SOILpak

Third edition

Edited by

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Preface

This manual is a guide to *best practice soil management for the Australian cotton industry*. It is based upon an accumulation of information derived over many years from numerous research workers, public and private sector advisers and agribusiness. Without that body of knowledge, this *SOILpak* could not have been produced.

Organisations and individuals who have contributed to the production of this manual include:

- NSW Agriculture
- growers and consultants in the cotton industry
- the Cooperative Research Centre (CRC) for Sustainable Cotton Production
- CSIRO
- Queensland Department of Natural Resources
- Queensland Department of Primary Industries
- University of Sydney
- University of New England
- University of Southern Queensland
- University of Queensland
- NSW Department of Land and Water Conservation.

The efforts of Ian Daniells and David Larsen in preparing *SOILpak*$_b$ are also acknowledged. Their manual provided the foundation for this *SOILpak*. A list of contributors and reference material is presented in Appendix 1.

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Disclaimer

IT IS IMPORTANT TO READ THIS DISCLAIMER BEFORE USING THE MANUAL

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Whilst every attempt has been made to ensure the accuracy and integrity of the information and description sheets supplied in this manual, it should be understood that (due to new research information, new industry experiences, unpredictable weather and variations in the way individual growers set up equipment or have access to equipment) no warranty or guarantee is given or implied by the above organisations nor the people working for or contracted by those organisations to supply the information.

The manual does not claim to be complete and all inclusive, but it aims to grow with the input of all who use and report on it.

Where trade names of products and equipment are used, no endorsement is intended nor is criticism implied of products not mentioned.

This manual does not contain a complete statement of all relevant legal obligations. You should seek your own legal advice as to both legislative and general legal obligations, in particular those legal obligations arising under environmental laws and the general laws of negligence.

A1. The aim of this manual

SOILpak for cotton growers, third edition, is a 'Best Practice' soil management manual for the Australian cotton industry. It focuses on irrigated cotton production, but contains a supplement for dryland growers.

Grey and brown cracking clays (sometimes referred to as Vertisols or Vertosols) are the most common of the soil types used by Australian cotton growers, so they receive the most attention in this manual. However, other soil types such as hardsetting red soil are important in some districts.

This SOILpak concentrates on the skills needed to:

- assess the condition of a soil, with emphasis on soil structure
- understand the management options for maintaining or improving soil condition.

The package does not aim to make the final decision for cotton growers. Instead, it provides options which can assist growers to develop successful soil management strategies.

Good soil management has economic benefits. Poor soil management can lead to large yield losses (up to one-half of the potential yield) and/or unnecessary input costs.

Sensible soil management also improves the condition of the surrounding environment by reducing erosion, deep drainage and emission of harmful gases.

The information in this manual was collated from a wide variety of sources, many of which are not easily accessible. Being in loose-leaf format, SOILpak can easily be updated.

SOILpak should be read in conjunction with:

- NUTRIpak, a companion manual dealing with cotton nutrition issues
- MACHINEpak, which describes the machinery available for land preparation
- Australian cotton industry *Best management practices manual* for minimising the impact of pesticides on the environment.

A companion manual, *SOILpak Pocket Notes*, provides a summary of field methods, laboratory procedures, critical limits and management options that are described in SOILpak:

- *SOILpak Pocket Notes* is a small, robust document that is very portable.
- The bulkier SOILpak manual is best kept in the office.

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See *SOILpak Pocket Notes*

INTENDED AUDIENCE

SOILpak is intended for the following groups within the Australian cotton industry:

- growers who want to learn more about how to manage their soil
- consultants and extension officers who wish to become more skilled in advising their clients on soil management.

The manual caters for two distinct types of cotton growers:

- users wanting an overview and/or quick help
- 'best management practice' users wanting measures of soil condition, and details of options for overcoming soil management problems.

Examples of pathways through the manual, and likely entry and exit points, are shown in Figure A1-1. To deal with a specific problem, refer to the index to find the relevant information—it is not necessary to work through the whole manual.

YOU CHOOSE

Those chapters that contain a list of management options have a step-by-step procedure to guide you towards a decision. You will be asked which of several circumstances best describes your situation. Each circumstance is matched with a list of possible options.

It will be up to you to decide, given your resources and economic situation, which option best suits your needs. Your decision must take account of insect, disease and weed management and equipment availability. You will have to decide how much time you have and what the risk of unfavourable weather is likely to be.

The weather is an over-riding factor in all farming operations. *Remember, when following any plans or guidelines, that the weather may not allow them to be realised.*

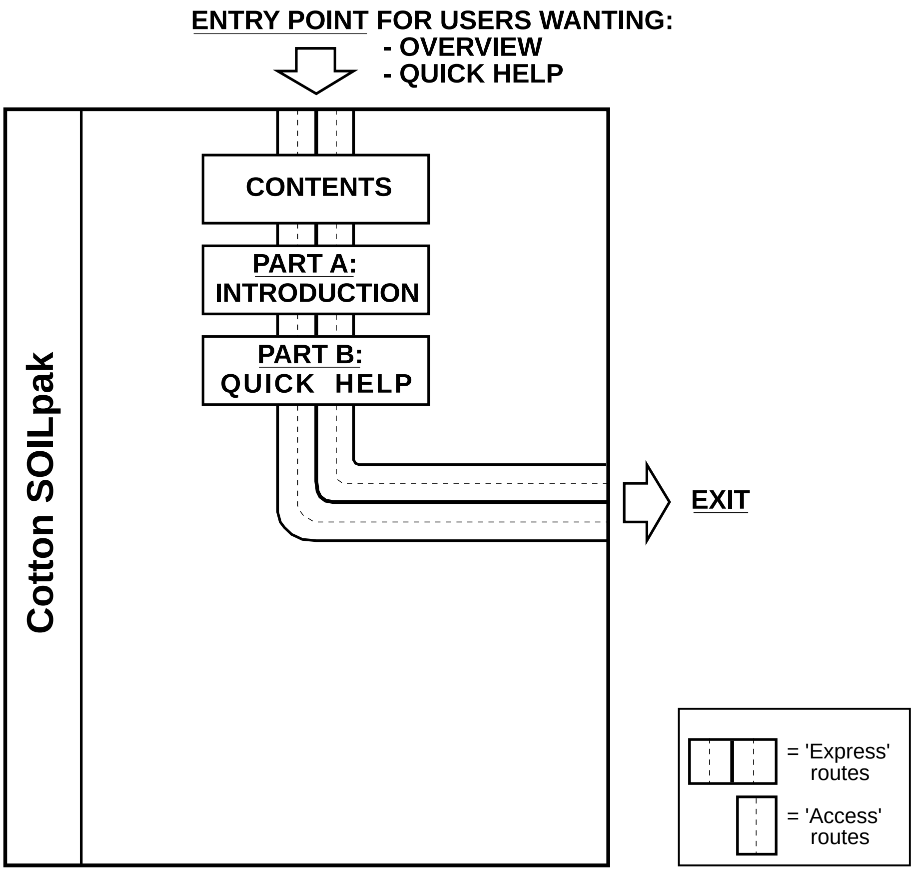
There is no doubt about the value of soil assessment—it is recommended strongly. However, the final decision about which soil management option to select is the responsibility of the growers and their advisers.

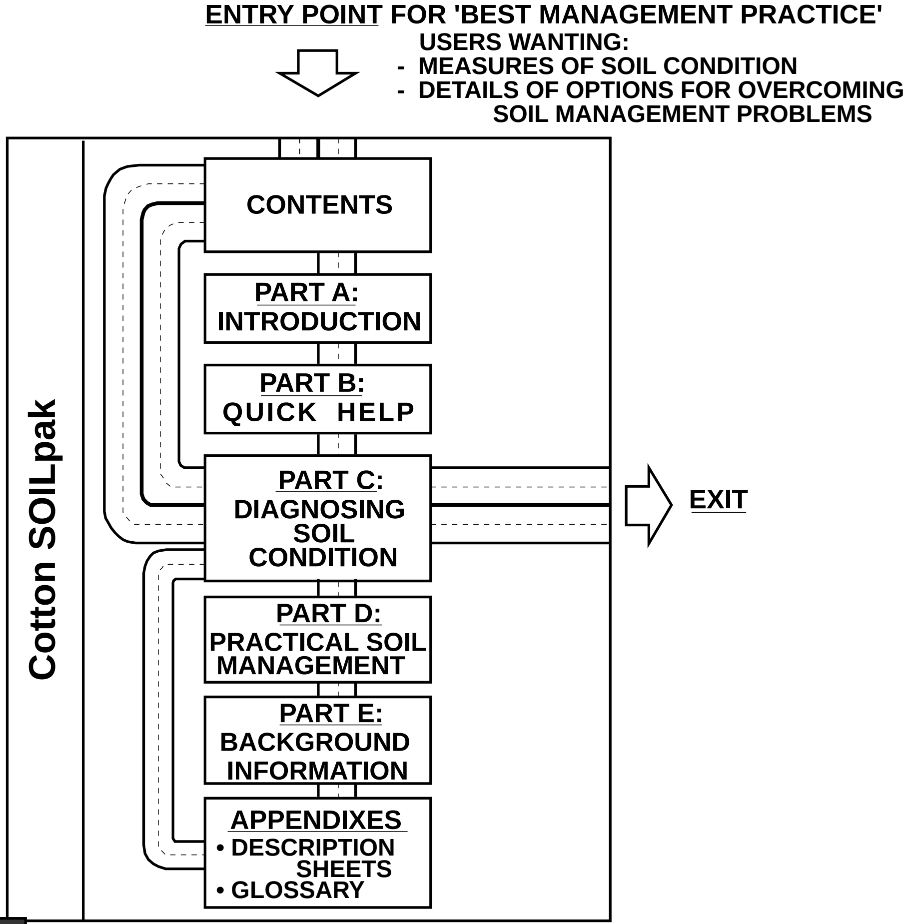
OVERVIEW OF CONTENTS:

The manual is divided into parts and chapters:

- The remainder of Part A describes an ideal soil so that you can form a picture of what to aim for.
- Part B offers help for a range of situations where you may need a quick solution without long explanations.
- Part C concentrates on the diagnosis of soil condition, with emphasis on soil structure and information from the field and laboratory. Other chapters may refer you back to Part C.
- Part D deals with the practical aspects of soil management (the 'how') following soil diagnosis, but includes some background information (the 'why') to help you make decisions with more confidence.
- Part E contains background reading. It has a more theoretical tone and focuses on soil processes.
- The appendixes include a glossary of soil management terminology, the description sheets and a further reading list.

Figure A1-1. Pathways to finding information in this manual





Each chapter starts with a summary outlining the contents of that chapter. *SOILpak Pocket Notes* provides a brief summary of the entire SOILpak manual.

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See SOILpak Pocket Notes

HOW TO USE THE SOILpak MANUAL– SOME EXAMPLES

To illustrate how the SOILpak manual can be used by cotton growers and their consultants, consider the following four examples:

Example 1

An entire cotton field near Warren had poor growth and disappointing yields during the previous summer. The following pathway was used to diagnose and overcome the problems:

Trouble-shooting guide

- Figure B1-1.
- Figure B1-3.

Field signs

Hard, dense subsoil; dispersion.

Soil pit digging: where, how and when?

- Chapter C1.

Diagnosis of soil condition; comparison with critical limits

- *Green* description sheet (Appendix 6).
- Chapters C2, C3 and C4.

Conclusion

Serious compaction caused by land development under wet conditions; sodic topsoil.

Management options

- Soil drying with a well-fertilised wheat crop (Chapter D2).
- Gypsum application (D2).
- Deep tillage (D2).
- Assess structure after deep tillage (C5).
- Controlled traffic (D1).
- Ongoing monitoring of soil condition (C10).

Example 2

Yield mapping of a cotton field near Wee Waa indicated a 250% difference in lint yield between the best and worst sections, even though a controlled traffic farming system had been introduced two years earlier. The following pathway was used to see if problems in the poor area were soil related:

Trouble-shooting guide

- Quick help (see Chapter B8).

Soil pit digging: where, how and when?

- Chapter C1.

Diagnosis of soil condition; comparison with critical limits

- *Green* description sheet (Appendix 6).
- Inspections in both the good and poor sections of the field.
- Chapters C2, C3 and C4.

Conclusion

Sodic subsurface and subsoil in areas with poor yield.

Management options

- Gypsum application; variable rate (see Chapter D2).
- Ongoing monitoring of soil condition (see Chapter C10).

Example 3

One hundred and twenty millimetres of rain fell half-way through harvest of a cotton crop near Dalby. Attempts to continue harvesting caused large ruts in the furrows. The following pathway was used to develop a soil management plan for the next cotton crop.

Trouble-shooting guide

- Quick help (see Chapters B3 and B4).

Soil pit digging: where, how and when?

- Chapter C1.

Diagnosis of soil condition; comparison with critical limits

- *Green* description sheet (Appendix 6).
- Inspections in both the damaged and undamaged sections of the field.
- Chapters C2, C3 and C4.

Conclusion

Encroachment of compacted wheel tracks into beds where wet picking occurred.

Management options

- Dry damaged soil with a rotation crop (Chapter D2).
- Assess structure after soil drying and cracking (Chapter C5); and deep plough if necessary.
- Use controlled traffic with narrow wheeled machinery (Chapter D1).
- Ongoing monitoring of soil condition (Chapter C10).

Example 4

A new cotton development was proposed in the lower Macintyre Valley. Recently published soil maps of the district suggested that salinity and sodicity were potential problems. The following pathway was used to produce a soil management plan for the development project.

Trouble-shooting guide

- Quick help: Soil survey for development or redevelopment (see Chapter B9).

Soil pit digging: where, how and when?

- Chapter C1.

Diagnosis of soil condition; comparison with critical limits

- *Orange* description sheet (Appendix 6).
- Pit inspection on a 150 m grid; EM survey.
- Chapters C2, C3, C4, C7 and C8.

Conclusion

Topsoil and sub-surface wetter than the plastic limit; sodic subsoil.

Management options before landforming

- Dry soil with a well-fertilised wheat crop (Chapter D2).
- Develop fields by using landforming contractors.

Management options after landforming

- Quick help (see Chapter B10).
- Chapter C1.

Diagnosis of soil condition; comparison with critical limits

- *Yellow* description sheet (Appendix 6).
- Inspection of three representative pits.
- Chapter C4.

Conclusion

Exposure of sodic subsoil; compacted sub-surface and subsoil.

Management options

Options to deal with problems identified during the grid survey and post-landforming inspection:

- Gypsum application (D2).
- Avoiding salinity problems (D4).
- Deep tillage (D2).
- Assess structure after deep tillage (C5).
- Controlled traffic (D1).
- Ongoing monitoring of soil condition (C10).

THE FUTURE

The producers of this edition of *SOILpak* have worked hard to keep its contents simple, relevant and accessible. The emphasis is on a system which is useful in the field and easily updated.

As research workers and farm managers develop and refine improved methods of diagnosing and improving soil condition, the new methods will be incorporated into *SOILpak* via updates.

We reserve the right to update or change this information at any time without notice. Your local agronomist can provide the latest list

of updated pages. If you have access to the Internet, updates will be provided through the Technology Resource Centre, Cooperative Research Centre for Sustainable Cotton Production, Narrabri. Their Home Page, *Oz cotton on line,* is at http://www.cotton.pi.csiro.au.

Soil management training courses (Figure A1-2) are being held in several regions through 1998–99 to demonstrate the use and application of the manual in the field.

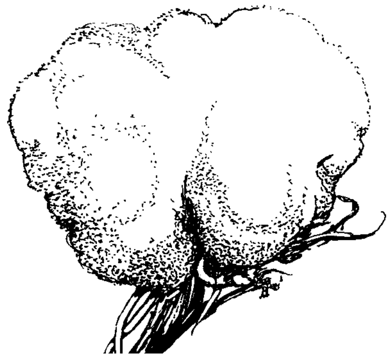
IDENTIFYING RESEARCH NEEDS

Compilation of this edition of *SOILpak* has highlighted several gaps in our knowledge, some of which are mentioned throughout the manual. Further research is needed, despite excellent progress over the last 15 years. Research leaders and the funding bodies have been given details of these problems.

On-farm trials are most important for testing new ideas and fine-tuning existing recommendations (see Appendix 3).

Figure A1-2. Participants in a soil management training course

A2. The ideal soil for cotton



PURPOSE OF THIS CHAPTER

A benchmark is provided against which irrigated and dryland cotton soil types can be compared.

CHAPTER OVERVIEW

This chapter covers the following points:

- infiltration and internal drainage
- plant available water capacity (PAWC)
- slope, surface drainage, waterlogging and flooding
- suitability of soil structure for seedling establishment
- suitability of soil structure for root growth
- salinity
- pH
- nutrition
- erosion control
- soil variability and micro-relief
- technical specifications (at the end of this chapter).

Other chapters to refer to:

- Chapter E3: 'Effects of sodicity and salinity on soil structure'
- Chapter E5: 'Organic matter and soil biota'
- Chapter E6: 'How soil structure and temperature affect plant growth'.

FEATURES OF AN IDEAL SOIL FOR COTTON- AN OVERVIEW

The ideal soil condition for high-yielding, low-cost cotton production is shown in Figure A2-1. The features mentioned in this diagram are explained in the following text.

Infiltration and internal drainage

Cotton has poor tolerance of waterlogging. To allow adequate water entry, and to encourage root exploration by quickly re-establishing aeration after irrigation and rainfall, cotton soil needs to have good porosity for infiltration and internal drainage.

The alluvial soil types, black earths and the better structured grey and brown clays—with their extensive cracking and vigorous root growth—provide favourable conditions. Soil types with dense, sodic subsoils have poor profile permeability and drainage.

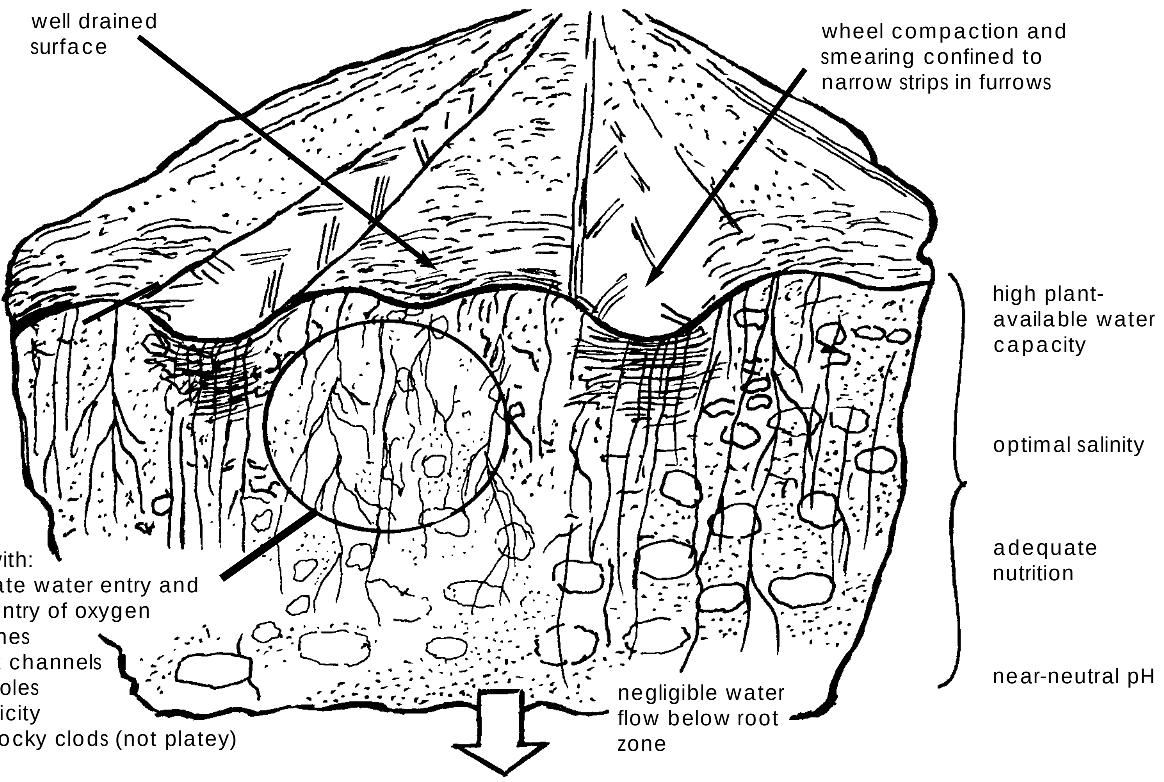
Structural damage, due to excessive traffic or tillage at incorrect moisture contents, may create large platey clods in any cotton soil. Such damage restricts permeability.

While the root zone should be permeable, the deep subsoil should be almost impermeable; excessive deep drainage may cause water tables to rise. Irrigation management and crop rotation should aim to minimise the amount of water draining to the deep subsoil.

Plant available water capacity (PAWC)

Large values of PAWC, which are found in some clay-rich alluvial soil types and deep black earths, allow a longer interval between furrow irrigations. Under dryland conditions, large values of PAWC delay the onset of drought stress in crops.

Figure A2-1. Features of an 'ideal' cotton soil



Total PAWC is poor in shallow soil over bedrock, in sandy soil, and in soil with dense sodic subsoil. The ability of crop roots to access the available soil moisture is reduced by structural damage. Compaction may also reduce the ability of a soil to allow water entry.

Slope, surface drainage, waterlogging and flooding

An appropriate slope and field length, in combination with furrows and hills/beds, will ensure good surface drainage and reduce waterlogging. Land forming using laser grading usually is needed to provide the required slope across all parts of a field, particularly under irrigation. Surface drainage and tail drains must be designed to minimise flooding during heavy rain, the consequences of which may be disastrous during the seedling stage.

Furrow-edge compaction and water application rates need to be matched so that the root zone does not become waterlogged due to excessive water intake.

Slopes that are too steep create erosion hazards.

Suitability of soil structure for seedling establishment

Rapid and uniform seedling emergence is most likely to occur where the surface tilth is friable and has fine water-stable clods. Those clay soil types with a surface structure that regenerates by swelling and shrinking as the soil is wetted and dried (self-mulching); e.g. black earths, and most grey and brown clays; provide ideal seedbed conditions if protected from mechanical compaction.

In some soil types, the surface may slake and disperse (collapse) and become waterlogged following irrigation and/or rain, then set hard when dry. This restricts water infiltration and seedling emergence. Soil types with low clay contents (less than about 35% clay) and insufficient organic matter (less than 2% organic matter) and poor biological activity are particularly prone, for example red-brown earths, solodized solonetz and solodics.

Even in soil that swells and shrinks strongly, an excess of sodium attached to the clay particles (sodicity) makes the seedbed dispersive and more prone to waterlogging, hard when dry and too cloddy when tilled.

Organic mulches (e.g. cereal straw) on top of the seedbed protect it from the damaging effects of raindrop impact, and may help to reduce slaking and dispersion when the soil is wet. Mulches encourage earthworms, which regenerate soil structure by producing burrows and stabilising soil aggregates.

Suitability of soil structure for root growth

Crops are more likely to produce high yields when their roots are able to grow freely.

Root growth is retarded by the same factors that restrict water entry and seedling growth (see the previous sections ‘Infiltration and internal drainage’ and ‘Suitability of soil structure for seedling establishment’). Subsoil sodicity tends, however, to cause waterlogging by the process of excessive swelling rather than dispersion of clay particles.

Salinity

Cotton is more tolerant of salinity than most other crops, although some crops grown in rotation with it are sensitive. Cotton grown on 'very highly saline' soil types will suffer yield loss. It is only semi-tolerant to boron salts.

A 'very highly saline' soil would have a root zone with an $EC_{1:5}$ greater then 1.33 dS/m for a medium clay, or greater than 1.72 dS/m for a heavy clay.

pH

The optimum pH range (measured in 0.01M $CaCl_2$) for cotton lies between 5.5 and 7.0. Acidic conditions, or extreme alkalinity caused by an accumulation of sodium carbonate, do not suit cotton crops. Their roots are very sensitive to soluble aluminium—concentrations of 0.5 ppm, which may develop when pH is less than 5.0, greatly reduce the root development of cotton seedlings.

Nutrition

Fertility status, other than for nitrogen, is generally medium to high in soil types used for cotton production in Australia. Total and available nitrogen levels are usually low (especially after several cotton crops) and satisfactory yields require applications of nitrogen fertiliser.

An ideal soil for cotton would contain sufficient plant nutrients for the crop's growth. Refer to *NUTRIpak* for further details.

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See NUTRIpak for more information on cotton nutrition.

For cations, the balance between the various elements is as important as their concentrations. Expressed as a percentage of the soil's cation exchange capacity, the desirable ranges are:

- calcium 65–80%
- magnesium 10–15%
- potassium 1–5%
- sodium 0–1%
- aluminium <5%.

Values of exchangeable magnesium percentage greater than 20 may induce potassium deficiency. Conversely, values of exchangeable potassium percentage above 10 may result in magnesium deficiency.

The desirable level of exchangeable sodium percentage (0–1%) is well below the danger level (5%) for clay dispersion. The desirable levels of calcium (65–80%) and magnesium (10–15%), besides providing adequate nutrition, also discourage clay dispersion.

Erosion control

The risk of soil loss by water and wind erosion is reduced if the soil surface is protected by a straw mulch. Coverage should be at least 30%, preferably anchored.

Soil variability and microrelief

To allow efficient management of each crop area as a single unit, it is highly desirable that the soil of the area be fairly uniform. A complex distribution of soil types with differing tillage and irrigation requirements, for example, cannot be managed optimally.

In some cotton growing locations cracking clays are intimately associated with hard-setting soil types. The latter, with poor intake of water, require more frequent irrigation than the former, and often there

are different fertiliser and herbicide requirements.

Gilgai micro-relief, once levelled, can also provide a complex mosaic with former mound and depression sites giving differing crop performance which may persist for many years.

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See Chapters C1 to C10 for more information on the tests mentioned in the tables.

FEATURES OF AN IDEAL SOIL FOR COTTON- TECHNICAL SPECIFICATIONS

Part C of this manual describes how to measure and interpret soil properties that influence the growth of cotton.

A summary of target values is shown in Tables A2-1 and A2-2. A

Table A2-1. Key soil properties influencing the growth of cotton

Process	Key soil properties	Targets
Water movement	**SOILpak score**	**>1.5 (depth = 0.0–1.0 m)**
		<0.5 (depth >1.0 m)
	ASWAT score*	**<6; preferably = 0**
		(depth = 0.0–1.0 m)
		>6 (depth >1.0 m)
Water storage	Plant Available Water Capacity	
	(PAWC)	maximise
Seed germination	**SOILpak score**	**>1.5 (topsoil; 0.0–0.1 m)**
	ASWAT score*	**<6; preferably = 0**
		(depth = 0.01–0.1 m)
	Soil temperature	18–31°C (diurnal range)
	Electrical conductivity (EC_e)	<6.8 dS/m
	pH (0.01 M $CaCl_2$)	5.5–7.0
	Nutrients	see Table A2-3
Root growth	**SOILpak score**	**>1.5 (depth = 0.0–1.0 m)**
	ASWAT score*	**<6; preferably = 0**
		(depth = 0.0–1.0 m)
	Temperature	18–31°C (diurnal range)
	Electrical conductivity (EC_e)	<7.7 dS/m
	pH (0.01 M $CaCl_2$)	5.5–7.0
	Nutrients	see Table A2-2
Erosion control	Organic residues	> 30% cover
	Field slope	0.01–0.05%
		(1:750–1:1500)

> = greater than, < = less than

* associated soil chemical factors (of relevance to soil structural stability in water) are summarised in Table A2-2

Table A2-2. Summary of chemical factors affecting soil structural stability in water

Soil factor	Values associated with stability (low ASWAT scores)	Values associated with instability (high ASWAT scores)
Exchangeable sodium percentage (ESP)	<2	>2 (low EC) >15 (high EC)
Electrochemical stability index ($EC_{1:5}$/ESP)(ESI)	>0.05	<0.05
Ratio of exchangeable calcium to exchangeable magnesium (Ca/Mg ratio)	>2.0	<2.0 (particularly <1.0)
Calcium carbonate ($CaCO_3$) content, %	>0.3	<0.3
Organic matter —total, %	*	*
—labile, %	*	*

> = greater than, < = less than

* critical limits for organic matter (OM) content have not yet been established for different types of cotton soil. However, in terms of soil structural condition, the more OM there is (particularly labile OM) the better, if accompanied by an adequate supply of calcium ions.

Table A2-3. Soil-test values below which nutrients may be deficient

	Nutrient		Extraction method*	Critical level (mg/kg)
**	nitrogen	NO_3	aqueous buffer	20–25
	phosphorus	P	bicarbonate	10–20
**	sulfur	S	Ca dihydrogen orthophosphate	5–10
***	iron	Fe	DTPA EDTA	2 80
	manganese	Mn	DTPA	2
***	zinc	Zn	DTPA EDTA	0.5 4.0
***	copper	Cu	DTPA EDTA	2 2
***	boron	B	magnesium chloride calcium chloride/mannitol hot water	1.5 0.4 0.15
				(cmol+/kg)
	calcium	Ca	ammonium chloride	20–35
	magnesium	Mg	ammonium chloride	10–12
	potassium	K	ammonium chloride	0.38 (150 ppm)

* Different laboratories may use different extraction methods.

** Nitrogen and sulfur are both dynamic nutrients. Their values can vary through the year, depending on such factors as soil temperature and moisture.

*** Soil tests for trace elements are unreliable. This table gives only a rough guide to critical levels.

A3. District soil management problems

Emerald
Theodore
Biloela
Dalby
Goondiwindi
St George
Mungindi
Moree
Collarenebri
Gunnedah
Narrabri
Wee Waa
Walgett
Trangie
Warren
Bourke

PURPOSE OF THIS CHAPTER

Some soil management problems under irrigated and dryland cotton—e.g. subsoil compaction—have been observed in all cotton growing districts. Other problems are more specific—e.g. erosion on steep fields at Emerald, and poor seedling emergence on hardsetting loam soil at Trangie.

This chapter describes the main soil management problems highlighted by extension leaders across the various districts.

Other chapters to refer to:

- Chapter E1: 'Australian cotton soil'.

summary of nutrient ‘critical limits’ is presented in Table A2-3.

DISTRICT PROBLEMS

Emerald

- On sloping black earths, considerable soil movement may occur when there is high intensity rainfall early in the season. With depth to the underlying bedrock usually less than 150 cm, such erosion losses are of concern.
- Watertable salinity has affected some areas, but drainage schemes have been installed to deal with the problem.
- 2 m wide permanent beds are not functional; the slope prevents adequate wetting-up.
- Poor trash breakdown during dry winters.
- Small blocks make rotation uneconomical.

Theodore/Biloela

- Small fields, mixed soil types, variable grades.
- Not much rotation.
- Seedling disease incidence increasing.

Darling Downs

- Most of the dryland area is subject to overland flow, with subsequent soil erosion problems.
- Soil-borne diseases are a big concern, particularly in the cooler areas.
- Very dry winters; problems with wetting up the soil and decomposing trash, but soil compaction problems are not severe.
- Legumes in rotation have fared poorly.
- Controlled traffic through fallow and rotation crops—problems with machinery compatibility.

St George

- Grey/brown clays which are quite variable across fields.
- No 2 m wide beds, because of subbing problems.
- Soil condition thought to be improving under irrigation, relative to pristine areas.

Macintyre Valley

- Problems in some areas with sodic soil.
- Long fallow disorder.

Northern New South Wales

- Some machinery tends to become heavier with the introduction of new models, e.g. cotton pickers.
- Compaction due to incompatible wheel track centres.
- Poor lateral subbing of irrigation water into beds, particularly on the lighter textured soil near Trangie.
- An excessive number of passes is required to manage permanent beds.

- Dryland salinity problems upstream of irrigation districts.
- Excessive soil movement with through-the-bank irrigation pipes.
- A small percentage of land in the Macquarie Valley and Bourke district is affected by salinity.
- Concern about weed control under reduced tillage.
- Herbicide incorporation is difficult where thick mulches are present.
- Possible adverse affect of agrochemicals on microorganisms that are required to break down organic residues.

All cotton growing districts:

- Poor subbing of irrigation water into permanent beds, particularly on lighter-textured soil.
- How to deal with furrow-edge compaction.
- Tractors often are too big, and their tyres are too wide, for bed farming (particularly during wet periods when the soil is most compactible).
- Guidance systems are needed to overcome 'guess row' variation.
- Uncertainty about when a topsoil is sufficiently disturbed by cultivation to destroy Heliothis pupae.
- How finely divided and incorporated should the stubble be?
- Under dryland conditions, an apparent conflict between Heliothis control and efficient intake of rainwater.
- Salt addition to soil through the use of bore water.

GETTING HELP

All of the problems identified above can be overcome, or at least eased, by good land management.

For assistance with any of the soil management problems that relate to the following issues, refer to Chapter B1:

- Poor seedling establishment.
- Disappointing yields and profitability.
- Excessive costs due to too much cultivation, N application and irrigation.
- Too much erosion.

Also in Part B are 'Quick help' sections to deal with specific on-farm soil management problems.

The apparent conflict between *Heliothis pupae control*, and the avoidance of soil structure problems, is discussed in Chapters B2, B4 and D1.

For specific questions about *red soil management*, refer to Chapter D10.

Questions about *stubble management* are dealt with in detail in Chapter E5.

Salinity hazards associated with the use of *bore water* are discussed in Chapter D4.

Correct *matching of farm machinery and bed architecture* is covered in Chapter D1.

PART B. QUICK HELP

B1. Trouble-shooting guide

As described in Chapter A2, the soil should supply plants with adequate water, oxygen, nutrients and support. When the soil does not furnish these needs, we say that there is a soil problem.

Common soil-related problems under cotton include:

- poor seedling emergence
- poor crop growth and disappointing yields
- excessive expenditure on land preparation and management
- too much soil loss by erosion.

A soil problem may be due to:

- recent management (for example, compaction, remoulding and smearing when `middle-busting' a soil that is too wet)
- a residual management problem (for example, deep subsoil compaction caused by heavy landforming equipment under moist conditions on soil with a poor self-regeneration potential).
- a 'natural' problem present at the time of European settlement (for example, sodicity caused by saline dust storms tens of thousands of years ago, or subsoil acidity created by brigalow forests).

Consider the needs of plants, examine the soil, and then deduce the problem. You will then be able to choose a management strategy to deal with the problem, keeping in mind that treatment costs should not exceed expected benefits.

The following figures will help you to determine the cause of a soil problem, and direct you to sections of the manual with more detailed information.

Figure B1-1. Soil related problems under cotton—introductory flow diagram

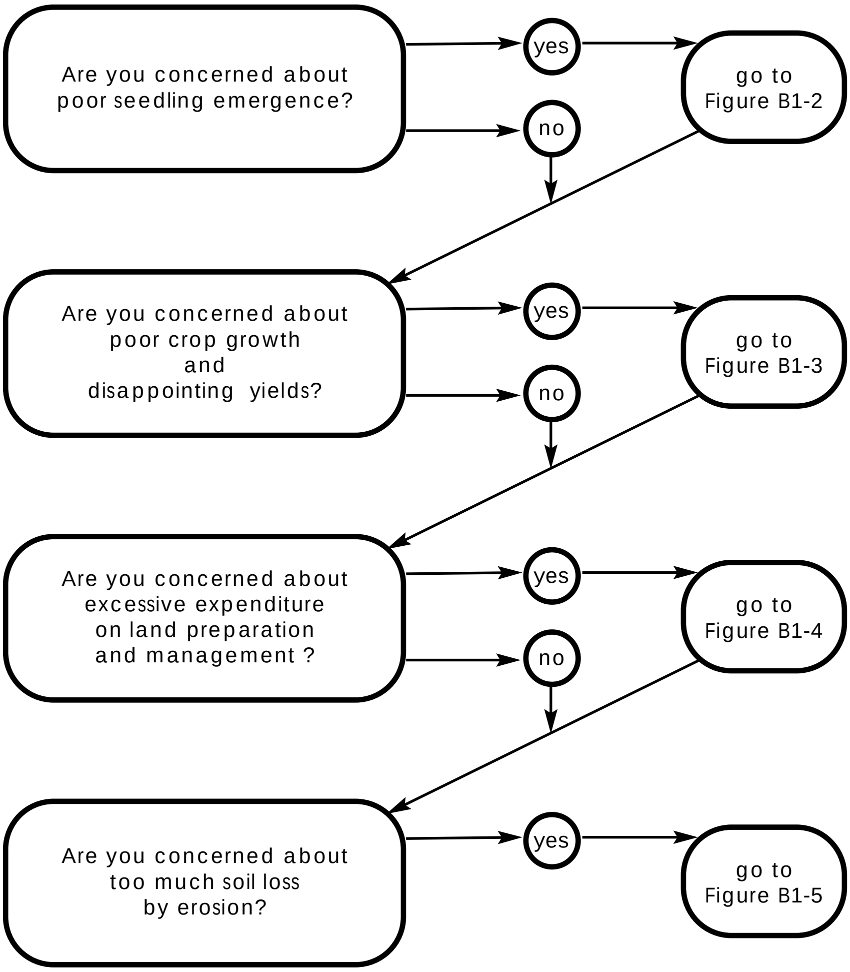
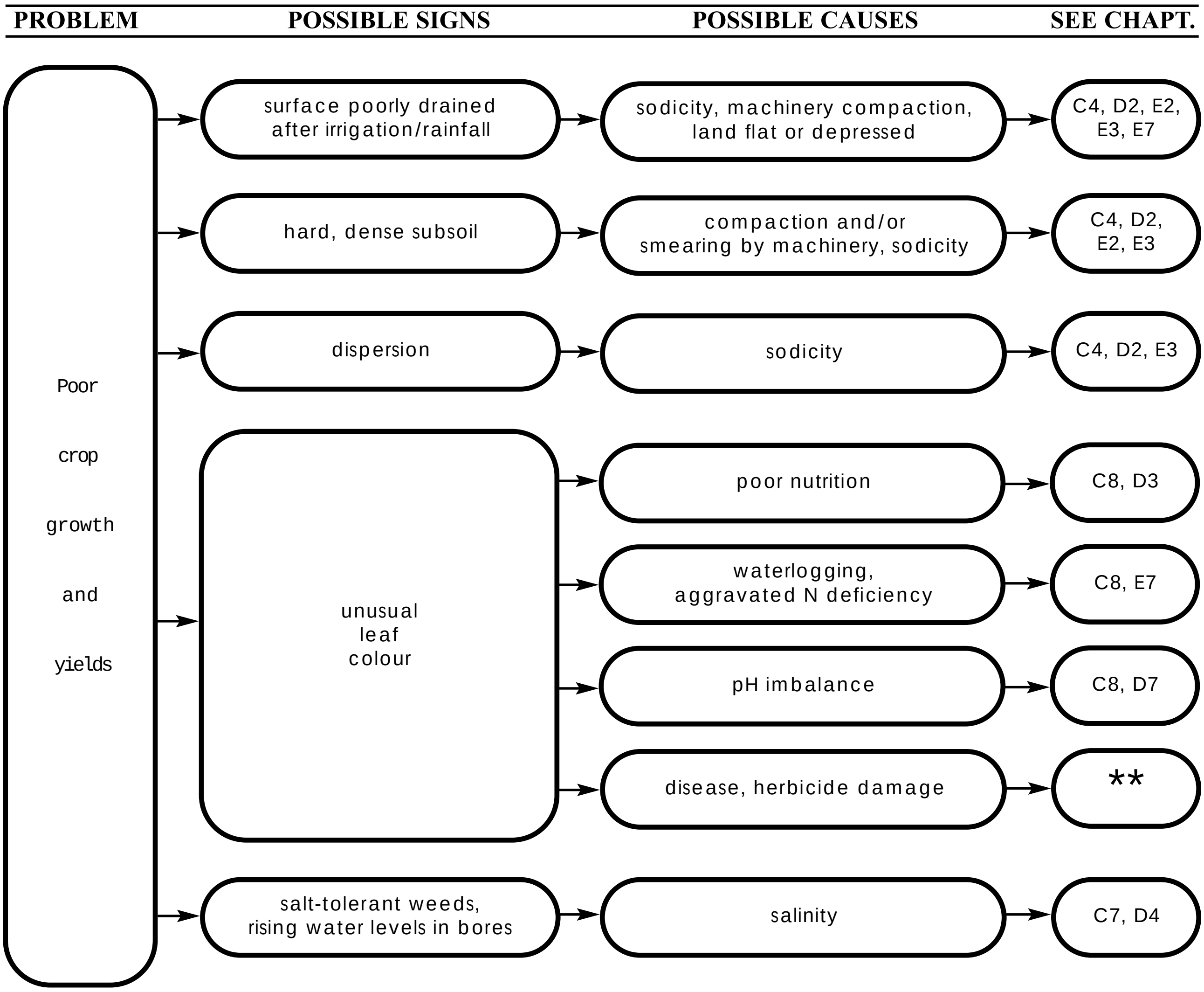


Figure B1-2. Soil problems associated with poor seedling emergence—possible causes and where to get help

PROBLEM	POSSIBLE SIGNS	POSSIBLE CAUSES	SEE CHAPT.
Poor seedling emergence	surface poorly drained after irrigation/rainfall	sodicity, compaction and/or land flat or depressed	C4, D2, E2, E3, E7
	dispersion*	sodicity	C4, D2, E3
	hard surface few cracks	hardsetting, sodicity	C4, D2, E2 E3
	too many large clods in seedbed ▼	hardsetting, sodicity, vehicle compaction and/or tillage equipment problems	C4, D2, E2, E3

* Dispersion shows as light coloured sand grains separated from the other soil components, with a skin of dispersed clay in the depressions.
▼ Excessive cloddiness also is associated with poor control of Heliothis pupae.

Figure B1-3. Soil problems associated with poor crop growth and yield—possible causes and where to get help



** See an agronomist for help with disease or herbicide problems.

Figure B1-4. Problems associated with excessive expenditure on land preparation and management—possible causes and where to get help

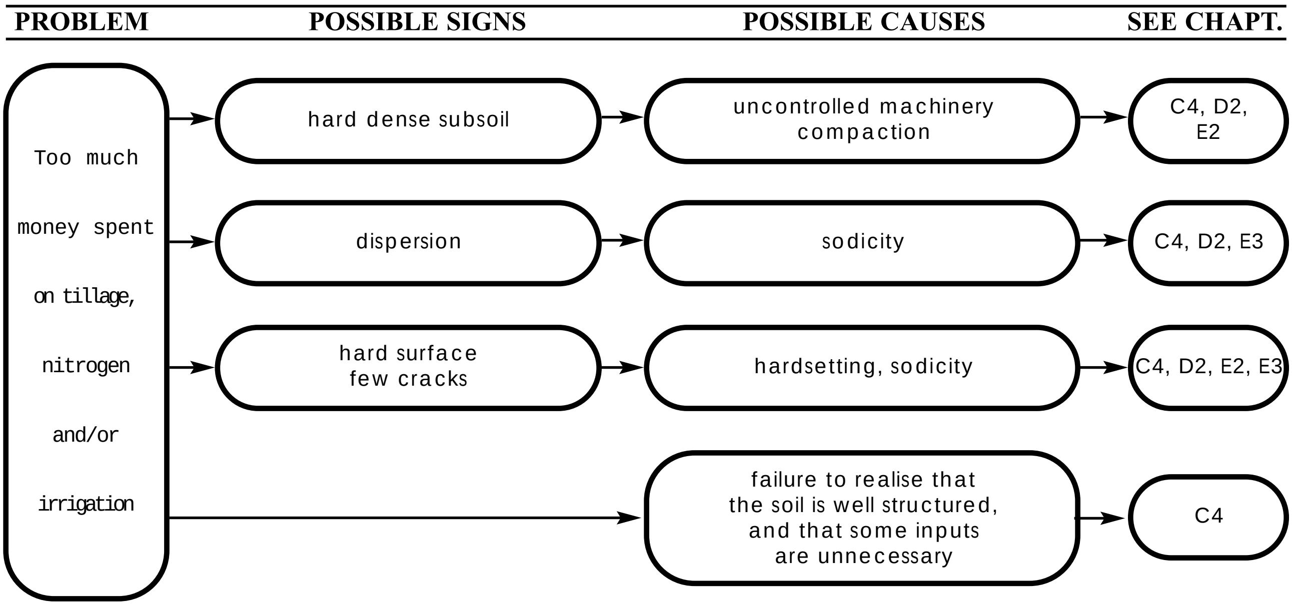
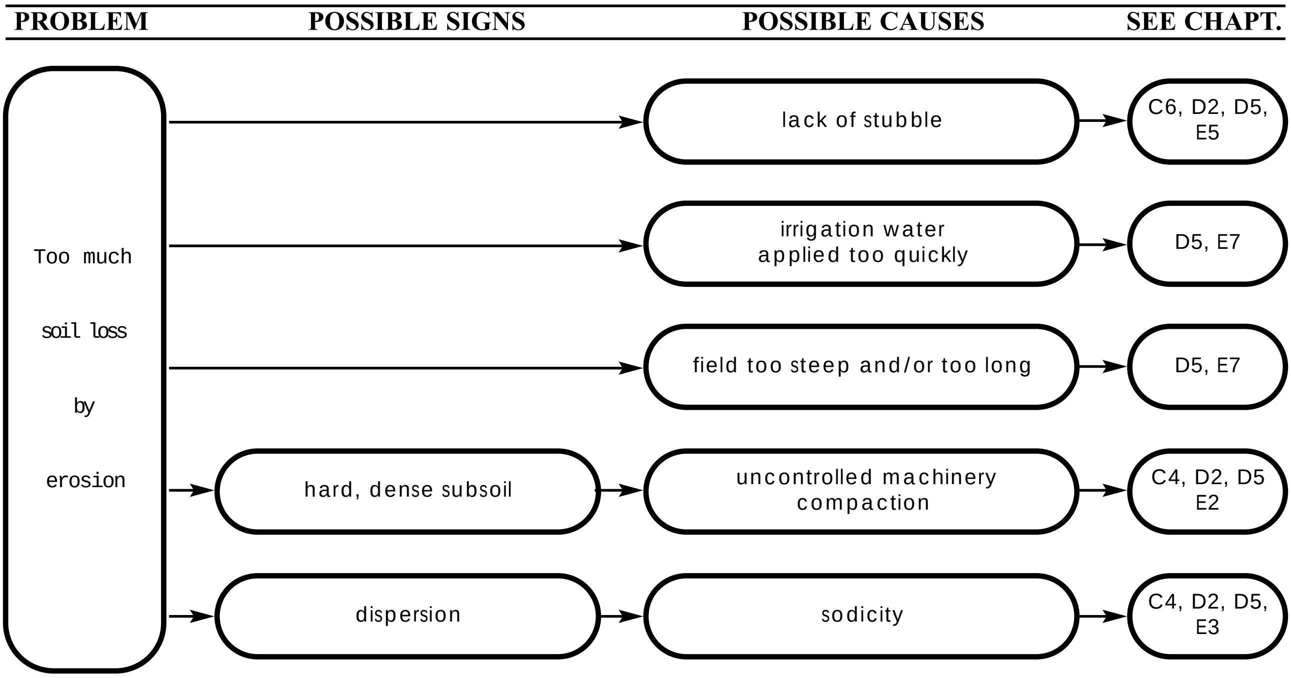


Figure B1-5. Problems associated with too much soil loss by erosion—possible causes and where to get help



The soil related problems outlined in Figures B1-1 to B1-5 tend to be inter-related. Often, several limitations occur simultaneously.

Farmers should develop programs for soil management that deal with as many of these limitations as possible while land is being prepared for the next cotton crop.

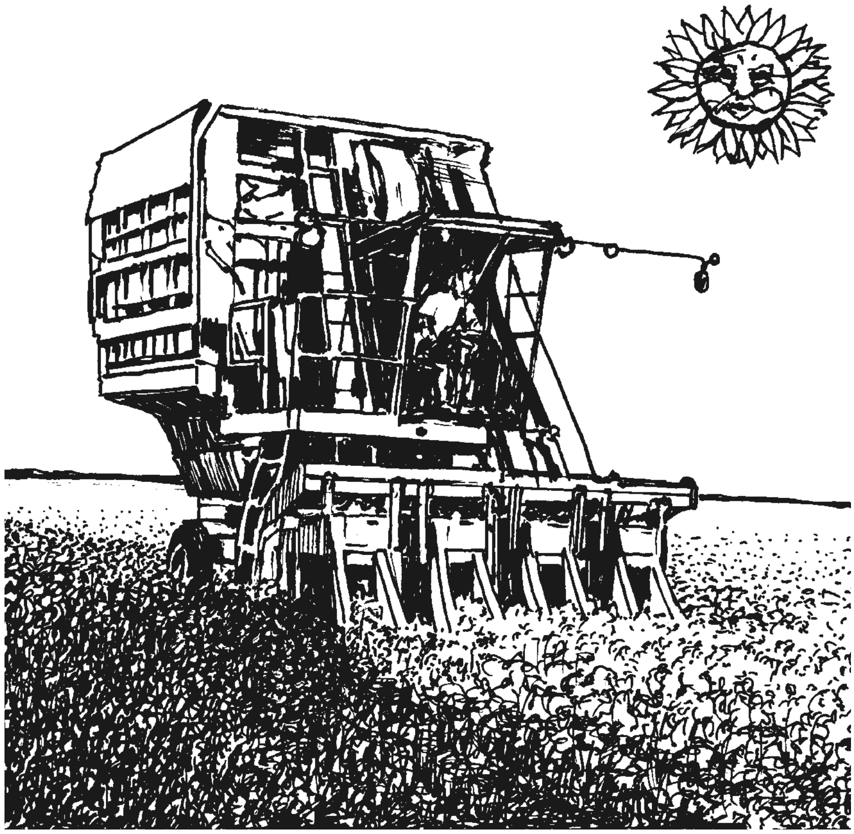
Failure to attend to just one of the many key factors influencing cotton growth may cause large declines in profitability.

The remaining chapters in Part B briefly describe practical options that can be ‘packaged’ to deal with soil-related problems at various stages of the cropping cycle under contrasting climatic conditions.

Topics include:

- soil preparation options after a wet cotton harvest (Chapter B4)
- managing variable fields; yield map interpretation (B8)
- soil survey for new developments (B9).

B2. Soil preparation options after a dry cotton harvest



PURPOSE OF THIS CHAPTER

This chapter outlines factors to consider following a dry harvest to maintain or improve soil structure. It takes into account the need to control over-wintering Helicoverpa (Heliothis) pupae, remove root growth restrictions and handle stubble efficiently.

CHAPTER OVERVIEW

This chapter covers the following points:

- pupae control
- checking compaction severity and subsoil moisture content
- choosing a tillage and/or rotation option
- stalk management.

Other chapters to refer to:

- Chapter C3: Soil moisture (before tillage), soil texture and available water
- Chapter C4: Structural condition
- Chapter C6: Stubble
- Chapter D2: Improving soil structure.

INTRODUCTION

When preparing soil after a dry harvest, the first priority is to deal with the over-wintering pupae of *Heliothis armigera* (also referred to as *Heliocoverpa armigera*). They are a major cause of increasing resistance to chemicals. A tillage strategy must be implemented to destroy the pupae by the end of August, while avoiding serious structural damage to the soil and minimising input costs.

Cotton pickers are very heavy, with front axle loads as great as 14 t. However, when the soil profile is dry at harvest, their impact on soil structure is not great. Wheel damage will not be nearly as severe as when the soil is moist, although wide tyres or dual front wheels may still compact loose beds.

It must be remembered, however, that serious soil compaction may have occurred earlier in the season (due to operations such as fertiliser application and weed control), or remain from previous seasons where the self-regeneration capacity of the soil is poor. Such damage may require treatment.

A big advantage of a dry harvest is that it gives you the widest possible range of options for preparation and improvement of cracking clay soils, provided that heavy rain does not follow soon afterwards. If you are contemplating using deep tillage, be aware that the previous cotton crop may not have had enough time to thoroughly dry the soil to an adequate depth before defoliation.

On non-swelling silty soil, however, excessive dust production may be a problem if it is heavily tilled when dry. When dusty soil is re-wetted rapidly, it will have very poor structure.

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See Chapter D9 for further information on red soil management.

PUPAE CONTROL

Tillage to a depth of at least 10 cm is most likely to kill over-wintering Heliothis pupae, if all of the very large clods (more than 50 mm wide) in the topsoil have been broken down and rearranged. However, be careful on silty soil where overly aggressive dry cultivation will create too much dust.

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See MACHINEpak for more information on which tillage equipment to use.

CHECKING COMPACTION DAMAGE AND MOISTURE

Go to the best yielding, average and worst yielding points within at least one representative field as soon as possible after picking. Dig at least one, preferably two or three, inspection holes at each of these points and assess soil structural condition. Look particularly at the zone directly below the plant lines next to and away from the main wheel tracks.

