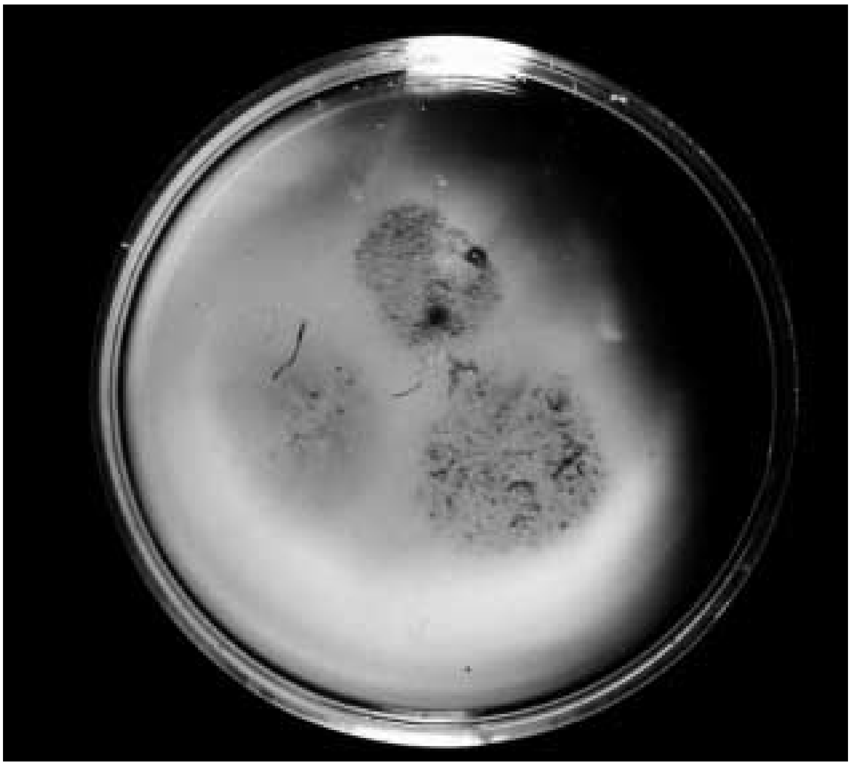
To confirm (and understand more thoroughly) the above conclusions about soil dispersibility, the following laboratory tests are recommended.

Follow-up laboratory tests at key sites to refine the ASWAT test recommendations

Exchangeable sodium percentage (ESP)

An excess of sodium ions attached to the clay particles leads to increased swelling of the clay and increases the likelihood of dispersion. Surface soil crusts or sets into hard blocks on drying. Subsoil has decreased permeability to water and air. Take soil samples (approximately 0.8 kg) from key sites of interest identified by the ASWAT test. Have them analysed for exchangeable sodium percentage

Figure C4-15. Clods of soil that have slaked and dispersed.



(ESP) at a NATA-certified laboratory. Ask them to analyse the samples using the ‘Tucker method’, which is the only reliable procedure that is available for exchangeable cation analysis in soil containing free lime (calcium carbonate) and gypsum (calcium sulfate). A soil with an ESP greater than 5 is referred to as sodic, although ESP values as low as 2 can cause soil structure problems if the concentration of salt in soil solution is very low.

You can ask your laboratory to test your irrigation water for dissolved cations.

The sodium adsorption ratio (SAR) of the water gives an indication of the potential for increasing the soil’s sodicity. If you are in an area with irrigation water which contains high amounts of sodium and magnesium in relation to calcium, do regular tests of soil ESP to determine if it is becoming worse.

Exchangeable calcium:magnesium (Ca:Mg) ratio

Exchangeable magnesium aggravates the adverse effects of sodium. It is measured at the same time as exchangeable sodium (see above), calcium and potassium (Tucker method).

A calcium:magnesium ratio of less than 2.0 (and particularly less than 1.0) indicates a tendency towards clay dispersion and poor soil structure.

Electrical conductivity, Electrochemical Stability Index (ESI), pH

Electrical conductivity (EC) of a soil is a measure of its salinity. As EC increases, soil dispersion decreases for a given sodicity value. Conversely, very low EC values mean that a soil may become dispersive where the ESP of the soil is only 2. Therefore, instead of looking just at ESP values, the ‘electrochemical stability index’ ($EC_{1:5}$ /ESP) (ESI) needs to be calculated. A tentative critical ESI value for Australian cotton soil is 0.05. An economically viable response to gypsum and/or lime can be expected where ESI values are at or below this level.

As the soil pH increases, the charge of some clay particles becomes more positive, so the soil will become more dispersive.

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See Chapters C7 and C8 for information about the measurement of soil salinity and pH.

Calcium carbonate content

As the calcium carbonate ($CaCO_3$) content of a soil becomes greater, the likelihood of a soil being dispersive decreases even when ESP values are high. When $CaCO_3$ concentration is above 0.3% (particularly if it is finely divided rather than in the form of nodules), soil stability in water is likely to be acceptable.

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See Chapter E3 for more information on the chemistry of sodic and saline soil.

Soil stability under the influence of compactive forces

The ability of soil to maintain its structure when compactive forces (for example, under the wheels of a tractor) are applied is affected mainly by the soil water content. As soil water content increases, soil resistance to deformation decreases.

At a given water content, there is variation in strength between soil types. For example, soil strength tends to increase as the content of cementing agents such as calcium carbonate becomes greater. However, soil resistance to compaction/remoulding is not usually measured in the field or laboratory because of the overwhelming (and, due to rain, often uncontrolled) influence of soil water content. Compaction under wheel tracks is inevitable, regardless of inherent soil properties. The main priority is to restrict compaction to narrow bands in some of the furrows. Apart from areas where poor surface drainage can be corrected (for example, by procedures such as increasing field slope and gypsum treatment of sodic areas), compaction control is a matter of machinery management rather than soil management.

STRUCTURAL RESILIENCE

A resilient soil is a soil with the ability to develop a desirable structure by natural processes after destructive forces (such as the compactive pressures under the wheels of heavy machinery) have been removed. Desirable processes include:

- the development of shrinkage cracks
- the loosening and mixing of hard layers by soil fauna such as earthworms and ants (particularly important in loamy soil)
- the formation of continuous, stable vertical channels in the soil by root systems.

Measurement of soil resilience

Field signs

The presence of shrinkage cracks when a soil is dry (Figure C4-16) clearly shows that a soil is resilient. If a soil is wet, place a piece of it in an oven for several hours to see whether or not it shrinks strongly. When you are down inspection pits in the field, another sign of soil resilience to look for is the presence of slickensides, that is, stress surfaces (often at an angle of about 45^{o} to the surface) that are polished and striated by one mass sliding past another.

The presence or absence of earthworms and/or ants in the topsoil indicates the short-term potential for soil improvement by these organisms. Much remains to be learnt about this topic.

Figure C4-16 Resilient soil regenerates soil structure by shrinking and swelling.

Laboratory tests

The sum of exchangeable calcium, magnesium, sodium and potassium in soil, also referred to as the ‘Cation Exchange Capacity’ (CEC), provides a rough index of the shrink-swell potential (resilience) of a cotton soil. As CEC increases, the soil becomes more structurally resilient. Note, however, that where soil is acidic, the sum of the four main exchangeable cations will be less that the actual CEC, due to the presence of other ions such as hydrogen and aluminium, so special testing is required. A recently developed resilience test from CSIRO Land and Water, Canberra, can also be used by laboratories. Referred to as the ‘Modified Coefficient of Linear Extensibility (COLE) Test’, it is a measure of how much soil aggregates shrink under standard conditions.

New tests are being developed to determine the inherent ability of a cotton soil to become friable and ‘self-mulching’—conditions that depend on both the soil resilience and structural stability in water.

It was noted earlier that as the ESP of the soil increases, so does the amount of soil swelling (and shrinking). While this is desirable from a resilience point of view, there are likely to be serious problems with dispersion. Therefore, the only sensible option for improving soil shrink-swell potential is to increase clay content, although usually this is not economically feasible.

Interpretation of the CEC and COLE (resilience) test results

Table C4-8 describes management options that should be considered (if economically viable) for the full range of CEC and COLE (resilience) test data.

Table C4-8. Response to the soil structural resilience diagnosis

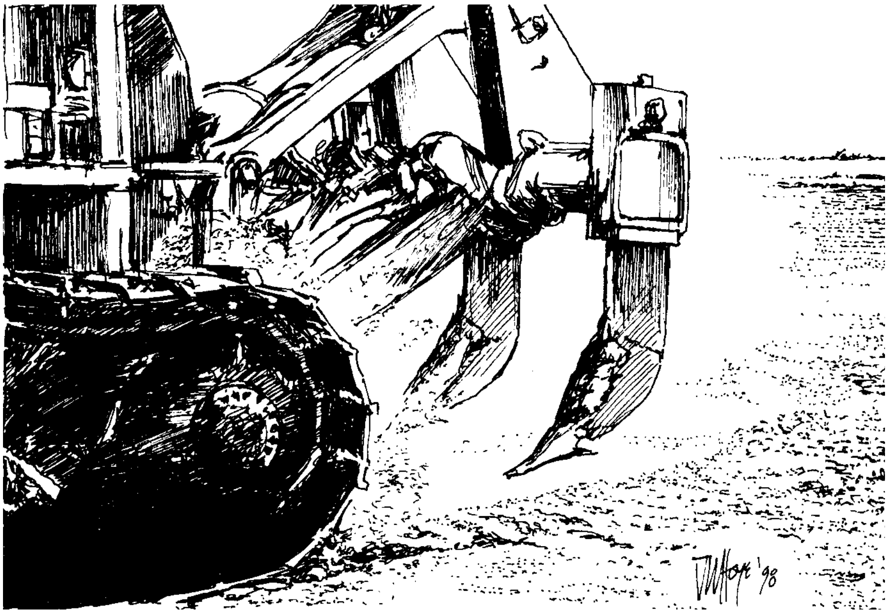
'Critical limits' CEC cmol(+)/kg	COLE value %	Soil resilience (regeneration potential)	Management options to consider when overcoming compaction problems
less than 20	less than 3	poor shrink-swell potential	• If the subsoil is a lot more resilient than the topsoil, consider bringing it to the surface with a mouldboard plough or slip plough. Otherwise, rely upon the plant root systems and soil fauna to permeate the soil with macropores (this may have to be preceded by mechanical loosening).
20–40	3–12	moderate shrink-swell potential	• Use shrink-swell cycles to loosen compacted soil, although mechanical loosening and biopore creation may be needed to accelerate the process.
greater than 40	greater than 12	good shrink-swell potential	• Rely mainly upon shrink-swell cycles to loosen compacted soil.

REMEMBER

To encourage the growth of cotton roots:

- minimise soil compaction
- maximise soil stability in water
- if compaction occurs, strongly resilient soil is easier to repair by natural processes than poorly-resilient soil.

C5. Structure after rotation crops and tillage



PURPOSE OF THIS CHAPTER

The aim of this chapter is to encourage you to inspect a soil after growing a rotation crop and after major tillage operations. You should compare results of the post-treatment inspections with the pre-treatment assessments at the same sites; a judgement can then be made about whether or not the selected soil improvement strategy was successful.

CHAPTER OVERVIEW

This chapter covers the following points:

- field observations
- conclusions and management options.

Associated chapters that you may need to refer to are:

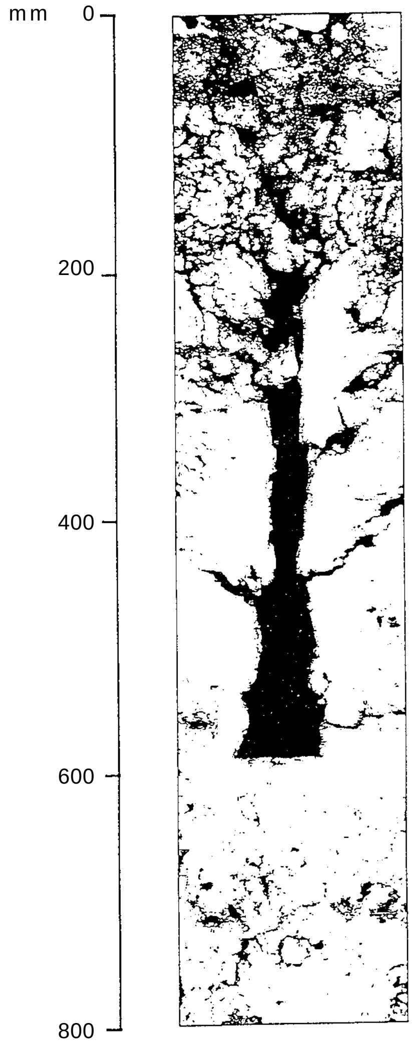
- Chapter C1: ‘Soil pit digging: where, how and when?’
- Chapter C4: ‘Structural condition’.

INTRODUCTION

After a serious compaction problem is identified, the use of a rotation crop and/or deep tillage may be required to loosen the soil. Chapter D2 will help you to select a suitable option.

Unfortunately, most farm managers assume that their selected option has been successful, rather than digging a hole to see how effective the operation has been. Those that do carry out an inspection are often shocked to discover that structural problems have been made worse rather than being improved. Farm managers also have to judge whether or not topsoil cultivation has produced a tilth that allows good control of Heliothis pupae. This chapter encourages you to carry out post-tillage and/or post-rotation observations, and then make appropriate adjustments to your future soil and equipment management programs.

Figure C5-1. Subsoil damage (below a depth of 25cm) caused by deep tillage in a moist clay soil; this vertical image was created using the SOLICON system.



Source: Koppi et al., 1994.

ASSESSMENT PROCEDURES FOR THE ENTIRE ROOT ZONE AFTER ROTATION/TILLAGE

Rapid field observations

In a field that has just been decompacted by a rotation crop and/or tillage, return to at least one of the post-cotton-harvest inspection sites and dig another pit. Sketch the main pit features, then reassess the SOILpak score (see Chapter C4) in the topsoil, sub-surface and subsoil. Compare the results with the pre-treatment assessment, and judge whether soil structural form is better, unchanged or poorer. If it is poorer, develop ways of improving the performance of the management inputs. The soil may be better after tillage, but worse a couple of months later, for example, after rain.

Resin impregnation and image analysis

To obtain a permanent record of post-treatment soil structural form, either vertically or horizontally, impregnate the soil with epoxy resin. The blocks of soil are then excavated, ground back and photographed under UV light. The resulting image may then be scanned, and described using the SOLICON system. Contact the Cooperative Research Centre for Sustainable Cotton Production, The University of Sydney, for further details.

Figure C5-1 illustrates (via the use of resin impregnation and image analysis) the consequences of deep ripping wet clay soil when it is too wet. Soil each side of the vertical slot left by the ripping tine was badly compacted below a depth of 25 cm. Roots entering this slot would have great difficulty re-entering the soil at lower depths. This SOLICON procedure is particularly useful for designers of tillage equipment.

POST-TILLAGE ASSESSMENT PROCEDURES FOR TOPSOIL

Rapid field observations

Carefully observe the condition of the topsoil (0–10 cm). Large clods (particularly those with a diameter greater than about 5 cm) may contain Heliothis pupae. Aim for a SOILpak score greater than about 1.5. If the surface soil is dispersive, treat it with gypsum/lime to encourage the development of a fine tilth. The average size of the aggregates can be determined by passing the soil through sieves of known diameter. However, great care must be taken to avoid clod breakage during this process.

In loamy soil, there is a risk of producing a tilth that is too fine. Dusty soil is prone to wind erosion, and tends to set very hard when it is re-wet. Therefore, do not over-cultivate loamy soil.

Resin impregnation and image analysis

A permanent and comprehensive record of surface soil structure (in both horizontal and vertical section) can be obtained using the SOLICON system (see above).

C6. Stubble

PURPOSE OF THIS CHAPTER

The issue of what constitutes a desirable cover of surface mulch for soil under irrigated and dryland cotton is not well understood. Nevertheless, this chapter gives some general guidelines about assessment and interpretation of the amount of stubble.

CHAPTER OVERVIEW

The following points are considered:

- a description of the type of stubble cover needed to protect the soil against raindrop impact and erosion, and to conserve moisture
- the carry-over of cotton diseases when organic residues are retained on the soil surface
- the need to maintain effective weed control when mulching the soil surface with organic residues

Associated chapters that you may need to refer to are:

- Chapter C2: 'Features of the description sheets'
- Chapter E5: 'Organic matter and soil biota'.

INTRODUCTION

Protecting the soil surface with crop residues has several benefits, including:

- erosion control
- provision of food for desirable soil organisms
- water conservation
- protection from extremes of temperature.

It is crucial that soil erosion be minimised on cotton farms. Transportation of soil particles by water and/or wind erosion may result in off-farm movement of soil nutrients, and pesticides such as endosulfan. The most effective way of preventing erosion is to protect the soil surface with crop residues. Some general guidelines are presented below about the type of cover that is required.

Possible adverse side-effects include disease carryover, insect build-up, nutrient tie-up, weed control problems and blockage of irrigation systems.

SURFACE MULCH SPECIFICATIONS FOR COTTON FARMING SYSTEMS

- Surface mulch coverage should be greater than 30% (preferably >70%). To visualise this, refer to the attached ‘Photostandards for winter cereals’ produced by QDPI (see Appendix 7). Cotton crops are unlikely to produce enough residue to provide this degree of protection. A well-managed winter wheat crop will give a residue that provides much better coverage.
- The residue should be at least partly anchored to prevent it from washing or blowing away. One way of doing this is to plant winter wheat (after tilling the topsoil to kill Heliothis pupae and weeds), but to spray it with herbicide just before planting a cotton crop. However, until herbicide resistant cotton varieties are widely available, weed control may be difficult during the early stages of cotton growth.
- Any residue that has been cut—for example wheat straw that has passed through a header—should be as short and evenly-spread as possible to minimise the risk of blockages during subsequent tillage and planting operations. However, it should not be ground up too finely—otherwise it may decompose too quickly.
- The residue needs to be sufficiently resistant to decomposition to allow persistence during the summer months when erosion risk is at a peak. This means that the ratio of carbon to nutrients such as nitrogen and sulfur should be as high as possible. Although cotton stalks do not have sufficient bulk to provide good surface coverage, they are resistant to decomposition. Recent research at UNE has shown that a typical C:N ratio for cotton stalks is 39 (>15 means that there is not enough N for micro-organisms to use the C); the associated N:S ratio was 8.7 (microbes need 15 N:1 S, so there is enough S in relation to N), and the P:S ratio was 1.3 (microbes need P>S), so P was not limiting their activity.