Determine the SOILpak score for the topsoil (0–10 cm), sub-surface (10–30 cm) and subsoil (30–100 cm). Enter the results onto the ‘post-harvest’ description sheet.

If the site has not been assessed previously, measure soil stability in water (ASWAT test). It is also advisable to collect soil samples from the SOILpak/ASWAT scoring sites and have them analysed in a laboratory for gypsum and/or lime requirement. An economically viable response to gypsum is likely where the ESI value is less than 0.05 (ASWAT score greater than 6). Soil salinity should also be assessed by measuring soil electrical conductivity.

Also, use clues such as plant symptoms and moisture probe data during the growing season, to indicate problem areas. Even after a dry harvest, check soil moisture at the depth, and slightly below the depth,

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See MACHINEpak for more information on pupae control.

☞

See Chapters C3 and C4 for further information on soil assessment.

at which you are going to till. This is important because although upper, easily examined layers of the soil are drier than the plastic limit (PL) and there has been no deep rutting of the soil by harvesting machinery, deeper levels of the soil may be wet enough to smear rather than fracture when tilled.

If your crop ripened in dry weather, there is a good chance that the soil is drier than permanent wilting point to an adequate depth. However, if defoliation took place when the crop was still active, there is a chance that soil moisture may still be moderate at the depth of tillage. Check the soil moisture.

COTTON STALK MANAGEMENT

Crop residues can carry disease, clog tail drains and/or interfere with herbicide incorporation or planting. However, stalk incorporation may improve the amount and quality of soil organic matter. Burning of cotton stalks should be avoided (wherever possible) because of loss of nutrients.

The stalks should be removed soon after harvest, and cut finely enough to avoid immediate management problems such as implement blockage. If the trash is broken down too finely, decomposition and nutrient release may occur too quickly—this can lead to loss of nutrients such as nitrogen. If fusarium wilt is a problem, it may be necessary to at least partially, disinfect the stalks by exposing them to UV light on the soil surface—burial is likely to aggravate the problem. Much remains to be learnt about fusarium wilt control.

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See Chapters D1, D2 and E5 for further information about cotton stalk management.

CHOOSING A TILLAGE AND/OR ROTATION OPTION

You may find that the crop you have just harvested has partly or wholly fixed the problem that had caused it to perform poorly. Cycles of wetting and drying during the growing cycle and deep drying by the crop after the last irrigation can crack the soil and improve structure to a point where deep tillage may not be necessary.

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See MACHINEpak for more information on trash-working equipment.

Other fields may not have had such good work done by the crop. Residual compaction may remain; and cracking by rotation crops, and/or deep tillage, may be required to improve yields and profits.

Four options should be considered. They are shown in Figure B2-1.

Option 1. Rotation crop and/or deep tillage

Full land preparation (ploughing the old hills and forming new ones) gives you the opportunity to ‘tidy up’ a field: removing hollows, straightening crooked rows, adjusting guess row spacing, and controlling weeds. Examine the soil structure using a spade or back-hoe pit. If the structure under the plant lines is poor (SOILpak score less than 0.5), consider deep tillage. Where the soil has moderate compaction damage (SOILpak score between 0.5 and 1.5) but does not have good shrink-swell potential (CEC less than 40), deep tillage is also likely to be beneficial, particularly where there is a great danger that new beds will lie over old wheel tracks with their associated compacted zones.

After examining the soil structure, assess soil moisture to determine to what depth tillage would be beneficial. The soil profile may not be at a uniform moisture content. It may be possible to till the upper, dry part of a compacted layer and leave the deeper, moist soil untouched (and unsmeared).

If a sodicity problem is identified, applications of gypsum and/or lime may be needed. Where the subsoil only is sodic, any deep tillage should loosen but not invert the soil profile.

Advantages:

- Good stubble incorporation for field hygiene.
- The opportunity to tidy up field architecture.
- Thorough control of Heliothis pupae
- Weed control.

Cautions:

- Reformed hills may lie over old compacted furrows, hence expensive deep working may be more necessary with this system.
- Deep ripped soil may become very boggy after heavy rain. Re-establish the main wheel tracks as soon as possible after ripping.

Instead of tilling the soil, it may be more economical to sow a rotation crop such as wheat or lucerne to improve soil structure by drying and cracking the soil. This option is particularly useful where there are problems with weeds and soil-borne cotton diseases, and where sufficient water is available to establish the crop satisfactorily.

A rotation crop will be particularly useful where compacted soil is not quite dry enough for deep tillage after a cotton crop. The soil can, if necessary, be deep tilled after growing the rotation crop to loosen the soil further.

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See Chapter D2 for further information about soil structure improvement.

Option II . Permanent beds with controlled traffic and middle busting

If moderate damage to soil structure is detected in the top 30 cm of soil under the plant lines (SOILpak score between 0.5 and 1.5), and the soil is drier than the plastic limit, you may be able to loosen it by middle busting without completely destroying the beds. Before this operation, the cotton stalks may need to be slashed, pulled and/or mulched.

Lightly chisel the furrow bottoms to create loose soil for reforming existing beds, and use gas knives to break up any serious bed-shoulder compaction. Reform the beds with soil from the furrows, using go-devils or sweeps. Ensure that all of the soil is disturbed to a depth of 10 cm; otherwise, some of the over-wintering pupae may survive.

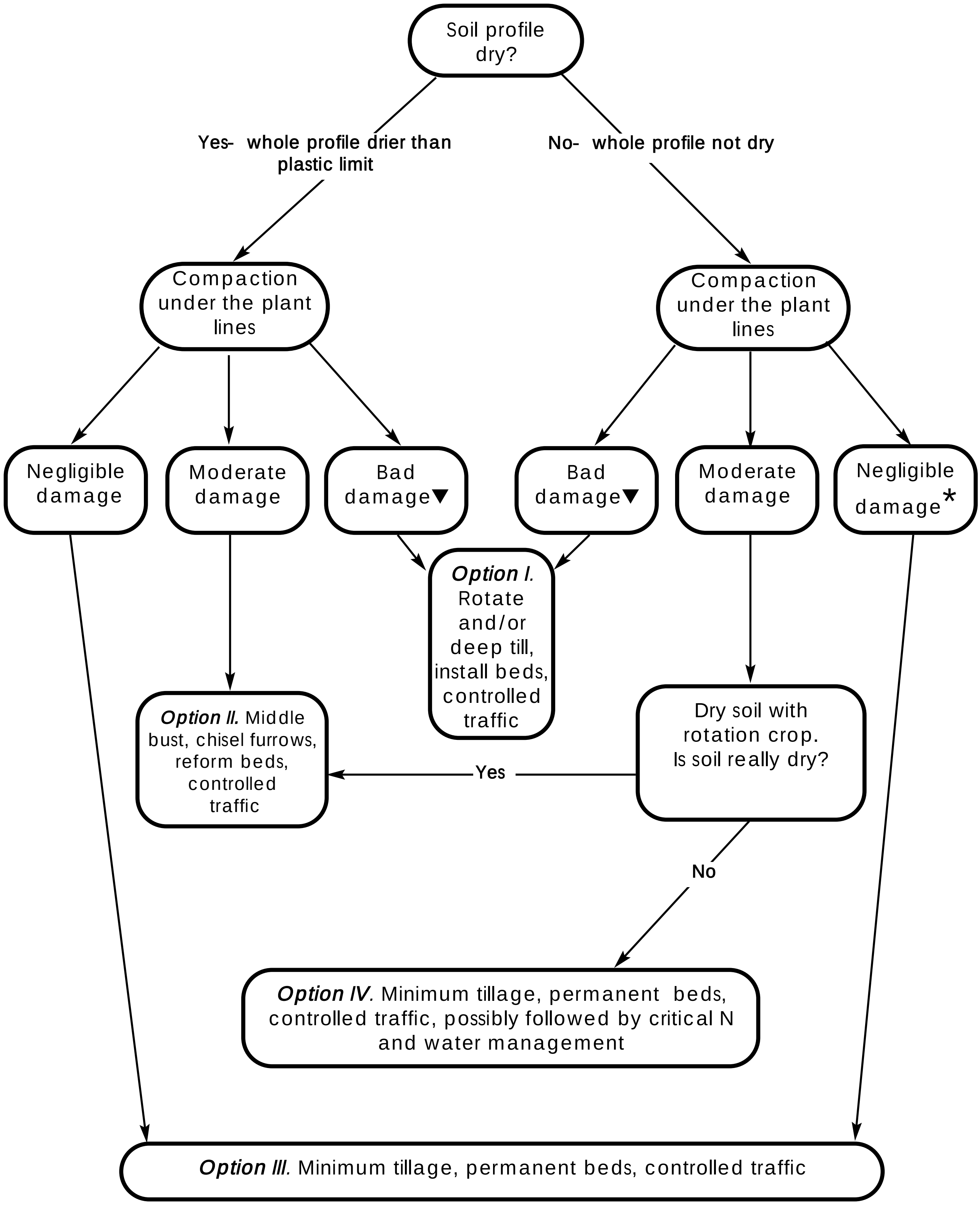
Advantages:

- Furrows are always present for surface drainage in the event of heavy rain.
- Leaves traffic lanes for vehicle support.

Cautions:

- Difficult to manage unless all the farm machinery has compatible wheel and/or track spacings.
- Weeds such as nutgrass may build up.

Figure B2-1. Tillage and rotation options after a dry harvest



* Bad damage = serious compaction in the bed subsoil, sub-surface and/or surface (SOILpak score less than 0.5).
Moderate damage = moderate compaction in the bed subsoil, sub-surface, and/or surface (SOILpak score between 0.5 and 1.5).
Negligible damage = absence of compaction problems (SOILpak score greater that 1.5)

▼ If economically necessary to grow cotton immediately, apply critical N and water management (see Chapter B6).

Option III. Permanent beds with controlled traffic and minimum tillage

If the soil structure under the plant lines has remained uncompacted (SOILpak score greater than 1.5) due to careful control of traffic, keep it that way by minimising soil disturbance below a depth of 10 cm. Slash, pull and/or mulch the cotton stalks.

Tillage of the topsoil may have to be repeated to ensure effective pupae control, particularly where the previous cotton crop was late. This operation should ensure good weed control.

Lightly chisel the furrow bottoms to create loose soil for reforming existing beds, and use gas knives to break up any serious bed-shoulder compaction. Reform the beds with soil from the furrows, using go-devils or sweeps. Ensure that all of the soil is disturbed to a depth of 10 cm; otherwise, some of the over-wintering pupae may survive.

Advantages:

- Fast and cheap.
- Maintains or improves soil structure and soil organic matter in the sub-surface and subsoil.
- Furrows are always present for drainage in the event of heavy rain.
- Leaves traffic lanes for vehicle support.

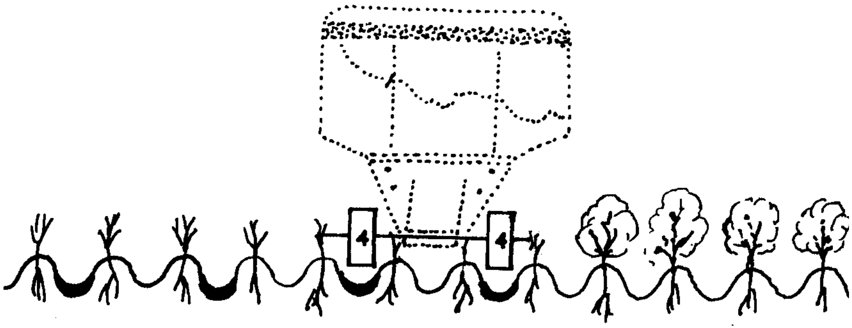
Cautions:

- Difficult to manage unless all the farm machinery has compatible wheel and/or track spacings.
- Weeds such as nutgrass may build up.

Option IV. Permanent beds with controlled traffic, minimum tillage and special nutrition and/or water management

The procedures described under Option III may also be used where there is moderate compaction under the plant lines (SOILpak score 0.5 to 1.5), but it is likely that critical management (extra N and more frequent irrigation) will be needed.

B3. Harvesting cotton on wet soil



PURPOSE OF THIS CHAPTER

This chapter gives you options for harvesting cotton when the soil is wet and soft, and suggests ways of minimising damage to soil structure.

CHAPTER OVERVIEW

This chapter covers the following points:

- improving the mobility of pickers
- minimising soil compaction.

Other chapters to refer to:

- Chapter B4: ‘Soil preparation options after a wet cotton harvest’
- Chapter D1: ‘Avoiding soil structure and waterlogging problems’.

TWO PROBLEMS: MOBILITY AND COMPACTION

There are two distinct problems involved with mechanised cotton picking on a wet soil—mobility of pickers and soil compaction.

If your major concern is getting the crop off, then you may have to accept a higher level of soil degradation. Once picking machinery is mobile in a wet field, think carefully about wheel patterns that provide the maximum number of unwheeled rows.

Pay particular attention to those fields in which you plan to grow cotton in the following season. The short period of time available before planting may not allow you to fully repair damaged soil. If possible, reserve the more damaging options suggested in this chapter for fields marked for rotation in the coming season.

As a guide to how damaging the harvesting operation is, watch a picker at work. If the wheels are producing deep ruts and are pushing plant rows sideways, the operation is probably causing severe damage to soil structure.

In general, fewer problems occur where there are permanent beds and unploughed wheel tracks.

INCREASING MOBILITY

Some of the methods suggested here to improve mobility of pickers will damage soil structure. These methods will help you to pick when the usual methods fail.

- Four-wheeled pickers are preferable to early-model three-wheeled pickers. Three-wheeled pickers are less mobile on soft soil and compact all the furrows and the middle of wide beds. The single rear wheel should be replaced by a pair of wheels in line with the front wheels.
- Rear wheel assisted drive increases mobility but does not, on its own, ensure that the picker heads stay out of the mud.
- Wider tyres help to prevent wheel sinkage. At the front of the machine, wide tyres help to keep the picker heads out of the mud. Twenty-four inch tyres improve flotation in very wet conditions. However, wide tyres compact the sides of the beds (see Figure B3-1)—this approach is a 'last resort' option. As the soil dries, convert back to narrower tyres to conserve tyres and to minimise compaction on the edges of cotton beds.

⚠ Risky option

- Tracks increase mobility greatly, consequently allowing a much earlier entry into the field. This comes at a price because damage to the soil is great. Tracks, also, are usually not readily available.
- Uneven furrows do not help mobility. A picker may bog more easily if one wheel runs along an already-compacted cultivating wheel track, and the other wheel runs on a soft furrow.

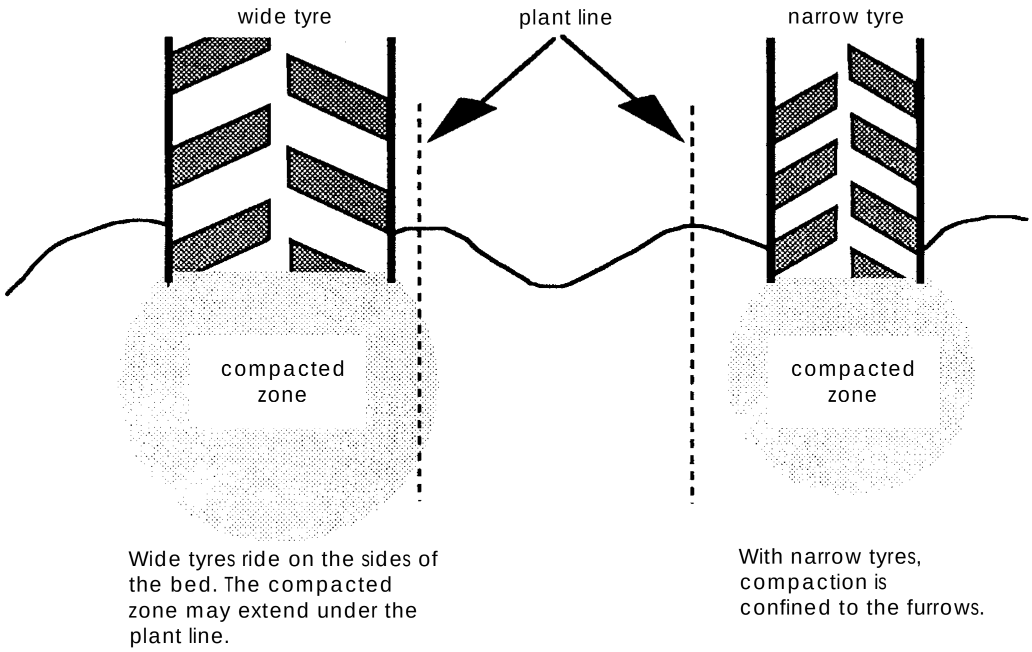
Try either to:

- Stay wholly on or wholly off cultivating wheel tracks; this may involve straddling guess rows with associated problems of running over beds and missing cotton.

⚠ Risky option

- Run the heavier side of the picker along the firmer furrow (cultivating wheel track).

Figure B3-1. Compaction under wide and narrow tyres on wet soil.



Advantages:

- These methods will allow you to pick when the usual methods fail.

Cautions:

- There is a trade-off between soil damage and a quick harvest.
- Cotton lint may not have time to brighten following rain (causing dollar penalties).
- Uncertainty about the next fall of rain makes it difficult to develop a soil management plan.

MINIMISING COMPACTION

As the soil dries and mobility is no longer your major concern, consider methods of minimising compaction.

Look after the existing beds; their condition strongly influences the next crop.

Leave some furrows untrafficked so that plant roots from the next year's crop can grow into them.

Plan your picking pattern

Even before a wet harvest, there are compaction zones beneath the furrows used by tractors during the growing season. Harvesting on wet soil will compact more furrows, but careful planning will enable you to leave the maximum number of furrows untrafficked.

About 90% of the potential compaction that occurs under wheels happens in the first pass of the machinery. Make use of the already-compacted furrows rather than attempting to spread the compaction.

Figures B3-2 to B3-5 show how the pattern of picker tracks affects the potential compaction of a field. The diagrams assume that you are not picking across guess rows.

With a six-row tillage system it is best to use two-row pickers only, as they will leave 50% of the furrows untrafficked. Using a four-row picker and a two-row picker in the same set of six rows leaves only 17% (one in six) of the furrows untrafficked (see Figure B3-3).

With a tillage system that spans four rows or multiples of four rows (4, 8, 12, 24) it is best to use four-row pickers only, as they will leave 50% of the furrows untrafficked. If you use a four-row picker and a two-row picker in the same tillage set, plan the picking pattern carefully to leave the maximum number of untrafficked furrows (see Figures B3-4 and 5).

Figure B3-6 is provided for you to enter your own picking pattern.

Stay off beds

Soft soil within the beds is very prone to severe damage. Keep picker wheels within the furrows. This may mean converting to narrower tyres.

If the soil is so soft that you need to use wide tyres that cover part of the beds, use tyres that are lugless or very worn to minimise the severity of near-surface compaction.

Increase ground contact area

A large area of ground contact spreads the weight of the picker and helps trafficability when the soil is very soft. For example, wide tyres are less likely to exceed the critical ground pressure, but when they do, they cause a deep, wide zone of damaged soil. In addition, wide tyres will damage the soft beds even if the beds are dry.

- Lower tyre pressure makes the tyres wider, but there is not much scope for making use of lower pressures. Reducing tyre pressure from 240 kPa to 140 kPa (35 psi to 20 psi) results in only 5% tyre deflection—not a large benefit. Low tyre pressures can cause increased tyre failures and tyre roll-off when cornering. When a picker empties its load, much of the weight is thrown to one side and soft tyres may fail.
- Dual front wheels spread the load of heavy pickers, but may cause serious damage to the middle of wide beds. Dual wheels with spacings that do not match exactly with the furrow centres should not be used; otherwise much of the root zone will be severely compacted. Deep subsoil compaction only starts to be reduced by dual wheels if their spacing is greater than 1.5 m. Tandem wheels lined up with the furrows cause much less damage than the same wheels in a dual configuration.
- Experience with half tracks in Australia has shown they do improve picker mobility in much wetter conditions than could be expected with wheels. However, soil damage was also much greater simply because the soil was wetter. Compaction from tracks is greater than expected because there are ‘spikes’ of extra pressure as the track rollers pass over the soil.

Always remember that subsoil compaction is related more to the axle load of a vehicle than tyre pressure.

Decrease the weight of pickers

There are very few options for decreasing picker weight. Even frequent emptying of the basket will not make a large percentage

Figure B3-2: Key for diagrams B3-3 to B3-6

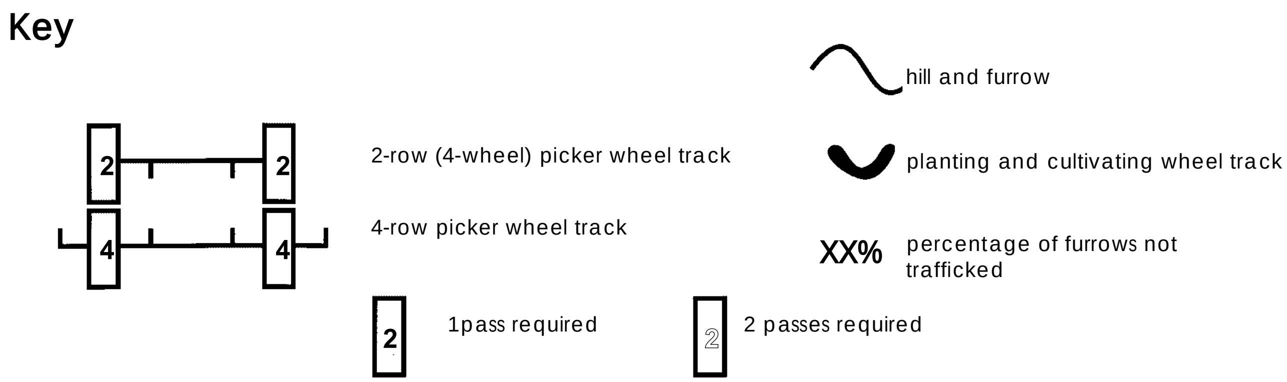
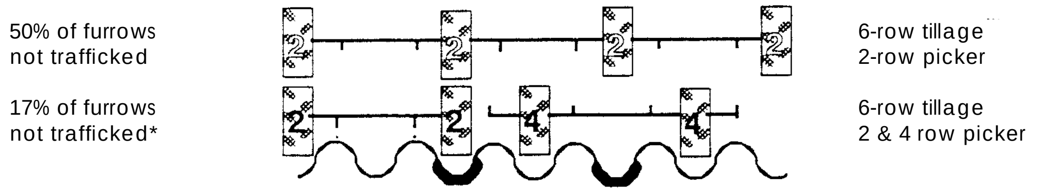
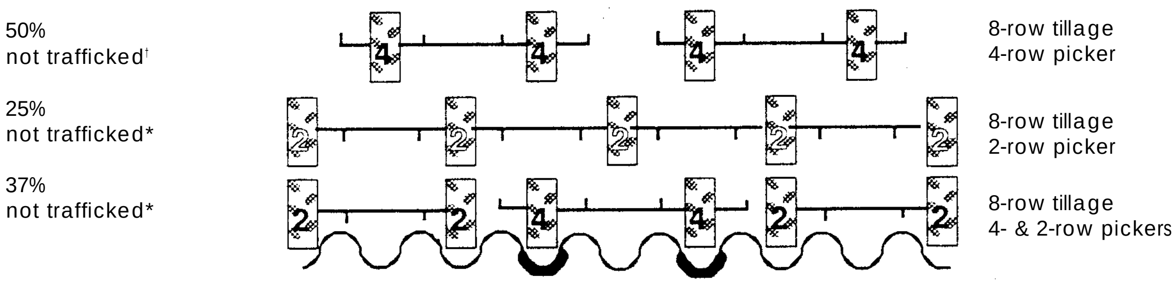


Figure B3-3. Potential compaction under the rarely used six-row tillage system



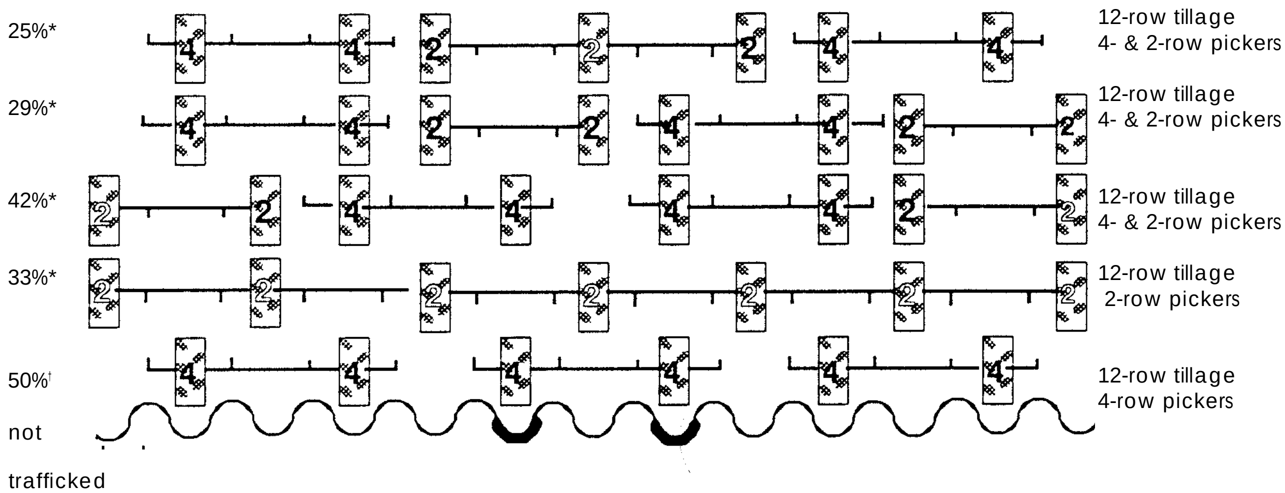
* not compatible with 2 m wide raised beds

Figure B3-4: Potential compaction under eight-row tillage system



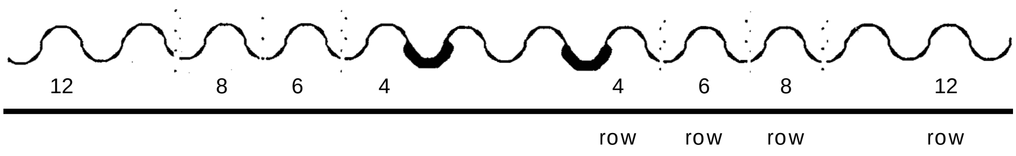
* not compatible with 2 m wide raised beds
† recommended

Figure B3-5: Potential compaction under twelve-row tillage system



* not compatible with 2 m wide raised beds
† recommended

Figure B3-6: Enter your own picking pattern



difference to the weight of the machine (roughly 10%). However, if a choice has to be made between the use of three four-row pickers and two (about to be released) six-row pickers, the first option would be preferable in terms of the lower axle load and more-shallow subsoil compaction.

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See Chapter E2 for more information on compaction processes.

SOIL DRYING

Soil drying improves trafficability (due to less sinkage and less wheel slip) but it will not lessen damage until the depth of dry surface soil exceeds half the tyre width (approximately). Transpiration ceases at defoliation, and little water will be lost by evaporation from a soil surface covered with leaves. Soil drying slows as autumn progresses.

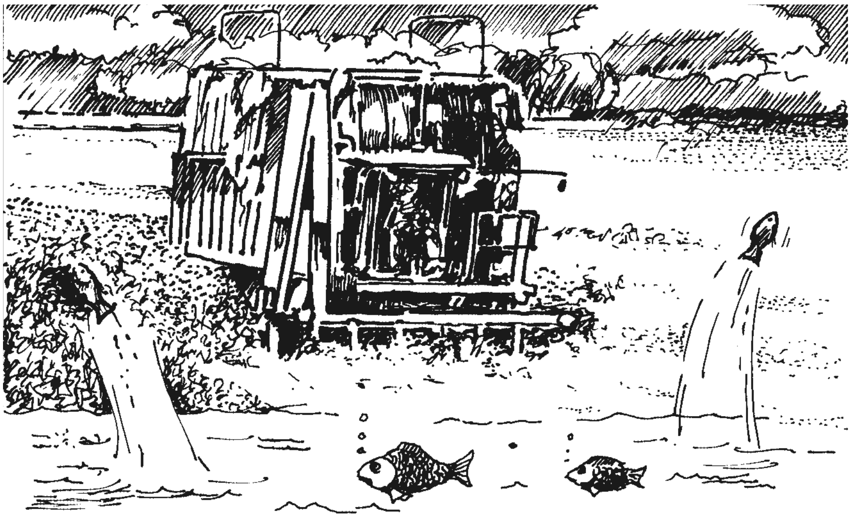
HARVESTING NARROW-ROW COTTON

The options given above refer to cotton grown with a row spacing of 1 m (40 inch).

Row spacing sometimes is reduced to 75 cm (30 inch) or less to minimise the time between planting and attainment of a full canopy cover. When this occurs, the wheel spacings of all row-cropping and harvesting equipment should be adjusted to:

- avoid breakage of rows of cotton plants by machinery wheels
- minimise percentage of the root zone compacted by wheels and tracks when the soil is moist.

B4. Soil preparation options after a wet cotton harvest



PURPOSE OF THIS CHAPTER

This chapter helps you to choose a tillage and rotation option when preparing land for the next cotton crop after a wet harvest. It takes into account the need to control over-wintering Heliothis pupae, deal with root growth restrictions and handle stubble efficiently.

Options vary. They depend on how badly the soil was compacted by pickers, how wet the soil is and how much time you have.

CHAPTER OVERVIEW

This chapter covers the following points:

- examining wheel ruts to assess the damage done by picking
- relating the appearance of wheel ruts to the actual damage beneath the soil surface
- deciding whether soil under the plant lines is badly, moderately or not compacted
- assessing soil moisture
- choosing a rotation/tillage option
- pupae control
- stalk management.

Other chapters to refer to:

- Chapter C3: 'Soil moisture (before tillage), soil texture and available water'
- Chapter C4: 'Structural condition'
- Chapter C6: 'Stubble'
- Chapter D2: 'Improving soil structure'.

INTRODUCTION

A wet harvest is referred to here as one where:

- rain prevents picking because the soil becomes too soft and sticky for pickers to work; and
- when you can start to pick again, the soil remains wet enough for the pickers to form ruts under the furrows.

THE SOIL PREPARATION PREDICAMENT

Picking on wet soil has, despite all your precautions, compacted the furrows and bed edges. Soil under the plant lines may be compacted too. The soil is still wet and you want to know how to prepare the land before planting another crop of cotton.

The two key points to remember are:

- Minimise wet soil disturbance; and
- Do what you have to do without undue delay. Delays may mean that you will miss the planting window in the coming season. Early land preparation often gives sufficient time for the surface soil to shrink, swell and mellow to form an acceptable seed bed.

Minimum disturbance

Current knowledge indicates that soil disturbance to kill over-wintering *Heliothis armigera* pupae must occur to a depth of 10 cm. If the top soil is wet, temporary structural damage may occur but this is unavoidable. Compaction and smearing due to deeper tillage under moist conditions will, however, create longer term problems and should be avoided.

Leave the existing beds in place—they will form the basis of next season's beds. With the beds still in place, the field can drain if rain continues. Be wary of discing, deep ripping or land planing. Any of these operations on wet soil will cause soil structural damage and reduce profitability.

Minimum delay

For most of the following options (where the soil is damaged) start to implement the recommendations as soon as conditions allow. Use a step-by-step approach as the soil dries.

You need to allow the maximum time for damaged soil to mellow under the action of the weather. An exception is when the soil is not damaged or is only slightly damaged (see Chapter B2, Options III and IV)—in this situation it is best to wait for the soil to dry before doing anything.

ASSESSING THE DAMAGE

Damage to soil structure caused by picking on wet soil can be assessed in three ways:

- examining the furrows
- digging into and under the beds with a spade
- examining the soil profile to a depth of 1.2 m in a backhoe pit.

Furrows

Examine each field and record notes on the following:

- In how many furrows is there a picker wheel track? Refer to the picker patterns sheet (see Chapter B3) to decide how well your various wheeled implements matched.
- How deep are the wheel ruts? Measure and record the depth of the furrow bottoms below the tops of the beds.
- Have the sides of the beds been squashed by wheels?
- Has the distance between plant lines been altered by harvest machinery? If so, it is likely that the soil was moderately or severely damaged.

Beds

Use a spade to examine the soil within and just under the beds/hills. The feel of the soil as you dig (easy or hard digging) will give you some idea of how far the compaction spreads into (or under) the beds. Note that clay soils become hard as they dry—if the soil has a dry layer that is hard to dig, don't necessarily attribute this to compaction.

Look for and record signs of platiness in the soil structure, especially under hills. Platy structure is often found in the bottom of the furrow above a zone of compaction. Platiness under the hills is a much more serious problem because that is the main region of root exploration.

Backhoe pits

From your observations on the furrows and the beds, select a few fields to represent a range of conditions from the worst to the least compacted. These fields are the ones to examine more thoroughly using backhoe pits.

A backhoe pit is the best way to assess compaction. A backhoe pit shows signs of damage other than that caused by picker wheels. Such damage may be the residual effects of tillage, sowing, and/or nitrogen application.

Relate your observations on the furrows and beds to what you see in the pits. In this way, you can form an opinion about the severity of compaction in each field without necessarily examining a pit in each.

After ranking your fields into order of severity of compaction, go to the best yielding, average and worst yielding points within representative fields as soon as possible after picking. Dig at least one inspection hole at each of these points and assess soil structural condition, with emphasis on the zone directly below the plant lines next to and away from the main wheel tracks.

Determine the SOILpak score for the topsoil (0–10 cm), subsurface (10–30 cm) and subsoil (30–100 cm). Enter the results onto the 'post-harvest' description sheet.

If the site has not been assessed previously, measure soil stability in water (ASWAT test). It is also advisable to collect soil samples from the SOILpak/ASWAT scoring sites and have them analysed in a laboratory for gypsum/lime requirement. An economically viable response to gypsum is likely where the ESI value is less than 0.05 (ASWAT score greater than 6). Soil salinity should also be assessed by measuring soil electrical conductivity.

Also use clues such as during-season plant symptoms and moisture probe data to point to areas that caused problems before harvest. Problems identified during post-harvest inspection may have occurred

during the wet harvest; others may have been there longer.

Check soil moisture throughout the soil profile. Most of it is likely to be wetter than the plastic limit (PL). However, if—for example—only the subsoil is drier than the PL, and this soil underlies a compacted layer, deep tillage should not damage that subsoil.

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See Chapters C3 and C4 for further information about soil assessment.

DAMAGE CLASSES

After observing the extent and severity of damage, place the site in one of the following classes:

- Badly damaged. Compaction occurs under the furrows and beds, and appears severe enough to inhibit root development into the subsoil (SOILpak score under the plant lines 0.0 to 0.4).
- Moderately damaged. Compaction in the furrows does not spread completely under the beds, and there is a connection of reasonably well-structured soil between the tops of the beds and the better-structured subsoil. Roots can extend below the compacted or degraded zones (SOILpak score under the plant lines 0.5 to 1.5).
- Slightly or not damaged. A broad band of well-structured soil is present below the plant lines. There will be a concentrated zone of compaction under the wheel tracks, but it will be narrow. Roots will be unimpeded and will have a large soil volume to exploit at all depths (SOILpak score under the plant lines 1.6 to 2.0).

Decide which option to follow for each field. The following list and Figure B4-1 are a brief summary of the options that should be considered.

For each damage category there are:

- four options (A, B, C and D) for a moist field with badly compacted soil;
- two options (C and D) for a moist field with moderately compacted soil; and
- two options (D and E) for a moist field with no damage or slight damage.

The choice is yours; and it depends on your resources of labour, machinery, available land and finances.

OVERVIEW OF THE OPTIONS

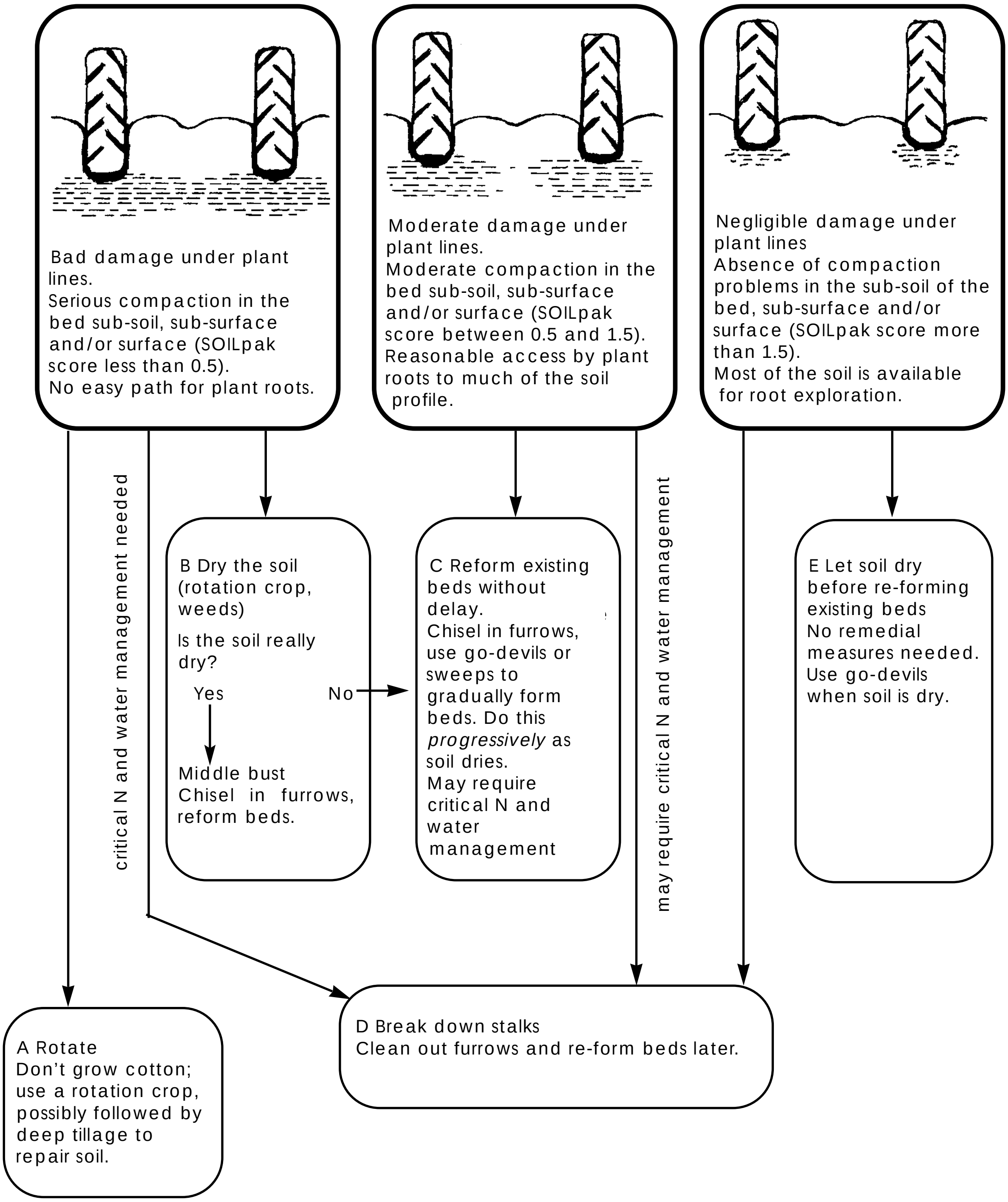
Option A. Repair damage using a full-season deep rooted dryland or irrigated rotation crop

Option A suits a field that did not yield well last season. The field may already have been compacted, and picking on wet soil has made it worse. Yield potential for the next season is not good, and it may be uneconomic to grow cotton before you fully repair existing damage. After a rotation crop has been used to dry and crack a soil, deep tillage may be necessary to further loosen it.

Option B. Quickly repair damage using a winter rotation crop

Option B attempts to repair damage quickly by drying the soil with plants (for example, using a winter cereal or legume that is killed with a herbicide before reaching maturity), but still aims to allow you to

Figure B4-1. Tillage strategies after a wet harvest



plant cotton in the coming season. If the drying is successful, this option has a good yield potential. If the drying is unsuccessful, you can fall back on an alternative strategy (option C).

Option C. Reform existing beds without delay

Option C, reforming existing beds without delay, has the disadvantage that picker wheel damage beneath the surface will not be repaired. Soil at such depth will not dry and crack before cotton planting without plant growth. Therefore, if the soil is badly damaged, yield potential is lower than for option B and management costs are likely to be greater. Choose option C if you are unsure that there is enough time for significant drying under option B.

Option D. Remove stalks and then plant

Option D involves minimal field operations and time. This is suitable for situations when the season remains wet after picking. Pull, slash and/or mulch the stalks, and clean out the furrows. Rebuild the beds after planting.

Option E. Allow soil to dry before reforming existing beds

Option E suits a field which received little damage during picking and which needs little work to be ready for replanting. However, because the soil is wet, you still need to take care. Wait as long as you can to allow the soil to dry before doing anything. The bed shoulders may need to be mechanically loosened if problems with water entry are anticipated.

FACTORS TO CONSIDER WHEN CHOOSING AN OPTION

Heliothis pupae

Heliothis armigera pupae spend the winter in the soil and emerge as moths in spring to mate and lay eggs. Control of such pupae is a vital part of pest management, particularly now that transgenic cotton varieties have been introduced. In cotton fields, pupae are likely to have a high survival rate (due to low numbers of predators and a high level of insecticide resistance). Clods that are at least 50 mm wide, and that remain after cultivation, may contain viable pupae.

These pupae must be destroyed before the end of August, by tillage to a depth of 10 cm. To be effective this operation may need to be repeated.

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See MACHINEpak for more information on what tillage equipment to use to control pupae.

Cotton stalks

Cotton stalks from the previous crop need to be slashed, pulled and/or mulched rather than being raked and burnt. This returns nutrients to the soil and boosts the reserves of soil organic matter. If fusarium wilt is present, it may be necessary to at least partially disinfect the stalks by exposing them to UV light on the soil surface—burial is likely to aggravate the problem.

Disc planters are better able to cope with cotton stalks. Boot planters may encounter difficulties if the stalk line is not removed.

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See Chapters D1, D2, E5 and MACHINEpak for more information on what equipment to use for management of cotton stalks.

Accepting yield loss and/or excessive land management costs

You may decide to grow cotton in a badly or moderately compacted field and accept penalties in yield and input costs. You will need to pay close attention to nitrogen nutrition and irrigation. Extra nitrogen fertiliser and more frequent watering will help, but will not fully compensate for poor soil structure.

Nitrogen application

The type of nitrogen-application machinery that you have will also affect your decision on a tillage option. An anhydrous ammonia shank running through the centre of a wet bed will damage the structure of soil in the planting line.

Leave the ruts

You may be concerned about the need to cultivate to remove wheel ruts, thus allowing irrigation water to run evenly down each furrow. Removing ruts is an operation that can wait—your top priority now is to choose and apply a tillage option for soil under the plant lines.

Match wheel tracks and introduce guidance systems

Matching wheel tracks helps you to avoid the compaction of a large proportion of a field. Do what you can with your existing machinery to match the working widths and re-use already-compacted furrows. Use guidance systems to steer machinery in a straight line.

FEATURES OF THE TILLAGE OPTIONS

Option A: Bad damage, repaired by a full-season dryland crop

The aim of Option A is to grow a crop such as wheat that can forage for moisture well, although irrigation may be necessary to ensure crop establishment. If the season is dry the crop can dry and crack the soil; if not, the small swelling and shrinking cycles between rainfalls can help soil structural improvement.

Conditions:

- Soil is badly compacted (serious compaction directly under the plant lines; SOILpak score less than 0.5).
- Soil is wet throughout the profile (water content greater than the ‘plastic limit’).
- You have decided not to plant cotton in this field next spring.

Procedure:

- Leave the existing beds in place.
- Sow a crop such as wheat, faba beans, field peas or safflower; and disturb the surface soil to effectively control Heliothis pupae.
- Ensure adequate soil nitrogen (if necessary apply fertiliser when the rotation crop is sown) to encourage vigorous root growth and rapid drying of the soil.
- You may need to irrigate to assist germination of the rotation crop seeds.
- Reassess soil condition as the crop dries the ground.
- Refer to Chapter B2 for information on preparing dry soil for your next cotton crop.
- If wheat is being grown and rain falls heavily before (or just after) harvest, consider growing a summer crop, e.g. a mix of forage sorghum and cowpeas, to re-dry the soil and further improve soil structure. However, in years with low water allocation it may be more profitable to conserve the moisture for the next cotton crop.

Advantages:

- Improved soil structure for the following year.
- Control of pests and weeds.

- More flexibility. You may decide not to harvest the winter crop, but to take advantage of dry soil and get on with preparing for your next cotton crop.

Cautions:

- Irrigate to achieve several extreme wetting and drying cycles, rather than aiming for high yield. Depending on the weather and availability of water, this may mean only one irrigation.
- Avoid late irrigation; allow the crop to dry and crack soil ready for the next land preparation.

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See Chapter D2 for more information on improving soil structure.

OPTION B. BAD DAMAGE, QUICKLY REPAIRED USING A WINTER ROTATION CROP

The aim of Option B is to dry the soil as much as possible (even only the top 10 cm) to repair some of the damage caused by picking, and to minimise further soil damage during seedbed preparation and pupae control.

Soil drying (to promote shrinkage cracks) and root growth (to perforate compacted soil) will, even if the soil is re-wet, bring about some repair of soil structure. A good cover of green plants can absorb light rains that would be a disaster on bare soil.

Option C is an alternative in situations where you are not convinced that there is enough time for significant drying. The yield of cotton expected for Option B is higher than for Option C because of improved soil structure through drying.

Conditions:

- The soil is badly compacted, through the beds (SOILpak score less than 0.5).
- The soil is wet.
- The time is soon after harvest.
- You are determined to grow back-to-back cotton.

Procedure:

- Leave the existing beds in place.
- Till the surface soil to control Heliothis pupae.
- Slash, pull and/or mulch the cotton stalks.
- Dry the soil by sowing winter cereals (e.g. wheat) or legumes (e.g. faba beans, field peas, vetch and sub. clover), with adequate fertiliser. When sowing, disturb the surface soil to effectively control Heliothis pupae. Weeds can also be used to dry the soil but remember that weeds can set seeds, can became large and difficult to handle and may be patchy in their distribution. If you used a rotation crop, you may decide not to harvest it.
- Reassess soil moisture as the crop dries the soil.
- If you chose this option and the soil dried out thoroughly to depth (at least as dry as the plastic limit, see Chapter C3) then consider the options outlined in Chapter B2. You have made good progress with your soil structure improvement!
- If you chose this option and the soil didn't dry out satisfactorily to depth then refer to Option C.

Advantages:

- Option B repairs some picker wheel damage.
- The soil will be drier than bare fallow if rain continues.
- Covering the surface with organic material protects it from raindrop impact.
- The use of winter legumes in rotation with back-to-back cotton, can supply large amounts of N for the following cotton crop.

Cautions:

- Remember that rain can occur at any time and may re-wet soil dried out by the crop.
- Time for significant soil drying is the deciding factor.
- Adjust nitrogen rates for the following crop if you plough in a crop or weeds; non-leguminous crops can tie-up nitrogen.
- Stubble management may be a problem.

☞ *See Chapter D2 for further information on improving soil structure.*

Option C: Reform existing beds without delay

The aim of Option C is to disturb the soil as little as possible in getting a seedbed ready for next season, and to do it as soon as possible so that the soil on the surface of the beds has time to mellow after shrinking and swelling cycles.

Do not be tempted to deep cultivate—the soil is too wet and will not benefit.

Conditions:

- The soil is moderately damaged (SOILpak score between 0.5 and 1.5) or badly damaged (SOILpak score less than 0.5).
- The soil is wet.
- The time is either soon after harvest, or close to planting time because Option B did not dry the soil satisfactorily.

Procedure:

- Leave the existing beds in place.
- Slash, pull and/or mulch the cotton stalks.
- Till the surface soil to control Heliothis pupae.
- Leave the field (for 2–3 weeks) until the soil surface is relatively dry.
- Loosen furrow bottoms (not the beds) by shallow chiselling to provide loose soil for bed building. Also loosen the bed edges with a gas knife to disrupt any compaction that is there.
- Reform beds with go-devils or sweeps. Do this progressively, as the furrows dry and the beds mulch, until a satisfactorily high bed is formed.
- When the surface is dry enough to avoid smearing, use a sled with Texas sweeps to work the top of the bed and remove any remaining stalks.

Advantages:

- Gives maximum time for damaged soil (thrown onto the beds) to mulch.

Cautions:

- Will not repair soil damage at depth. Yield potential may be limited if the damage is bad.

Option D. Remove stalks and then plant

The aim of Option D is to disturb the soil as little as possible in getting the next cotton crop planted. Choose this option when time has run out due to continuing rains, and planting on time is the most important factor. It is also an option if all is well—hills are in good shape and soil structure is suitable for unrestricted root growth (SOILpak score greater than 1.5).

Conditions:

- Any pre-existing soil structural form.

Procedure:

- Leave the existing beds in place.
- Slash/pull/mulch cotton stalks.
- Till the surface soil to control Heliothis pupae.
- Plant cotton.
- Clean out furrows and rebuild beds during crop cultivation to ensure good water flow and drainage.
- On badly damaged soil, watering intervals will need to be shorter and nitrogen rates should be higher (See Chapter B6). Do not expect crop yields and profitability to be as high as for crops grown on undamaged soil.

Advantages:

- Option D is fast and cheap. It may be the only option if rain continues.
- It leaves traffic lanes for vehicle support.
- It leaves old crack lines and root channels in place.

Cautions:

- Option D will not repair soil damage at depth. Yield potential may be limited if damage is bad.

Option E. Let the soil dry before reforming existing beds

The aim of Option E is to preserve the good soil structure by disturbing the wet soil as little as possible.

Conditions:

- Picking did no damage, or only slight damage to soil structure (SOILpak score greater than 1.5). Possibly you harvested before the rain.
- The soil is wet.
- The time is soon after harvest.

Procedure:

There is no need for remedial measures. You do not need tillage to loosen compacted soil—it is only needed for pupae control, and to assist with stalk incorporation. You do not need to reform beds from compacted soil in furrows. There is no need to allow the weather to mellow damaged soil. Wait for the soil to dry as much as possible (weeds will help, but can be a problem if they grow too large or are patchy) before reforming the beds and applying fertiliser.

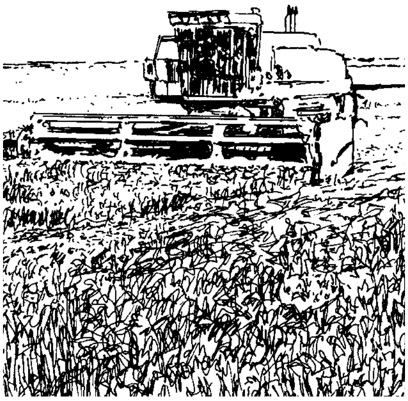
Advantages:

- Soil needs no remedial measures.

Cautions:

- Do not be tempted to spoil the good soil structure by thoughtless tillage or careless fertiliser application.

B5. Soil preparation options after a rotation crop



PURPOSE OF THIS CHAPTER

This chapter outlines factors to consider following harvest of a crop grown in rotation with cotton.

It takes into account the need to remove root growth restrictions before the next cotton crop, and to handle stubble efficiently.

CHAPTER OVERVIEW

This chapter covers the following points:

- checking compaction severity and soil moisture content
- choosing a tillage/rotation option
- stubble management.

Other chapters to refer to:

- Chapter C3: 'Soil moisture (before tillage), soil texture and available water'
- Chapter C4: 'Structural condition'
- Chapter C6: 'Stubble'
- Chapter D2: 'Improving soil structure'.

INTRODUCTION

Chapters B2 and B4 describe how rotation crops can be used to overcome compaction problems after cotton harvest. The shrink/swell cycles caused by soil water extraction and soil re-wetting loosen compacted layers.

Wheat is a popular choice. It is easy to establish and, when adequately fertilised, develops a vigorous fibrous root system that cracks the soil to a depth of about 80 cm.

Safflower is also used for ‘biological deep ripping’. It is more prone to diseases than wheat, but has taproots that penetrate to a depth of about 2 m. It extracts soil water later into the summer than wheat (if grown to maturity) and very deep shrinkage cracks may develop. An alternative to safflower is lucerne—it provides the extra benefit of adding nitrogen to the soil.

Winter legumes (e.g. faba beans, field peas, vetch and sub-clovers) provide the extra benefit of adding N to the soil, although some of their breakdown products may retard cotton growth.

Other benefits of rotation crops include:

- increase in soil organic matter content (often accompanied by a reduction in pH and sodicity)
- protection of the surface against erosion caused by raindrop impact and overland flow (cereals such as wheat provide the best cover)
- disruption of some disease cycles of cotton, e.g. wheat will decrease the incidence of seedling diseases and black root rot in subsequent cotton crops
- extraction of water and nutrients that otherwise may move below the cotton root zone.

This chapter describes the soil preparation options that are available after a rotation crop has been grown.

SOIL ASSESSMENT

If the soil was sampled before sowing of the rotation crop (as described in Chapters B2 and B4), return to the best and worst yielding points and dig an inspection hole. Re-assess soil structural condition, with emphasis on the zone directly below the old cotton plant lines next to and away from the main wheel tracks.

Determine the moisture status and SOILpak score for the topsoil (0–10 cm), sub-surface (10–30 cm) and subsoil (30–100 cm). Enter the results onto the ‘post-harvest’ description sheet.

If the site has not been assessed previously, follow the rest of the soil assessment procedure described in Chapter B2.

STUBBLE MANAGEMENT

Always attempt to maximise the amount of organic mulch on the soil surface, particularly on the siltier soils. Maximise the amount that is anchored to the soil. Herbicide options are reduced where stubble is retained, due to difficulties with the incorporation of products such as Treflan®. However, knockdown sprays such as Roundup® effectively control weeds in most situations. Weed control in cotton under a mulch will become easier when herbicide-resistant transgenic cotton cultivars become available.

The stubble can, however, cause problems by blocking tillage implements, unless the trash passing through harvesting equipment is chopped finely and spread evenly behind the combine harvester. Stubble burning should only occur as a last resort.

TILLAGE OPTIONS

The following four tillage options should be considered.

Option 1. Deep tillage, reforming of beds after thorough drying of the soil

Full land preparation (chisel ploughing and discing the old hills, and forming new ones) gives you the opportunity to 'tidy up' a field. Hollows can be removed, crooked rows straightened and guess row spacing adjusted. Weed problems, e.g. with nutgrass, can be eased by the mechanical disturbance, provided that the soil is dry enough to shatter.

If the soil structure under the proposed plant lines of the next cotton crop is poor (SOILpak score less than 0.5), consider deep tillage. Where the soil has moderate compaction damage (SOILpak score between 0.5 and 1.5), but does not have good shrink-swell potential (CEC less than 40), deep tillage is also likely to be beneficial. The soil profile may not be at a uniform moisture content. In situations where the rotation crop was unable to penetrate and dry the soil deeply, it may be possible to till the upper, dry part of a compacted layer and leave the deeper, moist soil untouched (and unsmeared).

Alternatively, if the soil was dried thoroughly by the rotation crop, but remained compacted and the surface was re-wet by rain, deep tillage can be carried out successfully if the ripping tines extend into the dry soil.

☞ *For further information about improvement of soil structure, see Chapter D2.*

If the rainfall is very great, however, and the whole profile is rewet, a follow-up summer rotation crop (e.g. a mixture of forage sorghum and cowpeas) may be required to re-dry the soil. This option will be particularly attractive if the soil compaction problem was aggravated by harvesting of the winter rotation crop using headers with wheel configurations that were incompatible with the cotton farming wheel tracks.

If a sodicity problem is identified, gypsum and/or lime may have to be applied. Where the subsoil only is sodic, any deep tillage should loosen but not invert the soil profile.

Option 2. 'Permanent beds– controlled traffic' with 'middle-busting'

If moderate damage to soil structure is detected in the top 30 cm of soil under the plant lines (SOILpak score in the range 0.5 to 1.5), and the soil is drier than the plastic limit, you may be able to loosen it by 'middle-busting' without completely destroying the beds.

Lightly chisel the furrow bottoms to create loose soil for reforming existing beds, and use gas knives to break up any serious bed-shoulder compaction. Reform the beds with soil from the furrows, using go-devils or sweeps.

Advantages:

- Furrows are always present for drainage in the event of heavy rain.

- Option 2 leaves traffic lanes for vehicle support.

Option 3. Permanent beds with controlled traffic and minimum tillage

If the soil structure under the plant lines is undamaged (SOILpak score greater than 1.5) keep it that way by minimising soil disturbance below a depth of 10 cm. Consider zonal tillage along the plant lines. Another option is to plant cotton between the rotation crop rows.

Lightly chisel the furrow bottoms to create loose soil for reforming existing beds, and use gas knives to break up any serious bed-shoulder compaction. Reform the beds with soil from the furrows, using go-devils or sweeps.

Advantages:

- Option 3 is fast and cheap.
- It maintains soil structure and soil organic matter.
- Furrows are always present for drainage in the event of heavy rain.
- Option 3 leaves traffic lanes for vehicle support.

Option 4. Permanent beds with controlled traffic, minimum tillage and special nutrition and/or water management

Alternatively, the procedures outlined in Option 3 may be used where there is moderate compaction under the plant lines (SOILpak score 0.5 to 1.5) following rotation, but the soil could not be kept dry. However, critical management (extra N and more-frequent irrigation) will be needed.

SPECIAL NOTES FOR COTTON PRODUCERS WITH COMPACTED NON-SWELLING SOIL

- Shrink/swell manipulation is not a strongly effective option, unless subsoil clay is brought to the surface.
- Chiselling usually is the only repair option (carried out at a water content near the ‘plastic limit’), followed by biopore encouragement. Biopores can be created by the action of rotation crop roots, earthworms and ants.

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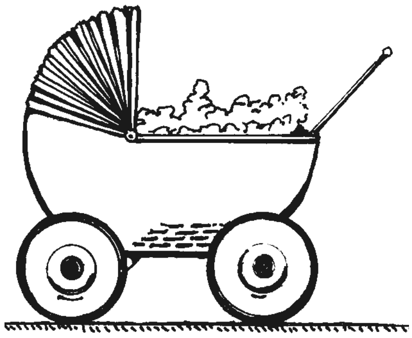
See Chapter D9 for more information on red soil management.

B6. Nursing a cotton crop in a damaged soil



PURPOSE OF THIS CHAPTER

This chapter explains how you can modify agronomic practices so that a cotton crop can grow better in a compacted soil.

This approach deals with symptoms rather than the actual problem and is not recommended as a long-term strategy.

Nevertheless, it may be necessary in situations where rain continues for several months after a wet harvest. It also is needed where cotton was harvested on dry soil, but subsequent heavy rain led to soil compaction problems whilst preparing for and planting the following cotton crop.

CHAPTER OVERVIEW

This chapter covers the following points:

- determining the severity of the problem before growing cotton
- changes to irrigation scheduling
- changes to nutrient needs
- structural improvement due to growth of the cotton (drying-wetting cycles).

Other chapters to refer to:

- Chapter B7: ‘Applying nutrients to the soil’
- Chapter C4: ‘Structural condition’.

INTRODUCTION

This chapter assumes that the crop will be planted into a compacted soil and that, because of soil moisture levels, tillage was not possible without causing further damage. Lack of time prevents the use of rotation crops to improve soil structure.

DEFINE THE PROBLEM

Defining the problem is an important step in managing your crop. Without a knowledge of the severity of soil compaction, you cannot make the best decisions for the crop. Look for clues and examine the soil following the previous harvest to assess severity of the problem.

Go to the best yielding, average and worst yielding points within at least one representative field as soon as possible after picking. Dig one inspection hole (preferably two or three) at each of these points and assess soil structural condition, with emphasis on the zone directly below the plant lines next to and away from the main wheel tracks.

Determine the SOILpak score for the topsoil (0–10 cm), sub-surface (10–30 cm) and subsoil (30–100 cm). Enter the results onto the ‘post-harvest’ description sheet.

If the site has not been assessed previously, measure soil stability in water (ASWAT test). It is also advisable to collect soil samples from the SOILpak/ASWAT scoring sites and have them analysed in a laboratory for gypsum/lime requirement. Soil salinity should also be assessed by measuring soil electrical conductivity.

Apart from clues such as deep ruts remaining after the last cotton harvest, also use clues such as during-season plant symptoms and moisture probe data to point to areas that caused problems before harvest. Problems identified during post-harvest inspection may have occurred during the wet harvest; others may have been there longer.

☞ *See Chapter C4 for more information on soil structural assessment*

As the severity of compaction increases, more care is needed to produce a crop. One of the problems with compaction is that the ability to supply adequate amounts of water and nutrients is restricted.

In a severely compacted soil (SOILpak score less than 0.5), the crop will have limitations which are impossible to overcome completely. However, careful attention to nitrogen and water will minimise plant stress and associated yield loss. Land management costs will be greater than for well-structured soil (SOILpak score more than 1.5) when this approach is used.

BEFORE PLANTING ON A COMPACTED SOIL

Do everything you can to improve soil conditions to ensure that the crop gets off to a good start.

Due to the increased chance of waterlogging in a compacted soil it is preferable before planting to pull up as high a bed as possible to allow good surface drainage. Well-formed furrows will also help drainage.

Pre-water beds and allow the soil to warm up before planting. Watering up after planting chills the soil and increases the risk of seedling disease.

Avoid using moisture-seekers if possible when sowing as they will flatten the beds—this will increase the chance of waterlogging.

COTTON VARIETIES

Unfortunately there is little difference between cotton varieties at

this stage with regard to seedling disease. The effects of waterlogging and compaction may make the plant more susceptible to bacterial blight. Avoid blight susceptible varieties if possible.

Different varieties show no difference in water extraction in a compacted soil. This situation may change in the future if new transgenic cotton varieties are introduced with waterlogging tolerance.

IRRIGATION

The major effect of compaction is to limit the growth of plant roots. Due to lack of oxygen and mechanical impedance, the plant is forced to survive with its roots confined to a smaller volume of soil. This volume has less available water for the plant, so water must be added more frequently.

Be aware that the presence of soil moisture at depth may not give you a good indication of the need to irrigate. The potential store of water at depth may be blocked from the plants by the compacted layer.

Increase irrigation frequency for a crop on compacted soil and closely monitor water use (for example, with a neutron probe) and stress levels. A crop on a compacted soil will become stressed (reach the refill point) much more rapidly than one on a well structured soil. Moisture stress causes the plants to lose fruit.

Table B6-1 outlines some examples of how compaction can affect irrigation intervals and daily water use of a crop.

Although you may need to increase the frequency of watering, be very cautious not to waterlog the soil by irrigating for longer than is absolutely necessary. Excessive water application will only compound the problem of waterlogging caused by compaction.

Plants will eventually penetrate the compacted zone. Daily water use and available water may increase through the season as the plants gain access to previously unavailable water.

There would be no advantage in purposely under-watering cotton to force soil drying, as the sacrifice in yield would be too great to justify.

CHANGES IN CROP NUTRIENT REQUIREMENTS

Root entry to compacted regions of the soil is limited; so the plants have difficulty extracting nitrogen, other nutrients (particularly potassium) and water from these regions. If roots cannot penetrate the degraded layers, nutrients deeper in the soil will also be unavailable to the plants.

Because of the increased chance of waterlogging in a compacted soil, the risk of nitrogen loss by denitrification is greater.

The low availability of nitrogen in compacted soil can be overcome to some extent by increasing the rates of nitrogen applied by about 10% above the usual rate for moderately compacted soil (SOILpak score in the range of 0.5 to 1.5) and by about 20% for badly compacted soil (SOILpak score less than 0.5). If too much N is applied, the cotton growth regulator Pix™ can be used to prevent rank growth.

Foliar application of nitrogen before irrigations can help to overcome the symptoms of waterlogging, but do not expect it to overcome all compaction problems. Cloudy and cold weather will make foliar applications less effective.

Table B6-1. Examples of daily water use and irrigation interval for soil with contrasting compaction severity during the period of peak water use
For more details about this topic, see Chapter C9.

	Daily water use (mm/day)	**Available water (mm)**	**Irrigation interval (days)**	**Notes**
Well structured soil	7	90	13	Plant internodes gradually shorten from 7 cm maximum as refill point is reached.
Moderately compacted	5–6	76	13–15	
Severely compacted	5	40–65	8–13	Plant internodes rapidly shorten from 5 cm as refill point is reached.

WHAT GROWING A CROP CAN ACHIEVE

Growing a cotton crop on a compacted soil can start to improve soil structure as the soil goes through wetting and drying cycles between irrigations.

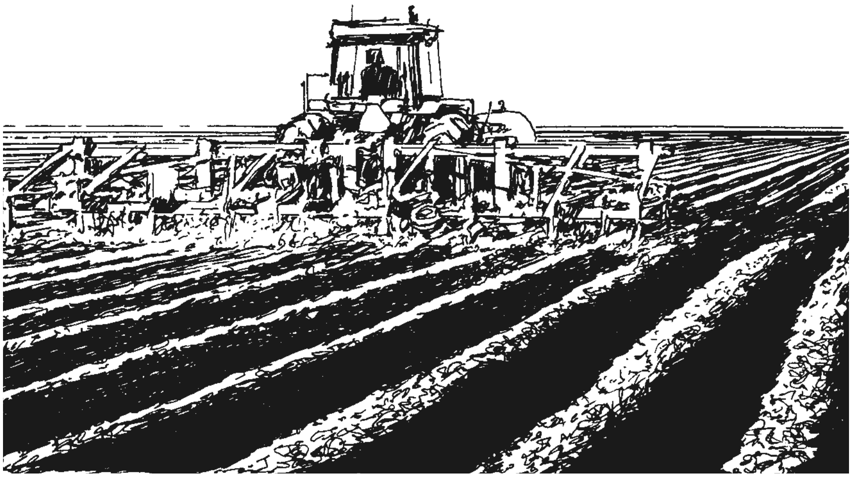
Advantages:

- Growing any sort of crop will assist in repairing soil structure for the next season.
- When cotton prices are high, cotton is more profitable than other crops, even with reduced yield and higher costs, on compacted soil.

Cautions:

- The inevitable penalty in yield for crops grown on compacted soils.
- Critical management is needed to obtain yields approaching (but not equalling) a crop on a well structured soil. Input costs are greater than for well-structured soil.

B7. Applying nutrients to the soil



PURPOSE OF THIS CHAPTER

This chapter discusses nutrient application in relation to soil structure management.

It should be read in conjunction with NUTRIpak, which gives details about how to determine the amount and form of nitrogen (N), potassium (K), phosphorus (P) and zinc (Zn) to apply to cotton and its rotation crops.

Nutrient inputs to the cotton farming system need to be matched with nutrient outputs, and nutrient losses to the atmosphere or into groundwater should be negligible.

CHAPTER OVERVIEW

This chapter covers the following points:

- selection of the best place to apply nutrients so that plant roots can extract them (based upon a knowledge of the structure and water content of the soil profile)
- the relationship between crop striping and soil compaction
- procedures to minimise structural damage when applying fertiliser to the soil.

Other chapters to refer to:

- Chapter B6: 'Nursing a cotton crop in a damaged soil'
- Chapter D3: 'Managing nutrients'.

WHERE TO APPLY NITROGEN

Before adding nitrogen to a compacted soil, first decide on the best place to apply it.

Observe where the soil is least compacted—this will be the zone which the roots can penetrate most easily. The centre of the bed is usually more accessible to roots than compacted furrows, which is the worst zone for placement of fertiliser.

Although an anhydrous ammonia shank will break up some of the compaction in furrows, roots will not easily grow into the fertiliser band because of rapid recompaction of the furrows by subsequent field operations.

If applying nitrogen near a compacted zone, keep the application relatively shallow. 'Cold-flow' anhydrous ammonia or solid fertilisers may help here.

N fertiliser placed in compact, waterlogged layers of soil may denitrify and be lost to the atmosphere as nitrous oxide gas.

If the soil is excessively cloddy, anhydrous ammonia may be lost directly to the atmosphere.

CROP STRIPING

When yellow striping (some rows of cotton more yellow than others) is evident, determine the cause. Is it from malfunctioning nitrogen application equipment or from compaction in some of the furrows and adjacent hills?

Adding extra nitrogen to the problem areas will help to alleviate the problem in both cases. However, if striping is apparent it already is too late to prevent all of the yield loss.

APPLYING FERTILISER WITHOUT DAMAGING SOIL STRUCTURE

Observe soil moisture. If the soil is wet, it may be better to apply fertiliser to the sides of the beds rather than smearing and compacting soil beneath the plant line with tines.

Fertiliser application to the sides of beds may cause smearing if the soil is wet, but the damage is away from the main lines of root growth. Also, it will be shallow enough to be quickly disrupted by shrink-swell cycles.

Dissolving nutrients in the irrigation water is a less-damaging way of transporting them to the root zone. Electrolyte concentration of the soil solution is increased by this option, which will reduce the risk of clay dispersion. Water-run urea can be applied well after the planting of a cotton crop.

There is uncertainty about the effects of anhydrous ammonia on soil structure. Ammonium ions do not persist for long in the soil before being converted to nitrate. However, while present they act in a similar fashion to exchangeable sodium ions and may make the soil more dispersive. The increase in pH that occurs when anhydrous ammonia is added also will make the clay particles more prone to dispersion (see Chapter E3 for an explanation). Further research is needed on this topic.

If the pH should be lowered, ammonium sulfate should be considered. It is a more expensive source of N than anhydrous ammonia or urea, but it is a useful option in situations where high pH appears to be destabilising the clay particles and inducing trace element deficiencies.

B8. Managing variable fields

PURPOSE OF THIS CHAPTER

All cotton farmers are aware of variations in soil condition and crop performance in at least some of their cotton fields.

This chapter provides some general guidelines about the management of obvious sources of soil-related crop variation. It also previews yield mapping technology, outlines how to sample the soil after studying a yield map, and describes how remote sensing data (for example, airborne thermal infra-red scanning) can assist.

CHAPTER OVERVIEW

This chapter covers the following points:

- sources of soil-related variation within fields
- production of within-field yield maps
- interpreting yield maps
- use of remote sensing data.

Other chapters to refer to:

- Chapter C4: ‘Structural condition’.

SOURCES OF SOIL-RELATED VARIATION WITHIN COTTON FIELDS

Variations in crop performance within a field may be due to any one (or combination) of a large number of inter-related factors.

These include:

- different insect and disease pressures
- passage of narrow, intense rain and hail storms
- differences in field slope
- presence of gilgais
- management variations (for example, contrasting periods of inundation by flood irrigation water between one end of a field and another)
- machinery malfunction (for example, uneven anhydrous ammonia application)
- contrasting soil physical and chemical properties.

Soil factors responsible for crop variations include:

- degree of compaction by farm machinery (due, for example, to heavy rain on a field part-way through a harvesting or landforming operation)
- soil stability in water (related to sodicity, electrical conductivity, pH, organic matter, clay mineral type and water content)
- soil texture (which influences infiltration rate, water-holding capacity and ability to shrink and swell)
- salinity
- pH
- nutrient reserves.

PRODUCTION OF WITHIN-FIELD YIELD MAPS

Widespread introduction (hopefully by the 1999 harvest) of cotton yield monitors on pickers will allow farm managers to more easily identify poor yielding areas within fields. Soil sampling in the low- and high-yielding sections of a field will allow the design of much more precise soil management programs.

Until yield monitors are fully developed, yield variations can be mapped by hand-picking small sub-sections of fields. Another approach is to map the average yield of large sub-sections of fields by weighing each module that leaves a field.

Aerial photographs, satellite imagery and airborne video scans of crops and bare soil can help to show the location of problem areas.

Even just a walk through a cotton crop will provide a rough indication of the best and worst performing sections of a field.

Because the effect of soil properties on crop growth usually is strongly influenced by temperature and rainfall, yield monitoring needs to be repeated over several contrasting growing seasons.

INTERPRETING YIELD MAPS

Much can be learnt, even from the most basic of yield maps, by assessing soil condition at the best, worst and average points within a field. If the field contains obviously different soil units—for example, a mosaic of red and grey soil—the best average and worst yielding

areas within each of these two soil groups should have their soil tested.

The ‘post-harvest’ soil description sheet should be filled out for each of these locations after digging inspection pits soon after harvest. The results can then be compared with the critical values presented in Chapter A2.

Soil compaction variations under the plant lines are becoming less of a problem due to the successful introduction of controlled traffic farming by most cotton growers. Yield limitations now are more likely to be due to soil instability in water, poor nutrition and/or inadequate field slope and bed height.

If a strong relationship is evident between the measured soil properties and cotton lint yield, these soil properties should then be mapped. The subsequent soil factor maps form the basis of soil management programs. For example, a soil stability map will indicate where gypsum or gypsum–lime mixes should be applied to the soil and at what rates. Remote sensing data may help to improve the accuracy of these soil factor maps (see the following section, `Use of remote sensing data’).

Yield maps are also useful for ensuring that access tubes for soil moisture monitoring are located in representative positions within a field.

USE OF REMOTE SENSING DATA

Patterns of variation of soil properties

Where there is a strong relationship between key soil factors and patterns seen in aerial photographs or videos, accurate maps can be produced of that soil factor.

For example, on a field near Warren it was shown that airborne thermal infra-red scanning (which measures surface soil temperature) related strongly to surface soil sodicity. The sodic soil was more poorly drained, and therefore cooler, than nearby well-structured soil. This relationship allowed surface soil sodicity to be mapped (with a resolution of 4 m x 4 m), and the soil requiring gypsum application was drawn onto a map of the field.

It is possible to connect the gypsum spreader to a Global Positioning System (GPS), and an on-board computer containing the sodicity map, and spread gypsum semi-automatically exactly where it is needed (ASWAT score greater than 6) and at the appropriate rate.

However, this relationship between remote sensing pattern and soil stability in water cannot be transferred directly to other fields because of differences in other factors influencing crop yield, for example field slope, nutrient reserves.

Problems such as inadequate field slope, caused for example by the reforming of gilgais, are not fixed as easily and cheaply. Field re-levelling may be required.

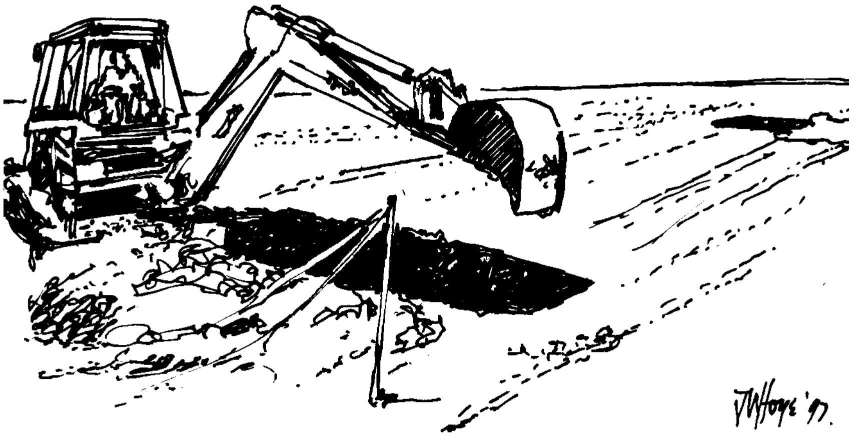
Patterns of variation of crop performance and lint yield

Airborne thermal infra-red scanning is being used commercially to indicate the relative performance of cotton within sub-sections of fields throughout the growing season. This procedure is based on the assumption that cotton with a high canopy temperature is under more stress (and therefore likely to have poorer lint yield) than cotton with a lower canopy temperature.

On a broader scale, ‘Landsat’ satellite imagery is being used commercially to give an approximate prediction of lint yield both between and within cotton fields.

Ideally, the remote sensing information described here should be used in conjunction with yield maps so that the reasons for variations in crop growth can be determined systematically. A Geographic Information System (GIS) on an office computer should be used to store the information.

B9. Soil survey for development or redevelopment



PURPOSE OF THIS CHAPTER

When planning a new cotton development, each management unit should have soil condition and slope as uniform as possible. To achieve this aim, the soil should be mapped before any irrigation design work is carried out.

In fields already under cotton, variability problems may be so severe that the field must be redeveloped. Again, soil surveys should be made before redesigning.

This chapter outlines how to carry out such surveys.

CHAPTER OVERVIEW

This chapter covers the following points:

- soil survey before new development for irrigated cotton
- soil survey before redevelopment of irrigated cotton fields
- 'available soil water' maps for drip irrigation design
- soil survey requirements for dryland cotton.

Other chapters to refer to:

- Chapter C3: 'Soil moisture (before tillage), soil texture and available water'
- Chapter C4: 'Structural condition'
- Chapter C7: 'Salinity'
- Chapter C8: 'Other tests'.

INTRODUCTION

When soil properties within a field are variable, it usually is impossible to deliver the required inputs to all sub-sections simultaneously when flood irrigation is used. Some parts of variable fields, therefore, will have lint yields that are lower than the field's potential, and product quality for the whole field will not be uniform.

In practice, it is unlikely to ever be economically feasible to completely remove across-field soil variability. However, if good quality soil survey information is available, the variation within each management unit can be minimised in a cost-effective fashion.

In locations where soil variability is considered excessive for all possible furrow irrigation layout designs, the feasibility of drip irrigation should be considered. Drip irrigation allows the required amounts of water to be added to sub-sections of a field when necessary, with minimal risk of losing water by deep drainage. Drip systems are much more expensive to develop than furrow irrigated fields, but deserve consideration in areas that have adequate water supplies and a suitable climate for cotton, but contain complex mosaics of soil with contrasting hydrological properties.

SOIL SURVEY BEFORE A NEW DEVELOPMENT FOR IRRIGATED COTTON

Money spent on a soil survey before development usually is repaid several times over because of the potential management problems that it highlights.

Soil survey information provides a benchmark that can be used to check progress with soil quality management as the cotton farming project proceeds.

In the Riverland district of South Australia, the Loxton Research Centre's 'Irrigated Crop Management Service' carries out soil surveys for landholders before land development for irrigated horticulture. This involves digging backhoe pits on a grid over a property at a spacing which varies from 50 m to 100 m.

The same procedure is recommended before land development for irrigated cotton, even though its value of production per hectare usually is less than for horticulture.

The best grid spacing to use for irrigated cotton developments is uncertain. However, as a first approximation a spacing of 100 m is recommended for land that obviously contains soil variation (for example, a mosaic of red and grey soil). For land with less-obvious variation, a spacing of 150 m is suggested. Further research is required to fine-tune these recommendations.

Using the 'SOILpak soil description sheet for cotton field development', assess the following features in the topsoil (0–10 cm), sub-surface (10–30 cm) and subsoil (30–100 cm):

- soil texture
- available water
- suitability of soil moisture for landforming
- aggregate stability in water
- natural regeneration potential
- salinity
- pH.

☞

See Chapters C3 and C4 for more information on soil assessment.

These soil factors should be mapped. Geographic Information Systems (GISs) are available for office computers—they allow the different layers of soil information for a field to be stored in an orderly fashion. Each of the soil factor maps can be converted to cost of repair maps.

Once all of the soil factors have been mapped in terms of the same unit ($/ha), they can be overlaid and added up to provide a ‘total cost of soil improvement’ map. Such a map will make the job of selecting suitable land for cotton development much more systematic, without making the process too complicated. The maps also allow soil with similar, difficult-to-modify, properties (for example; water holding capacity, shrink/swell potential) to be included within the same management units.

After design of the irrigation layout:

- landform each of the new fields (when dry if possible); try to avoid deep cuts into sodic subsoil
- create hills and/or beds; consider the use of guidance systems to make them very straight
- refer to Chapter B10 for suggestions about how to treat the soil before the first cotton crop is planted.

SOIL SURVEY BEFORE REDEVELOPMENT OF IRRIGATED COTTON FIELDS

Cotton fields are re-developed for a number of reasons, which include:

- subsided areas with poor surface drainage
- impractical field size or shape
- impractical mosaic of contrasting soil types
- inability to shed storm water in a controlled fashion.

Redevelopment provides an opportunity to properly assess, and if possible correct, soil problems that have been reducing farm profitability. It also allows soil with similar, difficult-to-modify properties (for example, water holding capacity) to be included within the same management units.

The procedures described above for ‘new cotton developments’ should be followed. The best grid spacing to use is uncertain. However, as a first approximation a spacing of 100 m is recommended for land that obviously contains soil variation (for example, a mosaic of red and grey soil). For land with less-obvious variation, a spacing of 150 m is suggested. Further research is required to fine-tune these recommendations.

Using the ‘SOILpak soil description sheet for new cotton developments’, assess the following features in the topsoil (0–10 cm), sub-surface (10–30 cm) and subsoil (30–100 cm):

- soil texture
- available water
- suitability of soil moisture for landforming
- aggregate stability in water
- natural regeneration potential

☞

See Chapters C3 and C4 for more information on soil assessment

- salinity
- pH.

These soil factors should be mapped. Geographic Information Systems (GISs) are available for office computers—they allow the different layers of soil information for a field to be stored in an orderly fashion. Each of the soil factor maps can be converted to cost of repair maps.

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After design of the irrigation layout:

- landform each of the new fields (when dry if possible); try to avoid deep cuts into sodic subsoil
- create hills and/or beds; and consider the use of guidance systems to make them very straight
- refer to Chapter B10 for suggestions about how to treat the soil before the first cotton crop.

'AVAILABLE SOIL WATER' MAPS FOR DRIP IRRIGATION DESIGN

Where it is impossible to devise management units that are large enough for furrow irrigated cotton—due to mosaics of soil with contrasting texture, infiltration characteristics and water holding capacity—consider the feasibility of installing drip irrigation.

Using 'plant available water capacity' (PAWC) maps, relatively-uniform drip irrigation management zones can be defined which receive neither too much nor too little water. This approach is used widely by the Australian wine industry to ensure that scarce water resources are used efficiently in vineyards with variable soil types.

SOIL SURVEY REQUIREMENTS FOR DRYLAND COTTON

Dryland cotton growers have fewer management options than irrigators when dealing with problem soil; their financial returns are lower.

Nevertheless, they should have a detailed knowledge of the soil on their farms. Degree of compaction at planting time, and soil water holding capacity, are particularly important.

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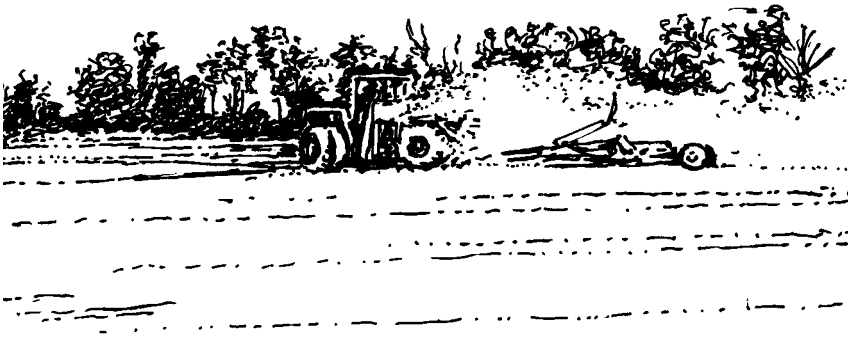
See Chapter D10 for more information on soil management for dryland cotton.

B10. Soil preparation after landforming



PURPOSE OF THIS CHAPTER

The aim of this chapter is to describe site assessment procedures that can be used after land development, and to outline the options that are available to deal with any problems that are identified.

CHAPTER OVERVIEW

This chapter covers the following points:

- soil management problems caused by land development
- available soil management options.

Other chapters to refer to:

- Chapter C3: 'Soil moisture (before tillage), soil texture and available water'
- Chapter C4: 'Structural condition'
- Chapter C8: 'Other tests'
- Chapter D2: 'Improving soil structure'.

INTRODUCTION

Landforming of cotton fields often creates soil problems that should be dealt with before cotton is grown. Issues include exposure and spreading of unstable subsoil, compaction, creation of abrupt texture-contrast boundaries and excessive dust production. These problems should be overcome before planting the next cotton crop.

Other soil problems (such as sodicity) that may have been identified during the pre-development soil survey can also be dealt with.

SOIL MANAGEMENT PROBLEMS THAT MAY OCCUR DURING AND AFTER LAND DEVELOPMENT

Exposure of unstable subsoil

Subsoil exposure usually is unavoidable because of the need to provide an even slope in irrigated fields. Even drip irrigated fields have to be landformed because of the need to quickly dispose of runoff water after heavy rain.

At best, the exposed subsoil will have inadequate organic matter. At worst, it will be sodic, depleted of mycorrhiza, have a high pH and perhaps be saline.

Where sodic subsoil is exposed, the scraped material also has poor physical properties. It may be spread thinly over low lying areas which previously had a favourable soil structure. Therefore it is desirable to stockpile the original topsoil, landform the subsoil, then replace the topsoil.

If stockpiling and replacement of the topsoil is not possible, the exposed sodic soil will have to be reclaimed by the use of gypsum, and perhaps by the growth of a well-fertilised barley crop. Zinc fertiliser may need to be added.

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See Chapter D2 for more information on improvement of sodic soil.

Compaction

Due to the tight schedules of landforming contractors, it is difficult to reshape fields at exactly the correct soil water content, particularly when there is a mix of grey and red soil. Nevertheless, a well-fertilised crop such as wheat should be grown just before landforming to maximise the chances of the soil being drier than the plastic limit (PL).

If, however, there is heavy rain before landforming and the contractors cannot be delayed, deep compaction may occur. In this situation, the soil needs to be carefully re-assessed.

Create beds and/or hills using a listing rig, preferably with a guidance system that ensures very straight furrows. Dig inspection pits close to at least three of the pre-development assessment sites, and use the soil inspection and interpretation procedures outlined in Part C. Fill out a ‘SOILpak soil description sheet for after landforming’ (see Chapter C2).

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See Chapters B4 and D2 for more information on overcoming soil compaction problems.

Creation of abrupt texture-contrast boundaries

Placement of scraped clay-rich subsoil over loamy topsoil may create a texture-contrast boundary that forms a perched water table. This may restrict cotton root growth due to waterlogging. Similar problems may arise when the buried topsoil has a thick layer of organic material that forms a wedge under the fill soil.

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See Chapter D9 for more information on red soil management.

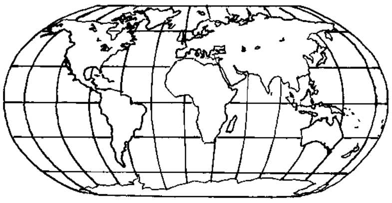
Once recognised, however, these impeding layers can be easily disrupted by deep tillage.

Excessive dust production

Silty soil is particularly difficult to landform because it compacts when it is wetter than the PL, but is reduced to fine dust when over-worked under dry conditions.

Generally the only option is to tolerate the dust problem until landforming has been completed, then take steps to improve soil structure as soon as possible afterwards. A cereal or forage crop should be grown promptly to protect the soil from wind erosion, boost soil organic matter content (to assist with re-aggregation of the surface soil) and permeate the potentially-hardsetting soil with stabilised root channels.

B11. Cotton soil management and the environment



PURPOSE OF THIS CHAPTER

Some cotton growers are gaining 'environmental accreditation' (for example, ISO 14000) for their farms. Such schemes commit participating growers to an ongoing improvement (or at least avoidance of a decline) in key environmental indicators (for example, soil fertility).

This chapter outlines the main soil related environmental issues that are relevant to cotton growers, and provides options for overcoming possible problems.

CHAPTER OVERVIEW

The following points are considered:

- soil and nutrient loss through water and wind erosion
- rising water tables and salinity
- greenhouse gas emissions
- pesticide and fertiliser residues.

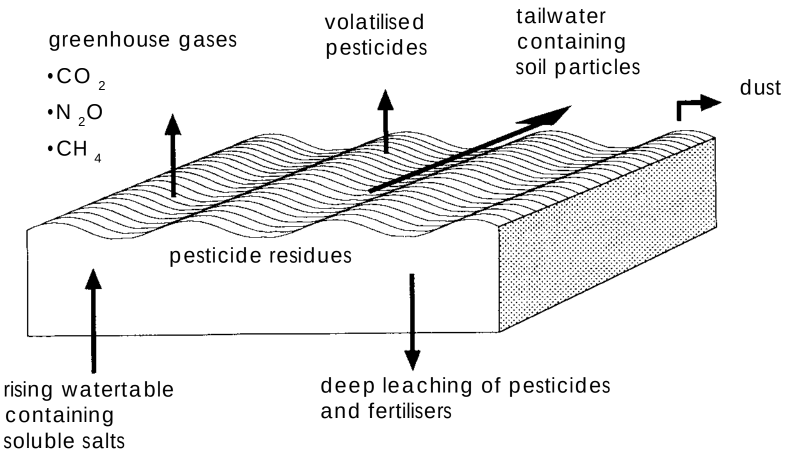
Other chapters to refer to:

- Chapter E3: 'Effects of sodicity and salinity on soil structure'
- Chapter E5: 'Organic matter and soil biota'
- Chapter E7: 'Water movement'.

INTRODUCTION

The Australian cotton industry is a pioneer amongst agricultural groups in Australia because of its attempts to define and minimise the adverse effects of its activities on our environment. The possible side-effects of insecticides have received detailed attention. However, there are several other issues, mainly associated with soil management, that deserve more consideration. Figure B11-1 summarises these issues.

Figure B11-1: Environmental issues that may be associated with soil management for cotton production



Whilst the exact impact of these problems remains unclear until further research is carried out, cotton growers can minimise them by making some simple and inexpensive modifications to their management procedures. This proactive approach should reduce the possibility of restrictive and expensive environmental legislation being imposed by government agencies. It is better to continue to responsibly address environmental issues as an industry, rather than being seen to be responding to pressure.

WATER AND WIND EROSION

Water erosion can move fertile topsoil, pesticides and dissolved nutrients. Most cotton farms now have tail water re-circulation systems, reducing losses off the farm. However, topsoil and nutrients may move to areas of the farm that are inaccessible to the growing crop—for example, the bottom of drainage ditches or storage dams.

The loss of topsoil and nutrients is likely to increase the need for fertiliser, and the regular excavation of drainage ditches is expensive. Eroded soil may carry adsorbed pesticides such as endosulfan. Also, increased concentrations of fine sand and silt in the furrows can reduce the soil infiltration rate.

Erosion usually occurs during heavy rain, although high-flow flood irrigation systems produce a similar effect.

Two metre wide raised beds are less prone to waterlogging than hills spaced 1 m apart; and this reduces the need for fast watering. Slowing the flow of water down the furrows will reduce soil erosion.

Organic mulches left on top of the beds, and on their steep sides will protect them from the erosive effects of raindrop impact during intense storms. Anchored straw is more useful than loose residue.

Wind erosion generally is a less serious problem than water erosion. However, dust blown from cotton fields may contain pesticide residues. Organic mulches will help to protect the soil surface from wind erosion within cotton fields, but pesticide drift onto dusty roads should be minimised.

RISING WATER TABLES AND SALINITY

Salinity is adversely affecting some small areas of cotton on silty soil in the Macquarie Valley. In most Australian soil types used for cotton, water movement beyond the root zone is considered by most authorities to have been negligible. However, on certain soil types deep drainage does add to the groundwater. The amount of pore space in the deep subsoil is very small, so 10 mm of water, for example, could raise the water table by as much as 300 mm.

As salt concentration in the subsoil increases, its ability to transmit water also increases (even in the heaviest clay soils). Therefore, all cotton soils can become leaky. Irrigation water contains dissolved salts that may accumulate over time.

Because the deep subsoil often has large amounts of sodium salts, it is crucial that the water table is never allowed to get within 2 m of the soil surface. Salinity is expensive to correct and it is difficult to dispose of saline drainage water.

To prevent the development of salinity in sensitive areas, the following management procedures are available:

- schedule irrigations to avoid over-watering
- monitor water movement to detect and then seal leaks in the system—for example from supply channels
- locate above-ground storages on the least-permeable parts of a farm
- grow vigorous rotation crops rather than leave fields in bare fallow
- plant trees and/or saltbush and lucerne to extract excess water.

Tree planting

Woodlots can occupy spare land, or trees can line fields provided there is no danger to aerial spraying operators. River red gum (*Eucalyptus camaldulensis*) is a suitable species. It is moderately tolerant of salinity and its roots can penetrate up to 10 m deep. It tolerates herbicide spray drift; but it requires good weed control over the first two years, and nitrogen fertiliser (70 kg/ha).

Inter-planting river red gum with saltbush (*Atriplex* species) or lucerne can increase water use. An established woodlot can remove 20–25 ML of water per hectare per year. Woodlots look good, reduce spray drift, absorb carbon dioxide, encourage wildlife, and provide timber for various uses.

A possible problem, however, is that the soluble salts in the groundwater may accumulate around the roots of trees and shrubs and adversely affect their growth. If this occurs, parts of the root zone should (if possible) be flushed with fresh water to translocate the harmful salts to other parts of the soil profile, or into drains and evaporation basins.

Alley cropping

In areas where lateral flow of near-surface groundwater is poor, the strips of vegetation for water table control need to be close together (about 70 m apart).

This form of farming is referred to as 'alley cropping'. It is becoming popular in parts of Western Australia. Optimal strip width and spacing for cotton soil needs to be determined by further research.

Lucerne strips for deep drainage control can also assist with insect management in cotton.

Deep-rooted winter rotation crops

Another option is to use a deep-rooted, well-fertilised rotation crop such as lucerne or safflower to dry all of the soil in a field to a depth of about 2 m. Because a flood irrigation usually will not wet the soil below a depth of about 0.8 m (at least for a few weeks after watering), the dry soil at 1–2 m depth acts as a buffer and absorbs any water leaking below the depth of rooting of cotton. Deep rooted rotation crops also help to overcome soil compaction problems—they create large cracks in the subsoil.

Persistent winter rain will recharge the deep subsoil, particularly if the land is fallowed. Under 'back-to-back' irrigated cotton, vigorous winter crops (for example wheat) reduce the risk of deep drainage losses. These winter crops are killed with herbicide just before the cotton is planted.

The decision about winter cropping is more difficult where dryland cotton is grown because of the need to conserve moisture for the next cotton crop. However, consider planting a crop such as wheat if plant available water is greater than 75% of capacity after cotton harvesting.

Salt inputs to cotton fields

Salt can move in from neighbouring areas—e.g. saline runoff from the Liverpool Plains enters the Namoi River and accumulates downstream in cotton fields at Wee Waa. Salinity control must involve the whole catchment, with detailed soil surveying to identify areas that are causing the problem, as well as areas under threat. Preventing the problem is likely to be much cheaper than finding a cure.

However, some salts are a lot more harmful than others. If the salt load in the irrigation water is dominated by calcium rather than by sodium, soil condition may actually be improved by the imported salt. Studies in the Macquarie Valley have shown, for example, that although about 1.5 t/ha of soluble salt accumulate in the soil for each cotton crop, through the irrigation water, the salt apparently consists mostly of calcium compounds.

GREENHOUSE GAS EMISSION

A build-up of greenhouse gases—mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)—in the Earth's atmosphere apparently is causing temperatures to rise. A greenhouse gas is transparent to short-wave infra-red radiation, but is somewhat opaque to long-wave infra-red radiation. Thus heat from the sun (short-wave infra-red radiation) can pass through the atmosphere to warm the Earth's surface; heat re-transmitted by the ground (long-wave infra-red radiation) is absorbed by these gases instead of escaping. The result is a warmer Earth.

Since pre-industrial times, CO_2, CH_4 and N_2O levels have risen markedly (in order, 23%, 110% and 8% rises). The predicted rises over the next 50 years are 45–115% for CO_2, 200–500% for CH_4 and 25–60% for N_2O.

An increase in the concentration of CO_2 may make crops grow faster, and higher temperatures may allow the cotton industry to expand southwards. However, these benefits could be out-weighed by national problems such as sea-level rises and changes in rainfall patterns.

The CSIRO Division of Atmospheric Research has predicted that, in the Macquarie Valley, the temperature will increase between 0.4 and 1.7°C by 2030. Average rainfall—particularly in winter—is expected to decline, but rain events are likely to be more extreme.

Nitrous oxide

Nitrous oxide (N_2O) has a greater ability to produce the greenhouse effect than the better known CO_2, so it is very important to control its emission. Another problem with N_2O is that when it eventually enters the stratosphere, it accelerates ozone breakdown, allowing extra input of ultra-violet radiation. This extra radiation increases the risk of skin cancer in humans and may have other, unknown environmental effects.

Man-made sources of N_2O include, in about equal proportions:

- fossil fuel combustion
- biomass burning
- losses from nitrogen fertiliser via the process of denitrification.

The total of these inputs is about 30% of that derived from natural sources.

Cotton farming, like other intensive forms of agriculture, may contribute substantial amounts of N_2O, although the actual amounts involved have not been measured. Experiments near Narrabri have shown that, if applied under less than ideal conditions, some of the nitrogen fertiliser is lost to the atmosphere as N_2O. Wet years and compacted soil increase the likelihood of loss.

Emission of N_2O from cotton farms can be minimised by management techniques such as:

- maintaining good soil structure
- avoiding unnecessarily early N application
- conserving crop residues
- using fuel efficiently.

Carbon dioxide

Burning organic residues releases carbon dioxide (CO_2) into the atmosphere. CO_2 is also released when soil organic matter decomposes. Decomposition is accelerated by tillage, and global warming is also likely to accelerate the process.

A study near Warren showed that the amount of organic matter in the upper 30 cm of the soil profile decreased by about 25% after 15 years of cotton farming, when compared with grazed natural pasture. If this loss has occurred in all Australian cotton soils (250,000 ha), approximately 6 million extra tonnes of carbon has entered the atmosphere.

This figure is very small when compared with the estimated world-wide totals of carbon (see Table B11-1).

Table B11-1. Amounts of naturally occurring carbon

Location of carbon	Estimated amount of carbon (billion tonnes)
Soil	1,456
Land plant biomass (about half of which is tropical rainforests):	827
The atmosphere:	725
Oceans:	
—shallow, exchangeable with the atmosphere	550
—deep, not easily exchanged with the atmosphere	36,450
Fossil fuels (coal, oil, gas)	7,243

The amount of carbon lost from our cotton soils is only a small proportion of the carbon that has been lost from cultivated soil in Australia—mainly used for dryland cereal production—over the period from 1860 to 1990 (an estimated 290 million tonnes of carbon). However, sown pastures and fertilised legumes in other parts of Australia have accumulated organic carbon that almost balances these losses.

Agriculture and forestry perhaps are the only enterprises that can counterbalance the huge increase in CO_2 emission from the burning of fossil fuels and from forest destruction in other parts of the world.

Any farming practices that encourage conservation or, if possible, accumulation of organic matter will help to reverse CO_2 build-up in the atmosphere. For example, reduced tillage conserves soil organic matter, and reduces the amount of CO_2 released by the burning of fuel in tractors.

Methane

Methane (CH_4) emission is not great under cotton, except where organic residues are burnt. Cattle grazing and rice production generate much greater quantities.

PESTICIDE AND FERTILISER RESIDUES

Pesticides

There is no clear evidence to show that pesticides (herbicides and insecticides) have an adverse effect upon the structure or biological activity of Australian cotton soils. Herbicides, in fact, can stimulate many of the organisms and biological processes in soil by providing them with an extra source of food. Anti-microbial chemicals—for example fungicides—generally have a greater inhibitory effect than other pesticides, but are not widely used for cotton production.

Toxic spills (for example, petroleum) have a much more serious effect on soil biological activity than properly-applied pesticides (Table B11-2). Pesticides are extensively screened for toxic effects upon the environment before their release, and are usually applied at low rates. Even if soil microbes are adversely affected by pesticides, populations return to their former levels within a few months unless there are unusually high concentrations of pesticides.

Table B11-2. The duration of the effects of people's activities on microbial communities or processes in soils

Activity	Duration
Crude oil spill	more than 10 years
Clear cutting of forests	300 years
Pesticide application	4–16 weeks
Strip mining	50–100 years

Some pesticides—for example DDT—may remain in the soil for many years, but can no longer be used. Modern pesticides used by the cotton industry are much more degradable. Before a pesticide can be registered for use, data on its persistence in the environment must be presented. For example, there is little carryover of either endosulfan or its decomposition products from one year to the next, although water and wind erosion has to be controlled to avoid off-site movement soon after application.

Soil compaction and depletion of soil organic matter may reduce the rate at which microbes can break down pesticide residues. Good soil structure and high biological activity should reduce the risk of pesticide residues building up. Organic matter in soil traps pesticides and reduces their volatile loss, allowing microbes to degrade the entrapped pesticides. Furthermore, repeated applications may even enhance microbial degradation of a particular pesticide.

Because most of the cotton pesticides are selective in their activity and do not persist for long periods in the soil, they are unlikely to adversely affect beneficial soil animals such as earthworms. It appears that earthworms are absent from most cotton fields because of disturbance by tillage, lack of food and excessive wetness and dryness of the soil, rather than because of pesticide residues.

Fertiliser impurities

Fertilisers and soil conditioners may contain toxic impurities. Some phosphate fertilisers and by-product gypsum contain traces of cadmium—a poisonous heavy metal that can accumulate in soil and be taken up by plants. Cadmium availability in soil decreases as pH becomes higher. High amounts of organic matter in soil help to limit cadmium uptake, but high chloride concentrations in the soil may increase cadmium uptake.

By-product gypsum may also contain fluorine impurities (up to 2%) but they become immobilised and unavailable to plants in clay soil. Mined gypsum generally has fewer toxic impurities than by-product gypsum.

Groundwater contamination by pesticides and fertilisers

In parts of the USA and Europe, pesticide residues are present in groundwater beneath cropping land, especially where the soil is light-textured. Australian cotton soil tends to be less permeable.

Nitrate salts can cause serious groundwater pollution, but the amounts involved are very low in most of the soil under cotton in Australia. Experimental work on a grey cracking clay near Narrabri has shown negligible leaching of nitrate below the root zone, but monitoring should continue.

Pollutants entering groundwater from normal application practices are said to come from non-point pollution sources; only very small amounts have the potential to enter the groundwater from any one location. However, point pollution sources (which include areas where empty drums have been buried, and places where spillage has occurred) can have much larger quantities of pesticides. The pollutants can move deeply and quickly if the point pollution source is close to an old bore.

Some early chemicals such as DDT were highly persistent, but not prone to leaching because of tight binding to soil particles. Now the trend is toward less persistent, but more highly mobile, chemicals that have a potential to pollute groundwater. Pesticides that normally break down quickly can remain active in groundwater because of low temperatures, and the lack of oxygen, ultra-violet light and biological activity. Table B11-3 compares the soil mobility of some of the chemicals used in cotton production.

The risk of groundwater contamination can be reduced by:

- following the recommended handling and application procedures
- accumulating soil organic matter, which encourages pesticide breakdown.
- careful application of irrigation water.

If there is no aquifer (sand or gravel layer) beneath the cotton field, or if the aquifer is very deep, risks are low. Where a problem is likely, use a pesticide from a lower mobility class (Table B11-3).

THE GOLDEN RULE OF ON-FARM ENVIRONMENT CONSERVATION

You can't be ***green*** when you're in the ***red***. A highly productive cotton enterprise is one of the few farming systems that is able to generate the wealth required to be environmentally constructive.

Table B11-3. Mobility of some of the chemicals used in cotton production.

Mobility Class **1** **very unlikely to leach**	**2** **slightly able to leach**	**3** **moderately able to leach**	**4** **easily able to leach**	**5** **highly likely to leach**
diquat disulfoton endosulfan glyphosate paraquat parathionphorate trifluralin	diuron prometryn	atrazine	amitrole dicamba endothal methomyl picloram	ethephon monocrotophos

B12. Case studies

PURPOSE OF THIS CHAPTER

The aim of this chapter is to present case studies involving soil diagnosis and management in a number of different situations.

YIELD MAP INTERPRETATION

Case study 1: Poor cotton yield in one corner of a field that had been heavily landformed

District: Gwydir Valley

Soil type: Grey cracking clay (Vertosol)

Soil diagnosis for high-yielding end of field

Field observations

Controlled traffic was used after precision deep tillage; there was evidence of hills having been moved sideways over old wheel tracks.

Soil test results

Depth (m)	Spak score	pH	EC	Cl	CEC	ESP	Ca/Mg	ESI	OC	C sand	F sand	Silt	Clay
Topsoil (0–0.1)	1.6	8.7	0.09	16	30	2.9	1.4	0.030	0.85	10	19	27	47
Subsurface (0.15–0.25)	1.6	8.5	0.16	48	29	4.0	1.5	0.039	0.75	11	18	27	47
Upper subsoil (0.4–0.5)	1.3	8.1	1.07	14	31	8.0	1.3	0.127	0.70	10	18	26	47
Mid subsoil (0.7–0.8)	1.2	8.0	1.80	26	34	11.3	1.3	0.158	0.60	7	17	30	50

KEY:
Spak score: SOILpak score (compaction severity under main plant lines); 0.0 = poor, 2.0 = excellent
pH: 1:5 soil:water
EC: dS/m; 1:5 soil:water
Cl: chloride in ppm; 1:5 soil:water
CEC: exchangeable cations in cmol(+)/kg, extracted using the Tucker method
ESP: exchangeable sodium percentage
Ca/Mg: calcium magnesium ratio (exchangeable cations)
ESI: electrochemical stability index (EC/ESP); values less than 0.05 indicate dispersion problems
OC: organic carbon (Walkley Black method)
Coarse sand (0.2–2 mm), fine sand (0.02–0.2 mm), silt (0.002–0.02 mm), clay (<0.002 mm), %

Interpretation of laboratory data

Slightly dispersive topsoil overlies a non-dispersive (ESI >0.05) but saline subsoil. Root growth by cotton is likely to be restricted below a depth of 0.7 m because of salinity. Structural regeneration potential is moderate (CEC = 20–40).