Further research is needed to refine these suggestions.

☞

See Chapter D2 for more information on disease carryover.

☞

See Chapter E5 for more information on stubble management.

PROBLEMS WITH ORGANIC RESIDUES ON THE SOIL SURFACE– FACTORS THAT SHOULD BE MONITORED

- Diseases may be carried over to the next cotton crop via cotton trash. Where these problems occur, the use of disease-resistant cotton varieties may be the best option if other approaches such as the use of break crops (for example, wheat) are not successful. Avoid burning cotton trash, because valuable nutrients are lost to the atmosphere, and soil organic matter reserves become depleted. Also try to avoid the deep incorporation of trash by discing, due to the risk of compaction and smearing in moist soil.
- Damaging insects, such as wireworms, may build up in rotation crop residues, but control methods are available.
- Cotton crops grown with mulches may suffer nutrient deficiencies, due to nutrient tie-up in the residues, unless extra fertiliser is added when required (see NUTRIpak for further details).
- Weeds generally are more difficult to control where mulch is present, relative to bare soil. The incorporation of pre-emergent herbicides is also more difficult, although the introduction of granular formulations can ease these problems. If soil surface monitoring indicates a serious build-up of problem weeds, get advice about their control from an agronomist.

C7. Salinity

PURPOSE OF THIS CHAPTER

Salinity may become a major soil management problem if the early warning signs are disregarded. This chapter describes some of the diagnostic tools that are available to recognise and prevent soil salinity problems.

CHAPTER OVERVIEW

This chapter covers the following points:

- recognition of a saline soil
- quality of irrigation water
- depth to watertable and deep drainage risk.

Associated chapters that you may need to refer to are:

- Chapter D4, 'Avoiding salinity problems'
- Chapter E3, 'Effects of sodicity and salinity on soil structure'.

INTRODUCTION

Cotton is more tolerant of salt than most other crops, but salinity problems can easily get to the stage where cotton growth may be retarded. Some of the crops that may have to be grown in rotation with cotton are more sensitive to salt (for example, winter legumes). The incidence of serious salinity in land used for irrigated and dryland cotton in Australia presently is very minor, but this situation could change. Some parts of the landscape contain large amounts of salt in the subsoil, and extra salt is being imported to fields via the irrigation water. All soil managers need to be able to recognise salinity problems, particularly during the early stages of development. It is an expensive issue to correct when it is well advanced. Procedures for testing soil salinity and water quality, and for monitoring groundwater, are described below.

SOIL SALINITY

Field signs

Salinity refers to an accumulation of salt in the plant root zone or on the soil surface. It usually occurs as a result of groundwater rising to within 2 metres of the soil surface, resulting in a concentration of salt in the root zone. Early signs include:

- poor crop growth
- increasing numbers of salt-tolerant weeds
- prolonged wetness, and/or unusually friable soil structure, in low-lying areas

Severe symptoms of salinity include:

- bare, salt-encrusted soil surface
- under dry conditions, white crystals that are salty to taste
- flocculation of suspended clay particles to give unusually clear water in puddles and drains
- decline of all but the most salt-tolerant plants
- greasy-looking black patches (‘black-alkali’), due to the dispersion of organic matter when high-pH bicarbonate salts are present
- death of trees in surrounding areas
- total crop failure.

Laboratory testing

To test a soil for salinity in the laboratory, a sample of soil is mixed with water, and an electric current is passed between two electrodes placed in the extract. The greater the salt concentration, the greater the current (conductivity). If no salt is present, very little electric current passes.

The most accurate way of preparing the sample is to make a ‘saturation extract’. This involves the addition of distilled water to a soil sample until a characteristic sticky point is reached. A suction filter is then used to extract a sufficient amount of water to perform an electrical conductivity (EC_e, dS/m) measurement. The advantage of this method is that it is related to the water-holding capacity of the soil and thus is representative of what a plant root would experience. Unfortunately, this saturation extract method is tedious and time consuming. A simpler and more commonly used approach is to mix the soil with five times its weight of distilled water. Salinity is estimated by measuring electrical conductivity of the 1:5 soil:water suspension ($EC_{1:5}$, dS/m) after it has been shaken for 1 hour. However, this procedure does not take into account the effects of soil texture—the readings from 2 different soil types cannot be compared directly. Another possible problem is that in soil with significant amounts of gypsum, $EC_{1:5}$ will be overestimated.

It is, however, possible to approximately relate the conductivity of a 1:5 soil:water extract to that of the saturation extract, and to predict likely effects on plant growth. These relationships are shown in Table C7-1. The critical salinity limits indicate (approximately) the EC_e value at which yield decline due to salinity starts. A portable (hand-held) EC meter can be used quickly to provide a first approximation of soil salinity in the field, for example, as provided in the 'Salt Action Field Salinity Kit'. However, laboratory testing will be more accurate. Experiments in the USA have shown that cotton yield decline starts when EC_e = 7.7 dS/m. A 50% yield decline corresponds to an EC_e value of 17 dS/m. Values for seedlings tend to be about 12% less than for adult plants.

Table C7-1. Conductivities of saturated extracts and 1:5 soil:water suspensions at which yield decline starts for plants associated with cotton farming systems

Plant Salt Tolerance	Soil Salinity Rating	Saturated Extract, EC_e (dS/m)	1:5 soil:water Suspension, $EC_{1:5}$ (dS/m) Soil Texture		
			Silt loam	Medium clay	Heavy clay
Sensitive (eg field peas)	Very low	<1.5	<0.16	<0.20	<0.26
Moderately sensitive (e.g. corn, lucerne, broccoli)	Low	1.5–3.0	0.16–0.32	0.20–0.40	0.26–0.52
Moderately tolerant (e.g. cowpea)	Medium	3.0–6.0	0.32–0.64	0.40–0.80	0.52–1.04
Tolerant (e.g. cotton, barley, wheat, sorghum)	High	6.0–10.0	0.64–1.05	0.80–1.33	1.04–1.72
Very tolerant (e.g. saltbush)	Very high	>10.0	>1.05	>1.33	>1.72

$EC_e/EC_{1:5}$ conversion factors for soil with textures other than silt loam, medium clay and heavy clay are shown in Appendix 4.

Some laboratories use units other than dS/m (deciSiemens per metre) as salinity units. Two commonly used conversion factors are as follows:

- dS/m (1 dS m^{-1}) = 1000 mS/cm
- EC (dS/m) = ppm (mg/kg) x 600 (1.56 dS/m = 1000 ppm). Other conversion factors are listed in Appendix 4.

Indirect methods – EM and TDR

Electromagnetic induction (EM) devices rapidly estimate soil salinity in the field by measuring the ease with which a magnetically-induced current passes through the soil.

Currently, three commercially available EM instruments are available. These include the EM38, EM31 and EM34-3. They are useful in describing apparent electrical conductivity (EC_a) across fields, but each site requires its own calibration because of variations in other soil factors such as water content and clay mineralogy.

Of these instruments, the EM38 best describes EC within the root zone (to a depth of about 1–2 m). The EM31, which is a slightly larger instrument, is better suited to deeper subsoil studies of shallow aquifers and deeper water tables (to a depth of approximately 3.5–7 m). Both the EM31 and EM38 instruments are used with a sampling interval of 25–50 m. In areas where salinity is evident, or more detailed information is deemed necessary, a more detailed sampling interval can be adopted.

The EM34-3 is an instrument that can measure EC to a depth of between 7 m and 30 m. It is used mainly for catchment scale surveys of soil salinity.

Another instrument that may be useful is a four-probe electrode configuration that can be used to resolve EC_a distribution within the beds and furrows of irrigated fields. It measures the resistance of the soil, which is the reciprocal of EC_a.

The EM instruments can be used by hand or by ground-rig, or in helicopters or aircraft. Another approach is to insert TDR (Time Domain Reflectometer) rods into the soil and estimate both water content (see Chapter C9) and salinity. As for the EM instruments, each new field site will require calibration.

To calibrate the EM38, EM31 and EM34-3, soil samples are required to depths, respectively, of 2, 7 and 15–30 m. The EC_e of the soil samples is measured in the laboratory. A minimum of 15 sites need to be selected, with an additional five used to validate the calibrations. Areas with the largest and smallest EM values need to be included in the soil sampling scheme. Research is being carried out at The University of Sydney to improve the efficiency of calibration.

Computer software products (GISs) are available to store, manipulate and map the large amounts of data generated by EM surveys. GPS instruments should be used to record the geographical position of each of the sampling points.

A soil manager at Warren has demonstrated how EM instruments can be used as part of a package to identify sites with leaky subsoil. Leaky sites are likely to transmit too much water (particularly if a reservoir is built there), and therefore cause saline water tables to move nearer the soil surface. He uses the following procedure:

- Inspect aerial photos of the area of interest. Look for evidence of prior streams, which are often underlaid by highly permeable sand and gravel lenses. Colour photos (if available) are more useful than black and white photos. Geology and hydrogeology maps may also be useful.
- Carry out an EM31 survey of the sites of interest. Soil types with the lowest EC readings are assumed to be the most leaky zones, due to the leaching of soluble salts.

- Use a drilling rig to obtain soil samples, to a depth of 3.6 m, from areas of interest defined by the EM survey.
- If the site is underlaid by a layer (with a thickness of at least 3 m) with a clay content of at least 'medium clay', and preferably dispersive in water, it is likely to have negligible deep drainage.

QUALITY OF IRRIGATION WATER

Because the quality of irrigation water strongly influences soil condition for plant growth, it should be assessed regularly at a NATA-certified water testing laboratory.

Salinity

Salinity guidelines for irrigation water are summarised in Table C7-2. They apply to both bore water and river water.

A 'leaching requirement' (LR) of 15% (that is, 15% of the applied irrigation water being used to 'wash out' accumulated salt) is desirable to avoid the excess accumulation of salt in the plant root zone. The greater the salinity of the applied water, the higher the LR. However, if the salt in the irrigation water is dominated by calcium (for example, as observed in the Macquarie River), which then becomes immobilised as calcium carbonate in the subsoil, the LR may be very small. This topic requires further investigation.

To calculate the total input of salt via the irrigation water (per cotton crop), use the following equation:

$$\text{salt input (t/ha/cotton crop)} = EC_{iw} \times W_I \times 0.67$$

where: EC_{iw} = electrical conductivity of irrigation water (dS/m)
W_I = total amount of applied irrigation water (megalitres).

Sodium hazard

Cotton does not suffer from the direct toxic effects of sodium ions (unlike sensitive crops such as citrus), but the soil structural stability may decline if the irrigation water is sodic. Sodium adsorption ratio (SAR) is a ratio for irrigation waters and soil extracts used to express the relative activity of sodium ions (in relation to calcium and magnesium) in exchange reactions with soil. Exchangeable sodium percentage (ESP) increases as the SAR of water passing through the soil becomes greater. SAR should be kept below about 4 (preferably less than 2) to avoid such problems. Further research is needed to refine this recommendation for Australian cotton soil. SAR is calculated as follows (units of cation concentrations = meq/L):

$$SAR = \frac{\text{(sodium concentration)}}{\sqrt{[(\text{calcium concentration} + \text{magnesium concentration})/2]}}$$

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See Chapter E3, 'Effects of sodicity and salinity on soil structure' for more information on the effects of sodicity.

Table C7-2. Salinity guidelines for irrigation water (EC_e ² EC_{iw} x 1.5)

Conductivity of water (EC_w), dS/m	Comments
0.0–0.28	Suitable for all uses. Some leaching is required to remove accumulated salt, but this occurs under normal irrigation practices, except in soil with extremely low permeability.
0.28–0.8	Medium level salinity water; can be used if moderate leaching occurs. Plants with medium salt tolerance (e.g. cotton) can be grown, usually without special measures for salinity control.
0.8–2.3	High salinity water; cannot be used on soil with restricted drainage. Even with adequate drainage, salt tolerance of the crops to be irrigated must be considered.
(1.8)	(Human taste threshold)
2.3–5.5	Very high salinity water; can be used (if there is no alternative) for salt tolerant crops (e.g. saltbush), but the soil must be permeable.
>5.5	Extremely high salinity water; best not to use it.
(63.0)	(Sea water)

Adapted from: Taylor 1996

Chloride hazard

Cotton is unlikely to suffer from a toxicity caused by too much chloride (Cl^-) in the soil solution. However, Cl^- is a useful tracer for predicting deep percolation (see below).

Encrustation (scaling)

The '$CaCO_3$ saturation index' (which describes the relationship between pH, salinity, alkalinity and hardness) is a measure of the amount of encrustation/scaling (due to calcium and magnesium salts) that can be expected in pipes when the irrigation water is pumped. The index should be maintained below 0.5 if there is concern about these problems.

Corrosion

Corrosion of metal surfaces is minimised if the '$CaCO_3$ saturation index' is kept above –0.5.

WATERTABLE MONITORING

Observation wells and piezometers

Where the volume of irrigation water plus rain exceeds evaporation and transpiration by plants, percolation into groundwater (referred to as 'recharge') takes place. Watertables may then rise. Rises may also be caused by the pressure of water, from other parts of the catchment, in strata underlying the root zone. However, watertable levels can drop where groundwater is pumped for irrigation. Groundwater within two metres of the soil surface can rise further up the soil profile into the plant root zone through capillary action. This may lead to an accumulation of salt in the root zone. In sloping fields, the groundwater may move laterally and seep into creeks and rivers at a lower altitude. The salt within this drainage water may cause problems downstream. There are two approaches to groundwater monitoring:

Observation well

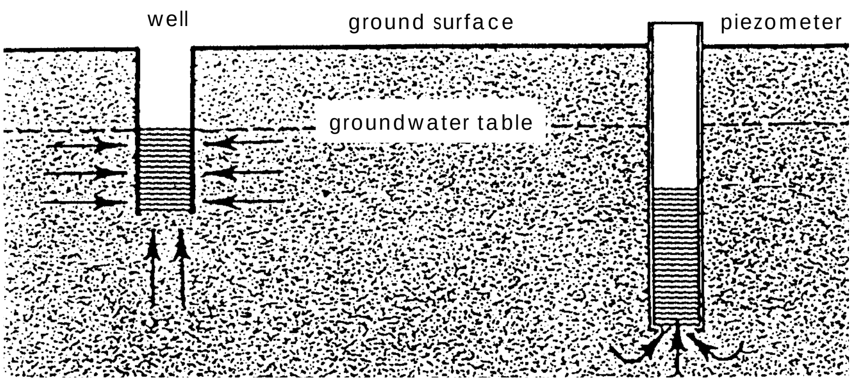
An observation well is a length of fully slotted tubing that is lowered into a bore hole and backfilled with sand around the outside of the tube. Water can freely enter the tube along its entire length, thus giving the position of the watertable in the soil (Figure C7-1). By observing a group of wells over time, trends in groundwater height can be monitored.

Piezometer

A piezometer is similar to an observation well, with a tube inserted and sealed into the soil, but only 1 to 2 metres or so is slotted, to allow water to enter at a chosen depth. The tube is then sealed off with bentonite, clay or cement. Water moves into the tube through the bottom or slotted section of the tube (Figure C7-1). The height to which the water rises is a measure of the hydraulic pressure at the chosen depth. It is an indication of the force that is pushing the groundwater towards the surface. Placement of piezometers to different depths will provide clues about groundwater dynamics when monitored over time (see Figure C7-2).

The quality of the water in piezometers and observation wells should be tested, as described in the previous section, to determine how hazardous it is.

Figure C7-1. Groundwater measurements made by observation wells and piezometers



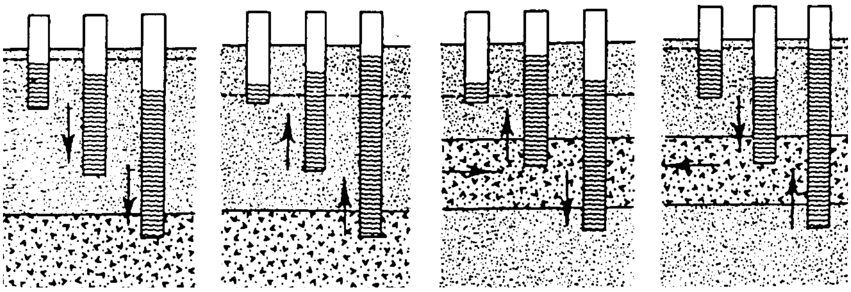
Source: Hunt and Gilkes, 1992

The quality of information from test wells and piezometers is strongly influenced by how well the tubes are installed. For example, if soil on the sides of the excavated holes is compacted and/or smeared, water movement is likely to be very different to that occurring in undisturbed soil. Therefore it is vital that the installations be set up professionally.

DEEP DRAINAGE RATE (DEEP PERCOLATION)

Managers of cotton soil should know the rate of leakage of water below the root zone of their crops. A recent study in the Macquarie Valley has shown the value of the ‘chloride mass balance’ method for estimating deep drainage (deep percolation). It is based on the relationship between chloride ion concentrations of irrigation water and soil in the root zone. The following equation is used:

Figure C7-2. Use of piezometers to provide clues about sub-surface flow



A
The piezometers indicate that the groundwater is going down and that there is some natural drainage.

B
The piezometers indicate a hydrostatic pressure, or that there is water coming up from deeper strata.

C
The piezometers indicate a hydrostatic pressure in a stratum, and that water is being forced both up and down from the stratum.

D
The piezometers indicate that groundwater is moving into a stratum and going out of the area.

Source: Hunt and Gilkes, 1992

$$DP = t\,(I + 0.8R)\,(C_i/C_z)$$

where: DP = total deep percolation
I = infiltration rate of irrigation water (mm/day)
R = infiltration rate of rain water (mm/day)
C_i = chloride concentration of irrigation water (mol/m^3)
C_z = mean chloride concentration (mol/m^3) of the soil solution over time at each measurement depth (z, m).

For further information, refer to the paper by Willis, Black and Meyer (Appendix 1).

The ‘sodium SaLF’ model that has been developed by QDNR at Indooroopilly is a very useful tool for predicting deep percolation under cotton. Methods for the direct measurement of deep percolation are described in Australian Soil and Land Survey Handbook Series, Volume 5—Soil Physics (details in Appendix 2).