Management options to consider

Gypsum application (5 t/ha) is an option that should be assessed via the use of test strips. Improve the guidance of traffic so that furrows remain narrow and in the same position. Minimise deep drainage of water.

Soil diagnosis for low yielding end of field

Field observations

The observation pit was on a small sub-section of the field that had been heavily cut during field development. Controlled traffic was used after precision deep tillage; there was evidence of hills having been moved sideways over old wheel tracks.

Soil test results

Depth (m)	Spak score	pH	EC	Cl	CEC	ESP	Ca/ Mg	ESI	OC	C sand	F sand	Silt	Clay
Topsoil (0–0.1)	1.0	9.3	0.24	8	31	12.7	1.8	0.018	0.65	16	19	16	51
Subsurface (0.15–0.25)	0.8	9.4	0.32	54	29	16.8	1.6	0.019	0.60	16	17	13	54
Upper subsoil (0.4–0.5)	0.5	8.4	2.09	84	32	22.3	1.8	0.093	0.40	15	15	16	55
Mid subsoil (0.7–0.8)	0.7	8.7	2.12	217	34	40.7	1.0	0.052	0.45	13	14	12	59

Interpretation of laboratory data

Strongly dispersive topsoil (ESI <0.05, ESP>5, high pH) overlies a non-dispersive (ESI >0.05) but strongly saline subsoil. Root growth by cotton is likely to be restricted below a depth of 0.3 m because of salinity. Structural regeneration potential is moderate (CEC = 20–40).

Differences in soil factors between 'high' yielding and 'low' yielding parts of the field

The 'poor' site is more sodic and saline than the 'good' site.

Management options to consider

Gypsum application (5 t/ha, possibly with 2.5 t/ha follow-up doses) is an option that should be assessed via the use of test strips. The soil is too alkaline for lime application to be successful. Improve the guidance of traffic so that furrows remain narrow and in the same position. Manage water application so that subsoil salt is pushed deeper (by no more than about 1 m). If sufficient summer rain falls, consider planting forage sorghum to overcome excessively-coarse tilth by shrink-swell processes.

If developing more land for cotton in this area, map the key soil properties such as sodicity. Try to avoid deep cuts when landforming if the subsoil is unstable in water.

Case study 2: Poor cotton yield in a strip through a light-textured cotton field

District: Macquarie Valley

Soil type: Hardsetting red soil (Chromosol)

Soil diagnosis for high-yielding section of field

Field observations

Lucerne was being grown after cotton, with controlled traffic. Shrinkage cracks were not obvious, although impregnation of the soil with a white paint solution indicated that they were the main macropores connecting the soil surface with the subsoil.

Soil test results

Depth (m)	Spak score	pH	EC	Cl	CEC	ESP	Ca/ Mg	ESI	OC	C sand	F sand	Silt	Clay
Topsoil (0–0.1)	1.3	7.4	0.15	35	9	1.1	2.4	0.135	1.10	21	29	24	26
Subsurface (0.15–0.25)	0.9	7.7	0.06	15	10	2.0	2.7	0.030	0.95	20	29	27	26
Upper subsoil (0.4–0.5)	1.4	8.5	0.22	57	21	3.3	2.1	0.066	0.50	8	16	30	47
Mid subsoil (0.7–0.8)	1.7	8.7	0.21	83	22	4.3	1.6	0.049	0.45	4	23	30	43

Interpretation of laboratory data

The soil is unlikely to disperse in water (ESI >0.05), particularly at the soil surface, but has poor regeneration potential (low CEC).

Management options to consider

It is important to continue to restrict compaction to narrow laneways. Tillage should be minimised, particularly when the soil is dry and prone to dust formation. As much organic mulch as possible should be maintained at the soil surface.

Soil diagnosis for low-yielding section of field

Field observations

Lucerne was being grown after cotton, with controlled traffic. Shrinkage cracks were not obvious, although impregnation of the soil with a white paint solution indicated that they were the main macropores connecting the soil surface with the subsoil.

Soil test results

Depth (m)	S pak score	pH	EC	Cl	CEC	ESP	Ca/ Mg	ESI	OC	C sand	F sand	Silt	Clay
Topsoil (0–0.1)	1.2	7.9	0.10	20	10	1.5	2.4	0.067	1.20	28	30	19	23
Subsurface (0.15–0.25)	1.3	7.8	0.07	15	8	1.3	2.9	0.056	1.15	27	31	18	22
Upper subsoil (0.4–0.5)	1.6	7.9	0.06	22	14	2.9	3.8	0.021	0.65	21	20	21	40
Mid subsoil (0.7–0.8)	1.8	8.0	0.04	15	18	2.8	2.8	0.014	0.55	16	16	25	44

Interpretation of laboratory data

The soil is unlikely to disperse in water (ESI>0.05), particularly at the surface. It has poor structural regeneration potential (low CEC).

Differences in soil factors between 'high' yielding and 'low' yielding parts of the field

The 'poor' site has more sand in the subsoil than the 'good' site, causing greater deep drainage of water and nutrients.

Management options to consider

It is important to continue to restrict compaction to narrow laneways, and to minimise tillage (particularly when the soil is dry). As much organic mulch as possible should be maintained at the soil surface. Careful water management is required to minimise deep drainage.

COMPACTION MANAGEMENT ON A CRACKING CLAY

Case study 3

District: Darling Downs

Soil type: Grey cracking clay (Vertosol)

Two adjacent sites had been cultivated for 30 years, and furrow-irrigated (mainly with bore water) for 20 years. Cotton yield histories for the sites (referred to as Fields A and B) had been similar and above-average. The soil was a self- mulching grey clay; clay content at the soil surface was 53%, and ESP was 5.

In Field A, cotton was harvested after rain. During harvest, the soil surface and subsoil were wet, and remained so during subsequent land preparation. All of the preparation was done very quickly (within 7 days) as time was limited between the late picking and planting of the next cotton crop. Land preparation involved five passes over the field; in all but the last, a 4-wheel drive tractor with dual wheels, front and back, was used. The operations were: first rotary slashing to cut the cotton stalks, then tillage with straight chisels with 0.05 m wide points (to 0.12 m depth), followed by another two tillage passes with straight shanks with 0.1 m sweeps (to 0.1 m depth) and finally the planting of cotton. No fertiliser was applied pre-planting, as the plan was to fertilise through the early part of the growing season.

In Field B, the soil was dry when the crop was harvested; it was picked just before the rain. Unlike in Field A, the grower decided not to flatten the hills completely from the previous cotton crop. There were five passes over the field with the same tractor used as in Field A for passes 1–4. The operations were slashing of the cotton stalks, followed by tillage with straight chisels with 0.05 m wide points (to 0.12 m depth), then tillage with straight tines with 0.15 m sweeps to 0.12 m in the furrow bottoms with ‘go-devils’ to shape up the cotton hills. MAP and urea fertiliser were applied down each side of the hills before planting of the next cotton crop.

The wet cultivation Field A resulted in a 30% decrease in air-filled pores in the 0.2–0.4 m zone in Field A relative to the same zone in Field B. At the first irrigation the plants in Field A turned yellow and many fell over; many of the plants had ‘L-shaped’ roots. This response was so severe that the grower, faced with water shortages, decided to stop irrigating Field A and manage it as a dryland crop. There was a 70% lint yield difference between Fields A and B.

The vital point is that the measured structure degradation caused by wet picking did not directly cause the large yield loss; rather, it severely limited the owner’s management options.

It is also likely that lint yield in Field B could have been even greater if narrow-wheeled or tracked tractors had been used instead of duals, parts of which would have run over the plant lines.

For further information, see the paper by McGarry (1990) listed in Appendix 1.

OVERCOMING PROBLEMS WITH WATER PENETRATION ON A HARDSETTING SOIL

Case study 4

District: Macquarie Valley

Soil type: Hardsetting red soil (Chromosol)

Hardsetting red soil is not easy to prepare conventionally because if it is cultivated too dry, it is like talcum powder. When re-wet and then dried, it sets like concrete and is difficult to irrigate.

Direct drilling of cotton into wheat stubble can deal with hardsetting problems.

The following example indicates the benefits. There were great improvements in water penetration, and longer intervals between irrigations.

Comparisons were made with a neighbouring field which had some wheat stubble, but which was incorporated before planting.

Planting

Both fields were planted on the same day (29 September 1997) to Sicala V2. The planter setup was the same for both fields, with 3 kg/ha of Temik^{R}.

The no-till area was slower to establish because of cooler soil temperatures. Eventually, the no-till field had a denser plant stand.

Ground preparation

No-till Field 29	Conventional Field 30
nil	1 Mulch 1 Go-devil 1 Sled (gas) 1 Sled (incorporated) 1 Lilliston (2nd incorporation) Roller

Herbicides

Herbicide timing	No-till Field 29	Conventional Field 30
Fallow	2 X Roundup @ 1.2 L/ha	–
Incorporated	Diurex @ 1.7 kg/ha Stomp @ 3 L/ha	Cotoran @ 3 L/ha. Trifluralin @ 2.1 L/ha
Plant	Cotoran @ 3 L/ha (100% Band)	Cotoran @ 3 L/ha (50% Band)
Lay by	–	Diurex @ 1.1 kg/ha Prometryn @ 2 L/ha

Fertiliser

No-till Field 29	Conventional Field 30
Total of 180 kg/ha of N flown on in 2 applications	Total of 160 kg/ha of N applied as gas, and side-dressed as urea

Water

No-till Field 29	Conventional Field 30
5 irrigations; still drawing water from depth at the end of the season; able to infiltrate more water to depth	7 irrigations; water not getting through profile >80 cm after 1st irrigation

Differential costs

The following table shows the difference in production costs between the two fields. It includes only costs that are different (that is, it does not include insecticides).

$/Hectare	No-till Field 29	Conventional Field 30
Ground preparation	–	250
Herbicides	110	120
Sowing costs	30	30
Fertiliser	150	150
Chipping	110	74
Total	400	624

For further information, see the paper by Soulsby, Ryan and Finney (1998) listed in Appendix 1.

DEVELOPMENT OF NEW COUNTRY

Case study 5

District: Narromine

Soil type: Recent alluvium

Severe inherent problems in subsoil and topsoil can be avoided if soil pits are dug before development.

If the soil will need amelioration before cropping, this can be costed into the project. Soil evaluation also allows you to select appropriate irrigation systems.

The Macquarie Soil Management Service inspected a series of four pits on part of a farm where irrigation development was proposed. Two of the pits showed excellent profiles of alluvial river soil to below 1.5.m, with lots of root activity and earthworm channels throughout. The other two pits showed the same soil for the first 20 cm, but underneath was a very tight red soil with negligible root activity. Use of a dispersion test showed that this soil was highly dispersive. Subsequent laboratory testing confirmed that the subsoil was very sodic and expensive to treat.

Pits dug soon afterwards on a grid pattern allowed the area with unsuitable subsoil to be mapped and excluded from the development.

For further information, see the paper by Kay (1988) listed in Appendix 1.

PART C. DIAGNOSING SOIL CONDITION

diagnosis

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.

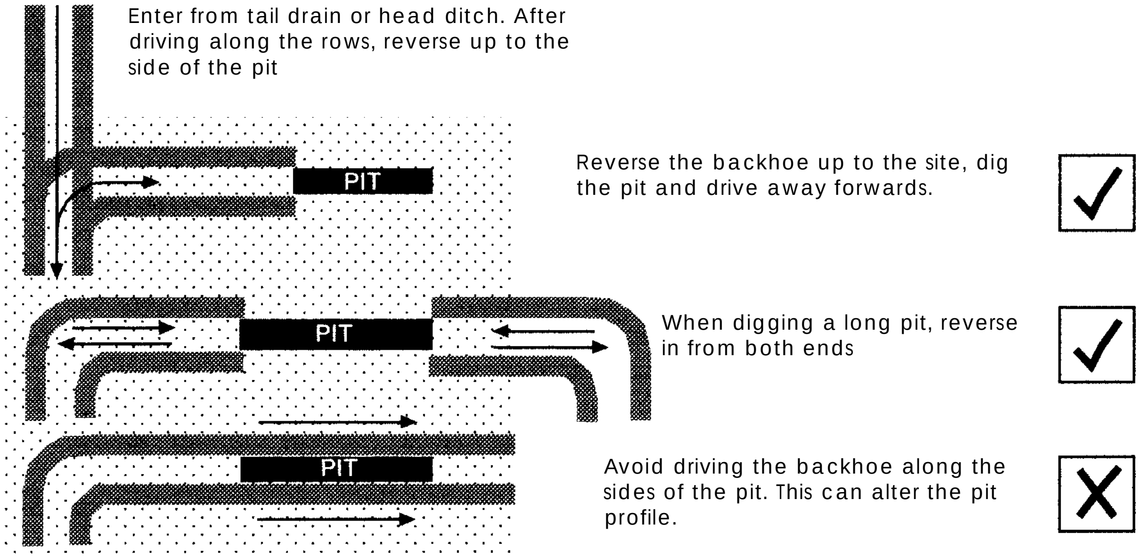
HOW TO DIG A BACKHOE PIT

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 C1-2).

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



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.

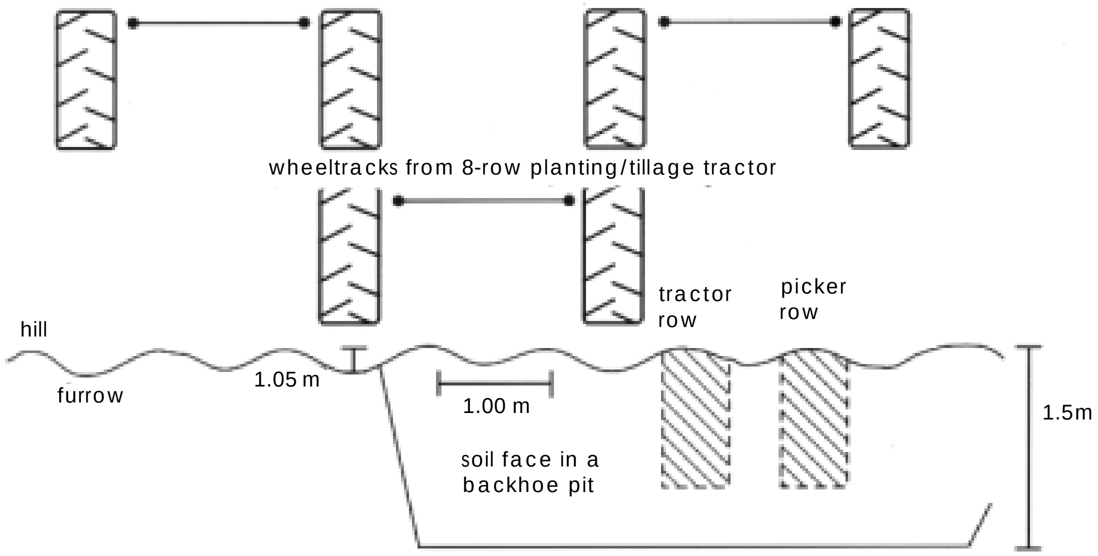
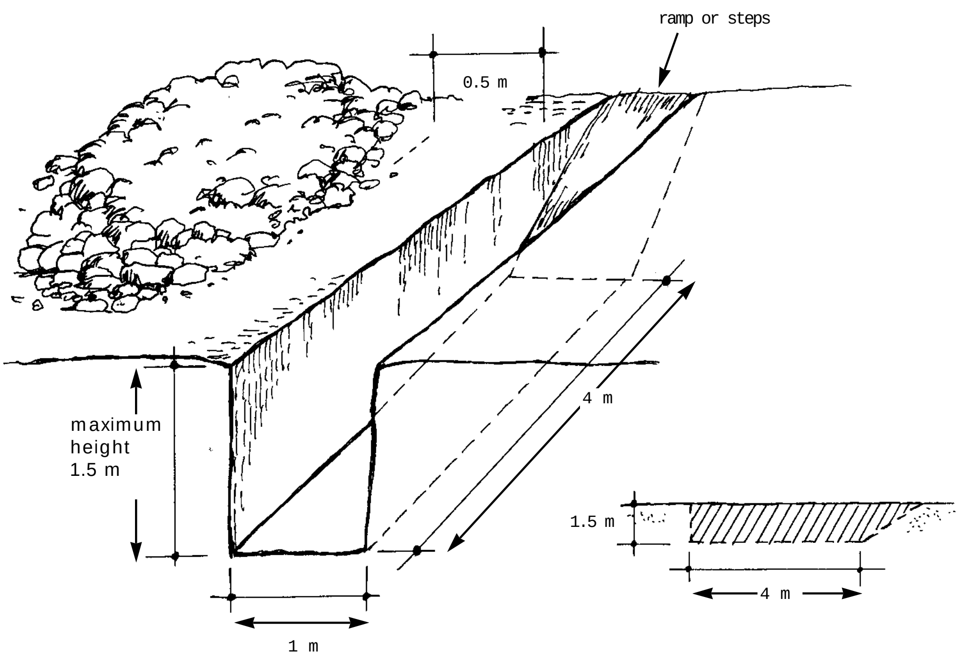
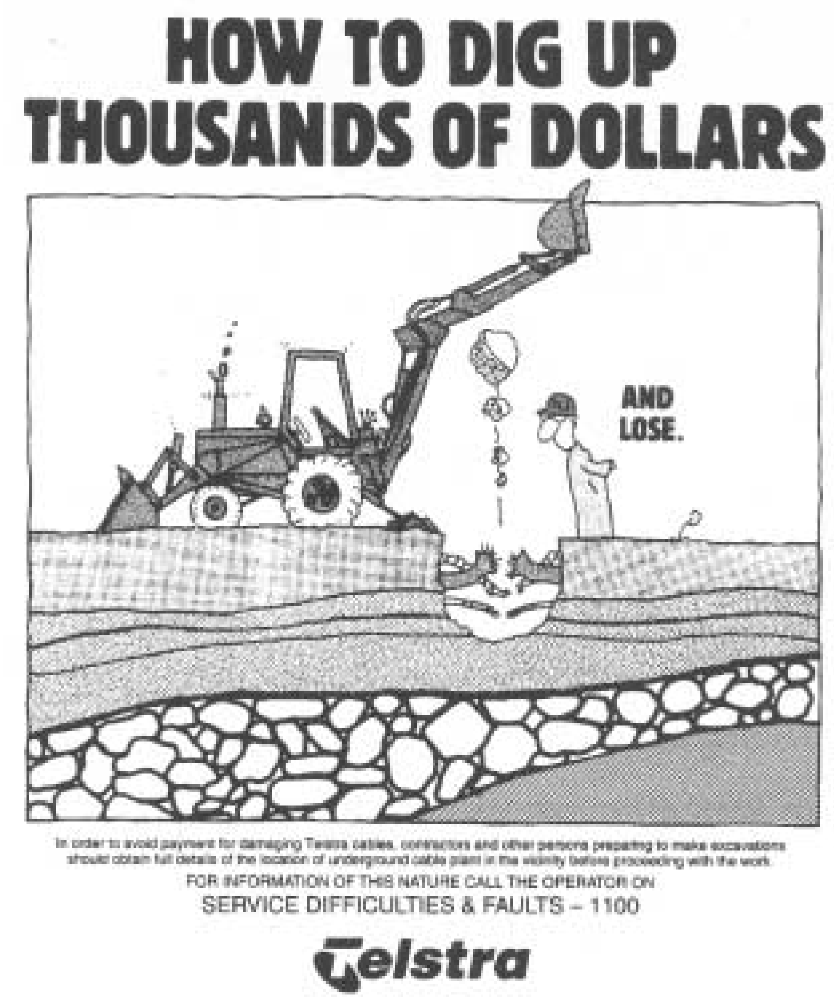


Figure C1-2. The recommended dimensions for a soil pit



- 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.

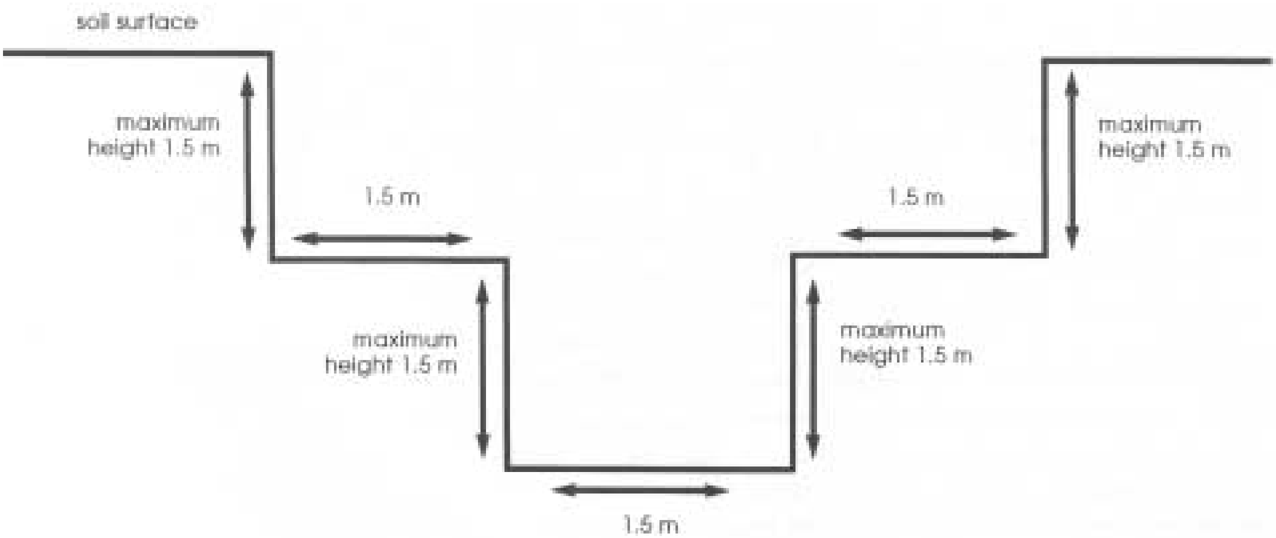
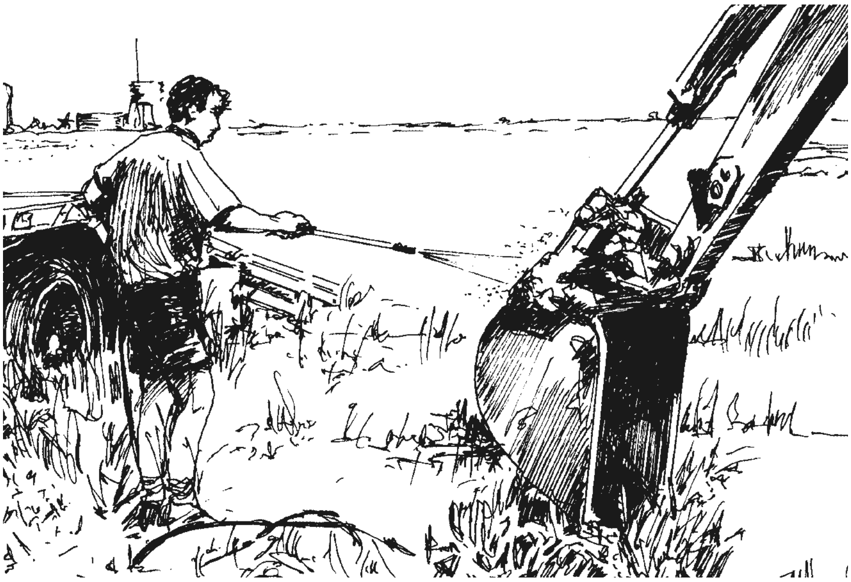


Figure C1-6. Excavation equipment must be disinfected to avoid the spread of cotton disease.



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.

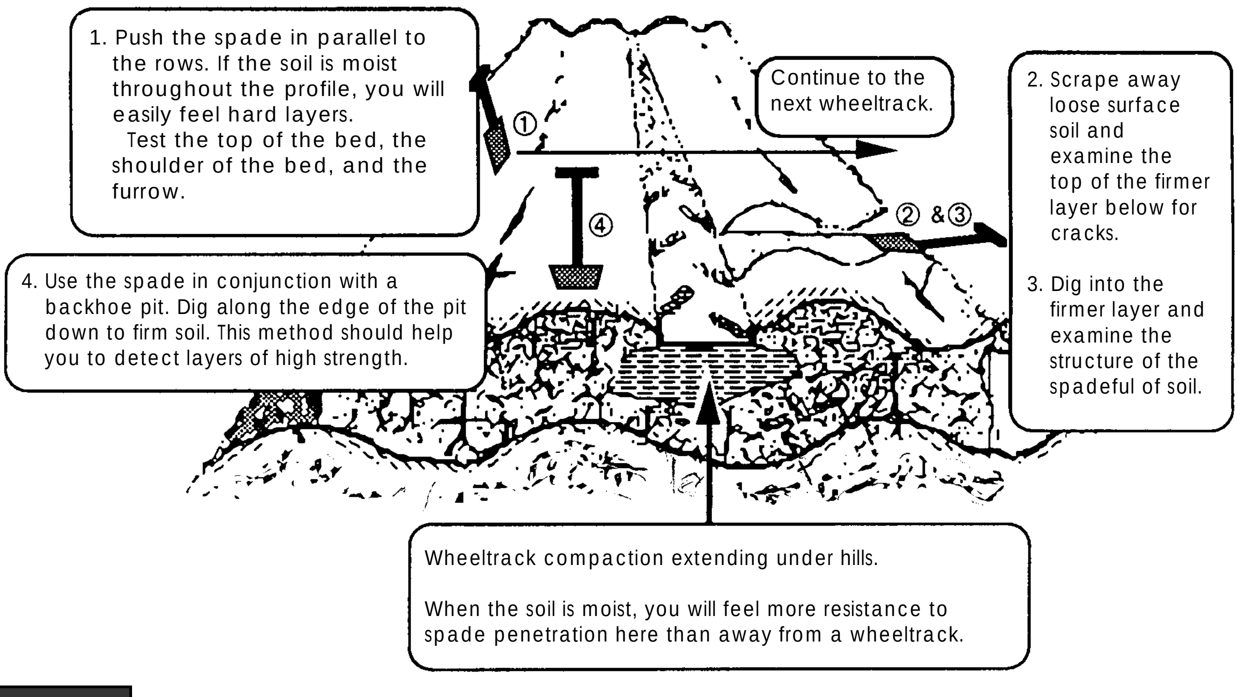
If you find hard zones under the beds, examine the soil in more detail. Use the spade to scrape away loose soil (moisture will affect how easily the loose soil can be removed) and note the depth and condition of the loose soil.

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.

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See Chapter C3 for more information on soil moisture sampling.

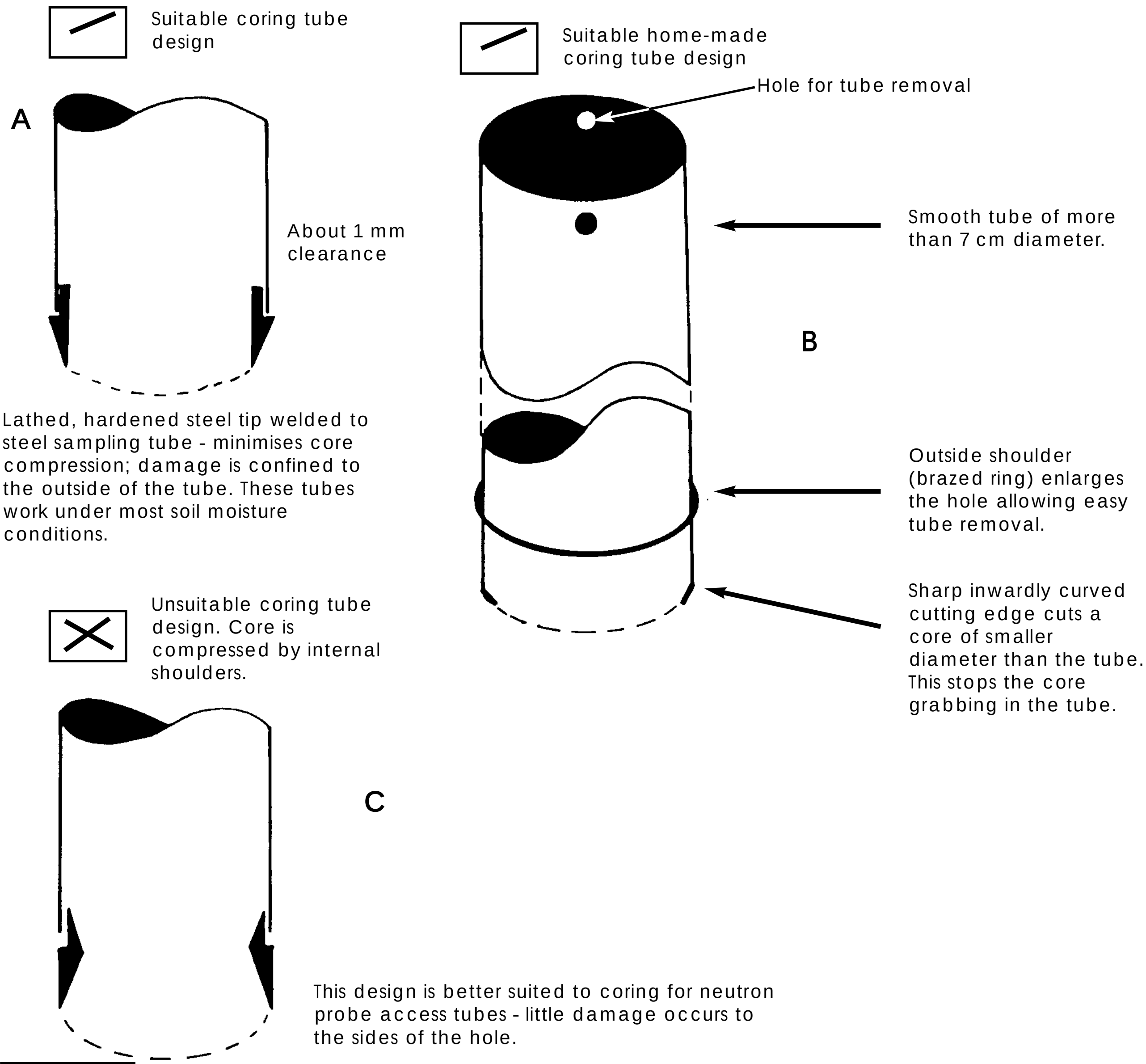
Advantages

- 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.

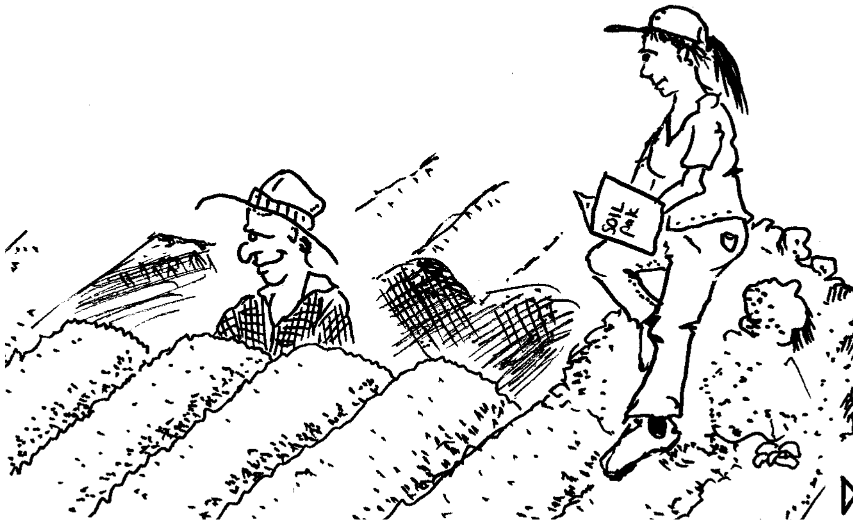
Comparisons between farmed and adjacent unfarmed (pristine) areas may be carried out at any time, but the comparison is most meaningful when all of the sites are examined at the same water content. The most suitable soil water content for soil examination is at, or just below, the plastic limit.

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, %)

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

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.

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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

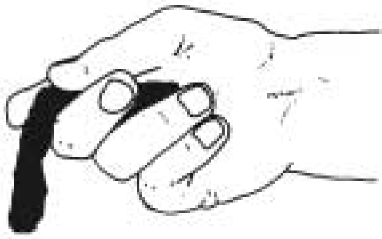
The following checklist is a quick reminder of things to do when digging a soil pit and filling in a SOILpak description sheet:

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.

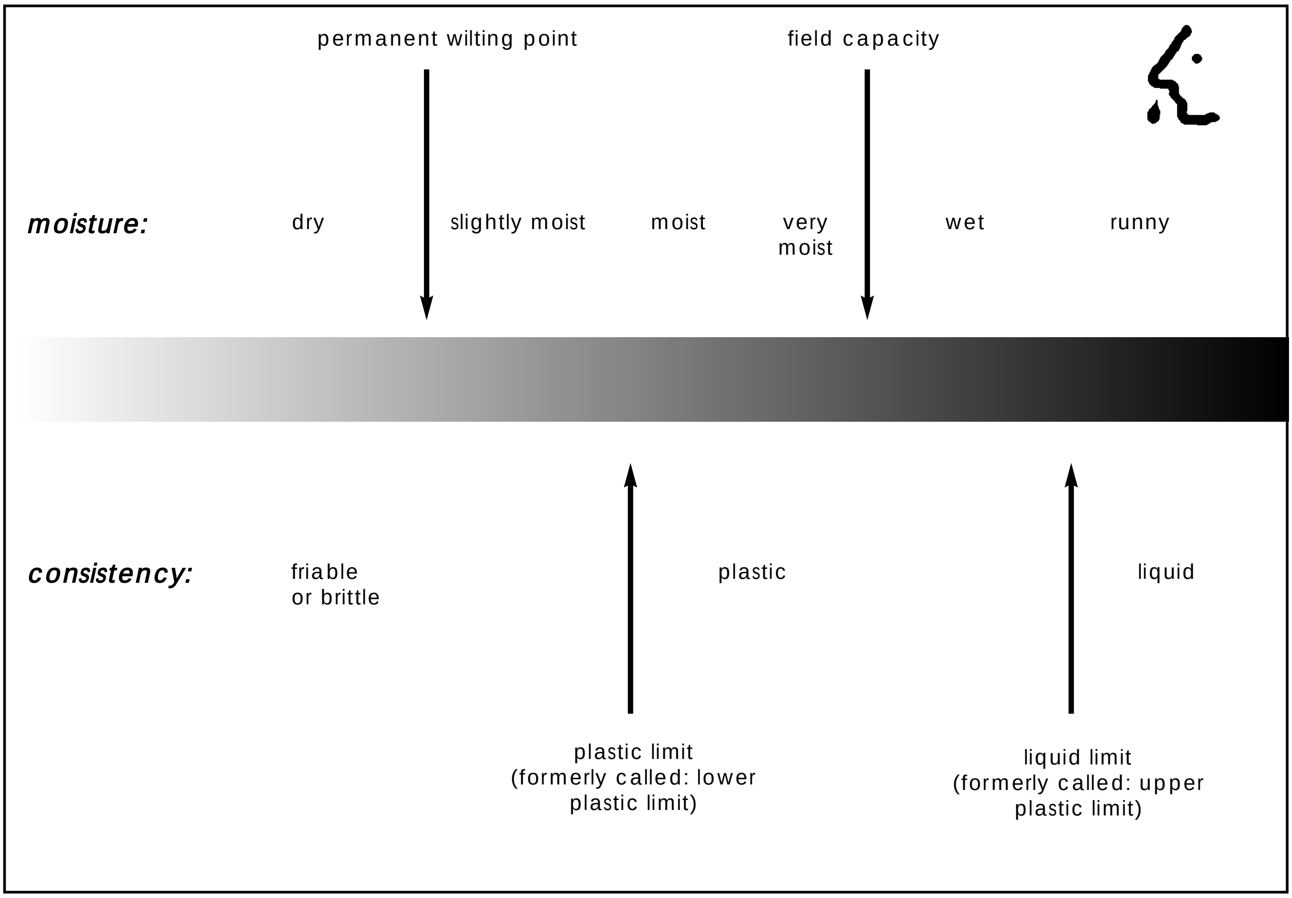
Moulding of soil samples in the hand

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

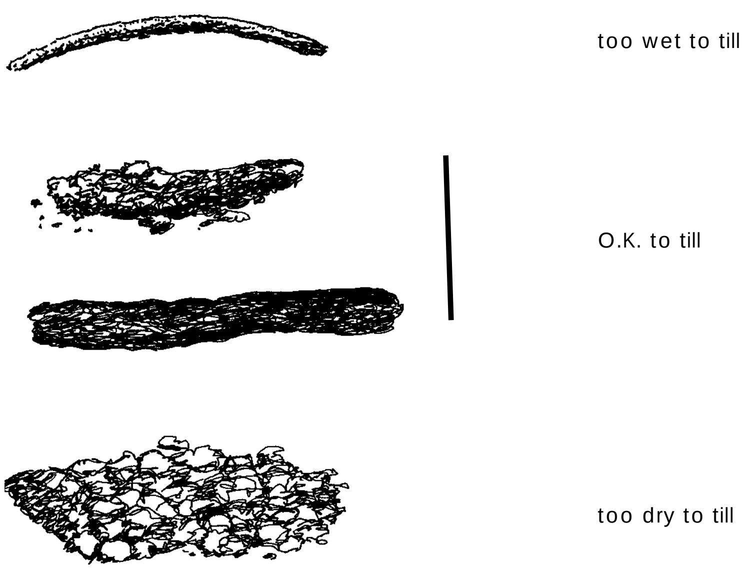


Table C3-1. Guide to assessing soil moisture

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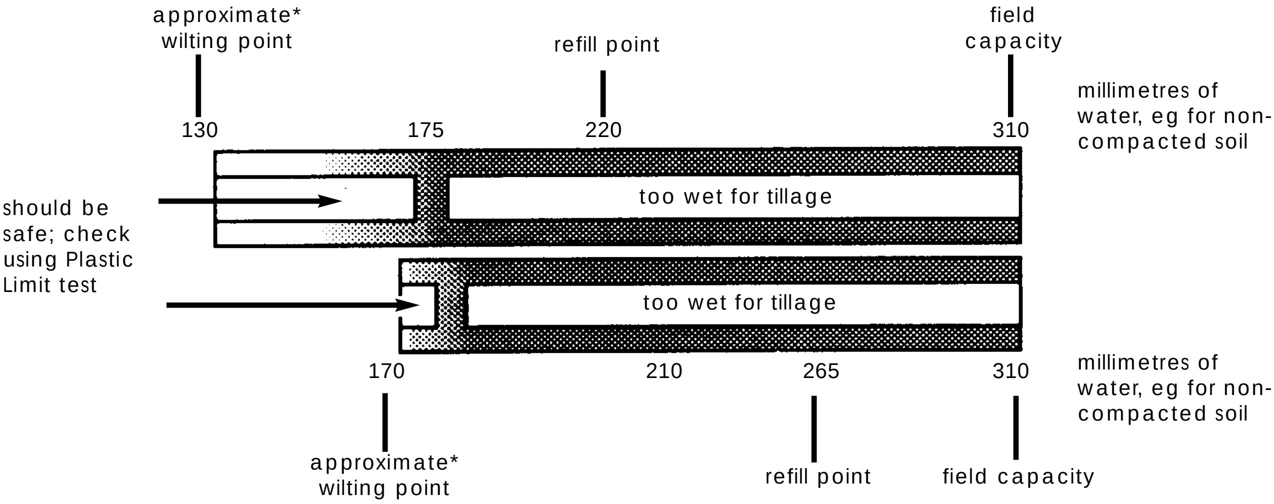
See Chapter C9 for more information on neutron and capacitance probes.

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).

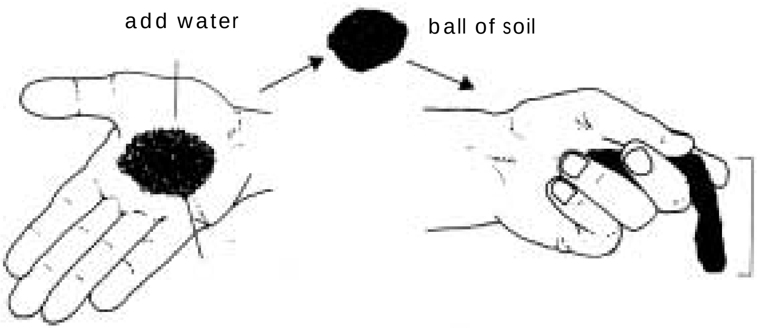
Table C3-2. Behaviour of moist bolus (ball) for contrasting types of cotton soil.

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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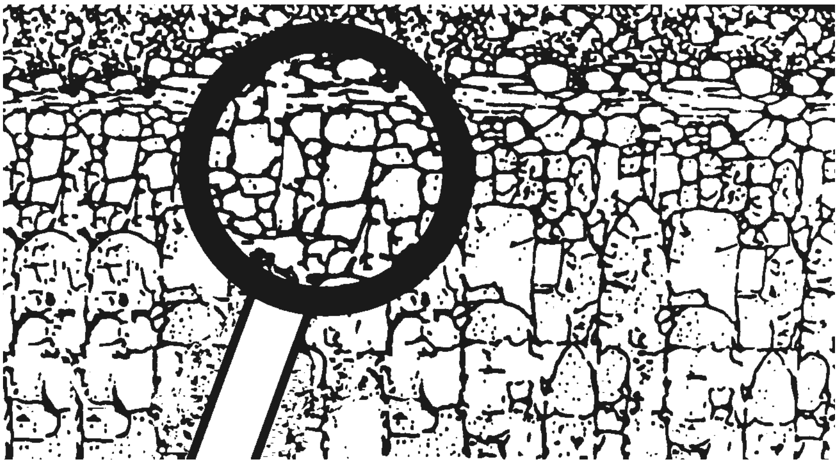
See Chapter C9 for more information on calculating available water.

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.

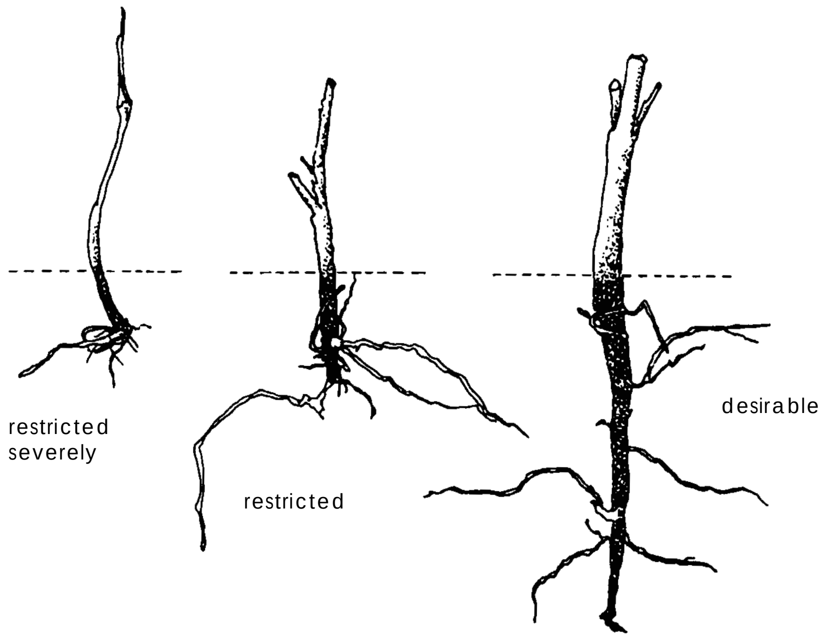
Root shape

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.

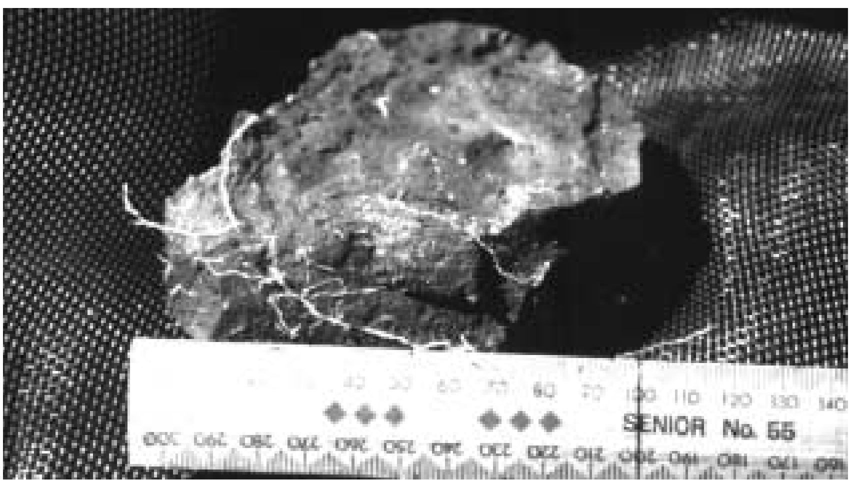


Figure C4-2. Large compact clod from under a hill that was accidentally placed on top of an old wheel track (SOILpak score = 0.2).

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

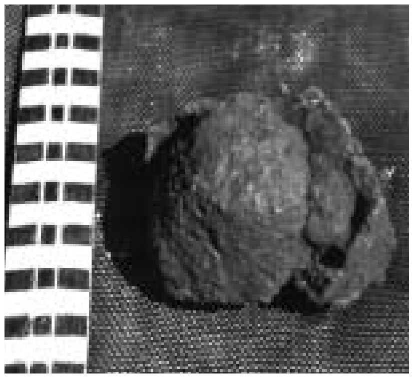
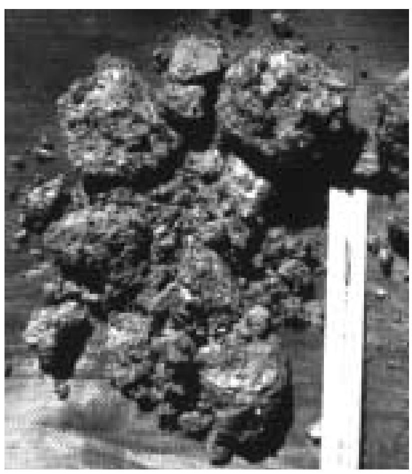


Figure C4-5. Well-structured clods that are associated with vigorous root growth (SOILpak score =

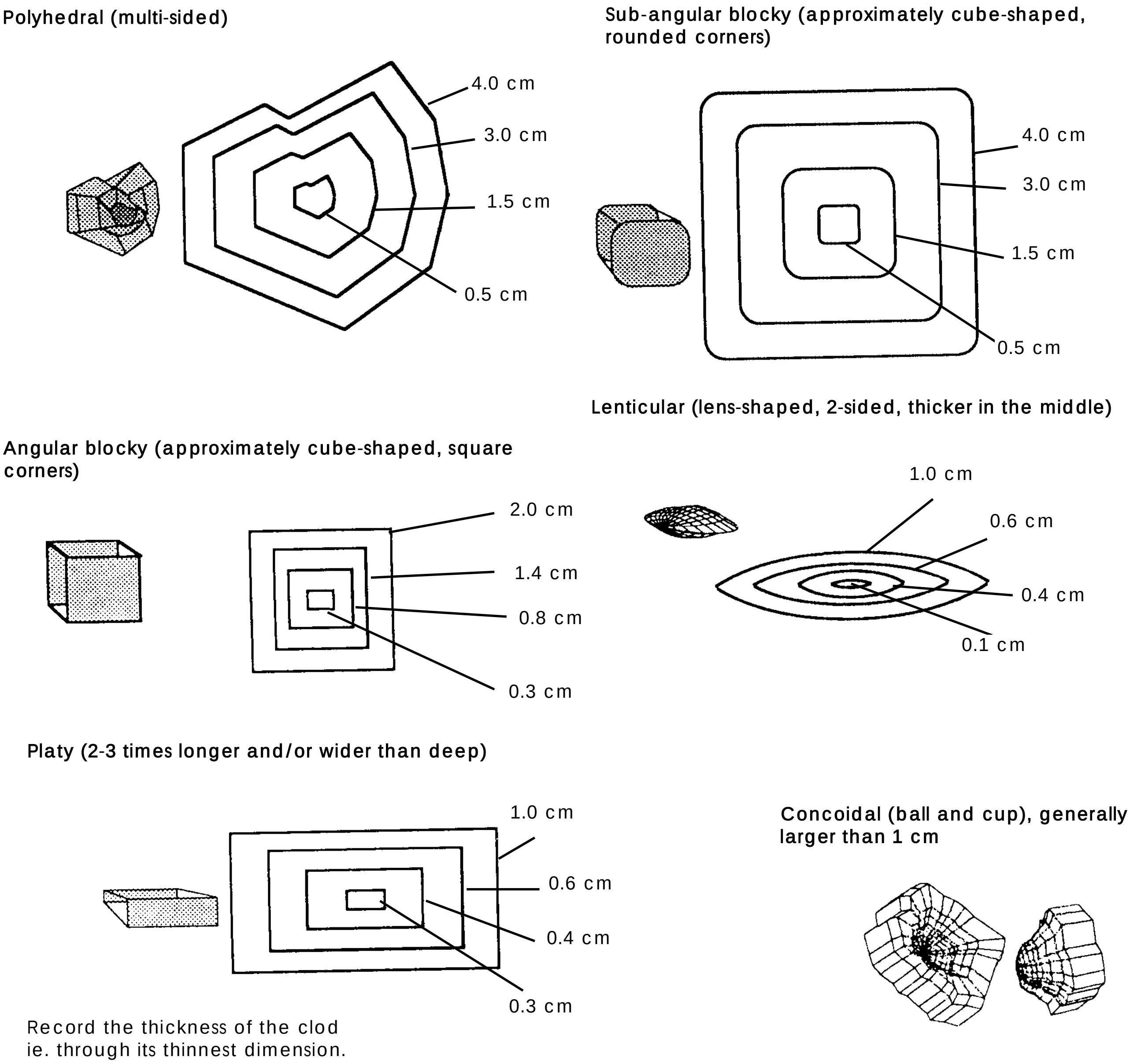


- surface crusting/hardsetting
- furrow encroachment.

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].

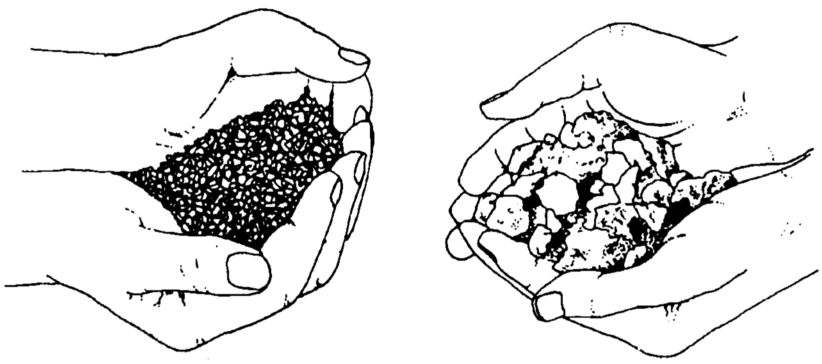
NOTE—In loamy soil (clay content less than 35%), ignore factor 2.

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

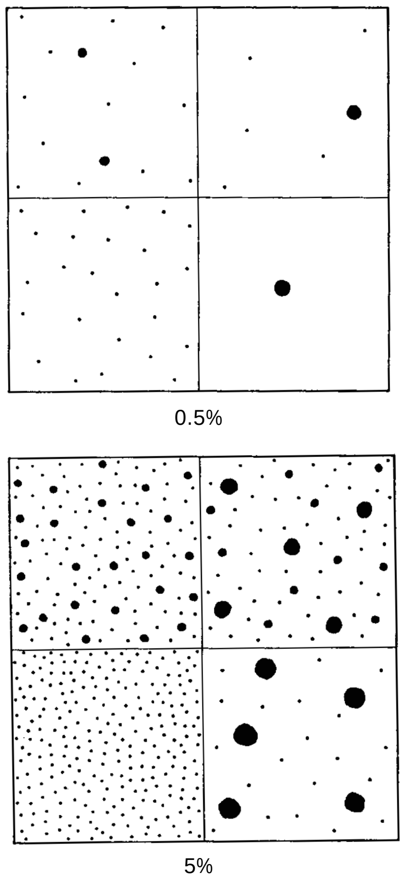
Usually there is a strong agreement between scores for each of the evaluated factors. However, sometimes the score for one factor for a particular sample of soil contradicts the score for another factor; that is, it differs by a value of more than 0.3. Under such circumstances, it is necessary to use 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.



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

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).

☞

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

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.

☞

See Chapter C9 for more information on moisture probes.

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.