RESPONSE TO THE SALINITY DIAGNOSIS

Options to consider if the soil is saline, or about to become so, include:

- Minimise leakage from storages and channels.
- Avoid bare fallows.
- Schedule irrigations according to actual crop requirements, and apply water in a way that minimises deep drainage losses.
- Groundwater pumping and recycling (need input from hydrogeology consultants).
- Planting of deep-rooted perennials in recharge zones.
- In soil that has become saline, investigate the use of hill/bed shapes that minimise salt accumulation around seedlings.
- Where sodic groundwater is added to the soil, gypsum may have to be applied to prevent the soil from becoming dispersive when it rains.

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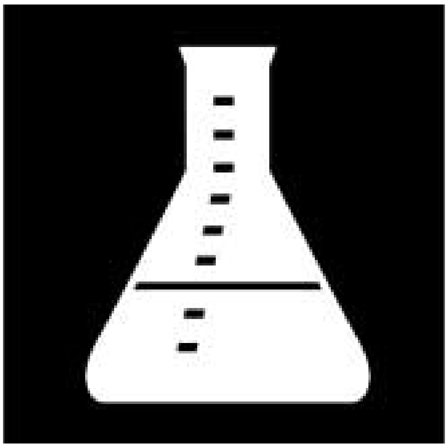
See Chapter D4, ‘Avoiding salinity problems’, and Chapter E3, ‘Effects of sodicity and salinity on soil structure’ for more information on the effects of salinity and sodicity.

C8. Other tests



PURPOSE OF THIS CHAPTER

This chapter contains brief descriptions of several soil tests that did not fit neatly into previous chapters.

CHAPTER OVERVIEW

This chapter describes testing of the following factors:

- pH
- nutrients
- mycorrhizae
- rate of soil loss
- pesticide residues.

Associated chapters that you may need to refer to are:

- Chapter C1, 'Soil pit digging: where, how and when?'

INTRODUCTION

To complete the soil assessment process outlined in earlier chapters, it is necessary to consider pH, soil nutrients, mycorrhizae, rate of soil loss, and pesticide residues.

pH TESTING

Soil pH is a measure of how acidic or alkaline a soil is. For cotton, soil pH should be in the range 5.5 to 7.0. If it is more alkaline, the availability of some nutrients (for example, zinc) becomes limiting. If it is more acidic, soluble aluminium may be released into the soil solution—cotton roots have a very poor tolerance of aluminium.

Very high pH values usually indicate the presence of sodium bicarbonate and carbonate salts. Alkaline sodic soil is formed if the irrigation water contains an excess of (carbonate and bicarbonate) ions over the (calcium and magnesium) ions present; the excess is referred to as residual sodium carbonate (RSC). The continued use of such water will lead to pH values as high as 10, and extremely high exchangeable sodium percentages.

Some soil used for cotton production is naturally acidic, particularly in the subsoil, due to the production and leaching of large amounts of nitrate under brigalow forests that grew before development.

Soil pH is measured using one of three methods:

- **Raupach's field method.** An approximate measure of soil pH can be obtained easily in the field using a 'Raupach' pH testing kit. It gives immediate results. Raupach indicator solution is added to a small sample of soil on a white tile until a smooth paste is obtained. The colour produced is highlighted by lightly dusting the paste with a white powder (barium sulfate). The colour is compared to a reference chart that shows pH to within half a unit. However, ensure that the indicator solution is not beyond its expiry date—old indicator is likely to give misleading pH results.
- **pH in water.** Measuring pH in water gives similar values of pH to that found using Raupach's field method. The pH in water is generally measured using a 1:5 soil:water extract. The pH is measured with a combined glass electrode and calomel electrode in the solution. Other soil:water ratios may be used, but they give different values of pH.
- **pH in 0.01 M $CaCl_2$.** A more accurate procedure, carried out in soil testing laboratories, is to measure the pH of a 1:5 'soil':'0.01 M calcium chloride' extract at 25°C. A calcium chloride solution is used, rather than water, because the latter dilutes the soil solution excessively; this leads to an overestimation of pH by about 0.5 for most soil types. Therefore, when you report pH values, it is important to state whether the pH was measured in calcium chloride ($CaCl_2$) or water (1:5). Results from the calcium chloride method are independent of the soil:solution ratio. Soil acidity varies with rainfall and temperature. Therefore, it is important to record sampling dates and to sample under similar conditions if you are comparing over different years. The use of fertilisers such as ammonium sulfate, as well as organic matter conservation, tends to acidify a soil, while lime is used to increase pH.

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See Chapter D7 for more information on methods for managing soil pH under cotton.

NUTRIENT TESTING

Cotton will grow badly, regardless of soil structural condition, if it is not provided with a well balanced and adequate supply of nutrients. Generally, the best way to monitor nutrients in cotton is via plant tissue analysis. Soil tests tend to be more difficult to interpret. Nevertheless, soil N, P, K and S testing is advisable before you plant cotton. For more information about nutrient testing and management, refer to NUTRIpak.

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See Chapter A2 for guidelines on the interpretation of nutrient testing.

MYCORRHIZA TESTING

Mycorrhizae (also referred to as VAM or AM) are beneficial soil-borne fungi that attach themselves to the growing roots of crops. They allow roots to scavenge more effectively for nutrients (particularly immobile nutrients such as phosphorus). Several cases of poor performance in cotton have been attributed to a lack of mycorrhizae in the soil. Microbiological tests are being developed to determine whether or not a cotton soil contains sufficient mycorrhizae, for example, the use of linseed seedlings (planted April–June) as indicator plants. Consult the Soil Biology team at ACRI, Narrabri, if you need further information.

RATE OF SOIL LOSS

Accurate monitoring of soil loss by wind and/or water erosion from cotton fields is an expensive exercise. It is usually done as part of research investigations. However, you can take preventive action in areas of concern if there is visual evidence of erosion. Signs to look out for are:

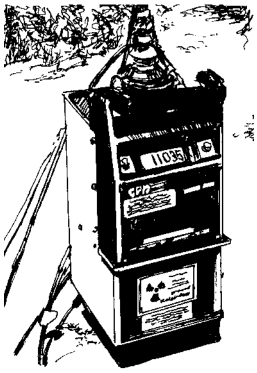
- rapid build-up of sediment in tail drains (often associated with rapid-flow irrigation systems)
- rills caused by flowing water within fields (particularly on the bed shoulders)
- dust movement when the weather is windy
- sand-blasting damage of seedlings after strong wind.

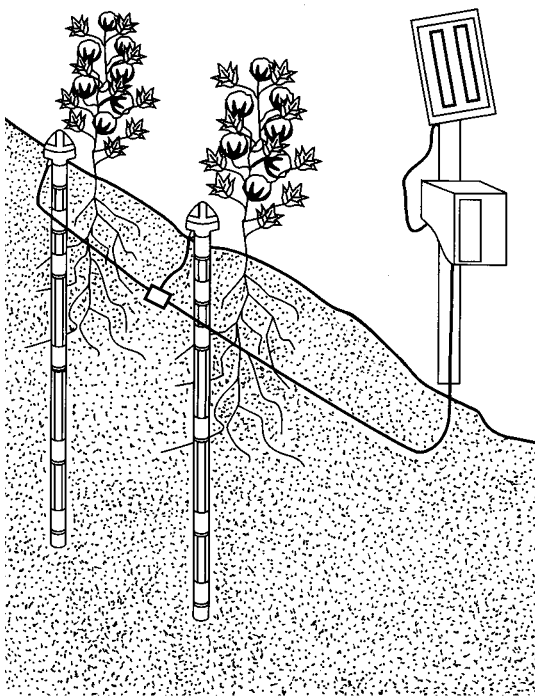
Protection of the soil surface with an organic mulch (see Chapter C6, ‘Stubble’) will do much to alleviate these problems.

TESTING FOR PESTICIDE RESIDUES

The build-up of pesticide residues is not regarded as a major problem within the Australian cotton industry, now that non-persistent chemicals are used (see Chapter B11, ‘Cotton soil management and the environment’). Nevertheless, growers who remain in doubt about the condition of soil within their fields can have it analysed comprehensively by commercial organic chemistry laboratories. Such testing can also be done if there are doubts about the quality of sediments excavated from tail-water dams and drainage ditches.

C9. Using moisture probe data





PURPOSE OF THIS CHAPTER

This chapter outlines how you can use soil water extraction information, measured by a moisture probe, to detect soil problems such as compaction.

CHAPTER OVERVIEW

This chapter covers the following points:

- types of moisture probe
- daily water use
- typical moisture extraction in a well-structured soil
- typical moisture extraction in compacted soil:
  —up to first irrigation
  —subsequent irrigations
- relating probe readings to stem internode lengths
- efficiency of water use, in terms of crop water use efficiency (CWUE) and irrigation efficiency (IE)
- prediction of refill points using pre-season soil measurements.

Associated chapters that you may need to refer to are:

- Chapter C3, 'Soil moisture (before tillage), soil texture and available water'
- Chapter C10, 'Monitoring soil condition'.

INTRODUCTION

As soil condition for crop growth becomes worse, there is a decline in the rate at which the crop roots can extract water. Of particular importance are subsoil problems such as compaction, salinity and acidity.