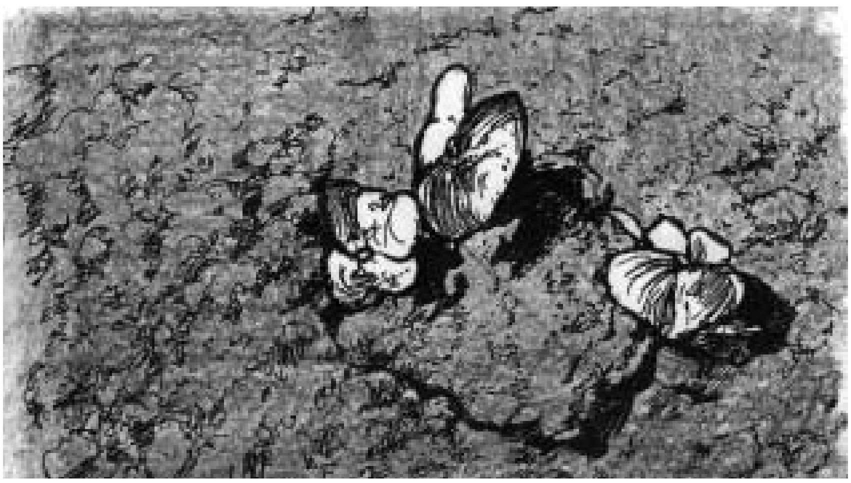
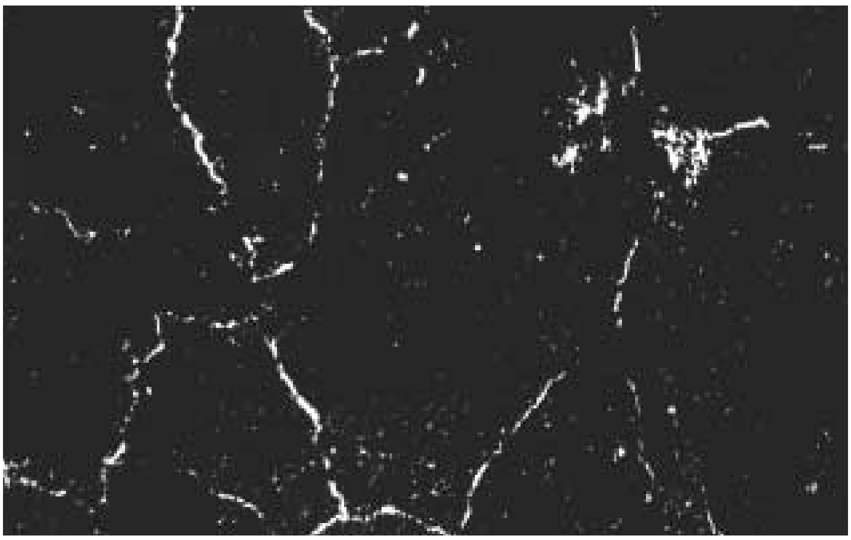


Table C4-6. Alternatives to the SOILpak 'severity of compaction/smearing' scoring procedure

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.

☞ *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

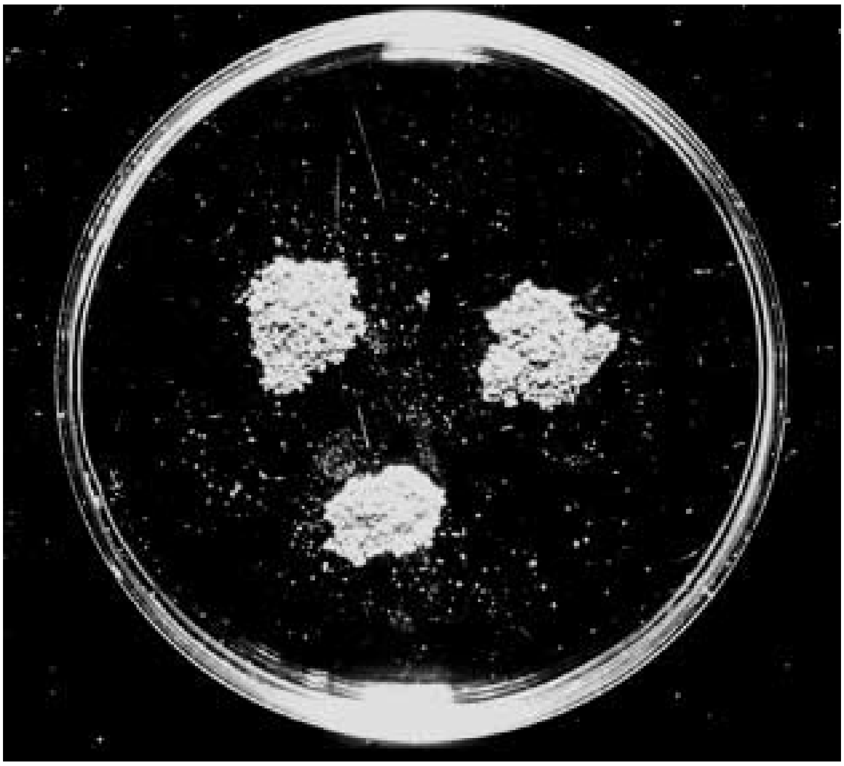


Table C4-7. Response to the soil structural stability diagnosis

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)

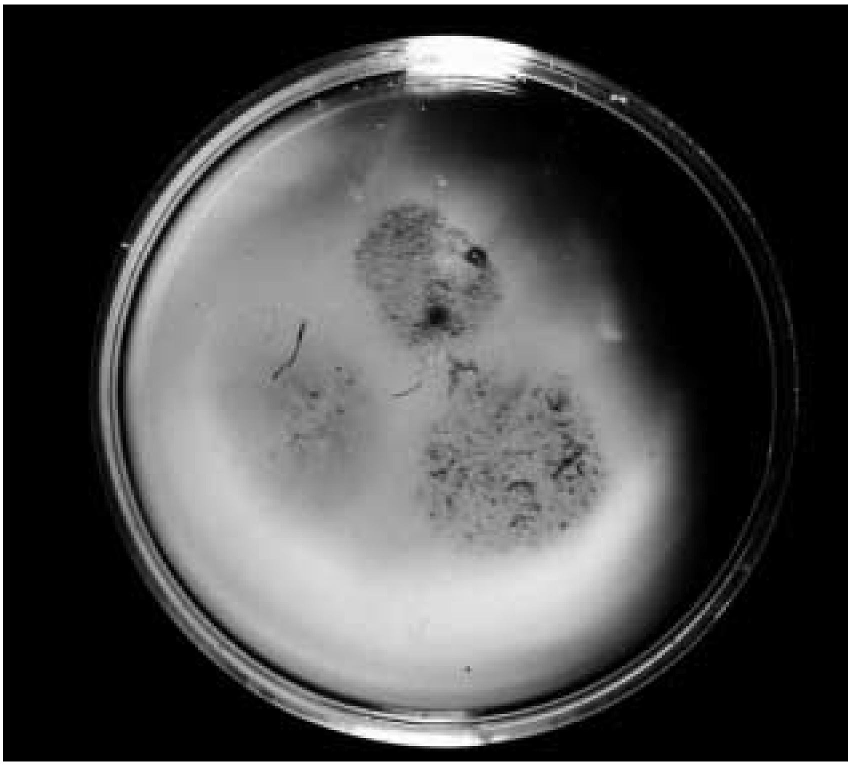
To confirm (and understand more thoroughly) the above conclusions about soil dispersibility, the following laboratory tests are recommended.

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.

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Error Diagnostic Information

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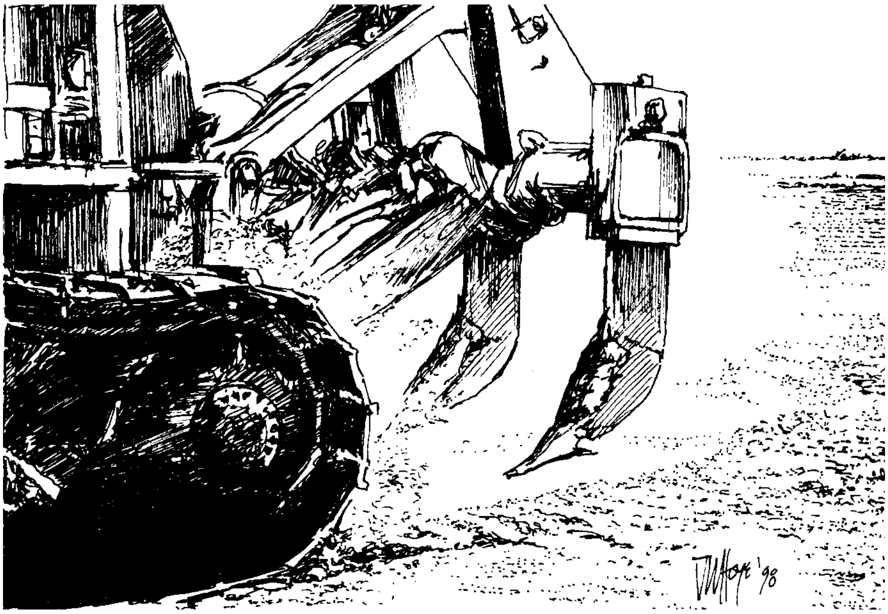
C5. Structure after rotation crops and tillage



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.

ASSESSMENT PROCEDURES FOR THE ENTIRE ROOT ZONE AFTER ROTATION/TILLAGE

Rapid field observations

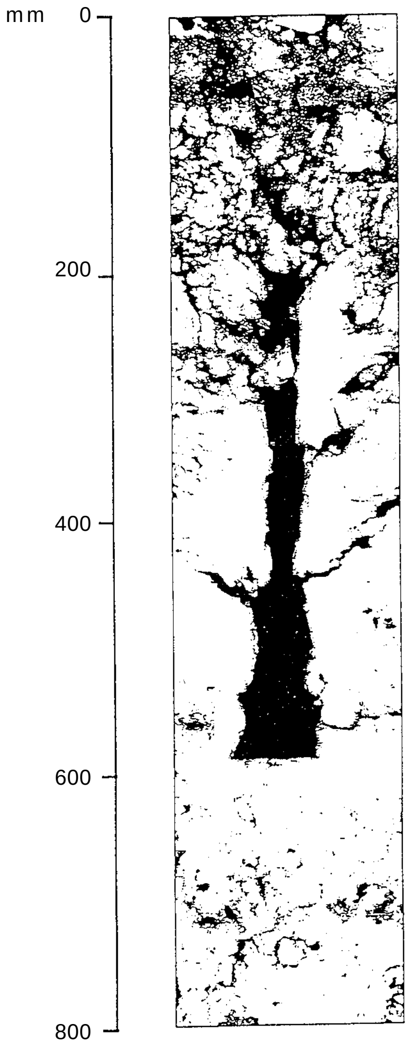
In a field that has just been decompacted by a rotation crop and/or tillage, return to at least one of the post-cotton-harvest inspection sites and dig another pit. Sketch the main pit features, then reassess the SOILpak score (see Chapter C4) in the topsoil, sub-surface and subsoil. Compare the results 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.

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.

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.

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

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See Chapter D2 for more information on disease carryover.

☞

See Chapter E5 for more information on stubble management.

- 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

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

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):

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

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

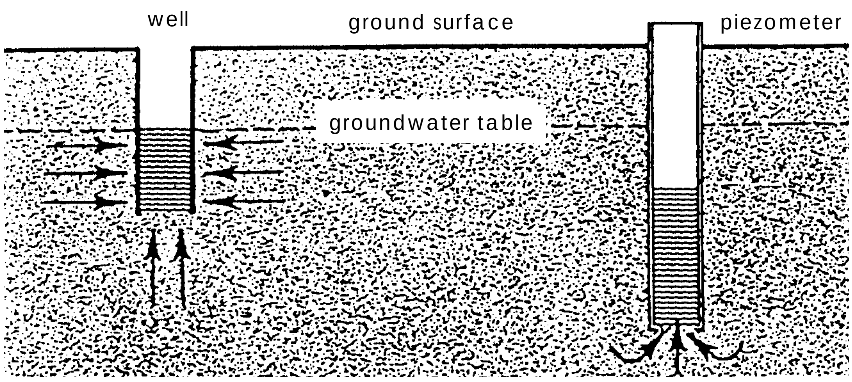
An observation well is a length of fully slotted tubing that is lowered into a bore hole and backfilled with sand around the outside of the tube. Water can freely enter the tube along its entire length, thus giving the position of the watertable in the soil (Figure C7-1). By observing a group of wells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



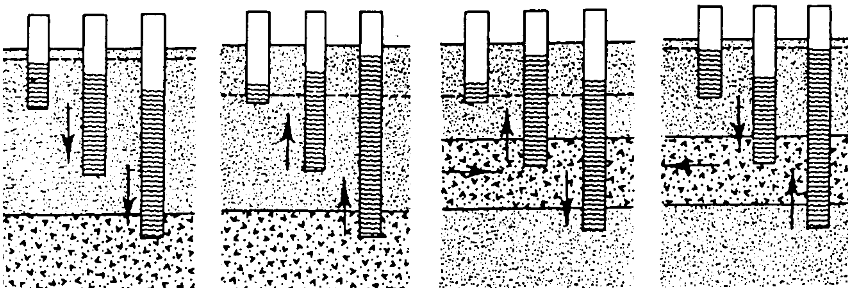
Source: Hunt and Gilkes, 1992

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).

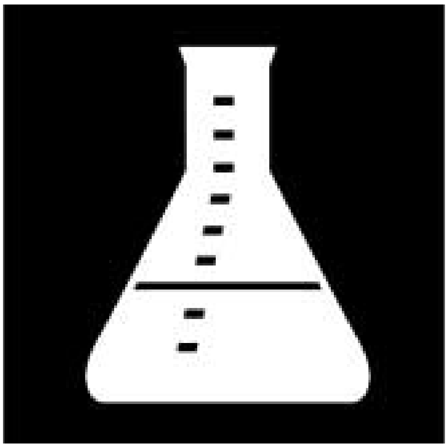
RESPONSE TO THE SALINITY DIAGNOSIS

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.

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:

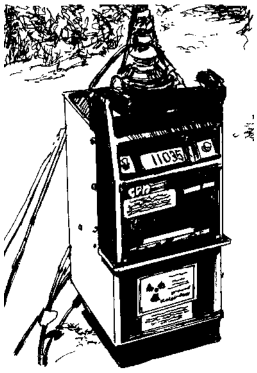
- rapid build-up of sediment in tail drains (often associated with rapid-flow irrigation systems)
- rills caused by flowing water within fields (particularly on the bed shoulders)
- dust movement when the weather is windy
- sand-blasting damage of seedlings after strong wind.

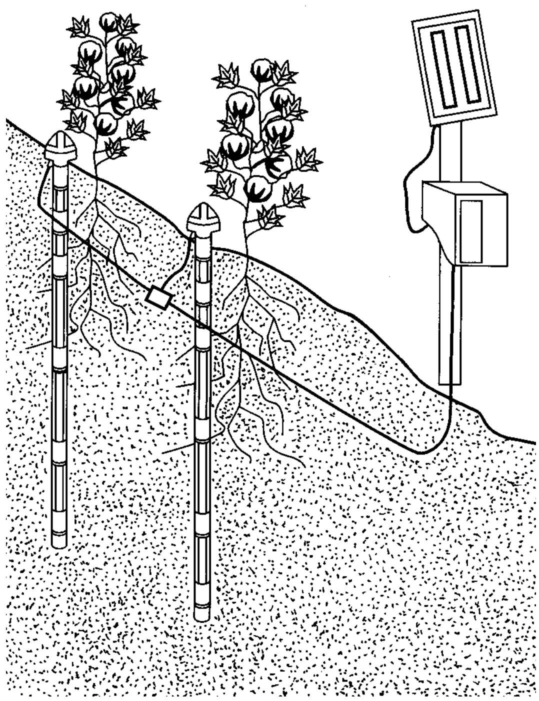
Protection of the soil surface with an organic mulch (see Chapter C6, ‘Stubble’) will do much to alleviate these problems.

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

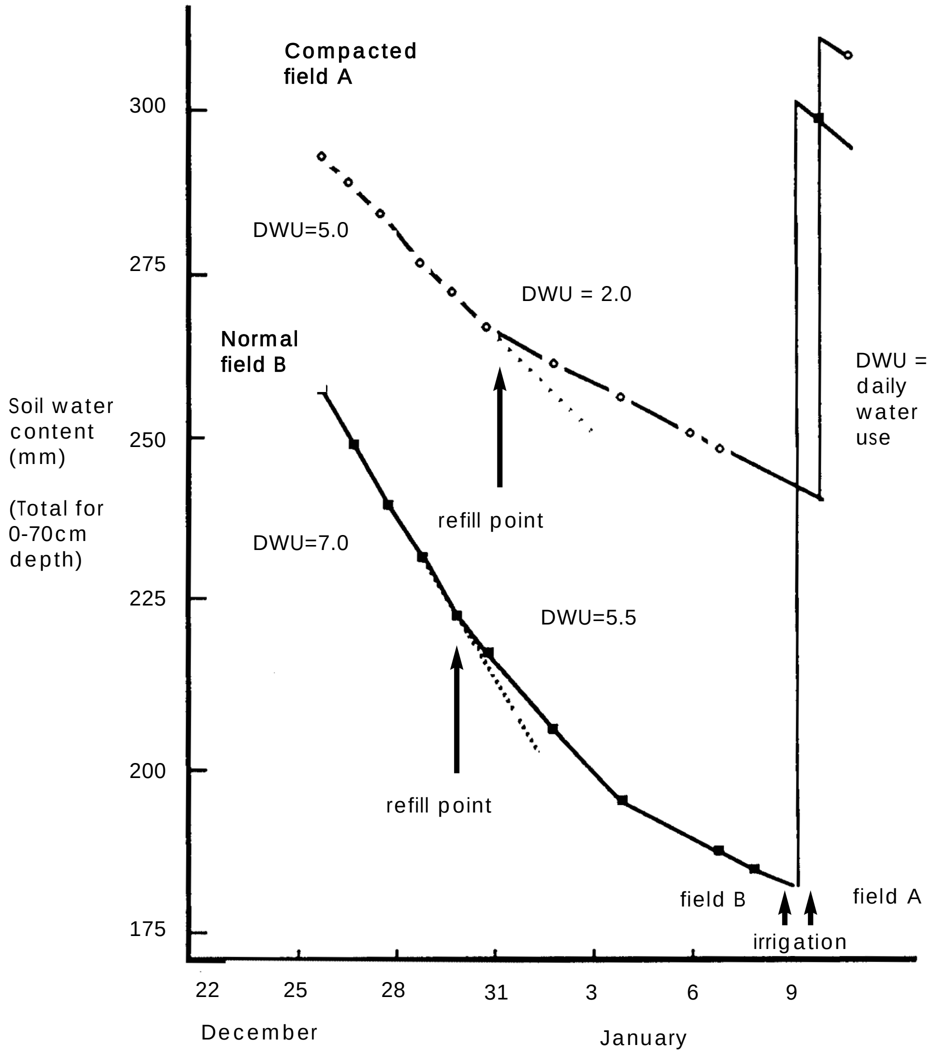
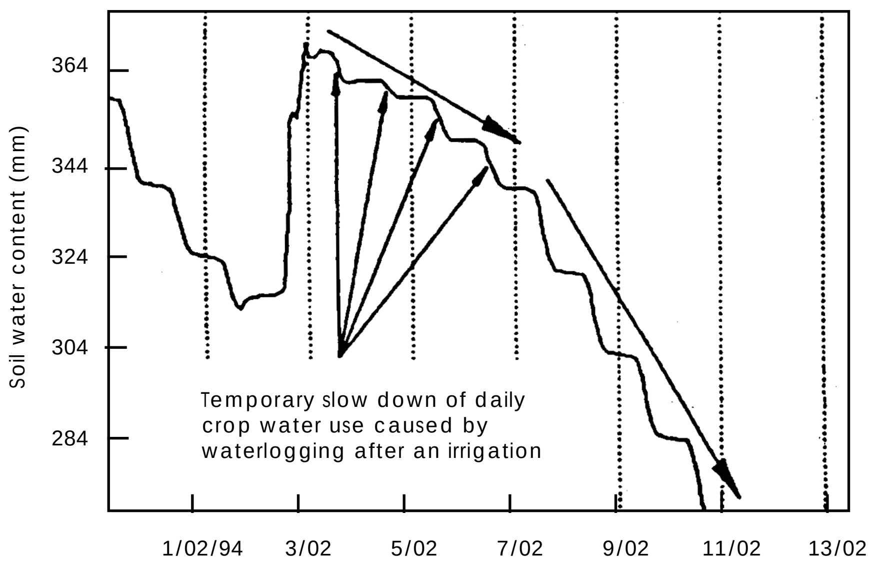


Figure C9-2. Changes in the water content in a clay soil under cotton at Emerald. The water content was measured to 100 cm depth, with a capacitance probe, just before and soon after irrigation.

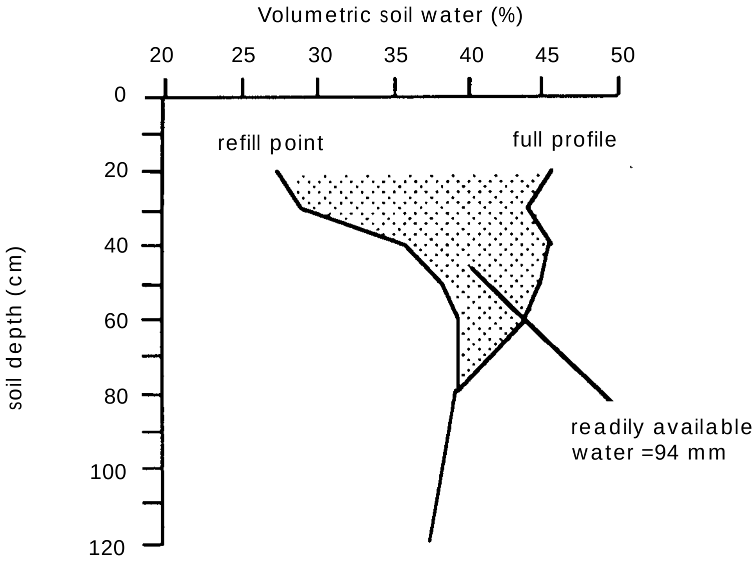


Moisture extraction profile

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



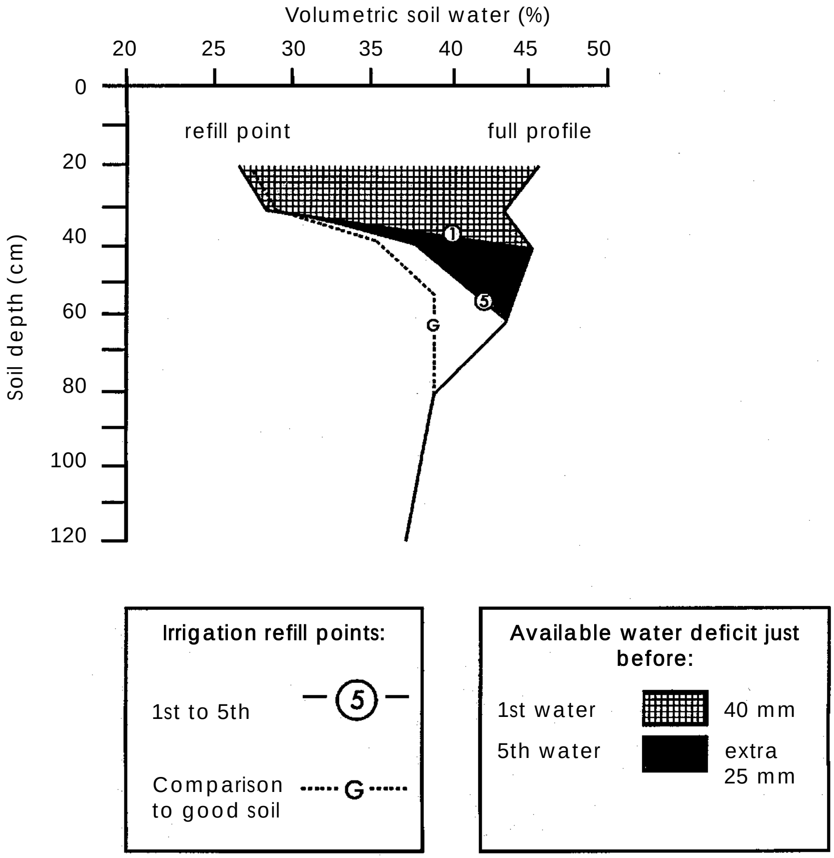
The soil water profiles in Figure C9-4 show what may happen with severe compaction. The diagram shows a series of refill points as the season progresses. On each irrigation the crop was able to use more water as it penetrated the compaction zone. However, at no stage was the crop able to extract as much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

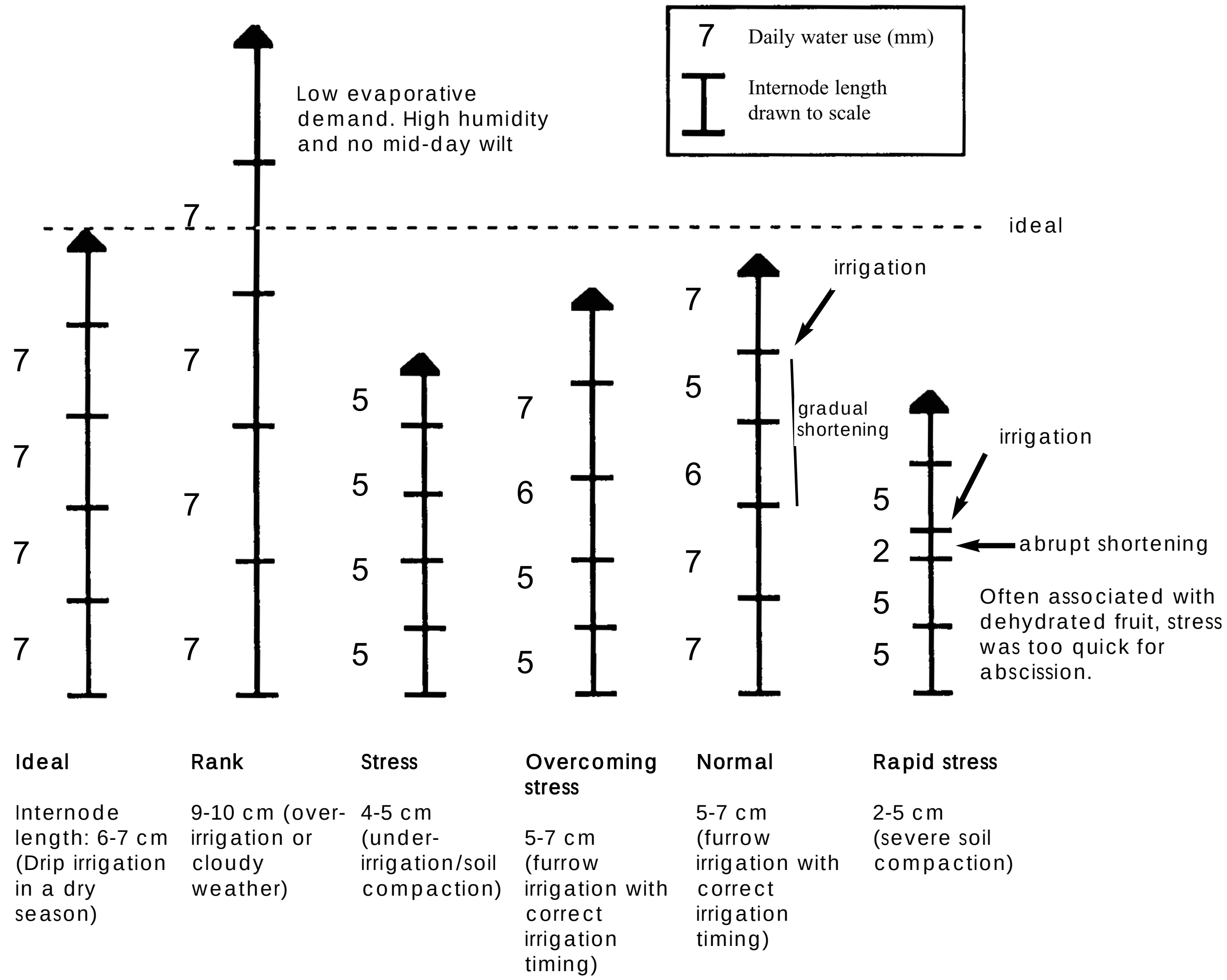


Figure C9-5 shows some different patterns of internode length and what they can tell you about the biological activity of the plant. The figure also shows the daily water use (as determined by a neutron probe) corresponding to each internode length. The observation of internode length can be made at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

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.

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.

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See Chapter C1 for more information on soil pit digging.

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See Chapter D2 for more information on improving soil structure.

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’.

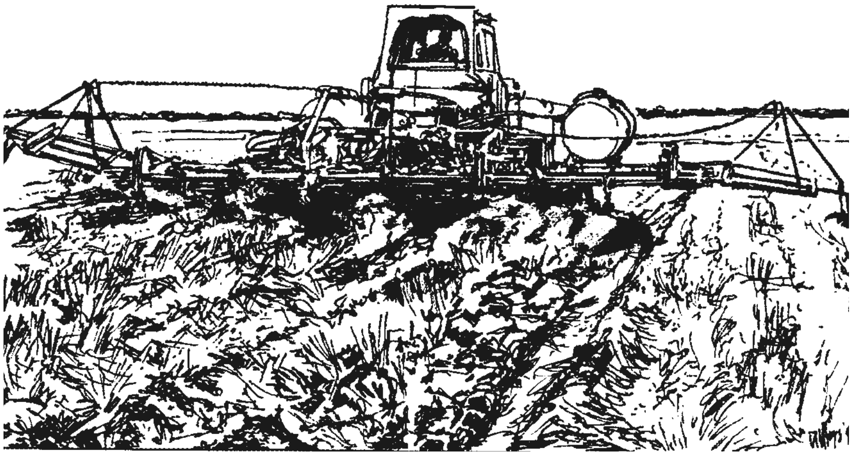
As an example, consider the measurement of exchangeable sodium in the laboratory. If five replicates of a soil sample have very similar ESP values, we say that the result is very precise. However, if the standard solutions used to calibrate the measuring instrument were prepared incorrectly, the results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

D1. Avoiding soil structure and waterlogging problems



PURPOSE OF THIS CHAPTER

This chapter explains how damage to the soil can be avoided so that optimal soil structure is maintained. It also describes how associated waterlogging problems can be minimised.

CHAPTER OVERVIEW

This chapter covers the following points:

- care under wet conditions
- machinery weight and controlled traffic systems
- minimum tillage
- organic matter accumulation
- crop residues and diseases of cotton
- crop rotations
- field architecture to prevent waterlogging
- implement adjustment
- preventing a decline in structural stability caused by poor quality irrigation water.

Other chapters to refer to are:

- Chapter B3: 'Harvesting cotton on wet soil'
- Chapter C3: 'Soil moisture (before tillage), soil texture • and available water'
- Chapter C4: 'Structural condition'
- Chapter D2: 'Improving soil structure'
- Chapter E2: 'Compaction and hardsetting'.

The MACHINEpak manual (available from the Technology Resource Centre, Australian Cotton Research Institute, Narrabri) contains detailed descriptions of the types of implements being used for conservation farming in the Australian cotton industry.

INTRODUCTION

Generally it is more profitable to avoid soil problems than to repair them.

This chapter describes options for maintaining a desirable soil structure when growing cotton. Tactics and strategies for avoiding soil problems are summarised in Table D1-1.

Table D1-1. Tactics and strategies to avoid soil structure problems when growing cotton.

Short-term tactics	Long-term strategies
avoid trafficking wet soil	minimum tillage
controlled traffic systems	controlled traffic systems
foliar and side-dress fertiliser	pre-plant fertiliser and water-run urea
quick irrigation	adequate drainage
sharp-tined implements	appropriate crop rotation
	conserve organic matter
	encourage soil biological activity

Always assess soil structural condition before embarking on a structural maintenance program. There may be pre-existing problems that need to be overcome, for example, by once-only deep ripping.

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See Chapter D2 for more information on improving the condition of your soil.

TAKING CARE UNDER WET CONDITIONS

On cotton soil, the soil strength varies greatly with the water content. Soil strength varies by a factor of about one hundred as the water content varies from wilting point to field capacity.

The rule of thumb for safe tillage and traffic is to have the soil drier than the plastic limit (PL). If the soil is wetter than the PL, the chance of suffering damage (compaction and smearing) is greatly increased.

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See Chapter C3 for more information on plastic limits.

At times, short-term considerations, such as the need to harvest a crop, will take precedence over the need to maintain soil structure. If circumstances require you to traffic the soil when doing this will cause damage, try to limit the damage to defined pathways and minimise wheel slip. This should preserve at least some zones with good soil structure for the following crop.

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See Chapter E2 for more information on compaction processes.

MACHINERY WEIGHT AND CONTROLLED TRAFFIC SYSTEMS

Controlling where wheels travel becomes increasingly important as the weight of machinery increases and the soil water content increases.

The amount of deep subsoil compaction increases as axle load increases. Cotton pickers have axle loads as great as 14 t. By limiting damage to known paths that are away from where plant roots will be foraging, large areas of soil can be preserved in optimum condition. This system is a key factor in the long-term control of compaction. Additionally, a conversion to controlled traffic farming systems is likely to reduce fuel consumption greatly in the row cropping equipment through a combination of lower draft requirements (as tillage is restricted to uncompacted plant lines) and less rolling resistance in the high strength ‘roadways’ between the plant lines.

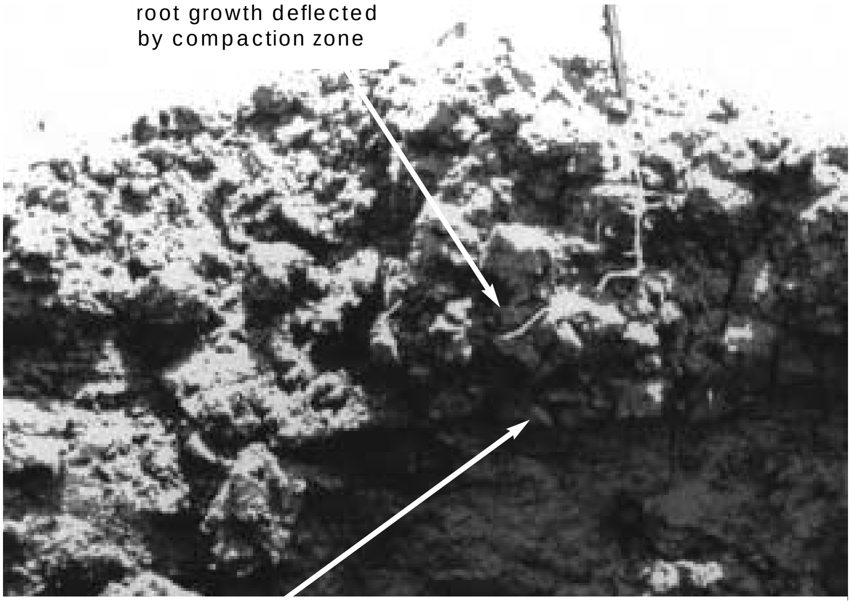
The biggest hurdle to overcome with controlled traffic is the matching of cultivation and sowing equipment with that of harvesting machinery.

Equipment manufacturers need quickly to develop industry-wide standards for wheel spacings. Excessively wide wheels and tracks also create problems; they should be as narrow as possible (see 'Field architecture to prevent waterlogging' section below).

Once compatible wheel spacings and widths have been developed, the next challenge is to steer the equipment in a straight line to minimise the lateral spread of compaction from the main wheel tracks. Recently developed guidance equipment, such as the 'USQ/Case Vision-Guidance' equipment and the 'Beeline' scheme, will help to minimise this problem.

If you have been using controlled traffic systems for a number of years, examine the soil occasionally to ensure that the plant line in the beds has not moved over previous wheel paths (see Figure D1-1).

Figure D1-1. Deflection of a cotton root where a hill was inadvertently shifted sideways on to an old furrow



MINIMUM TILLAGE

Minimum (reduced) tillage for cotton production refers to the maintenance of permanent ridges or beds, with only occasional furrow delving to build up the ridges, plus shallow tillage for Heliothis pupae and weed control. Reducing unnecessary tillage operations can lower the cost of crop production. It also minimises the risk of structurally unstable (sodic) material from the sub-surface and subsoil being brought to the surface.

'Minimum tillage' is a term that has been used to suggest a simple answer to all structural degradation problems; the reality tends to be more complex. A conversion of conventionally farmed land to minimum tillage often produces disappointment because of failure to recognise problems—such as compaction or sodicity—that require treatment before conversion.

If there is excessive soil moisture at planting time and uncontrolled traffic over fields designated as 'minimum till', there can be as much soil structural damage as that found on any conventionally cultivated land. Controlled traffic, therefore, is a vital component of minimum tillage systems.

ORGANIC MATTER ACCUMULATION

The maintenance or improvement of soil organic matter content is important, especially on lighter textured soils. This helps to aggregate the soil, and provides food for earthworms and ants, which permeate the soil with their burrows. It also provides a slow-release source of nutrients.

Cracking clay soil in general has naturally low organic matter levels.

Despite the low organic matter levels, cracking clays still have good structure, due to the self-mulching behaviour of the clay. Nutrients are also held by clay particles and are available to plant roots. Nevertheless, all cotton soil is likely to benefit from mulching.

Try to maintain a thick cover of cereal straw on top of the beds. Soil biologists at ACRI, Narrabri, have shown that mulches increase soil water content near the soil surface. This improves root accessibility to near-surface nutrients that normally lie unextracted in the very dry soil (at 0–10 cm), thus greatly improving the early-season growth of cotton. Mulches also protect the soil surface from raindrop impact, and reduce rill erosion of the bed edges.

Weed control is a major challenge under stubble on permanent beds. The application of granular herbicides activated by rain or irrigation is a useful option, but tends to have coverage problems. If there is increasing reliance on herbicides rather than tillage, herbicide resistance becomes a long-term concern. Another problem is the expense of herbicides, although prices are tending to decrease. On the other hand, mechanical weed control breaks the stubble anchorage and makes the stubble more prone to block equipment and float with the irrigation water. Much remains to be learnt about this important topic.

Wireworm activity may be increased by mulching, but these worms can be controlled by the application of granular insecticides at planting time. Nitrogen tie-up (N immobilisation) can be overcome by adding urea (20–30 kg N/ha).

Organic matter left on the surface between crops will lessen the effect of raindrop impact. Heavy raindrop impact can fragment the surface soil and lead to erosion, or break down the surface soil structure to create hardsetting of the surface layers.

In some soil, the presence of living organic matter in the non-cotton season may be critical in maintaining mycorrhizae for adequate cotton growth.

Living plants and their foraging root systems allow the soil to go through a number of drying (shrinking and cracking) and wetting (swelling) cycles that can improve the structure of cracking clay soil.

Exudates from plant roots and dead root material add to soil organic matter. The total amount from this source may not be great, but its placement along the sides of continuous vertical channels may greatly improve soil condition. Bare fallow cannot do this.

Cotton residue should, where possible, be conserved. It contains valuable nutrients. However, caution is required with diseases of cotton. Infested crop residues can float in tailwater and stormwater, and therefore may be moved from one field to another. Where disease control by crop rotation is not feasible (see below), it may be necessary to incorporate the cotton residues into the soil or—as a last resort—rake and burn. Consult a plant pathologist if you require further information on this topic.

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See Chapter E5 for more information on soil organic matter.

CROP RESIDUES AND DISEASES OF COTTON

The pathogens that cause the following cotton diseases can all survive from season to season in infected crop residues:

- seedling diseases, caused by *Pythium* spp. and *Rhizoctonia* spp.
- black root rot—this pathogen survives as spores in the soil surrounding the root channels from the previous crop and in root system residues in the hill; newly developing roots of the next crop will be positioned over the greatest concentration of inoculum if they follow old root channels
- verticillium wilt—stubble incorporation reduces survival by quick breakdown of residues; the use of resistant cultivars also helps to overcome the problem
- alternaria leaf spot—the pathogen survives from season to season on crop residues retained on the soil surface; most cotton cultivars are now resistant to this disease
- bacterial blight—rarely a problem now, due to the breeding of tolerant varieties.
- phytophthora boll rot—this occurs when inoculum in the soil is splashed up on to the low bolls of a crop by rain
- fusarium wilt—incorporation encourages the pathogen to sporulate further on the surface of each piece of infected residue; it is best to leave infected residues on the soil surface, where there is a greater chance of disinfection; another possible strategy is to inoculate the soil with suppressive organisms.

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See Chapter E5 for more information on crop residues.

Research is under way at ACRI, Narrabri, to develop control strategies for the two most serious soil-borne diseases, black root rot and fusarium wilt. The resultant farm management packages may, due to the lack of practical alternatives, have to include tillage and/or burning practices that make soil structure management more difficult.

CROP ROTATION

Crop rotation can be very useful in avoiding soil problems and maintaining soil structure.

- Appropriate rotation helps to suppress soil-borne disease and weeds.
- Rotations that avoid a long fallow can keep populations of symbiotic mycorrhizae active.
- Actively growing plant roots of rotation crops help to penetrate compacted layers of soil, leaving old root channels as pathways for water, and for the roots of subsequent crops. When the roots of rotation crops extract water, they loosen the soil by creating shrinkage cracks. Soil fauna (for example, ants and earthworms) may be encouraged by mulch from the rotation crop, thus creating more biopores.
- Irrigation management of the rotation crop should force the crop to explore the soil for moisture, rather than aim for maximum yield, so that extensive cracking occurs.
- The chances of being able to drive across a clay soil without causing compaction or smearing are greater where rotation crops are grown (as opposed to bare fallow), because of this moisture extraction.

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See Chapter D2 for more information on rotations.

FIELD ARCHITECTURE TO PREVENT WATERLOGGING

Bed/hill dimensions and management

As the bed height above the furrows becomes greater, waterlogging severity decreases and early-season temperatures increase, particularly on heavy clay soil. A practical limitation, however, is that steep bed edges are difficult to maintain (they tend to slump). Loose bed edges are prone to water erosion.

Beds that are 2 m wide have more soil protected from waterlogging than a pair of 1 m wide hills, provided that surface drainage is available for the shedding of excess stormwater from the bed centres. Surface drainage from bed centres, and from the main furrows spaced 2 m apart, becomes less of a problem as the field slope increases.

However, there may be problems with excessively slow lateral water penetration (subbing) into beds as the field slope becomes greater. Subbing problems are most evident on soil with severe bed shoulder compaction, on sodic soil, and on light-textured soil with water penetration problems. More detailed specifications about bed architecture cannot be given until further research has been done.

Options to deal with bed shoulder compaction problems include (see Figure D1-2):

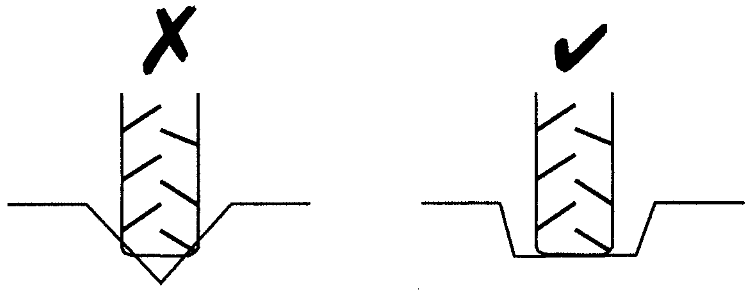
- Widen the furrows (perhaps each pair of cotton rows can be brought closer together, therefore widening the furrows between 2 m wide beds). Flattening the base of furrows will also help to reduce tyre pressure on the bed edges.
- Select wheels/tracks that are narrower.
- As a temporary measure, gas knives can be set to break out the zone that is impeding water flow into the root zone. Be careful, however, not to create a structure that allows too much water into the root zone. If the subsoil drainage is poor, water will tend to fill up the pores of soil in the overlying layers, and perhaps create a waterlogging problem.
- Where possible, avoid driving on the soil when it is wetter than the plastic limit.

An apparent advantage of beds is that calcium salts in the irrigation water concentrate near their centres and improve structural stability. In the Macquarie Valley, for example, about 1.5 t/ha of salt are deposited via the irrigation water. However, the sodium adsorption ratio (SAR) of the irrigation water (approximately 2) has (at least until now) been low enough for the salt to do more good than harm. Structural improvement in the bed centres is also due to freedom from wheel traffic, shrinking and swelling and biopore formation.

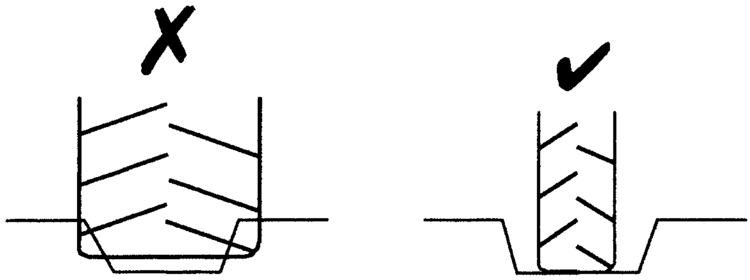
Under dryland conditions, waterlogging is a concern in some years. Therefore, raised beds have a role to play, particularly on heavy clay soil in flat areas, in rain-fed areas. Excess water is drained from the surface via the furrows. Beds also help to define the controlled traffic laneways.

Occasionally there are situations where cotton can be planted into flat soil without suffering major waterlogging problems—for example, well drained red soil, or clay soil with particularly good surface structure and a suitable slope. This may suit ‘narrow row cotton’ (85 cm spacing), where it is particularly difficult to build high hills/beds.

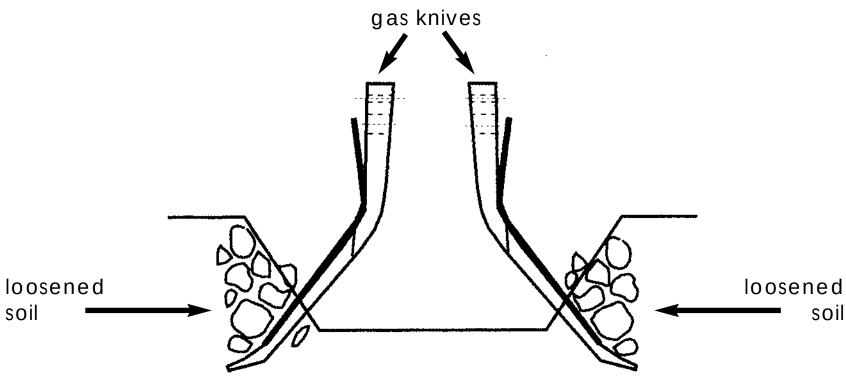
Figure D1-2. Options for dealing with bed shoulder compaction problems.



1. Widen and/or reshape the furrows



2. Make wheels and/or tracks more narrow



3. Break out damage with gas knives (a temporary solution)

However, this approach tends to be more risky than the use of raised hills and beds. To improve early season canopy closure, as well as to minimise waterlogging problems, the planting of ‘ultra-narrow row cotton’ (30 cm spacing) on 1.8 m wide raised beds may be the best option.

Water application

To minimise waterlogging damage on clay soil under surface irrigation, apply the water as quickly as possible via large siphons or multiple siphons. Furrows can be protected from water erosion by having anchored stubble on the bed edges, although this technology is not fully developed.

On hardsetting soil, small siphons can be used to apply irrigation water more slowly than with large ‘through-the-bank’ water outlets. Where beds of aggregates have been slowly wetted, the aggregates retain their identity when they are subsequently ponded. Cereal straw in the furrows may also slow the irrigation water, and encourage infiltration via biopores produced by roots of the cereal crop. It may

eventually become possible, by using accurate guidance systems, to run the wheels of machinery along the tops of the beds in hardsetting soil, and to dedicate the furrows to water delivery and surface drainage.

Another option to consider is the use of drip irrigation. Although it is very expensive to establish (about $3,000/ha), and requires a high degree of management expertise, drip irrigation allows water application to be restricted (usually to the middle of 2 m wide beds), thus allowing the wheel tracks to remain dry and firm when there is no rain. Therefore, the risk of wheel compaction and waterlogging is reduced, and there is extra space in the soil for storage of rain when it does fall.

Surface drainage

Cotton fields should have enough slope for efficient irrigation and drainage (no flatter than about 1:2,000). Waterlogging on poorly sloped fields can be responsible for significant yield reductions (12 kg lint/ha/hour of waterlogging). Flatter fields should have shorter run lengths to minimise the duration of flooding.

However, providing a desirable slope by landforming (preferably laser-guided) may expose sodic subsoil; the sodic material removed by cutting may be spread over large areas of a cotton field. Exposed sodic subsoil can create problems of poor water infiltration, and poor seedling survival due to waterlogging. If you have prior knowledge of the depth of sodic subsoil, you can conceive a design that minimises exposure of problem layers.

Although underground drainage is not considered an economically viable option in cotton, it is practised in other parts of the world to reduce waterlogging.

☞

See Chapter D4 for more information on subsoil drainage.

IMPLEMENT ADJUSTMENT AND WEAR

It is well known that certain designs of implement, for example disks and rotary hoes, are likely to cause plough layers or hardpans over large proportions of a field if used repeatedly at the same depth. Even the point of a chisel plough will cause smearing, particularly if used under moist conditions, but the percentage of a field affected by this damage will be relatively small.

Implements such as spading machines (spadevators) avoid smearing the bottom of the tilled zone, as the soil is contacted by the metal cutting edges only in the vertical direction. However, such devices are unable to cover large areas quickly and economically.

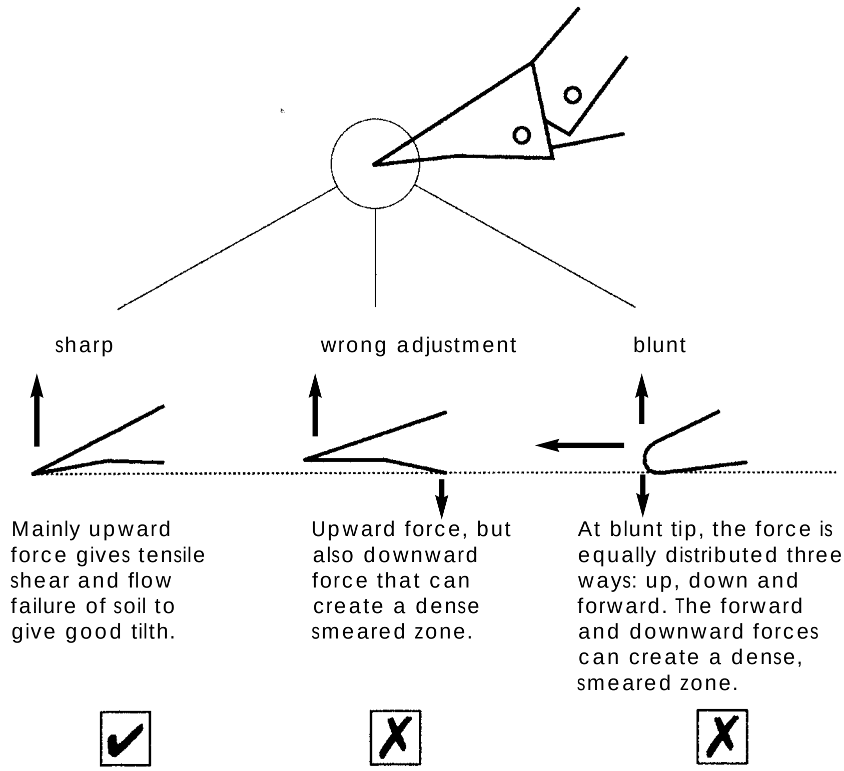
Implement adjustment and wear can also affect compaction, especially if the soil moisture level is above or near the plastic limit. As a tool wears and becomes blunt, the downward force from the tine into undisturbed soil increases (see Figure D1-3). Generally speaking, the compaction (smearing) will be severe, but will only extend over a short vertical distance.

WATER QUALITY AND SOIL STRUCTURE

All irrigation water contains dissolved salt, particularly if it is pumped from bores. Soil structural stability will be adversely affected if there is too much sodium in relation to calcium.

Test for this problem by sending water samples to your laboratory. Ask them to measure ‘sodium adsorption ratio’. If it is too high (see

Figure D1-3. Implement adjustment and wear in relation to the soil.



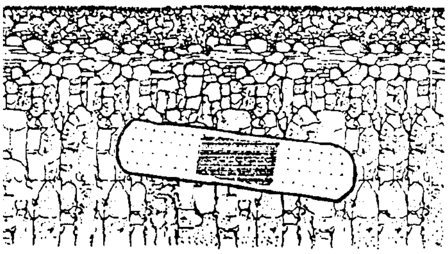
Chapter C7), counterbalance the sodium with calcium from gypsum. Soil structural decline caused by the use of sodic irrigation water can be severe enough to prevent water entry, even under drip irrigation.

OVERVIEW

Avoid serious damage to the soil structure along the plant lines. Carefully consider the following options:

- Where possible, till and drive in cotton fields at appropriate soil moisture contents.
- Use controlled traffic for all field operations (they will become easier to maintain as guidance systems become widely used); minimise vehicle weight.
- Provide a field architecture that encourages water entry without waterlogging the system.
- Encourage organic matter accumulation and biological activity, so that biopores are formed, but be careful not to aggravate cotton disease problems.
- Maximise soil swelling and shrinking.
- Adjust soil-engaging implements so that structural damage is minimised.
- Avoid sodium build-up via the irrigation water.

D2. Improving soil structure



PURPOSE OF THIS CHAPTER

This chapter presents options for repairing physically degraded cotton soil in a cost-effective fashion.

CHAPTER OVERVIEW

This chapter covers the following points:

- forms of structural damage
- 'biological ripping' with rotation crops
- deep tillage
- applying gypsum, lime and organic materials.

Other chapters to refer to are:

- Chapter A2: 'The ideal soil for cotton'
- Chapter B1: 'Trouble-shooting guide'
- Chapter B2: 'Soil preparation options after a dry cotton harvest' (Figure B2-1)
- Chapter B4: 'Soil preparation options after a wet cotton harvest' (Figure B4-1)
- Chapter B5: 'Soil preparation options after a rotation crop'
- Chapter B6: 'Nursing a cotton crop in a damaged soil'
- Chapter C3: 'Soil moisture (before tillage), soil texture and available water'
- Chapter C4: 'Structural condition'
- Chapter C5: 'Structure after rotation crops and tillage'.

WHAT IS A DAMAGED SOIL?

Soil degradation makes crop production less profitable than it could be. Types of damage include:

- structural damage
  - —mechanical damage
  - —chemical dispersion
- exhaustion of plant nutrients
- pH imbalance
- high salinity
- erosion
- impairment of soil biological function.

Structural damage can be a major concern on both cracking clay soils and hardsetting soils. It is caused mainly by:

- mechanical damage (which can involve compaction, smearing and remoulding) due to tilling the soil, or driving on it, when it is too wet
- chemical dispersion (disintegration of microaggregates in water); caused by high levels of exchangeable sodium and/or magnesium and/or a lack of electrolyte and organic matter; this is aggravated by remoulding.

REPAIRING STRUCTURAL DAMAGE

The three main methods for managing soil structural degradation under cotton are:

- ‘biological ripping’
- deep tillage
- adding soil conditioners.

‘Biological ripping’—growing a crop with no (or minimal) irrigation—creates the wetting/drying, shrinking/swelling cycles that disrupt compacted and smeared layers. The soil type and mineralogy will affect the speed of rehabilitation (some soil types swell and shrink more than others). Root growth also helps to restore continuous pores by penetrating massive soil, which leaves cylindrical pores when the roots die and decompose.

Deep tillage acts in a slightly different manner. When the soil is dry enough to shatter, deep tillage will help relieve compaction by creating large pores. Compacted clods then have room to expand when re-wet and crack freely when dry. However, deep tillage is unlikely to restore the ‘natural’ random clay orientation within clods; it is only a first step in restoring natural structure.

Soil conditioners such as gypsum, lime and organic matter can be added to the soil to overcome a soil cation imbalance. An excess of sodium, for example, contributes to poor soil structure by increasing the amount of dispersion within a soil.

The rest of this chapter deals with each of these topics in detail.

‘BIOLOGICAL RIPPING’

Farmers who have cracking clay soil are fortunate. This soil has the capacity to self-repair by shrinking and swelling during wetting and

drying cycles. Crops grown on damaged soil will accelerate the rate of drying. A compacted soil that has been loosened by shrink–swell cycles is said to have been ‘biologically ripped’.

Extreme drying can be brought about by growing a crop or pasture that, when well developed, will extract enough moisture from the soil to dry it to permanent wilting point. This will require favourable seasonal conditions (a dry period after good crop establishment and root growth). Direct drying of the sides of the shrinkage cracks (due to air movement, particularly when windy) may enlarge the cracks even more.

Each crop species has a different pattern of root growth, so different crops will improve different parts of the soil profile. However, a damaged soil may restrict the root growth of even strongly foraging plants.

Wheat (Figure D2-1) is a popular choice. It has vigorous seedlings that are able to cope with the often poor seedbed conditions immediately after cotton harvest. Safflower (Figure D2-2), if carefully managed, can greatly improve soil structure, but it is a less robust option.

Figure D2-1. Wheat

Figure D2-2. Safflower

Maximising shrinking and swelling

Maximise the number and intensity of wetting and drying cycles that the soil is subjected to. The frequency of wetting and drying is particularly important—repeated wet/dry cycles tend to produce smaller clods and finer cracking than a single big drying event.

It appears that black cracking clay soils with a high cation exchange capacity (CEC) require fewer shrink–swell cycles to overcome compaction problems than do grey clay soils with a lower CEC.

Improving crop vigour increases the total amount (and the rate) of moisture extraction from the soil. This can be achieved by using nitrogen fertiliser to stimulate plant growth. The size of clods produced is reduced if the rate of drying is increased.

Irrigate the crop early in its development to promote vigorous root growth and the rapid uptake of water. Wetting the soil with flood irrigation tends to slake and decompact damaged clods more quickly than rainfall.

Avoid late irrigations that will leave the soil moist at harvest. The restorative effects of any crop can be negated if the field has to be harvested when the soil is wet (following rain or late irrigation). A follow-up rotation crop—for example, sudax/cowpeas after wheat—may be required to re-dry the soil.

Biological ‘middle-busting’

Rather than growing a crop such as wheat over an entire field, it is possible to limit the sowing to the furrows and bed shoulders, so that crack formation is encouraged under the cotton plant lines. Soil cracks where it is weakest—that is, in the bare and moist soil mid-way between the lines of actively growing rotation crop plants.

The rotation crop therefore can be used as a low-cost ‘middle-busting’ operation to disrupt moderate compaction problems under the plant lines before you plant the next cotton crop.

Water extraction

Water extraction from the top 70 cm (where most compaction effects will lie) is more important for soil structure regeneration than the absolute depth of drying that a crop can achieve (See Table D2-1).

Table D2-1. Relative values of water extraction for a range of crops.

Of little value for soil drying. Soil may be left in a moist state	**Of some value for soil drying and restoration**	**Valuable for soil drying and restoration**
Water deficit in the top 70 cm: **80 mm** Depth of drying: **80 cm**	Water deficit in the top 70 cm: **100 mm** Depth of drying: **100–120 cm**	Water deficit in the top 70 cm: **140 mm** Depth of drying: **120 cm+**
Bare fallow with a few weeds Maize Soybeans	Cotton (late irrigation) Winter grain legumes Pasture (clovers)	Cotton (well established dryland crop or dry finish to irrigated crop) Wheat Safflower Sunflower Cereal crops in general Grain sorghum Faba beans Pasture (lucerne, ryegrass)

Pests, weeds and diseases

Rotation crops can either break or continue the life cycles of insect pests and disease organisms. Be aware of the potential of a crop to break or maintain these cycles (see Tables D2-2 and D2-3).

Table D2-2. Rotation crops and potential pest and weed risks.

Crop	Very helpful in breaking the cycle for:	Moderately helpful in breaking the cycle for:	No effect on:	Moderately likely to increase problems with:	Very likely to to increase problems with:
Cotton	wireworms			Heliothis[1]	
Wheat				thrips	wireworms
Safflower				weeds	mirids
Sunflower				weeds, Heliothis[2]	mirids
Soybean			mites	mites[3]	
Cereals				thrips	wireworms
Pasture					
Weed fallow				mites[4], weeds	weeds, wireworms, mirids
Maize		Heliothis[5]		Heliothis[6]	mites
Grain sorghum					Heliothis
Winter grain legumes					Heliothis
Bare fallow	Heliothis, mirids, mites			mycorrhiza deficiency	

[1] If not cultivated.
[2] If the sunflower is flowering in December.
[3] If soybeans are early and infested with mites in December or January.
[4] If weeds are left until just before planting (less than a month before) and are then turned under the soil, mites can survive on the green plant material under the soil for a short period. These mites will re-emerge to infest the cotton seedlings, giving a potential mite problem for the rest of the season.
[5] Flowering maize may briefly attract *H. armigera* away from cotton crops.
[6] When maize has finished flowering it is unattractive to the laying *H armigera* moths, but development of another generation of larvae will continue on the crop; important with December flowering maize.

Table D2-3. Rotation crops and potential disease risks.

Disease status when grown before a cotton crop	
INCREASE	Increases the problem
DECREASE	Combats the problem
?	Conflicting evidence
–	No information

	Bacterial blight	Verticillium wilt	Seedling disease	Phytophthora boll rot	Alternaria blight	Black root rot	Fusarium wilt
SUMMER CROPS							
Cotton – susceptible	INCREASE	INCREASE	INCREASE	INCREASE	INCREASE	INCREASE	–
– resistant	DECREASE	DECREASE	–	–	–	–	–
Soybeans	DECREASE	DECREASE	?	–	DECREASE	INCREASE	INCREASE
Sunflower	DECREASE	–	–	–	DECREASE	DECREASE	–
Maize, sorghum	DECREASE	DECREASE	DECREASE	–	DECREASE	DECREASE	INCREASE
Grain legumes, mung, navy	DECREASE	DECREASE	INCREASE	–	DECREASE	INCREASE	–

	Bacterial blight	Verticillium wilt	Seedling disease	Phytophthora boll rot	Alternaria blight	Black root rot	Fusarium wilt
WINTER CROPS							
Winter cereals	DECREASE	DECREASE (usually)	DECREASE	DECREASE	DECREASE	DECREASE	–
Winter oilseeds (safflower, canola, linseed)	DECREASE	?	–	–	DECREASE	DECREASE	–
Chickpeas, field peas	DECREASE	–	–	–	DECREASE	INCREASE	–
Weedy fallow	DECREASE	INCREASE	–	–	DECREASE	?	–
Bare fallow	DECREASE	DECREASE	DECREASE	DECREASE	DECREASE	DECREASE	–
Lucerne	DECREASE	DECREASE	–	–	DECREASE	INCREASE	–

Advantages of 'biological ripping'

Biological mending of degraded soil structure has several advantages over deep tillage:

- Shrinkage cracks can become natural lines of weakness that persist after the soil re-wets. Mechanically disturbed soil is more likely to consist of fragments touching at angular points. When the fragments re-wet and become soft, they may slump and coalesce back into large, massive blocks. Slaked soil may fill pore spaces.
- Root channels persist as continuous vertical pores. Deep tillage changes the orientation of soil fragments and the pores may no longer line up.
- Biological ripping maintains the strength of furrows, thus improving the soil's ability to support machinery.
- Growing a crop adds fresh organic matter, which is important for soil aggregation, and provides a mulch that protects the soil surface.

☞

See Chapter D4 for more information on mulch management issues.

Drawbacks of rotations

Rotation crops will use valuable reserves of nutrients and water that could have been used by the following cotton crop.

In the short term, growth of a low value crop is unlikely to be as profitable as cotton production.

After a thorough drying to depth, the soil may not return to field capacity with a single irrigation. Water infiltration to lower levels is slow (especially if the lower levels of the soil are sodic), and deep subsoil moisture may not be replenished. The available soil water for the following crop therefore may be limited and more frequent irrigations will be required. On the other hand, the dry subsoil will act as a 'sponge' for any water that leaks from above, thus preventing deep drainage losses when growing cotton.

Alternative crops

A winter crop is particularly useful, because it does not compete directly with cotton for irrigations. A common rotation with cotton is wheat.

Wheat or other cereals

Advantages

- Vigorous seedlings.
- Fibrous root system.
- Dry stubble, relatively easy to deal with.

Cautions

- Ploughed-in stubble can tie up nitrogen.
- Crop should be well established before winter for the best results—this may require early irrigation.
- Poor returns in some years.

Safflower

Severely compacted soil can retard the growth of safflower, although it will still do a good job of drying the soil. Safflower, with a taproot root system, will not improve the surface tilth as much as wheat, with its fibrous root system. The amount of drying in the surface 70 cm of soil (where most compaction will be found) is similar to that in wheat. However, it extracts moisture to a greater depth, and continues to do so well into the summer. Increase sowing rates in old cotton fields where herbicide residues may give poor seedling establishment. Deep tillage after safflower can produce large, boulder-like clods, which are difficult to manage unless they are subjected to wet/dry cycles.

Advantages

- Dries deeper than most other crops, and can create a dry buffer zone in the deep subsoil that controls drainage losses beneath the subsequent cotton crop.
- Drought-tolerant.
- Resistant to damage by birds, pigs and kangaroos.
- Nutrient recycling from the deep subsoil.
- Reduces the severity of nutgrass infestation.

Cautions

- Susceptible to phytophthora and alternaria, and carries other diseases.
- Can harbour cotton pests, especially mirids.
- Requires pest management for high yields.
- Poor competitor with broadleaf weeds.
- Susceptible to frost once out of rosette stage.
- Temperatures above 30°C reduce seed yield and oil content.
- Value of grain variable (consider short-season lucerne as an alternative if the price outlook for safflower is poor; see below).

Winter grain legumes: vetch, faba beans, chickpeas, lentils, field peas, lupins

Advantages

- May improve soil nitrogen fertility if inoculated.
- Grow well in alkaline soil that is deep and medium to heavy in texture.

Cautions

- Limited herbicide options for weed control.
- Poor tolerance of drought and waterlogging.
- Sensitive to high temperatures at flowering.
- Susceptible to Heliothis at pod fill.
- Susceptible to disease.
- Possible retardation of cotton growth due to the allelopathic effects of crop residues.
- Residues decompose quickly, so protection of the soil surface from erosion is limited.

Canola (rapeseed)

Advantages

- High value.

Cautions

- Intolerant of waterlogging.
- A good drying crop, but yields tend to be badly affected by compaction.
- Poor emergence if the soil crusts after rain.
- Does not host mycorrhizae.

Millets

Advantages

- Fibrous root system.
- Dry stubble easy to deal with; quick breakdown.
- Rapid growth and maturation.

Cautions

- Water after millet to germinate volunteers, then spray.
- Fluctuating prices.
- Ploughed-in stubble can tie up nitrogen.

Maize

Advantages

- Fibrous root system, which may increase the soil organic matter content.
- Short-term crop: 90–100 days.

Cautions

- High quantity of stubble.
- Water after maize to germinate volunteers, then spray.
- Uses large amounts of N.

Grain sorghum

Advantages

- Fibrous root system.

Cautions

- Volunteer sorghum in following crops.
- Uses large amounts of N.
- Sorghum herbicides (such as atrazine) may affect the following cotton crop.
- May require sprays for sorghum midge.
- Stubble may be difficult to incorporate.
- Low returns
- *H. armigera* build-up.

Summer grain legumes: Dolichos lablab, cowpeas

Advantages

- May improve soil nitrogen fertility if inoculated.
- Grows well in alkaline soil that is deep and medium to heavy in texture.

Cautions

- Limited herbicide options for weed control.
- Residues decompose quickly, so erosion protection is short-lived.

Sudax–cowpea forage

This mix is particularly useful as a ‘follow-up’ rotation crop when heavy rain has fallen on a field that has just been dried by a winter crop, such as wheat.

Advantages

- Intense drying of the soil with a mix of fibrous roots and taproots.

- Production of a large bulk of root material, which improves soil friability.
- Nitrogen fixation.

Disadvantages

- Disc ploughing may be required to incorporate the large quantities of organic material on the soil surface; this can disrupt the 'permanent bed' system.

Sunflower

Advantages

- Deep-drying.
- Easier in-crop weed control than safflower.
- Develops quicker than safflower.
- No bad disease problems.
- Stubble breaks down well.

Cautions

- Potential disease carrier.
- Can harbour cotton pests, especially mirids.
- May leave seeds that will be a weed problem in the following cotton crop.
- Killed if waterlogged, particularly when hot.
- Poor organic matter producer.
- Poor stubble protection against soil erosion.
- Low salinity tolerance.
- Sometimes severe bird damage.

Broccoli

Broccoli, a high-value vegetable crop sometimes grown in rotation with cotton, has a prolific near-surface root system that apparently improves friability of the surface soil. As friability increases, clod size becomes finer and Heliothis control by tillage is likely to be more effective.

Bare fallow

Soil structural degradation persists under bare fallow because there is little drying and cracking of the soil. Use bare fallow if there is insufficient time to grow a crop before cotton.

Controlling weeds by aerial spraying will save further damage by cultivation, and will conserve soil moisture.

Advantages

- Good weed control.
- Helps break disease cycles.
- Conserves soil moisture.

Cautions

- Will not improve soil structure.
- May cause excessive deep drainage.

- Surface structure may deteriorate if exposed to rain.
- Potential for soil erosion.
- Mycorrhizae depleted ('long fallow disorder').
- Further compaction may be associated with mechanical weed control.

Weed fallow

Certain weeds are hosts for diseases. For example, noogoora burr, bathurst burr, common thornapple, pigweed, saffron thistle, fat hen, red root and Canadian fleabane all host verticillium wilt.

Prevent seed-set by the weeds using herbicides (spray topping) at flowering.

Advantages

- Cheap way of drying soil.
- Weeds may be established long before a crop can be planted.
- Mixture of taprooted and fibrous-rooted plants with the potential to improve both topsoil and subsoil.

Cautions

- Weed seed build-up.
- Irregular stand (bare patches not dried out thoroughly).
- Disease carryover.

Short-term lucerne pasture phase (duration less than 12 months)

Advantages

- Greatly improves soil structure, due to shrink-swell cycles and biopore formation.
- Dries deeper than most other crops, and can create a dry buffer zone in the deep subsoil that controls drainage losses beneath the subsequent cotton crop.
- Fixes nitrogen.
- Acts as a trap crop to manage green mirids in cotton.
- Refuge for beneficial insects such as predatory beetles, bugs, lacewings and spiders, which prey on Heliothis, mites and other cotton pests.

Cautions:

- Intolerant of flooding.
- Difficult to kill (unless the soil is deep tilled).
- Poor emergence if the soil crusts after rain.
- Seed is expensive.
- Lower returns than most of the other rotation options.
- Needs fencing if grazed.

Other information

There are a number of publications by NSW Agriculture and the Queensland Department of Primary Industries that give details of the growing requirements and gross margins of alternative crops to cotton.

Contact these organisations for further information.

DEEP TILLAGE

Smeared, platy or massive layers prevent or slow the penetration of water, air and roots; this may reduce plant growth and yield. The aim of deep tillage is to shatter soil with these features. Usually it follows attempts at soil improvement using rotation crops.

It is important to maximise disturbance with the minimum amount of energy input, and to avoid bringing sodic subsoil to the surface, so selection of tine design is important.

The alternatives are illustrated in Figure D2–9. Parabolic designs are more energy-efficient than vertical ones, and tend not to invert the soil.

Deep tillage (deep ripping or subsoiling) is not always necessary in bed preparation—it should be regarded as a special operation used to cure a specific problem. Thus chisel ploughing to (say) 20 cm, giving just enough depth of loose soil to sweep into the beds, is not considered here to be deep tillage. Deep tillage implies soil loosening to well below the bottom of the seedbed, and is commonly deeper than 30 cm (Figure D2-3).

Figure D2-3. Chisel ploughing after wheat, to a depth of 35 cm.

Deep tillage refers to the disturbance of both hills and furrows. ‘Middle-busting’ is deep ploughing of the soil only under the plant lines. Furrow ripping is of limited value because the soil there will be quickly recompacted.

A mouldboard plough (Figure D2-4) or slip plough (Figure D2-5) can be used to increase the clay content of hardsetting red soil.

☞ *See Chapter D9 for more information on increasing the clay content of red soil.*

Loosening of the soil by mechanical methods is expensive. The economics of deep tillage will depend on the value of the expected increase in yield, in relation to equipment running costs.

Deep tillage may lead to disappointment. Remember that the yield of cotton is a function of a number of variables, one of which is soil structure. If soil structure was the limiting factor and this has been improved, adjust your management to ensure that no other factors are limiting. For example, if you deep till after using a cereal crop to dry the soil, be aware that the crop will have depleted soil nitrogen, which will have to be replenished.

Figure D2-4. Deep mouldboard ploughing to a depth of 40 cm in hardsetting soil near Trangie.

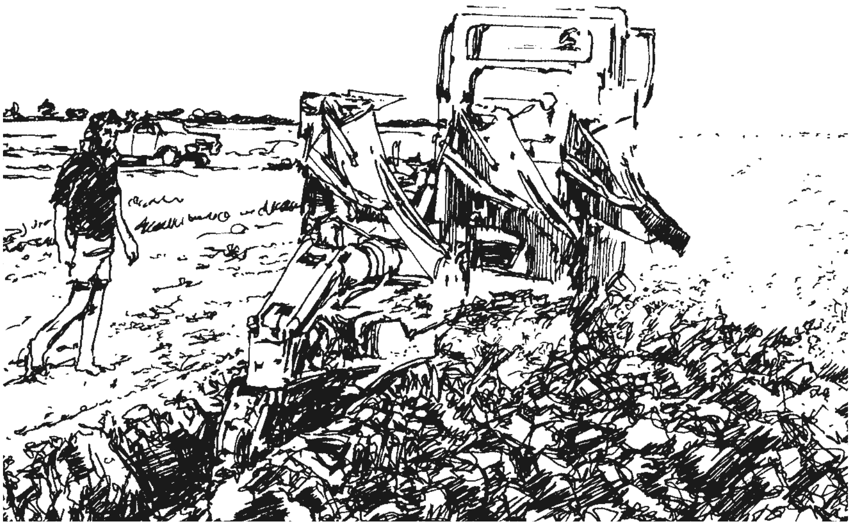


Figure D2-5. A Californian slip plough, which brings subsoil clay to the soil surface from a depth of about 1 m.

Why deep till and when ?

You may decide to deep till if:

- inspection of the soil profile in a pit shows degraded layers (particularly layers that are continuous and will impede root penetration) (SOILpak score less than 0.5) that are so severe that you cannot repair the structure with biological methods in a reasonable time
- the soil is dry (drier than the plastic limit) to at least the depth to which you need to till
- there are serious problems with nutgrass infestation.

Deep tillage sometimes fails

There are times when deep tillage shows, at best, no benefit or, at worst, yield loss. In such cases, ask the following questions:

- Was there a damaged layer that had to be disrupted?

- Was the operation done under the right conditions? (Was the soil drier than the plastic limit through the full depth of tillage?)
- Was the machinery suitable for the task?
- Was crop management adjusted to take account of the new soil conditions? Where the field is very flat and poorly drained, deep tillage can increase waterlogging by improving water intake into the subsoil. You may need to reassess irrigation timing.
- Was sodic soil brought to the surface?

Deep tillage principles

Get the soil moisture right

Soil water content strongly influences the effectiveness of any tillage. A cracking clay soil that is at or below the plastic limit is dry enough to till.

For loamy soil, aim for a water content just below the plastic limit; dust production may be a problem if the soil is tilled when too dry.

Do not deep till if the soil is moist and able to be remoulded. You are likely to do more damage than you will alleviate. Land preparation, including deep tillage, on wet soil causes a substantial reduction in yield (up to 35% yield loss). Best results in a degraded soil will be gained from a combination of drying with a crop, followed if necessary by deep tillage.

Be sure to determine the moisture status at different depths in the soil profile. Use an auger to sample soil across a field at a range of depths. Moulding the soil in your hand will indicate the maximum depth at which tillage can be carried out safely.

If there is any doubt about moisture, check the disturbed soil after a short run of the tillage implement. The danger point is when the implement is bringing up smeared clods, or when you see moist soil adhering to the tines. Smeared clods on the surface will soon mellow by weathering. However, the smeared surfaces within the soil that are associated with these clods will take much longer to improve.

Be prepared to re-examine the soil as the tillage process proceeds —soil moisture conditions may change due to factors such as weather, position within the field and soil drainage characteristics. When deep tilling, quality control is important!

☞

See Chapter C3 for more information on plastic limits

☞

See Chapter D9 for more information about the tillage of loamy soil.

☞

See Chapter C3 for more information on assessing the safe tillage depth for your soil.

Be aware of the critical depth

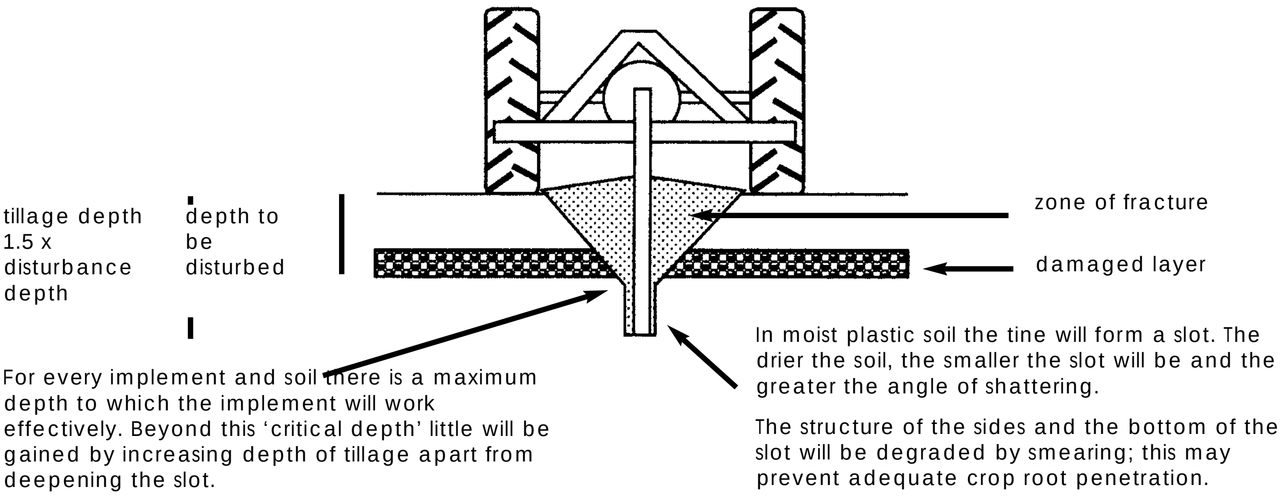
A single pass with a deep tillage implement will not loosen all soil to the working depth of the tine. A given design of tine has a critical depth, which varies with soil type and soil water content. Working deeper than the critical depth will not increase the depth of disturbed soil.

A disturbed area will form that at the most will be at an angle of 45° from some point on the tine to the surface (Figure D2-6). If a massive clay soil is very dry it will tend to break out in blocks; consequently the soil disturbance will be related more to block shape than to tine design.

Consider two passes

If you are trying to break a severely damaged layer, do two passes with the tillage implement. A single pass has the tendency to leave a slot (Figure D2-6), especially if moisture levels are high.

Figure D2-6. Deep tillage with tined implements.



You will get best results by crossing the two paths of deep tillage at 45° (the first pass at 90° to the rows). This gives extra depth, compared with crossing the paths at 90°. American trials have shown a small advantage using this method (an extra 3 cm of disturbed soil was gained, compared with crossing the ripping paths at 90°).

As a rule of thumb, you should run the deep tillage tine at 1.5 times the expected depth of tilled soil in order for the implement to loosen soil in the trench above the slot.

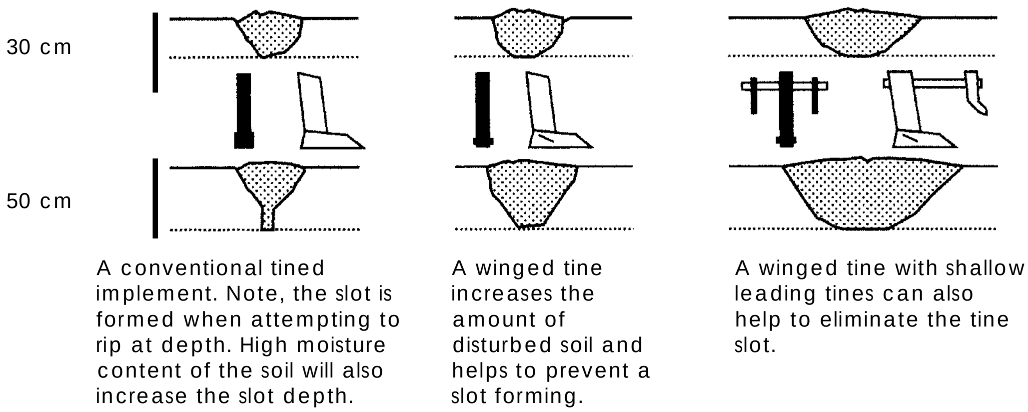
Use wings and leading tines

There are two methods of increasing soil disturbance with deep tillage. One method is to add wings to the tines; a second method is to use shallow leading tines that pass through the soil in front of the deep tines (Figure D2-7). These shallow tines are spaced apart at 2.5 times the depth of working of the deep tine. Shallow leading tines do not greatly increase implement draft.

The use of shallow leading tines may even allow deep tillage in soil with a water content greater than the plastic limit. Brittle fracture can be induced in such soil if the confining stresses are kept very low. However, this option should be regarded as being risky!

Shallow tillage followed by deep tillage in separate operations is often not successful. The first pass (shallow tillage) produces a soft surface, which reduces traction for the second, deeper pass.

Figure D2-7. A comparison of the patterns of soil disturbance of different implements at two depths (adapted from Spoor and Godwin 1978).



Another method that has helped to reduce energy requirements when tilling at depth is the laying out of the tines in a V-shaped pattern (Figure D2-8). This pattern allows the following tines to travel in partly disturbed soil, thus requiring less force to disturb a given depth of soil.

Choose an appropriate tine angle

Tillage implement designs used in the Australian cotton industry have changed greatly since the late 1970s. One of the major differences is the angle of penetration of the tillage tine. Old systems typically had a tine that penetrated the soil at 90°. These designs were more likely to smear slightly moist soil.

Most of the tines used currently have a sharper angle of entry, which directs the force applied to the soil upward (Figure D2-9). The upward force lifts and breaks compacted layers, giving better fracturing of soil with less draught.

A sharper angle of tine entry into the soil lowers the ratio of the front area of the tine to the contact area of the soil. This will, in effect, lower the pressure exerted on individual soil units with less likelihood of smearing.

Figure D2-8. V-arrangement of tines allows following tines to travel in disturbed soil, decreasing draught.

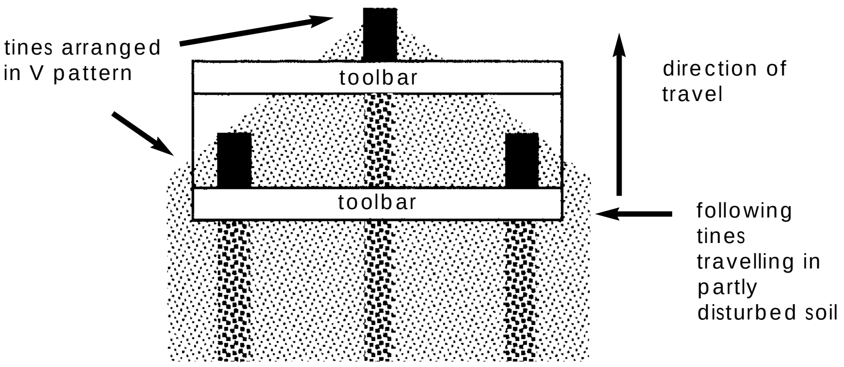
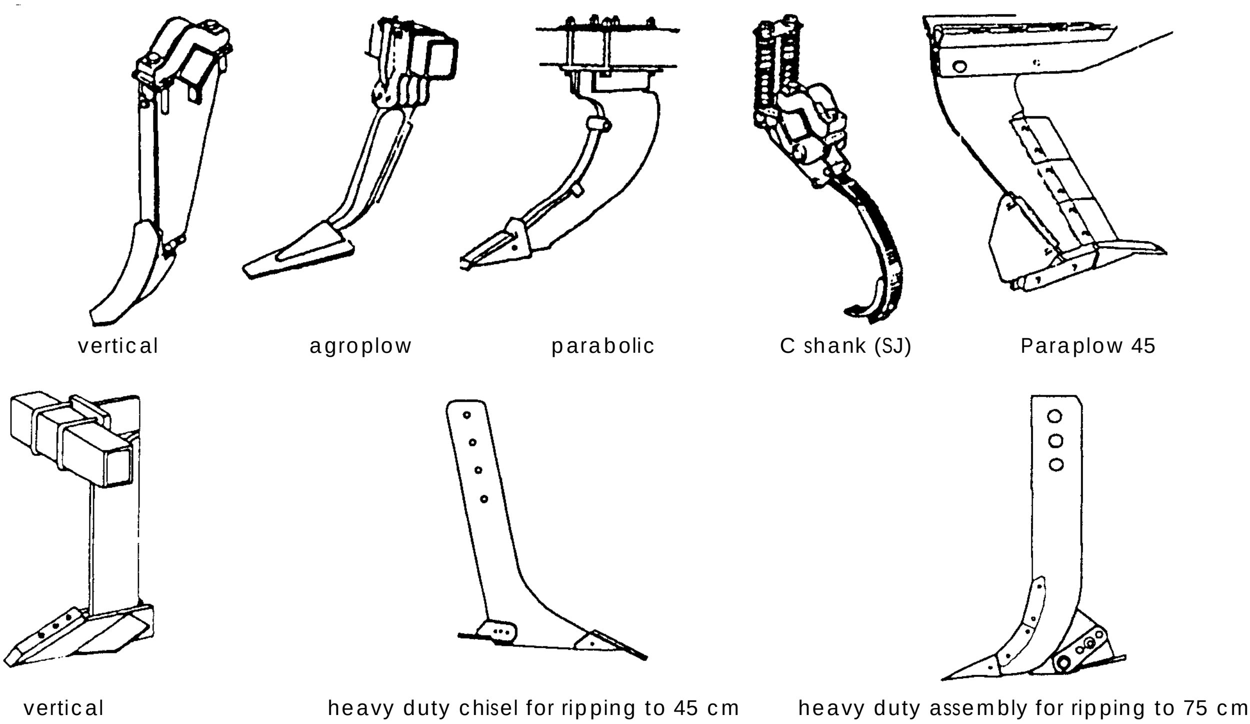


Figure D2-9. A range of tine designs for deep tillage.



Drawbacks and cautions

Deep tillage is expensive in terms of equipment, fuel and time. Deep tillage can alleviate structural problems, but not always completely.

There is a tendency for tines to follow old tine tracks if the field is deep tilled in the same direction as previously.

Deep tillage may make the soil less able to support heavy traffic. The soil will lack strength and will be very prone to re-compaction.

If deep tillage brings large blocks of soil to the surface, they will need time to break down—either naturally by wetting and drying or, less preferably, by further tillage. If the blocks are sodic, the surface soil will become dispersive and require gypsum treatment.

Check on the effectiveness of your deep tillage operation by digging a pit at right angles to the direction of tillage.

☞

See Chapter C5 for more information on assessing soil structure after tillage.

Spading machines

Spading machines (spadevators) may have a role when the soil is moister than the plastic limit, and the compacted zones are not too deep. Based on the principle of the garden spade, the bottom of the tillage layer is created by soil being torn off, rather than by an implement blade slicing the soil. The parts of the soil that the machine does smear are left open to the action of the weather. The action of spadevators is different to that of standard cultivating implements in that the bottom of the tillage layer is not defined by the implement itself.

Spading machines generally are too slow for use under broad-acre conditions, and require more maintenance than conventional tillage equipment. However, they appear to be particularly useful for the tillage of non-swelling alluvial soil when this soil is moister than the plastic limit.

Slit ploughing

Another option is ‘slit ploughing’. Used in the USA, slit ploughs have narrow straight coulters or knives that open slices of 5–10 mm width in the soil, penetrating to below the root-restricting layer.

USING SOIL CONDITIONERS- GYPSUM, LIME AND ORGANIC MATERIALS

Soil structural problems can be brought about by excessive levels of exchangeable sodium relative to calcium, particularly when the soil electrical conductivity (EC) is low (see Chapter E3). A lack of organic matter is associated with instability problems in hardsetting soil.

In a sodic soil, clay dispersion and increased swelling block the pores and reduce pore space. Water entry, aeration and drainage are adversely affected.

The addition of calcium in the form of gypsum (calcium sulfate—$CaSO_4$), or lime (calcium carbonate—$CaCO_3$) if the soil pH is low enough (below about 6.5, measured in 0.01 M $CaCl_2$), will help to lower the exchangeable sodium percentage (ESP) of the soil. Gypsum also boosts the soil EC, due to its moderate solubility in water. Lime may be associated with beneficial cementation processes within soil microaggregates.

How to determine gypsum responsiveness

The following tests will indicate the gypsum responsiveness of a soil:

ASWAT dispersion index. This is a simple field test that shows how readily a soil disperses. Consider gypsum and/or lime application when the ASWAT score exceeds 6.

☞

See Chapter C4 for details on the ASWAT test.

Exchangeable sodium percentage (ESP). Where the ESP of surface soil is greater than 5, expect the soil to be dispersive and therefore responsive to gypsum.

'Electrochemical stability index' ($EC_{1:5}$ /ESP) (ESI). Electrical conductivity (EC) of a soil is a measure of its salinity. As EC increases, soil dispersion decreases regardless of how sodic the soil is. 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, you should also calculate ESI. A tentative critical ESI value for Australian cotton soil is 0.05. An economically viable response to gypsum and/or lime can be expected if ESI values are below this level.

Calcium:magnesium (Ca:Mg) ratio. If the ratio is less than 2, the soil is predisposed to dispersion, especially for marginally sodic soils (ESP about 5).

pH. High pH (greater then 9) indicates possible high levels of exchangeable sodium or magnesium. As soil pH increases, the charge of some clay particles becomes more positive, so the soil will become more dispersive.

Trial strips of gypsum will indicate whether or not an economically viable response is likely. A suggested rate is 2.5 t/ha. Either treat a small strip, or leave a small strip untreated. If your soil types vary, include them all in the trial.

Applying gypsum

Highly sodic soils (ESP >10) may require an initial application of over 5 t/ha gypsum. Thereafter, 2.5–5.0 t/ha every few years will replace gypsum leached from the surface soil and maintain the electrolyte effect. Either mined or by-product gypsum can be used, although the latter may contain impurities such as fluorides and cadmium. It is usually applied with a mechanical spreader (Figure D2-10).

Figure D2-10. Spreading gypsum on the surface of sodic soil.

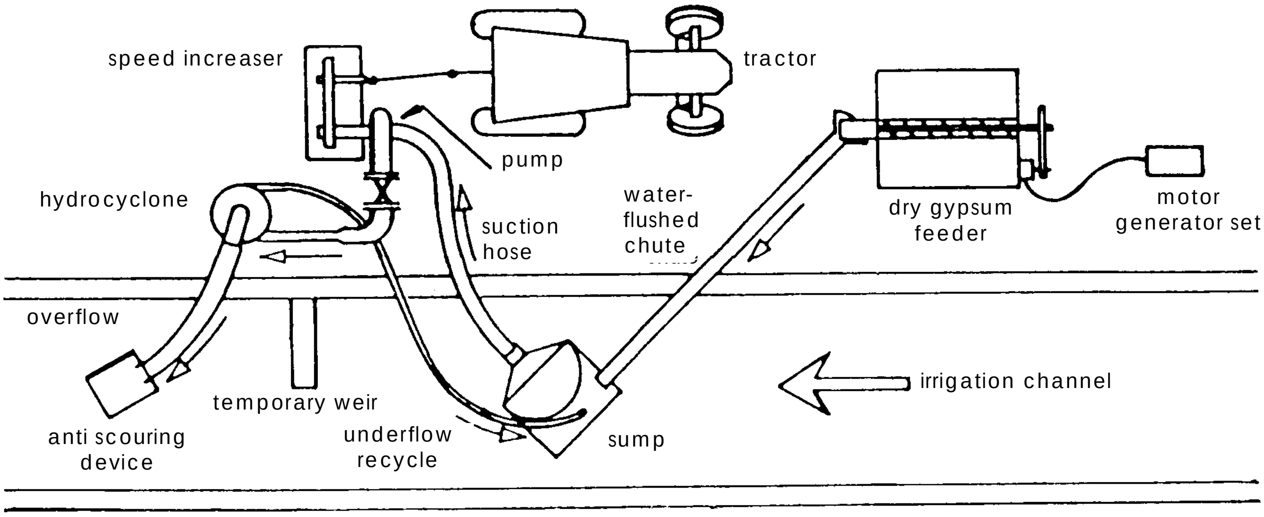
Where a field has been cut and filled or has variable soil types, it may pay to treat the areas individually with increased or decreased rates. Accurate soil mapping allows you to locate the areas.

Under a permanent bed system, you can apply the gypsum in a band along the plant line. If this is done after planting, the moderate salt concentration can adversely affect the germination of salt-sensitive species. Apply it well before planting so that rain can dissolve and re-distribute the gypsum throughout the root zone.

Water-run gypsum is an alternative to broadcast gypsum. Because the gypsum is already dissolved, it needs only small quantities (0.5–0.6 t/ha) to gain an effect. Figure D2-11 shows equipment used to dissolve the gypsum.

In a responsive soil, gypsum will improve surface aggregation (for better seedling emergence), decrease dry soil strength (to give easier tillage), increase water entry (with consequent longer irrigation intervals) and lengthen the time over which soil physical conditions are suitable for unimpeded root growth.

Figure D2-11. Design of equipment for dissolving gypsum in the irrigation water.



For gypsum:

Advantages

- In responsive soil, gypsum can improve farm profitability by overcoming dispersion, crusting/hardsetting and waterlogging problems near the surface.
- In the unlikely event of cotton soil being sulfur deficient, gypsum will alleviate the problem.

Cautions

- Not all soil responds to gypsum.
- Gypsum cannot, on its own, overcome compaction or smearing problems.
- May aggravate problems with loss of water and nutrients by deep drainage.
- May leach calcium carbonate from the topsoil and cause long-term dispersion problems.

Lime

Lime (finely ground limestone) dissolves easily in an acid soil. It raises soil pH and releases calcium ions. Lime is virtually insoluble in alkaline liquids, but it does dissolve slowly in alkaline soil. The following account explains how.

When we measure the pH of a soil, we are really measuring the average pH of a mixture of soil and water (or, if done properly, a mixture of soil and calcium chloride solution). Moreover, that soil sample comes from a larger sample that is thoroughly mixed, air dried and ground. The pH in the field may vary from the measured value, both from point to point and over time. For example, buried organic matter releases organic acids as it decomposes. Respiration by roots and soil organisms produces carbon dioxide, which produces a weak acid when dissolved in water. Thus there may be minute volumes of soil, which, from time to time, are sufficiently acid to dissolve some lime. Of course, the dissolved lime may be re-precipitated nearby, but it may move a short distance before this happens. Thus the lime is slowly incorporated within the soil. While dissolved, the lime supplies calcium ions to displace other ions on the exchange sites.

For cracking clays, lime has no quick effect on sodicity, but may be useful as a long-term supplier of calcium when the surface pH (0.01 M $CaCl_2$) is below about 6.5. Use gypsum to improve the soil quickly, and use lime for a more prolonged effect. Monitor soil dispersion and exchangeable cations to see when to reapply these compounds.

For lime:

Advantages

- Long-term effect compared with that of gypsum
- Less danger of deep drainage losses than with gypsum
- Unlikely to accelerate nitrate leaching
- Lime is a more concentrated source of calcium than gypsum.

Cautions

- Very slow to dissolve in neutral and alkaline soil, particularly when the particle size is coarse
- Positive responses are unlikely when lime and/or gypsum are added to sodic soil that has been built up into raised beds. This apparently is because salts dissolved in the irrigation water accumulate in the bed centre, and improve soil structure by increasing the soil electrical conductivity. Also, the bed architecture alone will ease waterlogging limitations caused by sodicity.
- Because there is no comprehensive database, we cannot accurately predict the long-term effects of lime application on the different types of cotton soil. Further research is needed.

For more information about lime and gypsum, see NSW Agriculture Agfact AC.10: *Improving soil structure with gypsum and lime.*

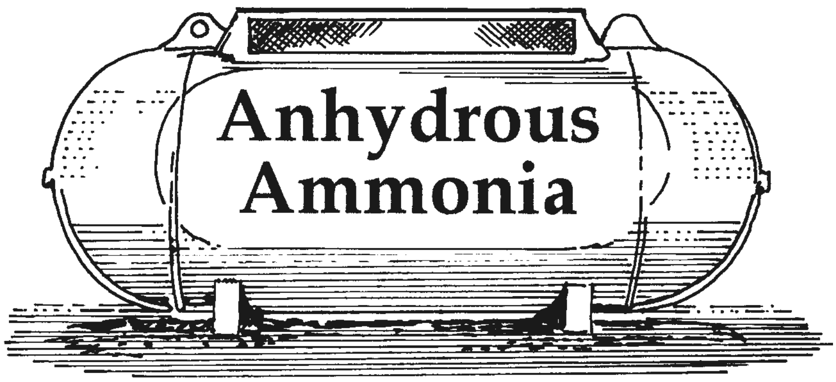
☞

See Chapter E5 for more information about adding imported organic materials.

Organic materials

Imported organic materials, in conjunction with calcium ions, can improve soil stability in water. Materials include crop residues, composted gin trash, sewage sludge and synthetic polymers (for example, anionic polyacrylamide). Much remains to be learnt about the response of cotton soil to these compounds, with and without the application of gypsum and/or lime.

D3. Managing nutrients



PURPOSE OF THIS CHAPTER

This chapter gives a brief description of the nutrients that are important for cotton production, and how to manage them.

CHAPTER OVERVIEW

This chapter covers the following points:

- important plant nutrients
- minimising losses of nutrients through appropriate soil management.

For more-detailed information, refer to NUTRIpak (available from Technology Resource Centre, Australian Cotton Research Institute, Narrabri).

INTRODUCTION

Soil nutrients need to be supplied at a rate that maximises crop profitability without causing off-site pollution problems. They should be replaced in the soil at the rate at which they are removed through crop products—inputs should approximately equal outputs.

Good soil nutrient management requires an understanding of:

- the different plant nutrients that are important
- various forms of nutrients
- nutrient availability
- tests that can be used to determine how much of a particular nutrient your soil needs.

Nutrient levels and balances between nutrients must be maintained. Any deficiencies need to be recognised and corrected.

For irrigated and dryland cotton farming, the main plant nutrient that needs to be added to the soil is nitrogen. Phosphorus and potassium sometimes have to be applied. Some nutrients are not replaced at their rate of removal. Table D3-1 indicates the relative nutrient uptake and removal by a 7.5 bale/ha cotton crop.

Ideally, nutrients should be added at rates appropriate to the needs of each sub-section of a field. This approach, referred to as 'variable rate application' (part of the 'precision agriculture' concept), is likely to be more profitable and 'environmentally friendly' than the use of blanket applications of fertiliser.

Table D3-1. Relative nutrient uptake and removal by a 7.5 bale/ha cotton crop (adapted from Donald 1964).

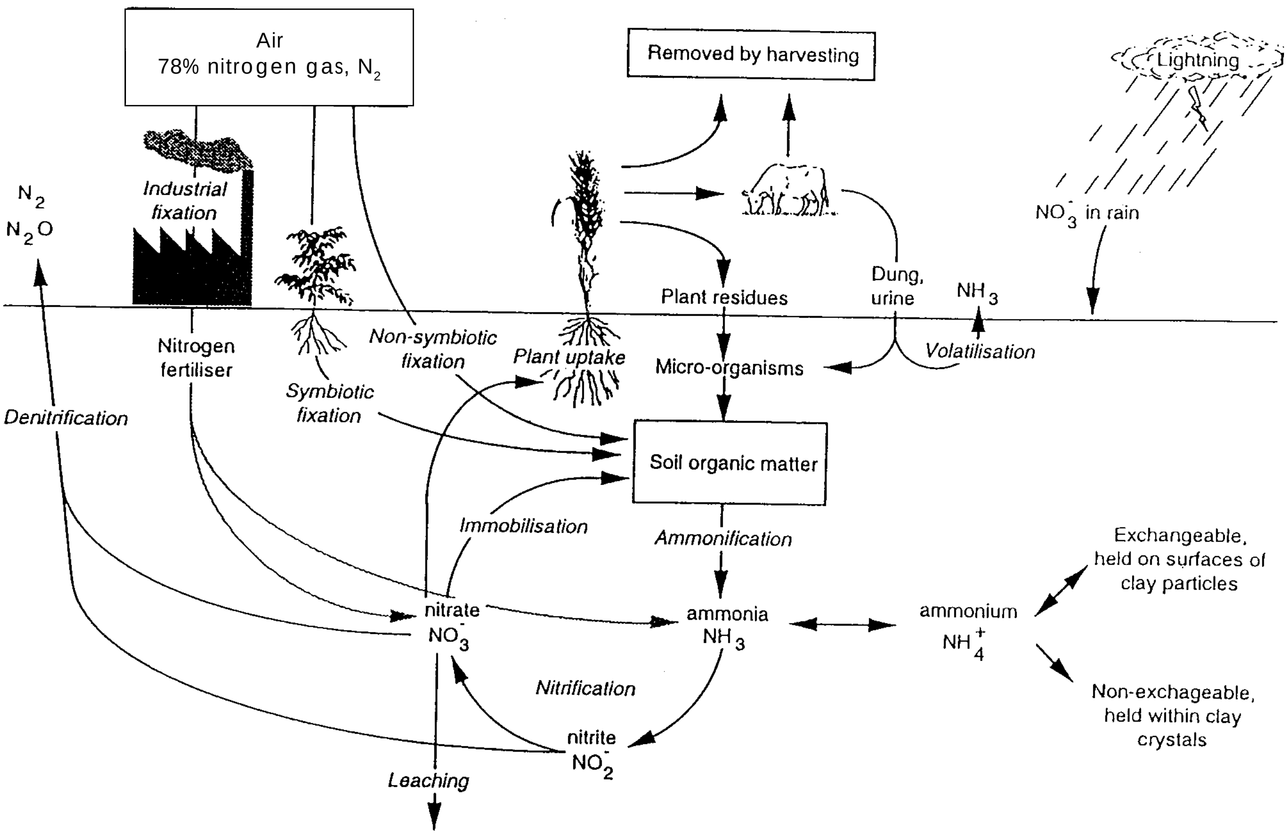
Major nutrients	Removal in lint + seed (kg/ha)	Total uptake (kg/ha)
Nitrogen	135	255
Phosphorus	30	45
Potassium	42	138
Calcium	6	102
Magnesium	12	39
Sulfur	6	N/A

Micronutrients	Removal in lint + seed (kg/ha)
Zinc	0.108
Manganese	0.036
Boron	trace
Copper	0.210
Iron	trace

NITROGEN

Nitrogen (N) is a constituent of all plant cells—in plant proteins and hormones, and in chlorophyll. Nitrogen deficiency results in reduced production of the green pigment chlorophyll, allowing the yellow leaf pigments to show. Nitrogen can be mobilised within the plant and moved from old leaves to young leaves. Therefore, N deficiency shows as yellowing of the older leaves.

Figure D3-1. The N cycle.



Nitrogen is very abundant in nature. It accounts for 78% of the gases in the air. However, most of it is in forms that are not available to plants. To be available to plants N must be in a soluble form, such as nitrate (NO_3^-) or ammonium (NH_4^+). Figure D3-1 shows the N cycle. A detailed description of the processes is given in NUTRIpak.

Losses of nitrogen from the soil

Denitrification

Some soil micro-organisms use nitrite and nitrate for respiration in the absence of oxygen. Therefore, in waterlogged soil, up to 40% of the mineral N is denitrified to dinitrogen (N_2) gas or nitrous oxide (N_2O) gas. Nitrous oxide is one of the gases implicated in the 'greenhouse effect' of global warming. The degree of waterlogging tends to become worse as the soil becomes more compacted.

Further N (around 30 kg N/ha) is lost into the atmosphere each year if cotton stems and roots are burnt.

Volatilisation

Nitrogen can be lost from the soil as ammonia gas. This is most likely in:

- dry soil (there is no water to dissolve the ammonia)
- soil with low cation exchange capacity, such as sand (there are few exchange sites to hold the ammonium cations)
- alkaline soil (there are no soil acids with which ammonia can react to form soluble salts). Only slight losses occur from soil with a pH below 7, while losses are high in calcareous soil when ammonium fertilisers are used.

Ammonia loss can be high when ammonium or urea fertilisers are

broadcast over the soil surface, rather than incorporated. Nitrogenous organic wastes, such as manures, lose significant amounts of ammonia when allowed to decompose on the soil surface.

Anhydrous ammonia gas is a common form of N fertiliser. Losses through volatilisation are not serious, provided that the gas is injected well below the surface of the soil, the soil has sufficient moisture to dissolve the ammonia gas, and the sorption capacity of the soil is not exceeded.

Leaching

Nitrogen is lost by leaching mainly as the nitrate form, although ammonium may be lost from sandy soil.