This chapter describes how to assess soil conditions for cotton root growth using moisture probe results.

TYPES OF MOISTURE PROBES

Neutron probe

The radioactive source in a neutron probe emits fast neutrons through an aluminium access tube installed to a depth of 1.5 m in the soil. Collisions between these fast particles and hydrogen atoms slow the neutrons down, and the detector in the neutron probe measures the concentration of slow neutrons in its vicinity. This allows you to assess the concentration of hydrogen atoms in soil surrounding the access tubes.

Hydrogen atoms are present in soil organic matter, soil clay minerals and soil water. The concentrations of clay and organic matter do not change over short periods of time, unlike the concentration of soil water. Therefore you can use a neutron probe to compare soil water contents at different times. A single reading tells you very little; comparisons of readings at different times can tell you a lot.

Capacitance probe

The sensors in capacitance probes use electrical capacitance to measure soil moisture. A high frequency electrical field is created around each sensor, which extends through the PVC access tube into the soil. The measured frequency (related to the dielectric constant of a soil) is a function of the soil water content. Special care must be taken with data interpretation in strongly shrinking soil, due to the formation of air gaps around the access tubes; this may alter the instrument calibration. The neutron probe has to be carried (sometimes through sticky mud) to the access tubes, but capacitance probe results are transmitted—whenever required—via cables to data recording equipment on the side of a field.

Other instruments

TDR (Time Domain Reflectometer) instruments measure soil dielectric constant and water content via parallel steel rods that are inserted into the soil. Recent versions allow simultaneous monitoring of soil salinity and soil water content.

In non-swelling soil, tensiometers may provide useful data. However, they tend to be difficult to maintain.

Simpler methods

In Chapter C3, it was noted that soil water content can be estimated very roughly using crop symptoms, and by the ‘feel’ of a soil. Another quick way of estimating soil water content is to try to push a pointed steel rod (‘moisture probe’) into the soil to a depth of about 1 m. It is assumed that as the soil becomes softer, the water content becomes greater. A problem with this approach is that hard compacted layers may have a high water content, but are assumed to be dry. A more accurate, and relatively simple, approach to soil water assessment is to collect cores of soil using sampling tubes, as described in Chapter C1. Soil water content is measured by weighing segments of the soil core, before and after oven-drying at a temperature of 105°C. This method, described in more detail in the APSRU publication (Appendix 1), does not have problems with calibration inaccuracies, but collection of an adequate number of replicates is a time consuming process.

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See Appendix 1 for more information about existing neutron probe calibration data in Australian cotton growing districts.

CALIBRATION OF MOISTURE-MEASURING INSTRUMENTS

Moisture probe results from different sites cannot be compared with confidence unless the instruments used have been calibrated properly. Nevertheless, the shape of the 'raw probe reading' vs 'time' graph, on its own, can be useful for soil condition interpretation at a given site.

HOW TO USE SOIL MOISTURE INFORMATION

To detect soil problems such as compaction with a moisture probe, you need a crop to extract water from a wet soil profile. Frequent measurements of soil moisture at closely-spaced depths at the same site allow you to monitor moisture extraction by the crop over depth and time.

Moisture probes do not replace crop observations. The probe becomes a more effective tool if you use it to help explain the other things you notice as a crop manager. You can use probe readings (converted to millimetres of soil water using the calibration equation appropriate to your probe) to detect soil problems by calculating:

- daily water use
- moisture extraction from different depths
- correlation with plant symptoms
- water use efficiency.

Daily water use and the 'refill point'

Calculate the soil water content (0–70 cm) in the profile for each reading date. Differences in total soil moisture (0–70 cm) between any two dates, divided by the number of days between those dates, gives you the average daily water use (DWU) for the crop over that period. As the crop depletes soil moisture, it experiences more difficulty in extracting water, and the daily water use declines. A decline in daily water use signals a close approach to the 'refill point' (the water content at which the soil profile needs to be refilled with water). A sharp decline signals compaction, especially if the refill point is higher (wetter) than usual. This may mean that some of the soil moisture is not readily available (even though the probe shows it to be in the 'available' range), due to poor access by roots (Figure C9-1). Note, however, that the rate of water extraction can be strongly influenced by non-soil factors, such as cool, wet weather. Take this into account when interpreting the information.

Capacitance probes are particularly useful for monitoring the rate of extraction of soil water just after an irrigation. Figure C9-2 clearly shows a slow-down of crop water use caused by temporary waterlogging.

Figure 9-1. A comparison of a series of probe readings including daily water use (DWU) from a compacted and a non-compacted field on the same farm

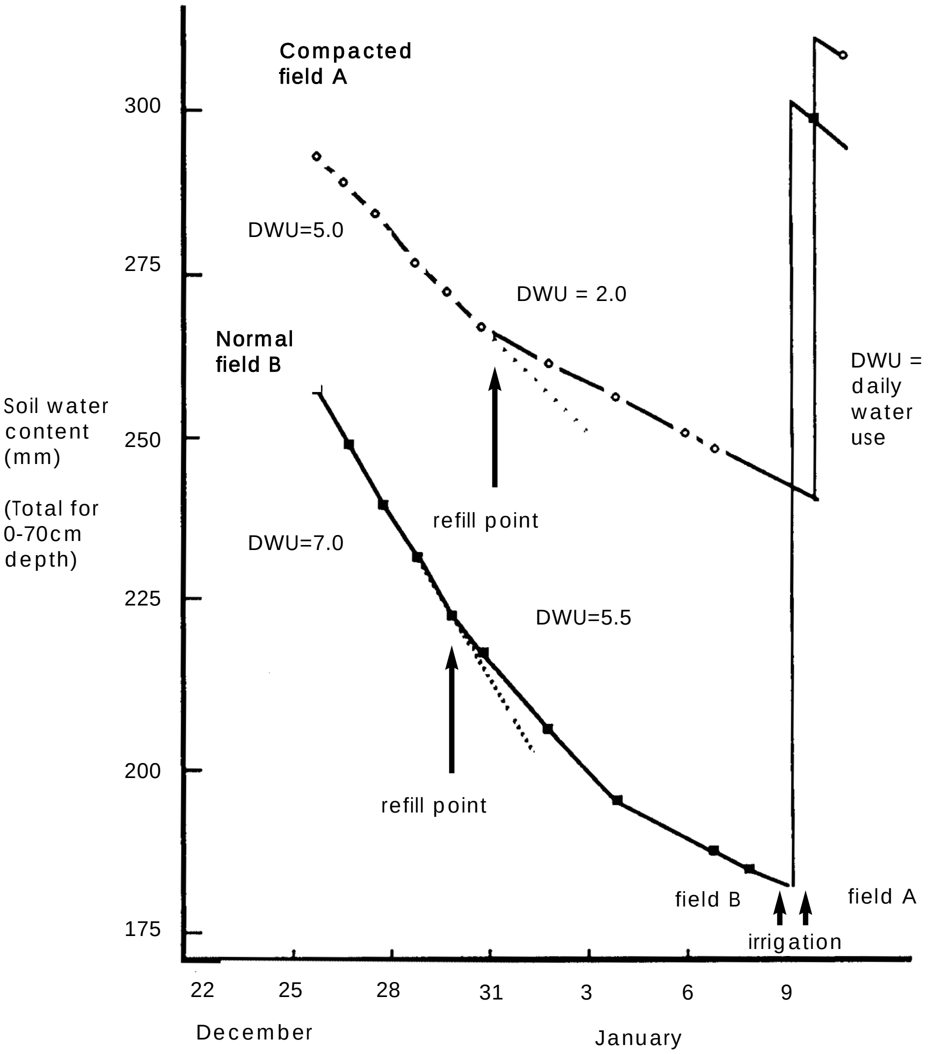
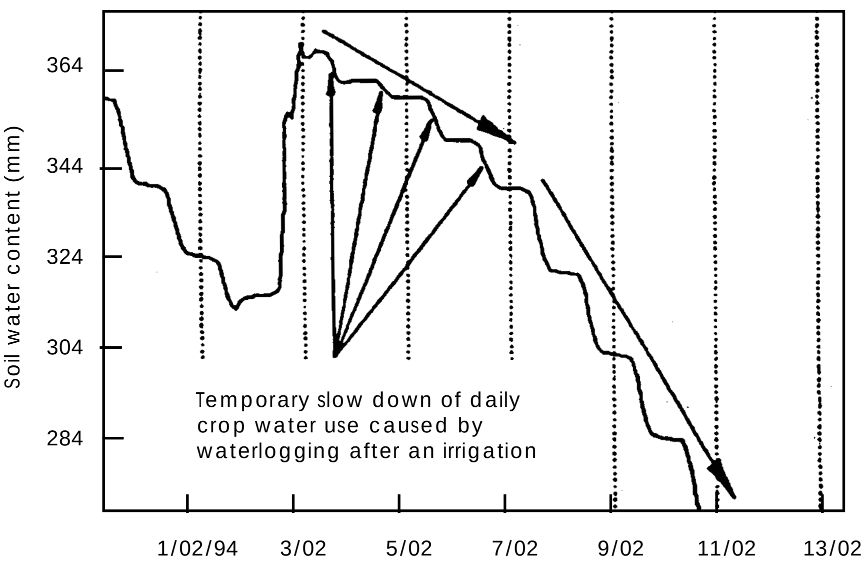


Figure C9-2. Changes in the water content in a clay soil under cotton at Emerald. The water content was measured to 100 cm depth, with a capacitance probe, just before and soon after irrigation.