In soil that is intensively cropped and if no fertiliser is used, the leaching loss is small. Frequent cropping keeps the nitrate content of the soil low, and less water passes through the soil. However, fallowing beyond the time when the soil profile is full of water may lead to leaching losses.

Nitrate leaching from the soil presents a potential pollution problem. If nitrate enters the groundwater and this groundwater is used for domestic supplies, it presents a serious health hazard. If the groundwater discharges into surface water bodies, nutrient enrichment may cause algal blooms. Nitrate leaching is also a major cause of soil acidification in agricultural land.

To minimise N loss by leaching, adopt farming strategies that use nitrate before it is lost below the root zone:

- Apply nitrogen fertiliser in several small applications, rather than one large dose, and time the applications to meet crop needs.
- Use opportunity cropping. Sow a crop as soon as the soil profile is 75% full of moisture. Choose the crop to suit the time of year.
- Occasionally use deep-rooted rotation crops such as safflower to extract N that has leached to just below the root zone of cotton.

How much N is required by cotton?

The steps required to calculate how much N should be applied to a cotton crop are shown in Figure D3-2. It takes into account the severity of soil compaction. Details of the recommendations are presented in NUTRIpak.

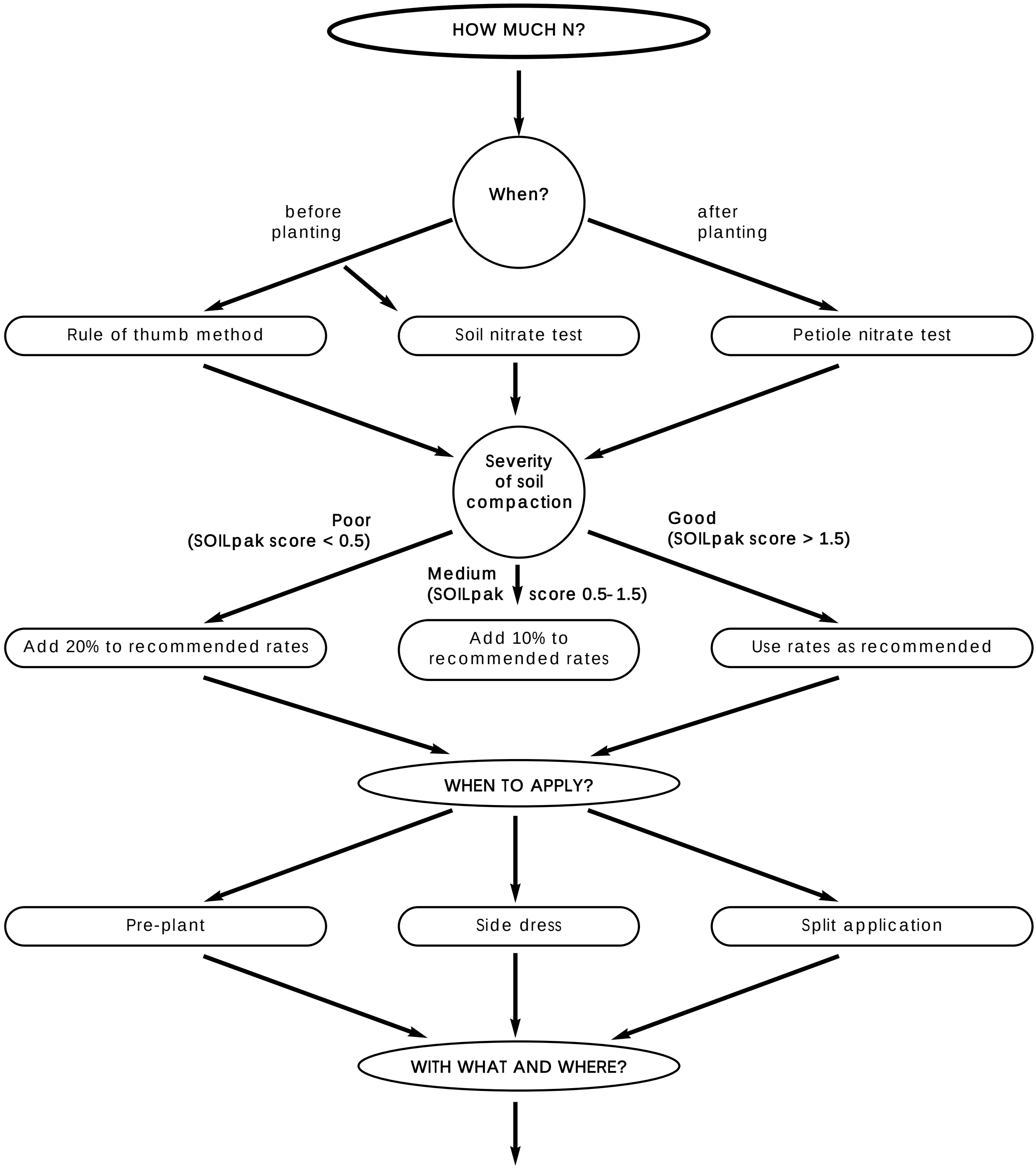
When the soil is very wet, use water-run urea to avoid smearing. If N must be injected into moist hills, use the sides rather than the middle of the hills. Because the variation in the output of anhydrous ammonia into each hill can be as great as 50%, ‘striping’ of crops is a widespread problem. Agricultural engineers at Trangie have developed an improved NH_3 distributor that has much lower variability.

PHOSPHORUS

Phosphorus (P) is a constituent of plant cells, essential for cell division and development of the growing tip of the plant. Without P, plants are stunted and spindly. Deficiency symptoms also include dull greyish-green leaves, red pigment in leaf bases and dying leaves. If plants are starved of P as seedlings they may not recover, even when P is applied later.

Phosphorus is not prone to leaching, except from sandy soil types under high rainfall. However, the availability of P derived from

Figure D3-2. Applying nitrogen to cotton.



	Under row centre	Sides of hill	Furrow	Surface top of hill	Water	Foliar
> 3 weeks pre-plant	NH_3	NH_3	NH_3	NH_3 CF*	–	–
	urea	urea	urea	urea	–	–
< 3 weeks pre-plant	NH_3	NH_3	NH_3	NH_3 CF*	–	–
	–	urea	urea	urea	–	–
post-emergence	–	NH_3	NH_3 CF*	NH_3 CF*	urea	urea

NH3 CF* Use a low pressure cold flow system

phosphate fertilisers decreases quickly as the phosphorus is converted to insoluble forms in soil.

Fertiliser P does not move far from where it is applied because of its rapid reaction with the soil. Phosphorus sorption occurs when clay minerals bind phosphate ions, and when phosphate forms insoluble compounds. In acid soil it forms iron phosphate and aluminium phosphate. In alkaline soil it forms calcium phosphate. These compounds have low solubility, and low availability to plants.

Because P is so easily fixed in the soil, crops and pastures take up only 5–20% of P applied in fertiliser. Fixed phosphate becomes remobilised, often over several years. The current phosphate availability in a soil may reflect the history of phosphate fertilising from several years ago.

Improving the uptake of phosphorus

In soil with low P availability, place the fertiliser close to the seed when sowing. This is very effective, and you need only half the rate of P compared with broadcast fertiliser.

If the soil is strongly acid, lime it. This will reduce the availability of iron and aluminium in the soil. Therefore, the amount of P tied up by iron and aluminium will decrease, leaving more available for plant use.

If a crop seems to get little benefit from P fertiliser, it may be that the soil P level is already high enough and the plants do not need any more.

Eutrophication

Phosphorus can be lost from soil by erosion. Soil eroded from farms without stormwater control systems carries away nutrients, including P. Eroded soil entering waterways may create water quality problems (eutrophication).

Even without soil erosion, water running off recently fertilised land can carry away P before the fertiliser has entered the soil.

Use the following guidelines to avoid waste and pollution when fertilising with phosphate:

- Match the supply of fertiliser to plant needs.
- Do not top-dress when heavy rain is expected.
- Maintain good ground cover to minimise soil erosion.
- Store and re-use run-off water from storms.

POTASSIUM

Potassium deficiency in cotton (associated with ‘premature senescence’) is likely to be a problem where soil testing indicates K levels below 150 ppm (< 0.38 meq/100 g soil), particularly when the crop has a heavy boll load. It is aggravated by restrictions to root growth, such as soil compaction and waterlogging.

Sulfate of potash (potassium sulfate—K_2SO_4) is recommended if potassium is deficient. Muriate of potash (potassium chloride—KCl) also corrects potassium deficiency, but prolonged use is not recommended. It adds chloride to the soil, and chloride at high levels is toxic to plants.

Potassium can also become deficient on intensively used areas—

such as irrigated lucerne paddocks—and areas constantly cut for hay or silage. These represent heavy nutrient removal.

ZINC

Zinc deficiency may have to be corrected, particularly in soil that was heavily cut during landforming.

SIGNS OF NUTRIENT DEFICIENCIES IN PLANTS

Excellent visual standards for nutrient deficiency in cotton (and in some of the crops grown in rotation with it) are presented in the book:

Grundon, N.J. 1987, *Hungry Crops: a Guide to Nutrient Deficiencies in Field Crops,* QDPI, Brisbane.

D4. Avoiding salinity problems

PURPOSE OF THIS CHAPTER

This chapter presents options for preventing salinity from becoming an issue or, where necessary, for dealing with a salinity problem.

CHAPTER OVERVIEW

The following points are covered:

- water balance
- minimising leakage from storages and channels
- making cotton fields less leaky
- using trees to keep salty watertables from rising
- salt uptake by plants
- catchment management
- avoiding yield losses when salt is present in the root zone.

INTRODUCTION

The key to avoiding salinity problems is to have an appreciation of the balance of water and salt in the field. If the system is in equilibrium (inputs to the root zone are equal to outputs), then salinity should not be a problem. It is easier to avoid a salinity problem than to rectify it.

Under irrigation, most of the water input is from irrigation, although rainfall adds large amounts of extra water in some years. Outputs include evapotranspiration, deep drainage and run-off.

☞ *See Chapter E7 for more information on the field water balance.*

Problems with salinity occur when a watertable rises to within 2 m of the soil surface. Sometimes water becomes perched on top of impermeable subsoil layers. Water is then able to rise to the surface via the process of capillary action. Salts accumulate in the root zone when the water evaporates. Soil structure may improve, but crop growth tends to be restricted. As the salt content of a soil increases and the structure becomes better, the rate of deep drainage will become significant even in heavy clay soil.

☞ *See Chapter E3 for more information on the effects of salinity on soil structure.*

Although some salts are toxic to crops grown in cotton farming systems, the main adverse effect of soil salinity on crop growth is via the osmotic balance of the soil. Water moves from areas of low osmotic potential (low salt content) to areas of high osmotic potential (high salt content). In non-saline soil, water will be easily extracted from the soil by plants because the salt content of plants is higher than in the soil solution. The water moves in an attempt to balance the salt concentration. When the soil is saline, plants may not be able to extract water from the soil because the soil may have a higher concentration of salts than plants. The plants therefore become water stressed, even if the soil is not dry. Seedlings tend to be more sensitive to salinity stress than mature plants.

Cotton itself is tolerant of salinity, but some of the crops grown in rotation with it (especially legumes) are less tolerant. Options for avoiding salinity problems are outlined below.

☞ *See Chapter C7 for critical limits for soil salinity.*

MINIMISING LEAKAGE FROM STORAGES AND CHANNELS

Seepage losses from earthen supply channels linking farms with rivers can be great. Losses of about 20–25% have been recorded in the Macquarie Valley in full-allocation years. Values as great as 50% have occurred in years of low water allocation. There is also evidence of leakage from the river itself.

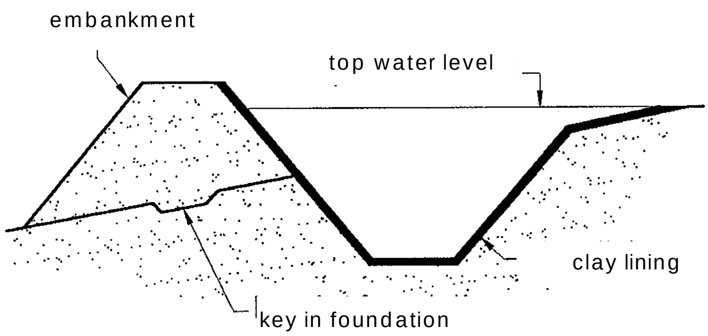
Large seepage losses (typically 1.5 mm/day) also may occur from earthen storages. Occasionally, above-ground storages burst due to embankment failure, caused by 'tunnelling' through soil that is structurally unstable. Tunnelling involves dispersion of soil from the sides of macropores that transmit water laterally. As the macropores become larger by this process, more and more water moves through, until the embankment finally collapses.

If leakage from storages and channels is (or expected to be) a problem, consider the following strategies:

- **Locate storages and channels on the most impermeable parts of a farm.** In the past, there has been a tendency to locate storages on the least productive parts of a farm—unfortunately, such areas may also be the most permeable. Do a soil survey of the farm and draw a map of soil texture. Areas with large amounts of clay are preferable to sites dominated by coarser (sandy) material.

- **Drain channels when not in use.**
- **Use appropriate construction procedures for reservoirs and channels.** Compacting the base of the water storage with a vibrating 'sheep's-foot' roller will reduce seepage, at least in the short-term. Applying a clay lining (about 15 cm thick) will also be useful (see Figure D4-1), but is expensive. Concrete lining is even better, but the cost is likely to be prohibitive. To minimise the risk of 'tunnelling' of water through embankments, and of failure along pipes buried in embankments, try to avoid the use of sodic clay during construction. However, compacting the embankment material (at a water content close to the plastic limit) tends to make stability issues less critical. The presence of sodic soil beneath storages and channels is desirable—it has a slower infiltration rate than calcium-dominated clay, so deep drainage losses are minimised.

Figure D4-1. Avoiding salinity problems by sealing leaking dams



MAKING COTTON FIELDS LESS LEAKY

Develop a less 'leaky' farming system by minimising the amount of water that moves below the root zone, into the groundwater. Consider the following options:

- Where possible, avoid long fallows that continue past the time when the profile is about 75% full.
- Use opportunity-cropping strategies, if economically viable. Ideally, once the soil profile has sufficient moisture, a crop suited to the time of year should be planted.
- Schedule crop irrigations according to actual crop requirements, and apply water in a way that minimises deep drainage losses. Such losses tend to be very minor (about 1–2 mm per irrigation) when a well-managed cotton crop under flood irrigation is growing strongly during the summer, but can be major in the two months that follow planting, and after crop defoliation. On a grey clay near Warren, prolonged rainfall after pre-irrigation and cotton planting in late-1992 led to a deep percolation loss of 214 mm. These occasional pulses of drainage water can raise watertables by several metres over just a few months. Therefore, try not to saturate the soil profile fully when pre-irrigating.
- Use rotation crops such as safflower or lucerne to provide a dry subsoil buffer (at a depth of about 0.8–2.0 m), into which drainage water from a subsequent cotton crop can be captured and stored.

Remember that salts accumulate in the soil with every year of

irrigation. For example, in the Macquarie Valley in the early 1980s, 1.5 t/ha salt were estimated to be added (per cotton crop) via the irrigation water. If all of this salt is soluble and retained in the root zone, the electrical conductivity of the 1 ML of plant available water stored in the soil will be increased by approximately 1 dS/m each time a cotton crop is grown. The proportion of the salt load that precipitates as low-solubility carbonate salts is not known.

Therefore, a small amount of deep percolation is required to leach the soluble salts so that the risk of salt build-up in the root zone is minimised. The required size of this so-called ‘leaching fraction’ tends to be greater where groundwater is used rather than river water. The inevitable build-up of salt in the deep subsoil associated with irrigation should be closely monitored; eventually, it may become necessary in some districts to drain the saline effluent into on-farm evaporation basins where the salt can be removed (particularly where the salt is very soluble and sodium-dominated). Producers of irrigated cotton who are not experiencing salt build-up must not be complacent—a lack of salt usually means that there has been substantial loss of water from the root zone by deep percolation.

It is important to identify ‘hotspots’ within a field where deep percolation losses are particularly bad. These zones often coincide with areas that are poor yielding—sick crops extract less of the water passing through the root zone than healthy crops. Yield mapping and remote sensing procedures help growers to identify leaky ‘hotspots’. Action can then be taken to improve crop performance in these sub-sections of the field by using variable-input farming techniques.

Queensland rainfall patterns are less likely than those of New South Wales to encourage watertable rise. There is a predominance of high intensity rainfall and high evapotranspiration during the summer ‘wet’ season in Queensland. Winter dominance of the rainfall becomes greater as one moves south.

LOWERING GROUNDWATER BY USING IT AS IRRIGATION WATER

Groundwater pumping

Groundwater pumping can lower watertables, and can provide a valuable water resource. It may be necessary to ‘shandy’ the groundwater with river water (referred to as ‘conjunctive use’) so that the salt concentration is suitable for the crops being grown.

If you are interested in this option, seek help from an adviser with a detailed knowledge of the local hydrogeology.

If sodic groundwater is added to the soil, gypsum should be applied to prevent the soil from becoming dispersive when it rains.

Subsoil drainage systems

Research by CSIRO at Griffith has shown that to drain clay soil effectively, traditional pipe (tile) drains (in-filled with gravel) at about 1.8 m depth would need to be 5–10 m apart, However, this is very expensive at about $5,000/ha.

A cheaper alternative for the removal of excess water within the root zone (and some of the accumulated salt) is to install mole drains. A mole drain is a tubular drain formed beneath the soil surface by pulling an expanding plug through wet soil. A laser guidance system has been developed by CSIRO to install these drains with a suitable,

even slope (about 1:200), 2 m apart and 50–80 cm deep. Their length cannot be greater than about 75 m, so in longer fields it is necessary to have several collector pipes at right-angles to the direction of flow of water.

Avoid highly dispersive subsoil, because there are problems with mole channel stability.

The mole drains can be used together with pipe drains to collect and deliver the water back to a sump or recirculation drain. If mole drains are installed in conjunction with a piped collector system to a sump with a pump, the initial cost is about $1,800/ha. Re-moling every few years will cost only about $140/ha.

For further information, contact CSIRO Land and Water, Griffith.

MANAGING SALINITY USING TREES AND THIRSTY CROPS

Before land was cleared for agriculture, native trees and perennial shrubs and grasses usually kept watertables from rising.

These plants have deep, extensive root systems with the ability to extract large amounts of water each day. In the past this prevented recharge of the groundwater from exceeding groundwater use in most years. A rise in watertable levels is particularly serious when the groundwater is salty, or has become salty because the extra water entering it has dissolved stored salt in the soil.

Planting trees, especially in rapid-recharge areas, can prevent the rise of a watertable. If grown vigorously through appropriate soil and pest management, they are capable of using much more water than the annual rainfall. However, be aware that excessive salt accumulation around tree roots will slow growth unless flushed occasionally by rainwater or irrigation. Your local Landcare group can give advice regarding which species are likely to be most suitable, and about the best methods for successful tree establishment. Consider converting a part of your farm to farm forestry (‘agroforestry’).

Trees and shrubs can be planted in strips rather than in clumps. ‘Alley cropping’, popular in Western Australia, is a farming system in which rows of trees (spaced approximately 70 m apart) are planted in conjunction with crops and pastures. This can also prevent wind erosion and spray drift. Plant trees along fence lines, waterways and roads where interference with your farming operations is minimal.

Another approach is to establish waterlogging-tolerant species (such as Melaleuca shrubs) in discharge areas to lower the watertable. They will also have to be salt-tolerant if the discharge water is saline.

Saltbush can be used to stall the spread of salinity. It is a deep-rooted species that lowers the watertable; it is also salt tolerant, provides a refuge for beneficial insects, and is tolerant of herbicide spray drift. Saltbush accumulates sodium salts in its foliage, but it has to be harvested and removed from the site to allow permanent export of the salt. Researchers in Sudan calculated that to remove all of the sodium applied to fields (under a rotation of cotton, sorghum and Dolichos lablab) via the local irrigation water, one crop of saltbush per 12–13 years would be sufficient.

CATCHMENT MANAGEMENT

Irrigation and dryland salinity is a catchment issue that does not stop at property boundaries. The problem needs to be tackled at the catchment level.

Your farming practices may be adding to the problem in your catchment (off-site) even if you are not directly affected (on-site) by salinity. Conversely, your salinity problems may be a result of the farming practices of someone else.

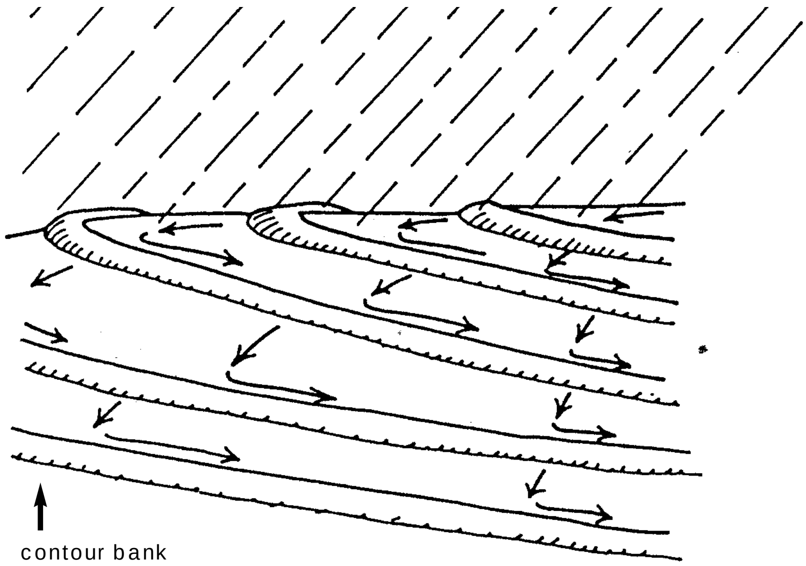
QDNR Indooroopilly has developed some very useful models (for example, 'Sodium-SaLF') to describe salinisation processes. Your local Landcare group will also have helpful information about this topic.

AVOIDING YIELD LOSSES WHEN SALT IS PRESENT IN THE ROOT ZONE

If salinity problems do develop, consider the following options:

- Because salt tends to concentrate on the top of hills next to the furrows, plant seeds on the sides of the hills.
- It may be possible to increase the salt tolerance of cotton (and the crops grown in rotation with it) by plant breeding.

D5. Minimising erosion and pesticide movement



PURPOSE OF THIS CHAPTER

Soil loss by water and wind erosion can create major problems for cotton growers. Of particular concern is water erosion under dryland conditions, where, because slopes are often steeper and there is usually little investment in stormwater control and capture, there tends to be a greater risk of off-site water movement than under irrigation. Eroded soil particles (particularly the finer material) carry nutrients and, sometimes, pesticide residues.

This chapter describes the main types of erosion, and outlines the available options for erosion control.

CHAPTER OVERVIEW

This chapter covers the following points:

- types of erosion
- options for the control of water erosion
- options for the control of wind erosion.

For further information about farm management to minimise pesticide movement, see:
Williams, A. 1997, *Best Management Practices Manual,* Australian Cotton Industry, Cotton Research and Development Corporation, Narrabri.

INTRODUCTION

Soil erosion can have great economic and environmental significance both on and off cotton farms. It is the movement of soil from a position where it is of value (on-field) to a position where it represents a cost (off-field and, perhaps, off-farm).

Eroded soil contains expensive-to-replace nutrients; if they are allowed to move into waterways, they can cause water quality problems (for example, eutrophication). Eroded soil may also carry pesticide residues; of particular concern is endosulfan and its breakdown products, which are very toxic to fish living in nearby waterways. De-silting of drains is expensive, and it produces difficult-to-manage material that may contain pesticide residues.

Erosion can be caused by water (rain and/or irrigation) or wind; much of the damage tends to occur infrequently over short periods of time. For example, most of the degradation from rain-induced water erosion takes place during occasional large and/or intense rainfall events. Complacency tends to develop when such incidents have not happened for several years.

Soil loss of 0.7 t/ha from just one pre-irrigation event has been recorded on a cotton field (slope = 1:1500; 0.07%) near Warren. On steeper land near Toowoomba, rates of soil loss (due to stormwater run-off) from a black cracking clay as great as 80 t/ha/year have been recorded under wheat – bare fallow. On a similar soil at Emerald, but under cotton and with a slope of 1–1.5%, rates of soil loss of 4–8 t/ha/year have been recorded. In comparison, the rate of soil formation is only about 0.14 t/ha/year (0.1 mm per year).

Although topsoil removal may occasionally expose subsoil with more favourable characteristics for crop growth, the usual scenario is exposure of difficult-to-manage sodic clay.

Usually it is too expensive to move eroded soil back to its original position. Therefore it is very important to control erosion through good soil management. The soil erosion control methods outlined in this chapter can also improve soil structure and water use efficiency.

TYPES OF WATER AND WIND EROSION

Sheet erosion

Sheet erosion is erosion from the entire surface of the soil. Sheet erosion by water is exacerbated by the impact of raindrops hitting the soil surface. Erodability of cotton soil tends to be in the order: grey cracking clay > red–brown earth > black cracking clay.

Sheet erosion by wind occurs on dry, bare soil. Soil cover (growing plants as well as stubble or straw) is the most effective way of reducing sheet erosion.

Rill erosion

Rill erosion occurs when water forms small channels (‘rills’) in the surface of the soil. Rill erosion is made worse by excessive run-off, steep slopes, and the presence of loose self-mulching soil that has been tilled. Rills are often seen at the end of an irrigated cotton field, cutting back from the tail drain.

The main methods of reducing this form of erosion are maintaining soil cover, and minimising tillage to maintain the soil in a firm, more erosion-resistant condition. However, some tillage may be necessary

to smooth the soil surface and reduce the concentration of run-off into rills. Erosion control banks stop rills becoming gullies.

Gully erosion

Gully erosion results when channels carved out by water erosion become so big that they cannot be removed by cultivation. It is caused by concentration of water flow, long slope lengths and the presence of dispersive soil. The main techniques used to reduce this form of erosion are surface cover to reduce run-off, and earthworks (diversion channels, erosion control banks and grassed waterways).

OPTIONS FOR THE CONTROL OF WATER EROSION

Where there is a risk of soil loss by water erosion, the main principles of soil conservation are:

- **Control water erosion by reducing run-off.** Because running water carries soil in suspension, reducing run-off means less erosion. Techniques for improving soil structure and infiltration rate will decrease the amount of run-off. It also is important to avoid having a full profile of soil water for extended periods. Either use the water by growing crops, or risk losing it through run-off.
- **Protect the soil surface from the disruptive effects of raindrop impact.** Bare soil is quickly loosened by the impact of raindrops, which have a diameter of about 5 mm and hit the ground at about 32 km/hr. Organic mulch provides good protection.
- **Slow the erosive agent.** Water erosion is reduced by slowing down the rate at which run-off travels. Anchored surface cover (growing plants and organic mulch) and earthworks are important. Minimise slope and slope length.
- **Minimise tillage.** Undisturbed soil with good surface cover has the most resistance to erosion; surface mulch protects soil from the disruptive effects of raindrop impact.
- **When irrigating, minimise the rate at which water is applied and minimise tail water volume.** These objectives have to be balanced against the need to control the severity of waterlogging and, on the other hand, the need to achieve sufficient subbing of water into hills and beds.

Field slope

Different slopes and slope lengths give run-off water contrasting erosive powers. For dryland cotton on flood plains with low slopes (0.5–1% slope), emphasis should be on the spreading and slowing of flood flows. Techniques include strip cropping.

On steeper ground, the emphasis is always on maintaining soil cover throughout the growing and fallow periods, and on avoiding the concentration of run-off water into rills. Surface cover is particularly important during periods of high erosion risk. On slopes greater than 2%, erosion control banks should be constructed. Land with slopes greater than 8% should not be cultivated. Terracing can be used to reduce slope, but generally it is too expensive to be considered seriously.

Slopes between 1% and 2% pose special problems. The land is too steep for strip cropping without erosion control banks, but not steep enough to grade the banks easily to dispose of water.

Although cotton fields generally are fairly flat (typically with a slope of about 0.07%; 1:1500), the edges of hills and beds are much steeper. This is where most of the erosion takes place under rainfall. Once in the furrows, eroded soil can then be transported by irrigation water.

Earthworks

Earthworks for erosion control are an integral part of conservation farming, especially on sloping ground. The aim of earthworks is to provide breaks in a slope. This divides the slope into segments, restricting the development of gullies. Within irrigated cotton fields, options for controlling run-off include the reduction of field length and tail drain length.

The erosion control banks in dryland fields also serve as a barrier to slow down run-off and collect sediment in the run-off. They also prevent run-off water gaining too much speed.

The banks can provide a means of diverting run-off safely from the field into a grassed waterway. Grassed waterways can be used to transport water to a storage dam.

The Queensland Department of Natural Resources or the New South Wales Department of Land and Water Conservation can offer you advice about the construction, design and layout of erosion control banks and channels, diversion channels and grassed waterways.

Surface cover

Providing adequate surface cover is a vital part of schemes for the control of water erosion.

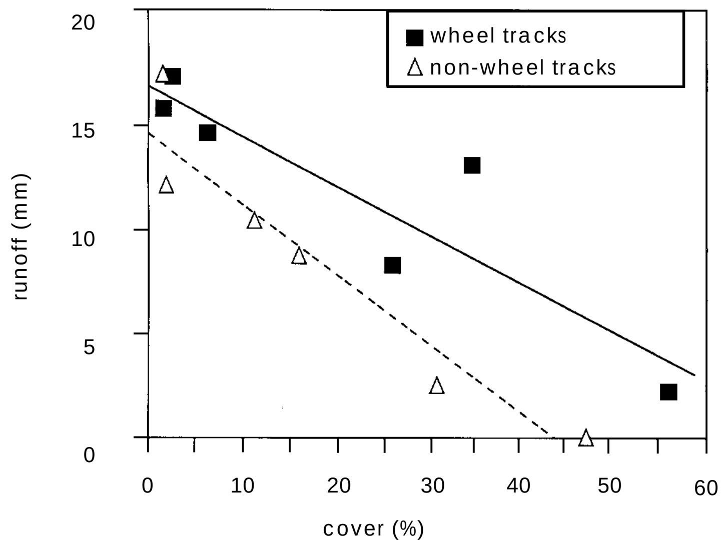
Surface cover protects the soil surface from raindrop impact, slows run-off water, traps sediment and encourages the activity of earthworms and ants, which improve infiltration. Its value is demonstrated in Figure D5-1. It has been shown near Emerald that between the harvest of one cotton crop and the planting of the next one, the soil can be tilled for Heliothis pupae control and then planted with wheat to provide mulch for the cotton.

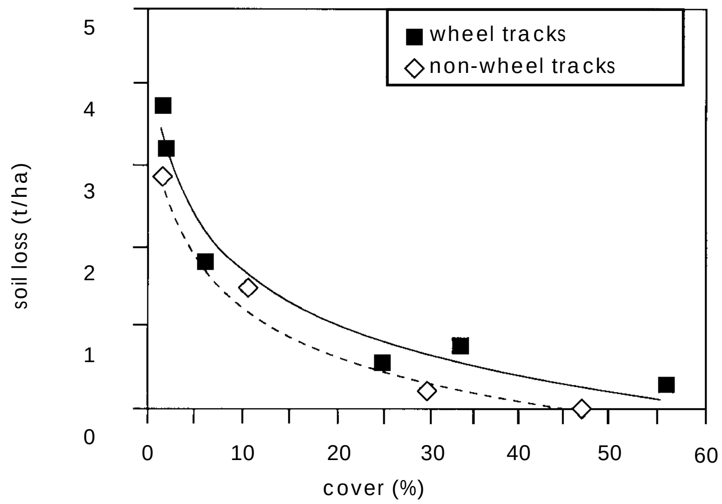
Healthy mature crops usually provide good protection, although some (such as sorghum) are better than others (such as sunflower). The residues remaining after wheat persist for longer than those produced by legumes. Cotton stubble provides poor surface protection.

Surface cover should be maintained at a minimum of 30%, but a cover of at least 70% is preferable. It should be remembered that crop residue breaks down over time and cultivation buries standing stubble and straw. To allow for this breakdown, cover should be no less than 40% at the start of a fallow period. Surface cover can become inadequate by the end of a very long fallow. Surface cover is most important during periods of high erosion risk.

For cover to be effective in reducing run-off and water erosion it must be able to resist being moved by run-off. Therefore ‘anchored’ cover (preferably standing) is better than loose cover (straw). Standing stubble decomposes more slowly than flattened stubble. In practice, this means leaving some standing stubble during the fallow period to anchor the loose straw.

Figure D5-1. Soil loss from a 40-minute storm as affected by cover and wheel traffic on a black cracking clay at Emerald (source: Silburn 1996).





To minimise the disturbance of standing cereal stubble (particularly on the edges of hills and beds), consider the following options:

- use zonal cultivation along the plant lines to incorporate pre-emergent herbicides, and to provide a suitable tilth for planting
- rake straw to the centre of beds, where it is less likely to cause blockages
- plant cotton between the rows of rotation crop plants, which should be located along the edges of hills/beds rather than in the middle.

Cultivation and planting on slopes

Research workers with QDNR have shown recently that growing dryland cotton up and down the slope (1%), in conjunction with using drive-over contour banks (and using a sprayed-out wheat crop to provide surface mulch), controls soil loss by water erosion. Run-off is restricted to furrows, each of which has its own discrete catchment. The field traffic is controlled in a parallel layout, rather than being random.

This is a major deviation from conventional wisdom, which promotes cultivation across the slope rather than up and down the

slope. The problem with tilling and planting around the contour is that water tends to concentrate and flow along the contour until it meets a slight depression, and then runs downhill, causing rilling. The new system avoids this problem, although further testing is needed before the practice can be recommended in all circumstances.

Adding flocculants to irrigation water

Off-site movement of clay particles in run-off water can be reduced by the addition of flocculants. One option is to dissolve gypsum in the irrigation water.

Another approach is to add ‘anionic polyacrylamide’ (at a rate of about 3 kg/ML) to the water. This substance has been shown to decrease soil movement by 75% during a pre-plant irrigation. However, further research is required to determine:

- cost-effective rates of application
- persistence in the soil
- the risk of accelerated deep drainage.

OPTIONS FOR THE CONTROL OF WIND EROSION

Wind erosion (Figure D5-2) is minimised by using windbreaks, and by having an adequate surface cover in place to intercept the wind. Surface cover minimises the amount of soil picked up by wind, and traps soil particles that are picked up by the wind.

Wind erosion risk declines as clod size becomes greater. Aim to have at least 30% of clods with diameters greater than 0.85 mm. This is easier to achieve on a cracking clay than on a hardsetting red soil, where dry cultivation creates dust.

Figure D5-2. Wind erosion on a recently cultivated, but unprotected, loam soil.

D6. Maximising water use efficiency

PURPOSE OF THIS CHAPTER

This chapter outlines methods for managing your soil moisture budget so that the water use efficiency of your cotton crops is improved.

CHAPTER OVERVIEW

The following points are covered:

- measures of water use efficiency
- soil management to maximise the intake and storage of water
- soil and weed management to minimise evaporation and deep drainage losses.

INTRODUCTION

Water is the most limiting natural resource in the Australian cotton industry.

Efficient farming systems are required to maximise the yield of cotton lint produced for a given amount of applied water.

There are six different pathways that water can follow when rain falls on, or irrigation water is added to, a cotton field. They are:

- infiltration and storage in the root zone
- run-off from the surface
- evaporation from the soil surface
- deep drainage (from the root zone)
- use by crops
- use by weeds.

The way water is allocated to these six processes is called a *soil moisture budget.*

Farmers can manage the budget so as to minimise losses and to maximise the conversion of water into valuable products. Soil management options that reduce deep drainage and minimise soil loss by water erosion will help to improve the efficiency of use of water by crops. These three processes are interrelated.

Calculating the water use efficiency allows the yield of a crop to be considered in terms of the efficiency of use of the most limiting resource, water.

☞

See Chapter E7 for more information about water movement.

DEFINITIONS OF WATER USE AND WATER USE EFFICIENCY

Water use efficiency is a measure of how efficiently a farming system converts water into yield.

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

$$\text{IE} = \frac{\text{evapotranspiration (ML) x 100}}{\text{water input to the farm via irrigation and rainfall (ML)}}$$

Evapotranspiration = water applied (ML) + available water in soil at start of season (ML) – available water at harvest (ML).

'Water applied' is the amount of rainfall and applied irrigation water that is retained in the soil profile. It can be monitored by measuring soil water content with a moisture probe just before and after irrigations and rainfall events. It is very important for the moisture probes to be calibrated accurately—otherwise, large measurement errors are likely.

Dryland cotton growers should calculate the *fallow efficiency,* which is the proportion of rainfall (after harvesting of the previous crop) that is stored in a soil before planting. This calculation should also be used by irrigators; with water being their most limiting resource, rainfall should be used to full advantage wherever possible.

Crop water use efficiency (CWUE), which is the amount of lint produced per ML of water used in evapotranspiration, is calculated as follows:

$$\text{CWUE} = \frac{\text{(lint yield in bales/ha)}}{\text{evapotranspiration (ML)}}$$

Water measurements in mm can be converted to megalitres (ML) by dividing by 100.

☞

See Chapter D10 for more information on fallow efficiency.

Low CWUE values (less than 1.33 bales of lint per ML) are caused by a wide range of possible factors. These include:

- excessive run-off and/or evaporation from the soil due to poor soil structure
- excessive deep drainage due to poor exploration of the soil profile by plant roots
- weed infestation
- lack of crop vigour, caused by disease, insect attack and/or poor nutrition.

☞

Problems related to soil structure and water movement can be diagnosed using the procedures outlined in Chapters C4 and C9.

MANAGING THE SOIL MOISTURE BUDGET

Aim to achieve the following with your water management program:

Maximise the intake of irrigation water and rainfall

When the soil is dry, keep the uppermost sections of vertical shrinkage cracks open. This will allow rapid movement of water into the root zone when the soil is furrow irrigated (Figure D6-1) or wet by rain.

Because infiltration rates decrease during a rainfall event (particularly on clay-rich soil), any practice during a fallow that holds rainfall on the soil surface, rather than letting it flow downhill, will help infiltration. Stubble retention and increasing surface roughness achieve this. Stubble can also increase infiltration by promoting the formation of biopores.

The presence of compaction layers will lead to reduced infiltration rates and therefore will limit the amount of stored water. Compacted layers need to be disrupted, and minimum tillage systems implemented. Good soil structure not only improves the intake of soil water—it also is required to allow rapid redistribution of water throughout the root zone. Otherwise, waterlogging may be a problem.

However, if the soil profile is more than 75% full of moisture, there is not much benefit in extending a fallow. Applied water will be lost as run-off and evaporation from a wet soil profile, regardless of its physical condition.

Figure D6-1. Surface (furrow) irrigation using hand siphons is the dominant watering system in the Australian cotton industry.

Figure D6-2. In some situations, drip irrigation has the potential to reduce the loss of water by evaporation and deep drainage (see Chapter D1).

Minimise evaporation

Mulches reduce evaporation losses. Gypsum application also may reduce evaporation losses—in sodic soil it encourages water to move quickly into storage in the subsoil.

Minimise deep drainage

Water can be lost through deep drainage. Drainage below the root zone occurs when the soil is saturated. Minimising the time that the soil profile is full of moisture is the best way to minimise drainage. Special care needs to be taken during the period between planting and the first irrigation—water may escape before the cotton roots become prolific throughout the soil profile. Drip irrigation (Figure D6-2) may be useful under these circumstances.

Control weeds

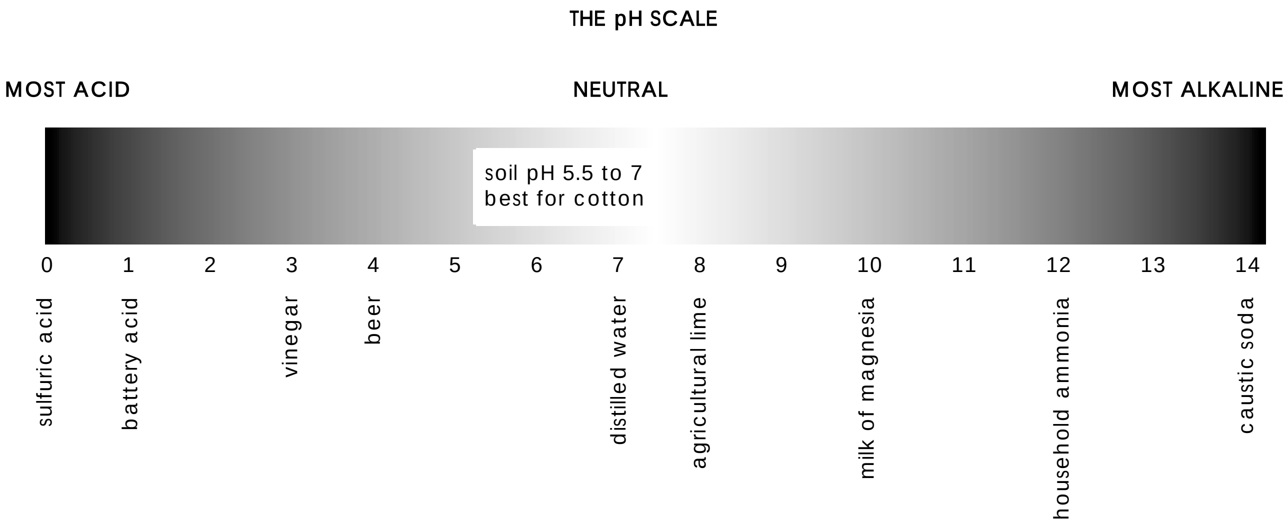
Control of weeds is critical during a fallow. It prevents the loss of valuable stored water. Weed control is also important during crop growth to reduce further wastage of water.

Cost-effective weed control requires long-term strategies using crop rotations to minimise weed burdens in a paddock, rather than just solving each weed problem as it arises.

Maximise on-farm water storage

Wastage of run-off water can be minimised by collecting it in farm dams. The water can be re-applied to the crop when the need arises. This reduces dependency on rainfall and water allocation.

D7. Achieving a suitable pH



PURPOSE OF THIS CHAPTER

This chapter discusses possible ways of modifying excessively high or very low pH in Australian cotton soil.

CHAPTER OVERVIEW

The following points are covered:

- management practices used to lower the pH of alkaline soil
- liming acid soil to increase pH.

INTRODUCTION

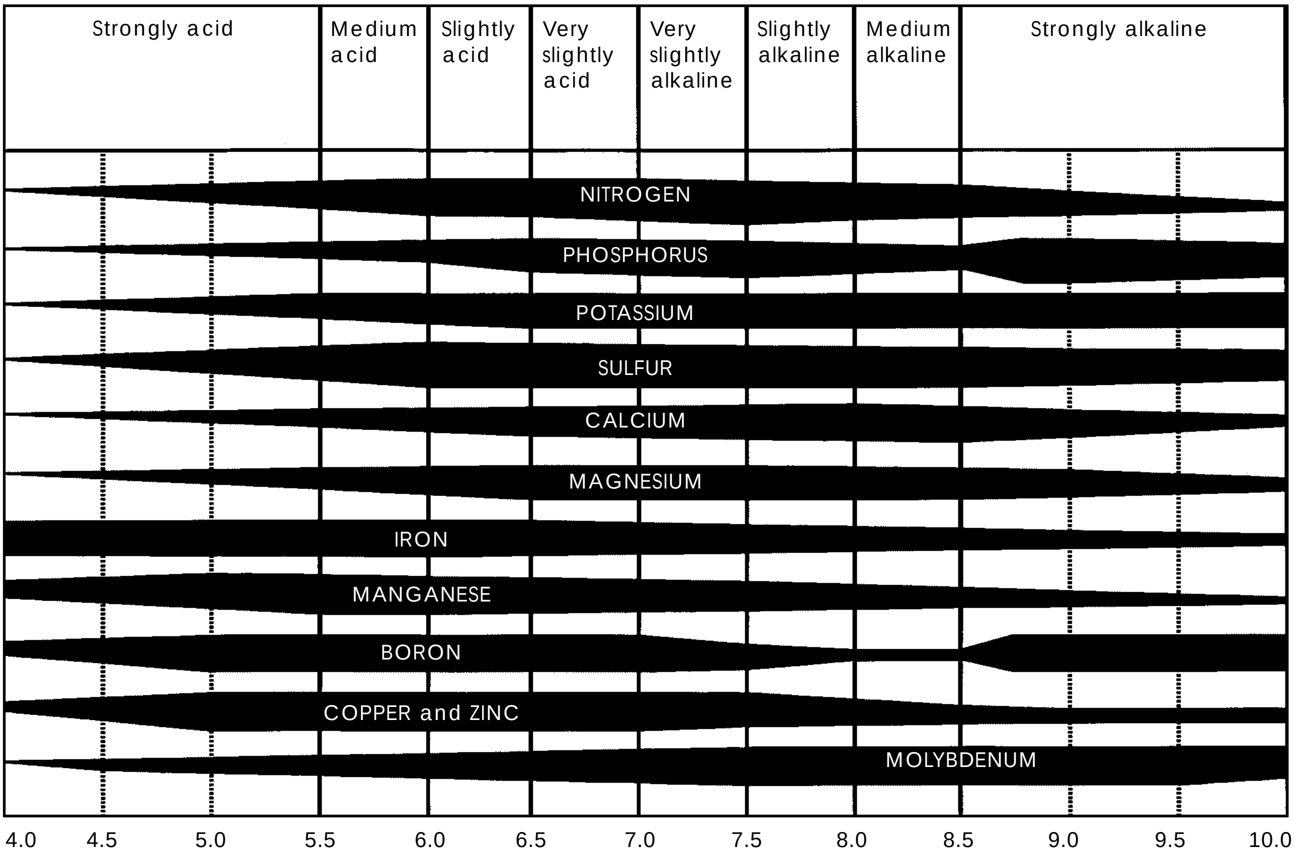
Cotton prefers a pH (measured in 0.01M $CaCl_2$) in the range 5.5 to 7.0. Wheat, the main rotation crop grown with cotton, has the same requirement. Above and below the optimum pH range, certain plant nutrients become unavailable to the plant (see Figure D7-1) or are released in toxic quantities (for example, aluminium at low pH). Cotton has a very poor tolerance of soluble aluminium.

Soil pH under Australian cotton is often greater than 7.0 and is occasionally less than 5.5.

Excessive alkalinity is associated with low amounts of organic matter, and with sodicity, in heavy clay soil used for cotton. Very high pH values (around 10) usually indicate the presence of sodium bicarbonate and carbonate salts ('white alkali') in the soil solution. When the pH is this great, some of the organic matter disperses to create 'black alkali'.

Lime is required to make the soil more alkaline if the pH is too low. As soon as the pH falls below 6 you should consider a liming program.

Figure D7-1. The influence of pH on nutrient availability



MANAGEMENT PRACTICES USED TO LOWER THE pH OF ALKALINE SOIL

Many modern agricultural practices acidify the soil. Acidification will be slower in soils with a high clay content and organic matter content. This is because these soils have a greater buffering capacity. (The buffering capacity of a soil is its ability to resist changes in pH.)

Practices that tend to acidify the soil include:

- applying an acidifying fertiliser, such as ammonium sulfate
- conserving organic matter (when carbon dioxide emitted by decomposing organic matter and respiring organisms dissolves in the soil solution, carbonic acid forms)
- growing nitrogen-producing legumes
- leaching of nitrate into the deep subsoil
- removing nutrients from the paddock.

A more direct approach is to add sulfuric acid directly to the soil.

Research is needed to determine the extent of alkalinity problems in Australian cotton soil, and the rate at which they can be overcome by these management options.

LIMING THE SOIL TO INCREASE pH

Subsoil acidity can be an inherent problem where brigalow forest once grew. Brigalow fixes large amounts of nitrogen; when the nitrogen is leached from the soil in the form of nitrate, the soil is acidified. Some cotton is grown on country that once grew brigalow, and may be restricted by low pH.

Applying ground limestone (lime—$CaCO_3$) will increase soil pH. The aim of liming the soil is to reduce the exchangeable aluminium to zero. Get help from your soil testing laboratory, local soil scientist or district agronomist when determining how much to apply. Thereafter, consider maintenance applications of lime at 5 to 10 year intervals, depending on the rate of acidification of your soil.

Lime application may also improve soil structural stability by adding calcium to the soil.

☞ *See Chapter D2 for more information on adding lime.*

However, an increase in pH will (depending on the clay mineralogy) tend to make the clay particles more dispersive.

☞ *See Chapter E4 for more information on the properties of clay minerals.*

The effectiveness of a liming operation depends on factors such as the neutralising value (NV) and fineness rating of the lime, the evenness of spreading and whether incorporation is thorough or not. The cost of liming depends on the source cost, the transport cost and the spreading cost.

If finely ground agricultural lime (100% passes through a 0.25 mm sieve) is incorporated into the soil, it reacts with the soil that it is in contact with as soon as moisture is available. However, lime moves very slowly through the soil and therefore may take many years to reach an acid subsoil. Coarse lime is slow to act and its use is not advised.

In acid soil with substantial amounts of iron and aluminium oxides, it is possible to reduce aluminium toxicity problems by applying gypsum. The gypsum is a lot more soluble and mobile than lime, and is quickly leached into the subsoil, where it ‘locks up’ the soluble aluminium.

The capacity of a liming material to neutralise soil acidity is called its neutralising value (NV). The higher the NV, the greater the ability of the product to correct acidity. Pure lime (pure calcium carbonate) is taken as the standard, with an NV of 100. Hydrated (slaked) lime and burnt (quick) lime have NVs of 120 and 160 respectively.

D8. Dealing with gilgais

PURPOSE OF THIS CHAPTER

This chapter describes the features of gilgais, and discusses management problems associated with them under cotton.

CHAPTER OVERVIEW

The following points are covered:

- features of gilgais
- overcoming management problems associated with gilgais in cotton fields.

INTRODUCTION

A feature of some clay soil used for cotton production is the occurrence of small-scale undulations, the alternate hummocks and hollows of which show some degree of regularity. These undulations are referred to as 'gilgais' or 'melon-holes'. 'Gilgai' is an aboriginal word meaning 'small water-hole'.

To avoid problems with poor surface drainage, the surface humps and depressions of gilgais have to be landformed to provide an even slope. However, the subsoil features of gilgais remain after landforming, and may cause large variations in crop growth across a field.

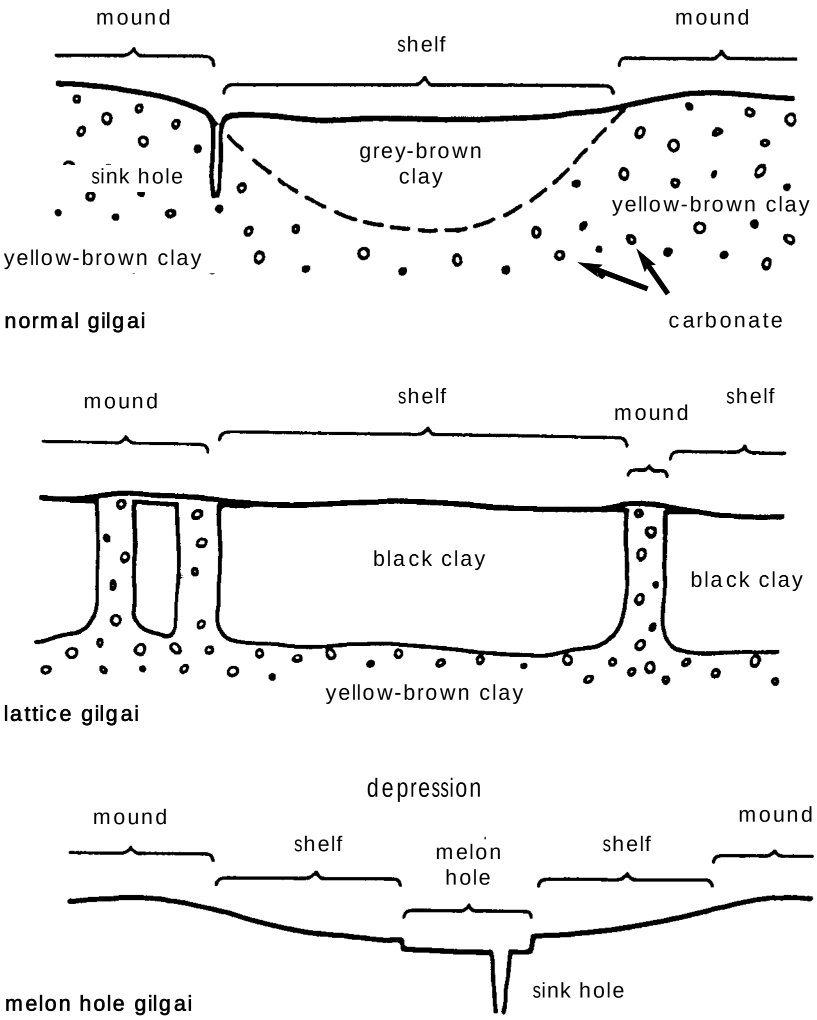
FEATURES OF GILGAIS

Cross-sectional views of several types of gilgai are shown in Figure D8-1. They are found in all cotton growing districts on grey, brown and black cracking clay soil.