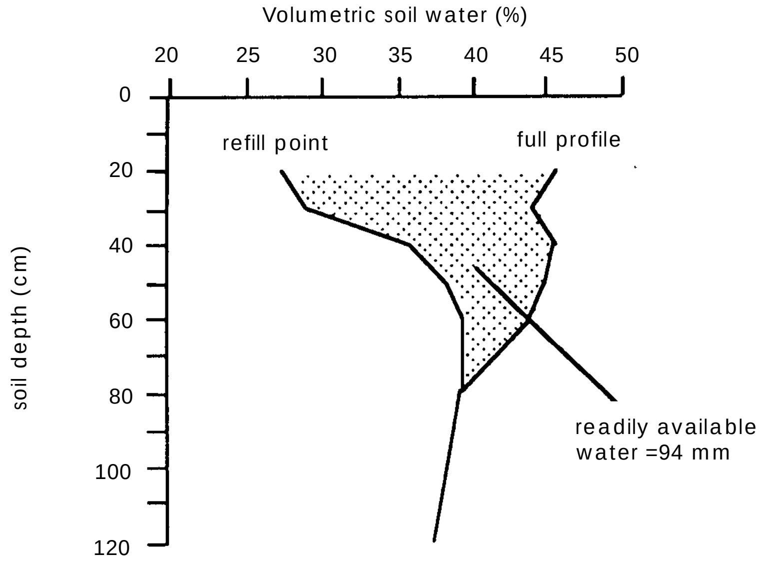


Moisture extraction profile

Graph your data as soil water against depth for each reading date. Changes in water content at each depth will tell you the depths from which the crop is extracting the most moisture, and the depths where extraction is limited. Differences between good and poor fields may show up soon after irrigation.

The soil water profiles in Figure C9-3 show a typical extraction pattern from a well-structured soil. The soil is able to provide the plant with 94 mm of water. Extraction has taken place to a depth of 80 cm. The right-hand line is the amount of water in the profile after an irrigation, and the line on the left is the amount in the soil when the plants are starting to show signs of requiring water.

Figure C9-3. Water extraction in a good soil



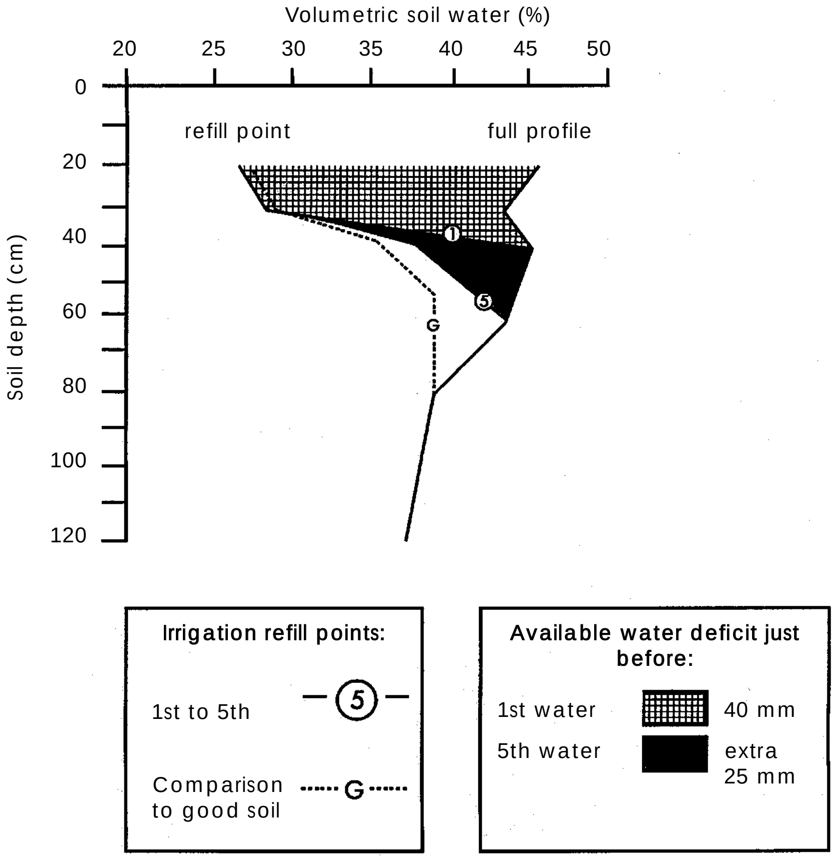
The soil water profiles in Figure C9-4 show what may happen with severe compaction. The diagram shows a series of refill points as the season progresses. On each irrigation the crop was able to use more water as it penetrated the compaction zone. However, at no stage was the crop able to extract as much as a crop on a well structured soil (the G line).

Lack of moisture extraction from the subsoil does not always indicate compaction. For example, if the subsoil is dry and the surface soil is wet, there is little subsoil moisture for the crop to extract. Such a situation may arise if steady, soaking rain wets and seals the surface of a dry profile of a cracking clay. This sealing can prevent deep infiltration of irrigation water. Poor moisture extraction from the subsoil may also be due to excessive salinity and/or pH extremes.

Highlighting water entry problems in hardsetting soil

In hardsetting soil, or in cracking clays with a sodicity problem, monitor the maximum soil water contents—observed immediately after an irrigation—over the entire growing season. If a decline is observed, treat the soil surface after harvest (possibly with gypsum) to restore its permeability.

Figure C9-4. Water extraction profiles on a badly compacted soil



The available water deficit at which the cotton crop requires irrigation has improved by 25 mm (from 40 mm to 65 mm) due to structural improvement (by shrink/swell processes) between the first and fifth irrigations.

PLANT SYMPTOMS

You should always relate neutron probe readings to plant symptoms. Compare the extraction profiles and daily water use figures with:

- signs of wilting
- rows that are slow to close over
- short plants
- short internodes.

If the neutron probe readings show apparently adequate reserves of soil moisture when the plant symptoms and daily water use are showing otherwise, then your refill point is wrong. You need to irrigate more often (raise the refill point); this indicates the possibility of compaction.

Correlating internode lengths and probe readings

One of the best plant symptoms to use for determining previous waterlogging and drought stress is the internode length (the distance between branches on the main stem). By the time the seventh node is formed, in late November or early December, the weather is usually warm enough to ensure that temperature no longer limits growth (or internode length). The ideal length for cotton internodes once temperatures are not limiting the growth of the plant is about 6 to 7 cm. It is possible to get this length consistently in a dry season under drip irrigation.

Figure C9-5. Cotton internode length and daily water use.

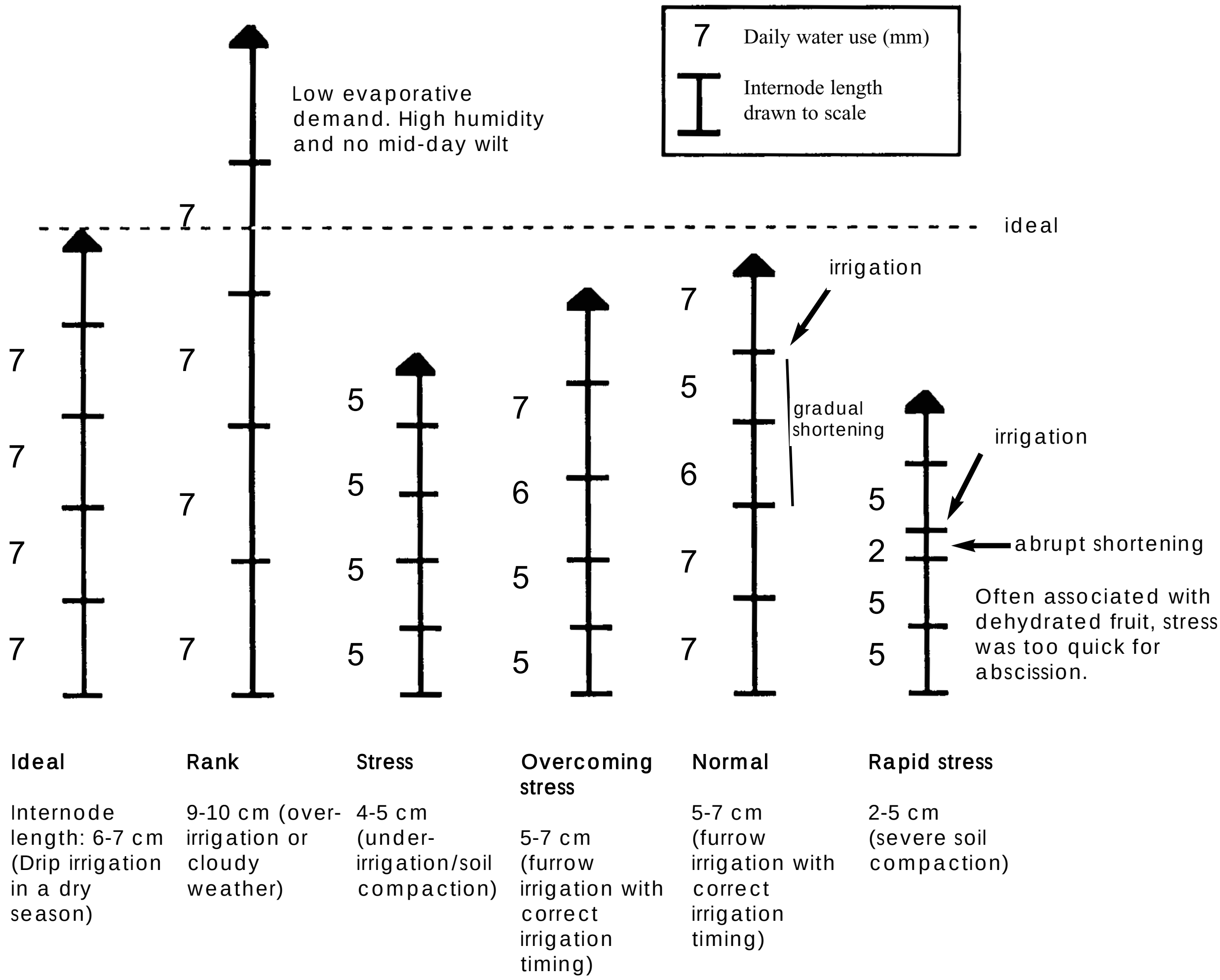


Figure C9-5 shows some different patterns of internode length and what they can tell you about the biological activity of the plant. The figure also shows the daily water use (as determined by a neutron probe) corresponding to each internode length. The observation of internode length can be made at the end of the season as well as during the season.

Beware of situations where there are very short internodes (5 cm or less). This indicates severe stress on the plant, especially if the daily water use is relatively less than in nearby fields, for example 5 mm per day instead of 7 mm per day.

WATER USE EFFICIENCY

Crop water use efficiency

A good soil for irrigation will produce higher yields for a given amount of irrigation water than a poor soil under irrigation. Conversely, the good soil can produce the same yield with less water than the poor soil will require. Yield (bales/ha) per megalitre of water used is a measure of water use efficiency. Poor soil structure may mean that a crop needs more frequent irrigation (the refill point is higher). The more irrigations a crop needs, the less efficiently the crop uses irrigation water (for example, due to evaporation losses).

After harvest you can rank your fields in order of crop water use efficiency (CWUE) as follows. This method ignores seepage losses from channels and excess water lost in tail drainage; it gives irrigation efficiency within a field.

- Compare neutron probe readings before and after each irrigation through the season.
- Calculate the irrigation increment (number of mm of water infiltrated into the soil) and sum the total for the season.
- Add to the total the number of mm of rain infiltrated (probe readings before and after rain will allow you to estimate rainfall).
- Add to the total the number of mm of water present in the soil at the start of the season.
- Subtract from the total the number of mm of water left in the soil at the end of the season. The total now is the number of mm of water that the crop used, plus deep drainage.
- Divide by 100 to convert mm to megalitres per hectare (ML/ha).
- Divide the yield of cotton (bales/ha) by the water use (ML/ha) to obtain irrigation efficiency (bales/ML) for each field. A bale of cotton weighs approximately 225 kg.

Ideally, the above calculation should take into account the amount of deep drainage; attempt to estimate this via 'chloride mass balance' calculations (see Chapter C7). Aim for CWUE values greater than 1.33 bales/ML.

A lower than usual CWUE value for a given field will alert you to possible compaction problems. Water use efficiency is a guide to which fields to check with backhoe pits.

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See Chapter C1 for more information on soil pit digging.

Fields with high CWUE values are the best fields for cotton next season. For fields with low water use efficiency, consider repair strategies.

Note that CWUE information applies to the previous season's irrigation cycle. Any degradation that occurs following the termination of the irrigation cycle will not be exposed using this method. For example, soil damage during picking will not be detected by CWUE calculations, but may affect water use efficiency in the forthcoming season.

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See Chapter D2 for more information on improving soil structure.

The calculations are demonstrated in the following example: Assume field A water use is 730 mm max (7.3 ML/ha) and yield is 10 bales/ha. Then:

Efficiency = 10/7.3 = 1.37 bales/ML

Assume field B water use is 650 mm (6.5 ML/ha) and yield is 6.25 bales/ha:

Efficiency = 6.25/6.5 = 0.96 bales/ML

If we use a criterion of 1.33 bales/ML as being good, we can see that there may be room for improvement in field B, even though the overall water use was lower than for field A.

Irrigation efficiency

Irrigation efficiency (IE) is the percentage of water inputs, including rainfall, used in crop evapotranspiration. It includes losses of water in the storage and distribution system. Aim for IE values greater than 75%.

'REFILL POINT' PREDICTION USING PRE-SEASON SOIL STRUCTURE MEASUREMENTS

A major challenge on large cotton farms is prediction of the date of the first irrigation on all of the fields growing cotton. Irrigating too early tends to waste scarce water resources; irrigating too late will stress the crop and cause yield losses.

An approach that should be considered is to measure the severity of compaction in as many of the fields as possible. The resultant SOILpak scores (see Chapter C4) can then be used to provide an estimate of the water content at which root growth is likely to be restricted (details are given in Chapter E6). These estimates are not very accurate, but they do allow fields to be ranked from worst to best in terms of their structure. Frequent (at least twice daily) monitoring of water content should then be done at the most degraded site to establish the actual value of its refill point. Watering should start at this site as soon as possible after refill point definition, then at the other sites in the order worst structure to best structure.

C10. Monitoring soil condition

PURPOSE OF THIS CHAPTER

The aim of this chapter is to outline some of the measurement errors that need to be considered when establishing an on-farm soil monitoring program.

CHAPTER OVERVIEW

This chapter covers the following points:

- issues to consider when establishing an on-farm soil monitoring program.

Associated chapters that you may need to refer to are:

- Chapter C1, ‘Soil pit digging: where, how and when?’
- Chapter C4, ‘Structural condition’
- Chapter C7, ‘Salinity’.

INTRODUCTION

Cotton growers generally are very keen to improve, or at least maintain, soil condition on their farms over time. It has recently become possible to document such progress via the so-called 'ISO 14000' environmental accreditation scheme, which is administered by Standards Australia. Any cotton grower who enters such a 'crop auditing' scheme (presumably to boost the market acceptability of their produce) has to demonstrate that his/her soil condition is improving—or, at least, not going backwards.

To provide such proof, you need to consider the following issues.

ERRORS ASSOCIATED WITH MEASURING SOIL PROPERTIES OVER TIME

A difference may be measured in a soil factor—for example, pH—between 2 sampling dates. However, it is necessary to carry out an error analysis to see if the difference is real, or due to errors caused by field variability and/or measurement inaccuracies. Error analysis indicates the odds (for example, 95%) of a difference being real. Such an analysis also will allow you to determine the best way to minimise measurement errors so that changes in soil condition are easier to recognise.

Errors to be considered include:

- broad-scale field variation (over a range of at least several hundred metres)
- localised soil variation (within a range of a few metres) at a monitoring site
- field measurement inaccuracy (contains two components, precision and bias)
- laboratory measurement inaccuracy (precision, bias).

DEALING WITH ERRORS CAUSED BY FIELD VARIABILITY

Broad-scale variation in soil condition is at least partly dealt with by establishing monitoring sites within, at least, the 'best yielding' and 'worst yielding' sections of a cotton field.

Localised soil variation at a nominated monitoring site is more difficult to deal with. Destructive sampling (using pits) means that sampling cannot be repeated at exactly the same place as before. However, compaction patterns caused by the wheels/tracks of machinery tend not to vary greatly over a space of about 30 m where controlled traffic systems are used.

When testing for soil salinity, an advantage of electromagnetic induction equipment is that it is non-destructive. Measurements can be repeated at exactly the same points within a field, but the instruments need to be properly calibrated. There are situations where airborne video scanning can be used to predict (and perhaps monitor) soil sodicity. Studies at Auscott Warren showed that the 'thermal infra-red' channel of air-borne video scanners can detect sodic sections of a field, due to their cool waterlogged condition. The established relationship between sodicity and remote sensing pattern, however, can vary greatly from site to site—the calibration has to be checked at each new site under investigation.

Most soil properties change as depth in the profile becomes greater. Therefore, it is vital that the depth of soil sampling remains constant while monitoring is taking place over time.

MEASUREMENT ERRORS– PRECISION AND BIAS

If large measurement errors are present, trends in soil condition over time are very difficult to detect. The accuracy of a soil water measurement is influenced by both bias and precision. Bias is defined as the difference between the 'statistically true value' and the 'scientifically true value'. Precision refers to the scatter of the observations, regardless of whether the mean value around which the scatter of points is measured approximates the 'scientifically true value'.

As an example, consider the measurement of exchangeable sodium in the laboratory. If five replicates of a soil sample have very similar ESP values, we say that the result is very precise. However, if the standard solutions used to calibrate the measuring instrument were prepared incorrectly, the results will be inaccurate because of a bias problem.

Bias may be introduced to soil water measurements if inappropriate calibration equations are used with, for example, a neutron probe. Therefore, try not to deviate from the measurement procedures recommended in this manual. Choose a soil testing laboratory that is NATA-certified.

FURTHER INFORMATION

If you are in doubt about the issues described above, consult a geostatistician or biometrician.