Where the land is flat, the depressions tend to be circular. As the slope increases, the mounds and depressions tend to become aligned up and down the slope; these are known as 'linear gilgais', and are prominent in the Warialda – North Star district of northern New South Wales.

Under natural conditions, gilgai soil is in a state of slow continuous

Figure D8-1. Cross-sectional view of several types of gilgai formation (source: Stace, H.C.T. *et al.* 1968)



movement in which soil from the deeper layers is brought to the surface on the mounds, and soil from the surface slips down to lower levels in the cracks of the depressions.

The reason for the initial appearance of gilgais is unclear. It appears, however, that after a clay soil has been strongly dried, aggregates settle downwards. Rewetting of the entire profile causes swelling. With less total volume to fit into than before aggregate settling, buckling of the entire profile takes place. Another theory is that the growth of large individual trees before European settlement caused an uneven distribution of cations in the subsoil, thus causing differences in subsoil swelling potential next to and away from the trees.

OVERCOMING MANAGEMENT PROBLEMS ASSOCIATED WITH GILGAIS IN COTTON FIELDS

If the humps and hollows of gilgais are smoothed by grading and cultivation they tend to reappear within about 15 years. This leads to problems with variation in crop performance, due to waterlogging in the hollows, and difficulties with field operations due to uneven soil trafficability. This may lead to uneven patterns of soil compaction.

Even before the reappearance of humps and hollows, exposed subsoil in the mounds tends to be more sodic and saline—and with less organic matter, phosphorus and zinc— than the former topsoil, or the soil in the adjacent depressions.

The subsoil components of the gilgai formations remain unmixed by landforming and cultivation for cotton (see Figure D8-2), and continue to exert an influence on soil processes.

To deal with these problems, consider the following options:

- If new land is being developed for cotton, map the distribution of gilgais using aerial photos. In land already developed for cotton, aerial photos and/or airborne video scans taken throughout the growth of a cotton crop are likely to highlight any crop performance variations caused by gilgais.
- Sample the soil in the problem areas, and produce maps of the soil management inputs needed to improve crop performance (in a cost-effective fashion) within those sub-sections of a cotton field.
- Reshape the field with landforming equipment if gilgai depressions have reformed over a significant area.

Reducing soil and crop variability in cotton fields with well-developed gilgai features is the ‘ultimate challenge’ for ‘precision agriculturists’!

D9. Red soil management

PURPOSE OF THIS CHAPTER

Most Australian cotton is grown on cracking clay soil. However, land with loam topsoil is important for cotton production in some districts.

Red soil with a loam texture (at least in the topsoil) requires special management when used to produce cotton. It responds particularly well to minimum tillage, after restrictive layers have been treated. This chapter summarises management options that are available for this soil.

CHAPTER OVERVIEW

The following points are covered:

- advantages and disadvantages of loams
- improving layers that restrict water flow and root growth:
  - —deep mouldboard ploughing and slip ploughing
  - —deep ripping and deep chiselling
  - —biopore formation using rotation crops
  - —aggresizing
  - —gypsum, lime and polymers
  - —crust breaking
- using minimum tillage, mulches and slow-wetting irrigation systems to preserve favourable structural features.

INTRODUCTION

Red soil has a reputation for being more difficult to grow cotton on than cracking clay soil, particularly during crop establishment. However, exceptional lint yields can be obtained on it. At Bourke during the 1995–96 season, a 12.8 bales/ha cotton crop was grown in a 36 ha red soil field. It was grown on narrow (75 cm) rows.

The following loam soil characteristics enhance plant growth through maximum root development:

- There is relative freedom from waterlogging, because the soil has a lower clay content than cracking clay. (This is a very important feature.)
- The soil is trafficable soon after irrigation or rain, and there is relative resistance to mechanical compaction and smearing, due to more rapid drainage and drying than in cracking clay.
- The soil tends to have a good supply of nutrients, such as phosphorus.
- Exchangeable sodium and salinity tend to be low at the soil surface.
- The plant-available water capacity is moderate to high.

However, other characteristics (listed below) of loam soil mean that seedling emergence and root extension can be restricted without good soil management. Slow water entry at the surface, and hardsetting, crusting and/or flaking when the soil is dry, can be a problem. These features also make other aspects of farm management more difficult:

- The particle size distribution of a loamy soil makes it prone to hardsetting.
- Insufficient non-sodic swelling clay occurs at the surface to promote self-mulching and deep vertical cracking.
- Insufficient organic matter causes slaking (collapse) when the soil is wetted.
- Low electrolyte concentration at the soil surface promotes dispersion.
- Dust is produced when the soil is cultivated under dry conditions, causing loss of nutrient-rich topsoil by wind erosion; disc ploughs and rotary hoes are particularly damaging.
- Soil is lost by water erosion on relatively steep slopes when irrigation water is applied too quickly.
- The surface dries quickly; often successful seed germination can be made to occur only by ‘watering up’ with irrigation after planting, rather than with the standard ‘planting into moisture’.
- Subsoil layers are often excessively permeable (mainly in recent alluvium).
- Naturally restrictive subsoil layers limit root penetration (mainly where sodicity is a problem) at most water contents.
- The dry soil quickly wears out tillage equipment, unless the tines are hard-faced.

MANAGEMENT OPTIONS

Two main options are available for the management of loams:

- Disrupt any restrictive layers (SOILpak score < 1.0) using rotation crops and/or tillage. Remember that the 'window of opportunity' for successful tillage in loamy soil is very narrow—aim for a water content just below the plastic limit before tilling. However, clay-rich subsoil can be successfully tilled at much lower water contents.
- If the soil is well structured, use minimum tillage, mulches, slow wetting irrigation systems and (where soil is dispersive) soil conditioners such as gypsum to preserve the favourable features.

Unlike on cracking clays, where it is possible to live temporarily with degradation, crop production on loams with severe surface damage is nearly always unprofitable, even if water is applied very slowly using drip irrigation systems. It is necessary to repair red soil before cropping, because of its poor regeneration potential.

IMPROVEMENT OF RESTRICTIVE LAYERS

Rotation crops

Soil diagnosis: Hardsetting or crusting surface that restricts water intake, seedling emergence and root extension. (SOILpak score <1.0).

Available technology: Winter cereals, through their fibrous root system, can create pathways for water and root movement and improve surface soil friability.

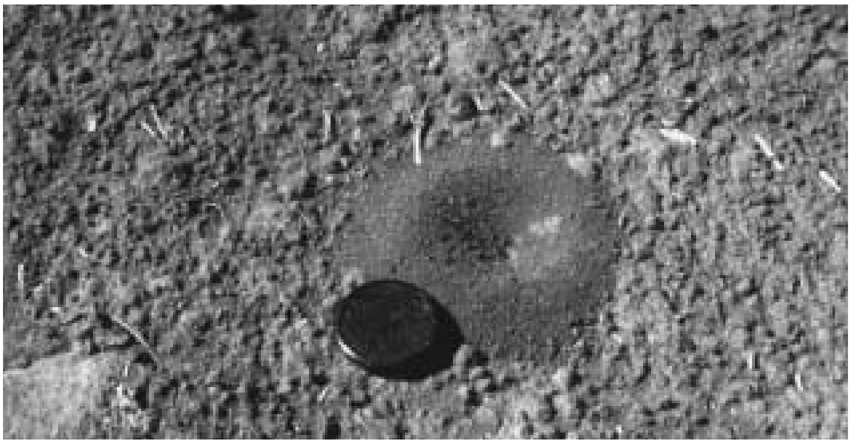
Where the cereal stubble is retained in the furrows, substantial increases in water uptake following irrigation have been found for subsequent summer crops. The increases are believed to be due to the stubble slowing down the rate of water movement and hence increasing the time water remains in the furrows and moves down the biopores.

The cereal straw needs to be chopped into small lengths to prevent trash build-up around soil-engaging implements. However, some of it also needs to be standing and anchored so that the mulch does not float down the field. The mulch may encourage soil biota such as earthworms (Figure D9-1) and ants (Figure D9-2) to improve soil structure by building biopores, stabilising clods and perhaps by bringing subsoil clay to the soil surface.

Winter (field peas) and summer (lablab) legumes also show promise as soil ameliorants. Field peas, sown in April and lightly turned into the soil in late August before cotton planting, have been found by cotton growers to improve soil friability, increase water uptake, and add 60–80 kg N/ha to the soil.

Figure D9-1. The casts produced by earthworms improve the structural stability of loam soil.

Figure D9-2. Ants may improve the structural resilience of loam soil by bringing subsoil clay to the surface.



However, care is required when turning the green manure crops into the soil, as the extra tillage required may negate improvements in soil structure gained from the organic matter associated with root channels and biopores. Further research is needed to quantify the effects of these rotation crops on cotton production.

Taprooted crops such as safflower and lucerne have been used to dry and crack cracking clay soil. They tend to have limited value for structural improvement in loams unless the surface clay content has been increased markedly by mouldboard ploughing. Nevertheless, useful cracks can be created in a 'non-swelling' topsoil if it is underlaid by a cracking clay subsoil that has been thoroughly dried by a crop such as lucerne. Lucerne also produces large biopores, after its roots have died and decomposed.

Rotation crops may also be important for preventing 'long fallow disorder' in cotton. This condition is associated with inadequate levels of soil-borne fungi known as vesicular arbuscular mycorrhizae (VAM), which attach to roots and aid cotton nutrient uptake.

Deep mouldboard ploughing

Soil diagnosis: Hard-set surface (SOILpak score < 1.0); topsoil thickness not greater than about 30 cm; bleached layer thickness not greater than about 5 cm; subsoil clay not saline or highly sodic; values of subsoil resilience (measures of the soil's ability to swell and shrink; CEC and COLE) at least double those of the topsoil; tillage zone with a water content just below the plastic limit.

Available technology: Deep (50 cm) mouldboard ploughing shatters hard-set layers and brings subsoil swelling clay to the surface. Large yield increases usually pay for this operation and associated gypsum application (approximately 5 t/ha) in the first season. However, these effects tend not to continue beyond two years unless the soil is carefully managed under minimum tillage with controlled traffic. This is believed to be due to the mouldboard ploughed soil being more compactable and slightly less stable because of lower organic matter levels.

Mouldboard ploughing is also likely to be successful where thin layers of recent alluvium overlie cracking clays.

Where suitable subsoil clay lies deeper than 30 cm, consider the use of a 'slip plough'. A technique known as 'slotting', developed by CSIRO at Griffith, also mixes subsoil clay with hardsetting surface layers, but it appears not to be economically viable.

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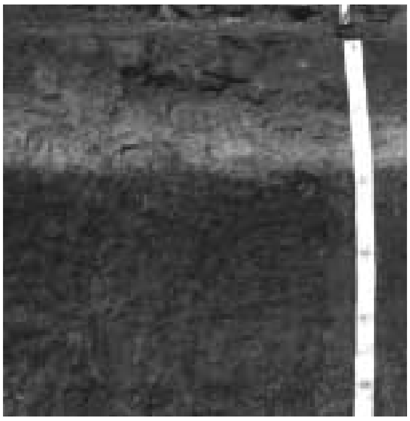
See Chapter D2 for more information on mouldboard ploughing and slip ploughing

Figure D9-3. A hardsetting loam overyling a 'bleached' A2 horizon provides a poor environment for rooth growth.



Deep ripping and chiselling

Soil diagnosis: Surface and/or sub-surface layers that restrict water entry and impede root growth (for example, a bleached layer just above subsoil; see Figure D9-3) (SOILpak score less than 1.0); tillage zone with a water content just below the plastic limit.

Available technology: Farmer experience suggests that the benefits of deep ripping on hardsetting red–brown earths do not last as long as those of deep mouldboard ploughing (as little as a year or two when managed conventionally). However, experiments carried out at Trangie under controlled traffic and zero tillage showed that deep ripping (45 cm depth, carried out at a water content just below the plastic limit) persisted for longer, with higher yields, than the more expensive deep mouldboard ploughed (45 cm depth) treatments. The difference between research results and farmer experience has yet to be resolved, but could be due to differing management systems after ripping, variations in water content when tilled, or different tine designs.

Some growers chisel plough furrows under dry conditions during the cotton season in an attempt to improve water penetration at the next irrigation. Short-term improvements in water entry may occur, but repeated pulverisation of the soil usually creates serious damage due to organic matter loss and dust formation. Actively growing cotton roots under the furrows may be damaged. Compaction and smearing problems develop when the soil is tilled when too wet. These problems are difficult and costly to repair.

An implement known as a 'Dammer-Dyker' (Figure D9-4) has been used to improve retention of water after irrigation by increasing soil surface roughness in furrows. This implement has rows of spade-like arms that radiate from a rotating horizontal axle tractor. The technique is effective under spray irrigation, but the depressions tend to fill up quickly with silt under furrow irrigation unless filled with straw ('vertical mulching').

Figure D9-4. An implement for increasing surface roughness on a hardsetting soil

Aggresizing

Soil diagnosis: Hard-setting surface (SOILpak score < 1.0).

Available technology: When tilled at the plastic limit using spring-tined cultivators, some loamy soil will form clods 1 to 4 mm in

diameter, which, once dried, are stable on re-wetting. This process has been referred to as ‘aggresizing’. Substantial increases in water infiltration into ridges and beds have been demonstrated in Tatura in northern Victoria using this technique.

As yet there is no information on how loams used for cotton production respond to aggresizing. It is believed aggresized ridges or furrows could substantially improve water penetration and lateral subbing under cotton, but the on-farm problem of economically treating hundreds of hectares of furrow-irrigated loams at the correct water content is substantial.

Gypsum application

Soil diagnosis: Clay content at least 30%; surface ESI <0.05.

Available technology: Applying gypsum to the surface of most loams used for cotton production slightly improves water penetration and cotton yield, but gypsum is usually too expensive to be profitable. However, better responses are likely after applying gypsum to sodic clay-rich subsoil exposed by mouldboarding, or following heavy cutting associated with landforming. Application rates are similar to those suggested for cracking clays.

The effects of lime on loams used for cotton production have not yet been investigated. Blends of lime and gypsum should be evaluated.

Organic matter

A laboratory experiment has shown that ‘anionic polyacrylamide’ (at a rate of 7 kg/ha) significantly increased cotton emergence on a hardsetting soil. It may be possible to improve crop establishment by applying this compound via a spray along the plant lines just after planting.

Composted gin trash is another organic material that requires further evaluation, possibly in conjunction with the application of calcium salts.

Crust breaking

A crust breaking roller (spiked roller) is a cheap and effective implement for improving seedling emergence in soil with a hard crust or flake.

Minimum tillage, mulches and slow wetting

Soil diagnosis: Good physical condition (SOILpak score >1.5) under ridges (adequate water intake, negligible waterlogging and little resistance to seedling establishment and root growth).

Available technology: The minimum tillage principles outlined for cracking clays also apply to loams, although channels created by root systems and soil fauna tend to be more important than shrinkage cracks.

High ridges or beds to control waterlogging are less crucial for loams than for cracking clays, but occasional furrow delving under moist conditions may be needed to disrupt impermeable layers of fine sand, silt and dispersed clay deposited by flowing irrigation water. Loosening of furrow sides compacted by wheel traffic may be needed at the same time, although the use of narrow tyres to prevent damage is preferable. Slow subbing of irrigation water means that 1 m wide hills are preferred to 2 m wide beds.

Under minimum tillage, wheat is a popular rotation crop because its vigorous seedlings allow direct drilling into existing cotton beds and furrows, and it produces a thick surface mulch.

The problem of slaking, which reduces soil permeability, and leads to excessive hardness when the soil is dry, becomes more severe as the rate of wetting increases and initial water content decreases. To overcome this problem on loams:

- where cotton is furrow irrigated, start irrigation with normal discharge siphons, then swap over to low discharge (for example, 15 mm) siphons
- where spray irrigation is used, reduce the size and distance of travel of droplets
- retain a straw cover in the furrows to minimise raindrop impact damage, retain moisture and slow the wetting front when furrow irrigating; however, weed growth under the straw may be a problem. Weed control on red soil will become easier after the introduction of herbicide-tolerant cotton varieties.

Organic matter accumulation at the soil surface can dramatically reduce hardsetting problems, but the greatest improvement is confined to the top few centimetres. Therefore, it is important not to invert the topsoil once a desirable soil structure has been created. If tillage is required to loosen soil under the plant lines, and perhaps incorporate a pre-emergent herbicide, consider the use of ‘zonal tillage’ implements. They restrict the disturbance of soil and mulch on top of the hills to strips just 5 cm wide.

A danger with the prolonged use of small siphons is that leakage from continuously full supply channels may lead to problems with salinity. Lining leaking channels with bentonite, and/or compaction of the channel base, can overcome the problem. Spray or drip irrigation may be cheaper and simpler where these problems exist. Excessive deep drainage has been recorded in recent alluvium due to vigorous earthworm activity under pasture, but conventional cultivation soon resolves this problem.

D10. Extra notes for dryland growers

PURPOSE OF THIS CHAPTER

This chapter summarises the key soil management issues that should be considered by dryland cotton growers.

CHAPTER OVERVIEW

The following points are covered:

- the critical importance of repair and prevention of soil structural problems
- the need to maximise water entry and storage
- the need to provide a suitable seedbed
- the dangers of deep percolation and soil loss by water erosion.

For further information about dryland cotton production, refer to:
Australian Dryland Cotton Production Guide, by P. Castor et al., QDPI Dalby, and *Cotton Production During Drought,* by D. Gibb, CRC Narrabri.

INTRODUCTION

Cotton is usually brought into dryland cropping systems following a twelve-month fallow that was preceded by a winter cereal. Acceptable lint yields have been obtained from cotton grown from a short (six-month) fallow from sorghum or mung bean in years with at least average rainfall.

The opportunity to plant cotton into adequate soil moisture (140–180 mm stored plant-available water) soon after the harvest of a winter cereal crop may occur in up to 20–30% of years in the more northern parts of the cotton growing area. Only in years of well above average winter/spring rainfall would back-to-back cotton be likely in a dryland situation. In such years, it may be possible to grow winter wheat, then spray it in about August to provide surface mulch without consuming too much stored water.

When soil structure problems occur, producers of dryland cotton have fewer economically viable options available to them than growers who can irrigate. Nursing a crop in damaged soil is not a feasible strategy—it is not possible to add extra water to help root growth by softening compacted layers. Soil compaction problems under dryland cropping tend to be more severe than under irrigation, because of poorer guidance of farm machinery.

The emphasis should be on removing problems well before planting cotton, and on avoiding further problems by using controlled traffic (‘tramlining’). Site assessment before planting is a crucial part of the planning process.

SOIL REQUIREMENTS FOR DRYLAND COTTON

Dryland cotton has some unique soil management requirements:

- Excellent soil structure is needed to maximise rainfall intake and storage (both during fallow and while the crop is being grown), and to allow deep and thorough root penetration. Skip-row plantings use this water more slowly than crops with solid plantings.
- Due to serious erosion risks, surface cover is vital.
- Even under dryland conditions, waterlogging can be a major problem. On flat areas, consider raised beds rather than planting on the flat.

SOIL MANAGEMENT OPTIONS FOR DRYLAND COTTON

Assess soil suitability for water entry and root growth

Carefully assess the soil condition at the start of the fallow period that precedes the next cotton crop. Focus your attention on those parts of your farm with soil that has a high water holding capacity (over 140 mm), and with freedom from restrictions to root growth, such as soil compaction. These areas will have the greatest potential for profitable crop production.

Compacted soil limits water entry, particularly after shrinkage cracks have closed. Rather than being stored in the soil, rainwater will be lost via run-off and evaporation. Run-off may cause soil loss by water erosion.

Red soil with a loamy topsoil tends to be avoided by producers of dryland cotton. However, many have a water holding capacity

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See Chapter D9 for more details on red soil management

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See Chapter D2 for more information on overcoming soil compaction or smearing.

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See Chapter D2 for more information on gypsum and lime treatment.

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See Chapter D6 for more information on maximising crop water use efficiency.

(approximately 180 mm) that is greater than that of some of the cracking clays used for cotton production. The main problem on red soil is managing the loamy surface so that water can enter the soil profile.

Overcome soil problems early in the fallow phase

The previous dryland cotton crop should have thoroughly cracked and loosened the soil profile. However, if a compaction/smearing problem is identified (SOILpak score <0.5), develop a soil management plan that will overcome the limitation quickly in a cost-effective way. If the surface soil is sodic (ESI<0.05), treat it with gypsum and/or lime.

Apart from soil structure issues, other potential limitations such as salinity, acidity and poor nutrition need to be overcome before the yield potential for a given amount of rain can be approached. Soil problems limit the ability of roots to extract soil water that otherwise would be readily available.

Monitor the fallow efficiency (FE), which is the proportion of rainfall between crops that is stored by the soil. Values generally range from 5–40%. Research in Central Queensland has shown that soil compaction from a single wheel pass decreased FE from 35% to 13%. It has been estimated that each extra millimetre of water stored in a hectare of soil is worth $4.36 (when cotton is selling for $450 per bale).

$$\text{Fallow efficiency (FE)} = \frac{\text{change in soil water storage (in mm)} \times 100}{\text{rainfall (in mm)}}$$

While the crop is being grown, aim to maximise crop water use efficiency.

Use controlled traffic systems and mulches

Effective treatment of compacted soil by deep tillage can be expensive. Heavy tillage operations that create a rough, open surface may require several subsequent passes to produce a suitable seedbed. Therefore, preventing such problems is of even greater importance than for irrigators, who have much greater potential returns.

Dryland cotton should be grown using controlled traffic machinery with narrow tyres and accurate guidance systems.

Water intake (and soil erosion control) in uncompacted soil between the wheel tracks can be enhanced by reducing tillage, by protecting the soil surface from raindrop impact via organic mulches, and by encouraging biopore formation using earthworms and ants. Mulches also protect seedlings from sandblasting damage in windy weather. Weed control under mulches can be difficult, but the introduction of herbicide-tolerant cotton varieties should make it easier.

Control Heliothis pupae

The pupae of *Heliothis armigera* must be destroyed by tillage soon after cotton harvest. Otherwise this pest will become even more difficult to manage because of resistance to pesticides. Where skip-row cotton is grown, the full field area has to be cultivated, because larvae can move to the centre of skips (up to 1.5 m from the plant lines) looking for soft soil in which to burrow. However, after the

cotton harvest the soil can be tilled for pupae control, then sown with wheat. After the wheat has been harvested (or, if necessary, sprayed with herbicides before harvest), the straw-covered soil with large open shrinkage cracks at the soil surface should be disturbed as little as possible. This will encourage moisture accumulation and conservation.

Soon after the cotton harvest, a particularly difficult challenge is to keep cracks in the soil unblocked for efficient water entry after harvest, given that the aim of tillage for Heliothis pupae control is to provide loose, finely divided clods. Weed control, which is vital for moisture conservation, may produce a similar tilth if done mechanically.

Another problem associated with tillage for pupae control is loss of stored water when the soil is disturbed.

Refer to 'MACHINEpak' for further details.

Prepare a suitable seedbed

Cotton can be a difficult crop to establish. A seedbed of fine tilth is required to ensure good seed-soil contact and even germination. Often the soil will have to be tilled during the fallow to obtain the desired tilth, and to incorporate pre-emergent herbicides. Some form of 'zonal tillage' should be used at, or before, planting so that not all of the soil surface is disturbed.

The seed needs to be placed in moist soil when planted. An advantage of using raised beds for dryland cotton is that when the weather is dry around planting time, soil can be knocked off them to expose soil with an ideal water content for planting.

Cotton seedlings are very sensitive to soil temperature at germination. Effective spreading of the stubble when harvesting the previous crop helps to avoid zones of variable soil temperature and moisture.

Reduce the risk of adverse side-effects

Sustainability issues that have to be addressed are the potential for excessive soil erosion, deep percolation (causing dryland salinity) and nutrient export.

Recent research in Central Queensland suggests that running the wheel tracks of controlled traffic machinery up and down the slope is the best option for erosion control, possibly in conjunction with contour banks (connected to grassed waterways) that can be driven over. This approach, which works best when the soil surface is protected by cereal straw, avoids excessive concentration of the run-off water.

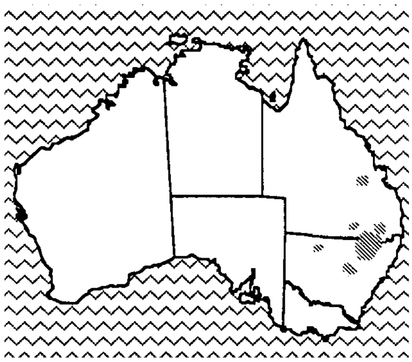
Try not to make the time interval between harvesting of one crop and planting the next too long. Otherwise, mycorrhiza populations may become badly depleted. Also, the risk of water loss via deep drainage becomes greater as fallow length becomes greater.

After the soil has been filled to about 75% of capacity, consider the economic viability of planting a crop (not necessarily cotton) to minimise the risk of water loss by run-off and/or deep drainage at a later date. This decision is a difficult one, because the rotation crop may be followed by drought, leaving insufficient water to grow a profitable crop of cotton.

Use the 'NUTRIpak' manual to ensure that the crop is receiving adequate nutrition.

PART E. BACKGROUND INFORMATION

E1. Australian cotton soil



PURPOSE OF THIS CHAPTER

This chapter describes soil types found in the main cotton growing regions of Australia.

CHAPTER OVERVIEW

Major soil types and landscapes of the main cotton growing localities are outlined, and processes associated with their formation are discussed briefly.

Two main soil classification schemes are referred to: the ‘Great Soil Groups’ classification, and the new ‘Australian Soil Classification’ scheme devised by Ray Isbell.

Other chapters to refer to are:

- Chapter A2: ‘The ideal soil for cotton’
- Chapter A3: ‘District soil management problems’.

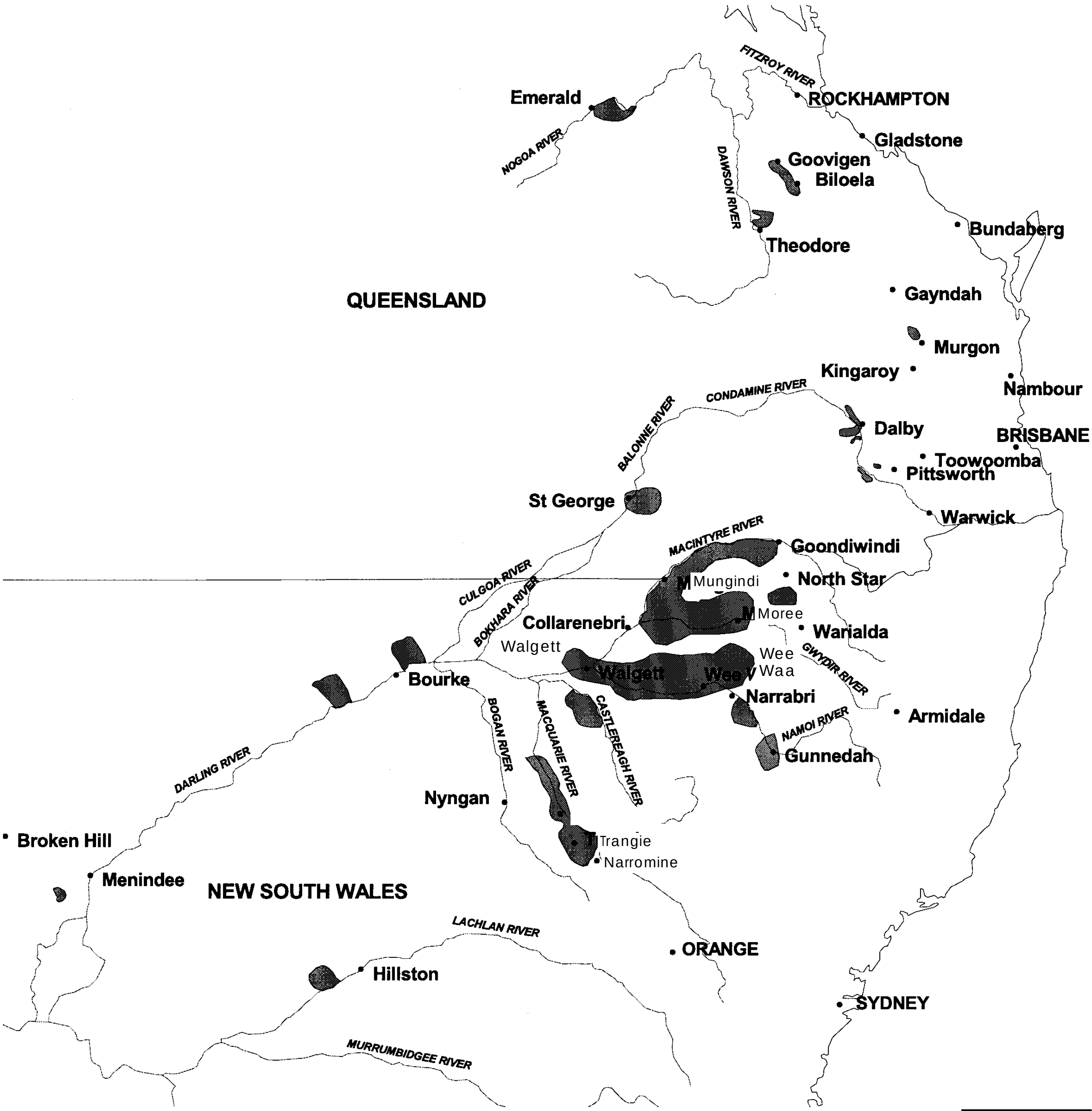
COTTON GROWING AREAS

The cotton growing areas of New South Wales and Queensland (Figure E1-1) are scattered between the southern latitudes of 23° 30' and 32° 30'.

Most of the cotton is irrigated, with major areas in the Gwydir, Namoi and Macquarie Valleys; near Bourke and Walgett on the Darling River of NSW; and in the St George, Darling Downs, Theodore–Biloela and Emerald districts of Queensland.

Rain-fed cotton in Queensland is grown primarily in the Dawson and Callide Valleys, on the Darling Downs and in the Emerald area. In northern NSW it is grown mainly east of Moree and west of Warialda. Some sowings exist as far south as the Breeza Plains near Gunnedah. In both States there are substantial areas of suitable soil for the expansion of rain-fed cotton sowings, should the economics prove worthwhile.

Figure E1-1. Cotton-growing localities of Queensland and New South Wales.



MAIN SOIL TYPES

Most cotton growing areas in Australia are dominated by cracking clay soil (black earths and grey and brown clays). These are sometimes referred to as Vertosols (Australian Soil Classification terminology) or Vertisols (US terminology).

In the Macquarie Valley, and to a lesser extent in the Namoi and Gwydir Valleys, red–brown earths are a minor component. In many of the Queensland districts, solodic and solodised–solonetz duplex soil types are minor components. These soil types are referred to as either Chromosols or Sodosols or Kurosols, depending on their characteristics and properties (Australian Soil Classification terminology).

Relatively young alluvial soil occurs on levees in the Dawson and Callide Valleys. There are also small areas of alluvial soil in the Macquarie, Upper Namoi, and Gwydir Valleys.

The soil types, and their positions in the landscape, for each of the major districts in Queensland and New South Wales, are described in Table E1-1. Even in their natural condition, most are less than ideal for cotton.

The main features of each soil type are summarised in Figure E1-2.

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See Chapter A2 for more information on the features of an ideal soil for cotton.

Table E1-1. Major soil types and soil landscapes of the Australian cotton industry.

(a) Queensland

Locality	Soil series	Great Soil Group	Soil Landscape
Emerald	B Ug-2	Black earth	Crest, upper and mid slopes of gently undulating basalt rises.
	Tb Ug-2	Black earth	Mid and lower slopes of gently undulating basalt rises.
	A Ug	Black earth and grey clay	Alluvial floodplains and terraces of mixed origins.
Dawson and Callide Valleys	Vermont	Grey clay	Alluvial flood plains of mixed origin.
	Retro	Solodised solonetz and solodic soil	Levees and flood plains of mixed origin.
	Warrinilla	Alluvial soil	Levees of mixed alluvial origin.
	Clemantis	Alluvial soil	Levees of mixed alluvial origin.
Darling Downs	Anchorfield	Black earth	Crests and slopes of very low ridges in alluvial plains of mixed but largely basaltic origin.
	Mywybilla	Black earth	Alluvial plains of mixed origin, some basaltic.
	Condamine	Black earth	Flood plains of mixed alluvium, largely basaltic.
	Waco	Black earth	Fans of basaltic alluvium from nearby hills.
St George irrigation area	Unnamed	Grey clays	Alluvial plains of mixed origin
	Unnamed	Solodised solonetz and solodic soil	Slightly elevated areas in the grey clay alluvial plains.
Waggamba Shire (Macintyre Valley)	Unnamed	Grey clays	Alluvial flood plains of mixed origin.

(b) New South Wales

Macintyre Valley	Unnamed	Grey clays	Alluvial plains of mixed origin.
Gwydir Valley	Unnamed	Black earth	Mid and lower slopes of gently undulating basalt rises.
		Grey and brown clays	Alluvial plains of mixed origin.
		Red–brown earths	Slightly elevated ridges in clay plains.
		Solodised solonetz	Slightly elevated ridges in clay plains.
Namoi Valley	Unnamed	Black earth	Mid and lower slopes of gently undulating basalt rises.
		Grey and brown clays	Alluvial plains of mixed origin.
		Red–brown earths	Slightly elevated ridges in clay plains.
Breeza/Spring Ridge	Unnamed	Black earth	Alluvial plains of basaltic origin.
Macquarie Valley	Mullah/ Buddah/ Snake	Grey and brown clays clays]	] Alluvial soil of mixed origin, but less basaltic influence than for the Namoi and Gwydir Valleys.
	Mitchell/ Wilga/ Byron	Red–brown earths]	]
	Macquarie	Alluvial soil]	]
Bourke	Unnamed	Grey clays	Flood plain of the Darling River.
Walgett	Unnamed	Grey clays	Flood plain of the Barwon/ Darling Rivers.

Cracking clays

Grey and brown clays

Typically, grey and brown clays are moderately deep to very deep clay soil types with a relatively uniform colour and uniform clay content to beyond a depth of one metre. They crack deeply on drying.

The surface structure is often self-mulching—that is, the cracking clay surface develops a soft and crumbly condition composed of fine units after wetting and drying. Sometimes they have a fragile surface crust a few millimetres thick. Less often the surface is hard and poorly structured with widely spaced cracks, such forms usually being associated with lower clay contents. Below about 5 cm there is a rapid change from fine (2-5 mm diameter) to coarse (>50 mm diameter) units, with many large diagonal shear planes (slickensides) below 40 cm.

Often grey and brown clays are alkaline (pH $CaCl_2$> 7) and calcareous (lime nodules present) from the surface down the whole profile. Sometimes they are slightly acid (pH, $CaCl_2$< 7) at the surface and become alkaline and calcareous at shallow depths. Occasionally, especially where brigalow once grew, they may be strongly acid in the deep subsoil, below either an alkaline or slightly acid topsoil.

Naturally occurring gypsum may or may not be present in the deep subsoil. Surface soil salinity is low, but below 0.5 to l.0 m, low to high amounts of soluble salts occur. Surface soil is generally non-sodic, but subsoil is often sodic to strongly sodic.

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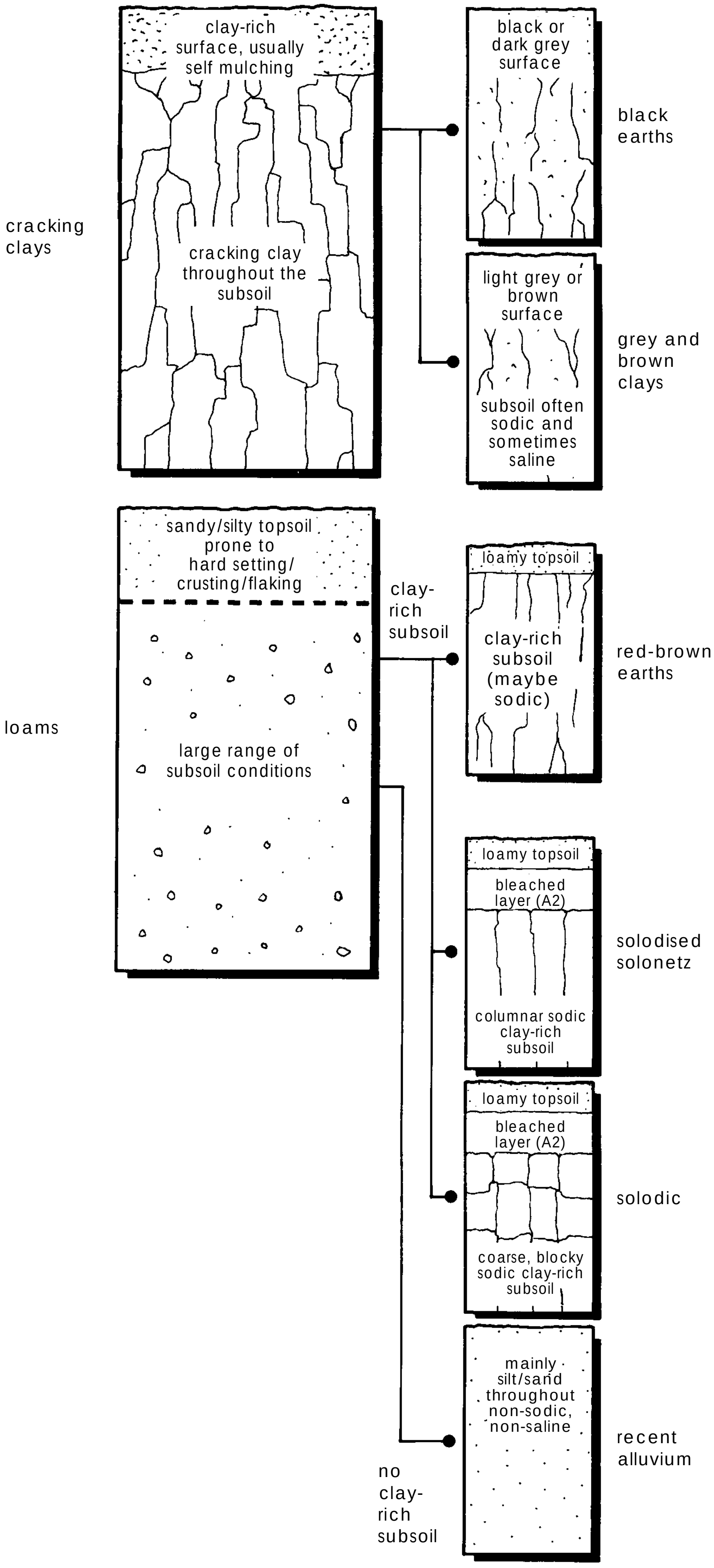
See Chapter E3 for a definition of sodicity and salinity.

Figure E1-2. Main features of contrasting soil types used for cotton production in Australia.



Black earths (black self-mulching clays)

These very dark grey brown or almost black clay soil types are typically alkaline, although the upper 25 to 30 cm are sometimes near neutral (pH $CaCl_2$ = 7). They develop closely spaced, wide, deep cracks on drying. The surface is usually strongly self-mulching, with aggregates grading through fine to coarse in the subsoil, with diagonal shear planes below about 40 cm.

Lime is usually present in the subsoil and soluble salts are present in low or moderate amounts. Anchorfield (Darling Downs) and the BUg-2 (Emerald) black earths have non-sodic subsoil; other black earths may have sodic or strongly sodic subsoil.

Some of the black earths are formed directly on basalt (a dark, fine-grained volcanic rock), as at Emerald. Others, for example those listed for the Darling Downs, are generally deeper and overly clayey materials deposited after movement by water.

Classifying cracking clays using the Australian Soil Classification system

The terms ‘grey clay’, ‘brown clay’ and ‘black earth’ come from the ‘Great Soil Groups’ soil classification system (see Stace et al. 1968—reference in Appendix 1). Australian soil is now being classified using the ‘Australian Soil Classification’ (ASC) soil classification system (see Isbell, 1996—reference in Appendix 1). Definitions of soil types based on the ASC have been obtained from Isbell (1996) and Isbell et al. (1997) (see Appendix 1).

Using the ASC system, grey and brown clays and black earths will be classified as Vertosols at the first hierarchical level (Orders). There are five hierarchical levels in the ASC: Order, Suborder, Great Groups, Subgroups and Family Criteria.

For a soil to be classified as a Vertosol it must have all of the following features:

- a clay field texture, or 35% or more clay throughout the soil profile, except for thin, crusty horizons 30 mm or less thick
- when dry, open cracks occur at least some time in most years. These are at least 5 mm wide and extend upward to the surface or to the base of any plough layer, self-mulching horizon, or thin, crusty horizon.
- slickensides and/or lenticular peds at some depth in the soil profile.

Many Vertosols are self-mulching. Gilgai micro-relief is sometimes associated with Vertosols, but it is not restricted to this soil type.

At the second hierarchical level (Suborders) Vertosols are primarily distinguished by colour. Therefore grey clays will be ‘Grey Vertosols’; brown clays, ‘Brown Vertosols’; and black earths, ‘Black Vertosols’. Further subdivision reflects other soil characteristics such as self-mulching behaviour, presence of a thin surface crust, acidity, salinity and sodicity.

Written in full, an example of a cracking clay classified using the ASC is:

Endohypersodic, Self-mulching, Grey Vertosol; non-gravelly, medium fine, very fine, very deep.

This name can be shortened, depending on how many levels of the hierarchy can be determined, for example, *Self-mulching, Grey Vertosol.*

The above Vertosol would be dominantly grey in the major part of the upper 0.5 m of the profile, self-mulching and have a sub-horizon

below 0.5 m that has an ESP of 15 or greater. The surface of the soil and A1 (topsoil) horizon would contain less than 2% gravel, the clay content of the upper 0.1 m (excluding any surface crusty horizon) would be between 45 and 60%, the B horizon maximum clay content would be greater than 60% clay, and the depth of the soil would be 1.5–5.0 m.

Soil with a loamy topsoil

Red-brown earths

A reddish sandy, fine sandy, silt loam or clay loam surface layer (often weakly structured with few shrinkage cracks, and 10 to 45 cm thick) overlies a red–brown clay subsoil, usually with well defined clods separated by cracks.

Red–brown earths may have an A2 horizon in the lower topsoil. An A2 horizon is identified by the fact that it is paler than the A1 horizon above and the B horizon below. It is pale because it has less organic matter than the A1 horizon and because iron has leached from it (a sign of periodic waterlogging).

The deeper subsoil is usually yellowish or olive-brown, contains some lime, and is more friable and sandier than the upper subsoil.

The surface is usually slightly acid to acid, while the subsoil is normally alkaline and sodic or strongly sodic, sometimes containing appreciable soluble salts in the lower part.

After cultivation and subsequent loss of organic matter, red–brown earths may develop a hardsetting layer in the surface soil. Surface crusting is common.

Using the ASC system, red-brown earths (Great Soil Groups terminology) will be classified as either Chromosols, Sodosols or Kurosols at the Order level. Because they are dominantly red in the B2 horizon (subsoil) they will be known as Red Chromosols, Red Sodosols or Red Kurosols at the Suborder level.

Chromosols have a strong texture contrast between A and B horizons. Their B2 horizons are not strongly acid and are not sodic (ESP < 6) in their upper 0.2 m (or the major part of the B2 horizon if it is less than 0.2 m thick). Strongly acid soil is considered to have a pH of less than 5.5 (1:5 soil:water) or less than 4.6 (1:5 soil:0.01 M $CaCl_2$). Hardsetting in Chromosols can be exacerbated after years of cultivation.

Sodosols, which cover 13% of Australia, have the same features as Chromosols, except that the upper 0.2 m of the B2 horizon is sodic (ESP > 6). The sodic clay B horizons of Sodosols generally have a restricted hydraulic conductivity. This poor internal drainage can result in a seasonal perched watertable. Many Sodosols are hardsetting. Because the B horizons are sodic and highly dispersive they are particularly prone to tunnel and gully erosion if they are exposed to wind and water.

It is not likely that cotton is grown on naturally occurring Kurosols, as they are not widespread in Australia. Like the Chromosols and Sodosols they have a strong texture contrast between the A and B horizons, but the upper part of the B2 horizon is strongly acidic and may or may not be sodic. Agricultural practices may lead to Chromosols and Sodosols becoming Kurosols.

Solodised solonetz and solodic soil (red pine soil)

The surface layer of grey-brown sandy loam to clay loam is usually conspicuously bleached in the lower part. The surface layer abruptly overlies a sodic clay or sandy clay subsoil.

A solodised solonetz subsoil has a strong coarse columnar structure. A solodic subsoil is coarsely cloddy. The surface and upper subsoil are acid, grading to strongly alkaline horizons with lime and gypsum at depths below 60–90 cm. Limited data suggest that, in general, their subsoil is sodic, rather than strongly sodic.

Solodised solonetz and solodic soils can be classified as either Chromosols, Sodosols or Kurosols using the ASC system. Unlike the red-brown earths, they are not red in the subsoil, and so will not be defined as 'Red' at the Suborder level. They will likely be classified as 'Yellow' at the Suborder level.

Alluvial soil (river soil)

Soil types with a broad range of clay contents occur on young alluvium. They show variable organic matter accumulation in the darker surface horizons, overlying layers of gravel, sand, loam, and clay. They tend to be non-saline and non-sodic.

HOW AUSTRALIAN COTTON SOIL WAS FORMED

An understanding of how the different types of cotton soil were formed provides a framework for the transfer of soil management knowledge between different parts of a valley, as well as between neighbouring cotton growing districts. A knowledge of the location and features of old stream channels associated with the soil types helps us to predict, for example, which cotton soil is most prone to deep drainage losses.

In previous centuries, when the climate was much wetter, western rivers were a lot larger than they are today. Large amounts of gravel and sand were deposited during floods and underlie many Australian cotton fields.

The wet periods were interspersed with extremely arid periods when large amounts of dust and salt were deposited over the Murray–Darling Basin.

These events, and their effect on modern-day soil condition in the lower Macquarie Valley, have been described by CSIRO staff (see the 'Further Reading' section, Appendix 2). District geological maps provide similar, but less detailed, information.

KEY SOIL PROPERTIES– STATUS IN 1998

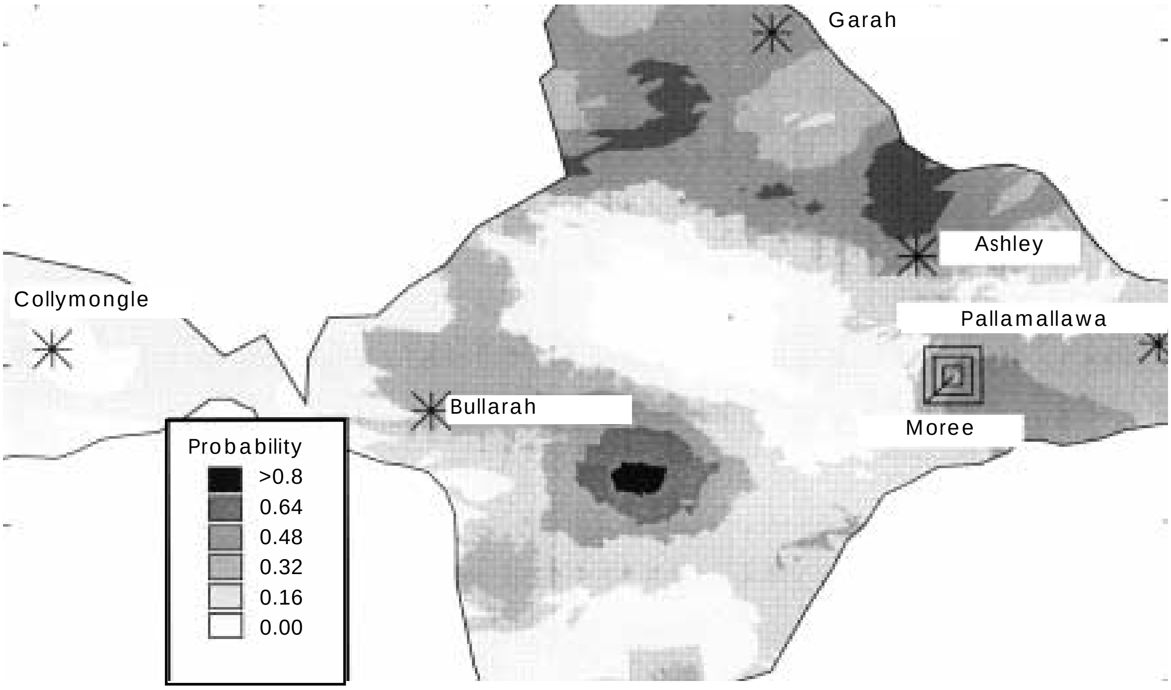
Sodicity and salinity

Sodicity and salinity trends in the Macintyre, Gwydir and Namoi Valleys are being mapped by staff at the Cotton CRC, University of Sydney. A sample of their information is shown in Figure E1-3.

Preliminary analysis of the lower Macintyre soil data set has found that:

- salinity increases from east to west across the valley, with subsoil EC_e values ranging from 0.2 to 27.0 dS/m.
- the pH of soil on irrigated cotton farms ranges from 4.7 to 9.7.

Figure E1-3. Map of the lower Gwydir Valley, showing the probabilities of needing gypsum for soil structural improvement



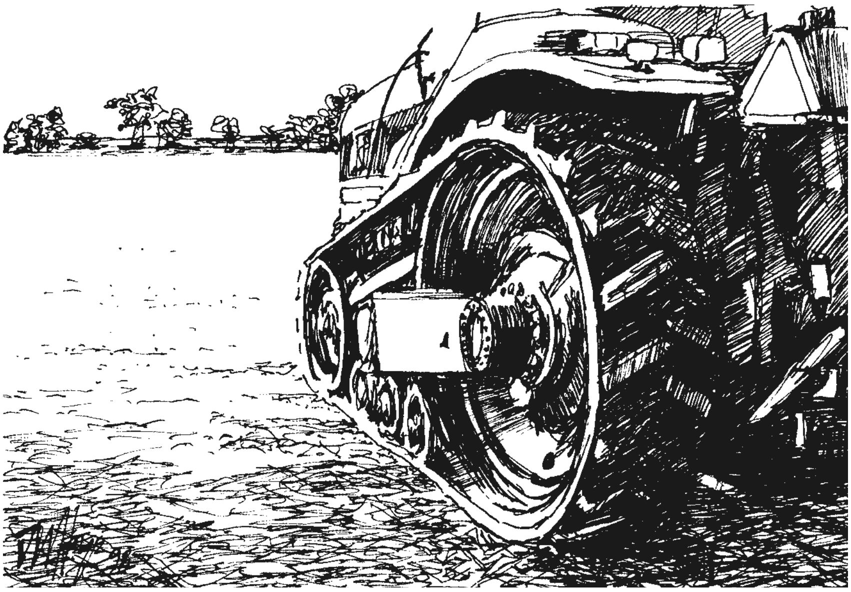
Other soil factors

Ideally, as well as having maps of sodicity and salinity, we need to develop maps (preferably at a scale of 1:25,000 or less) of the following soil factors for all cotton growing districts:

- shrink/swell potential
- organic matter
- pH
- nutrients
- compaction severity/risk.

Such maps should be accompanied by watertable and crop productivity maps. Geographic Information System packages are available to organise this information in an orderly fashion on desktop computers.

E2. Compaction and hardsetting



PURPOSE OF THIS CHAPTER

This chapter provides an overview of compaction and hardsetting processes in cotton soil.

CHAPTER OVERVIEW

The following points are covered:

- soil pores influenced by compaction
- the importance of soil water content
- processes associated with soil compaction:
  —vehicle contact pressure (near-surface)
  —vehicle pressure (subsoil)
  —deep clay movement
  —deep subsoil swelling
- smearing (compaction in narrow bands)
- remoulding
- hardsetting and crusting.

Other chapters to refer to are:

- Chapter E6: 'How soil structure and temperature affect plant growth'.

INTRODUCTION

Compaction refers to the compression of a soil or a layer to give increased bulk density (that is, decreased porosity). Compression usually results from a vertical force, such as that produced by wheeled or tracked vehicles, on soil that is too moist and soft (wetter than the plastic limit) to resist deformation. Compaction may be accompanied by remoulding, which is the rearrangement of soil pores without an increase in bulk density.

Soil bulk density can also increase when an inherently unstable soil slumps in water and then suffers hardsetting or crusting when dried.

SOIL PORES INFLUENCED BY COMPACTION

The larger (and generally most useful) pores are the most easily compressed under wheels, because they are more likely to be full of air; the air is forced out of the soil when compacted. Smaller pores are less easily compressed. They are more likely to be full of water, which cannot be compressed and is not easily squeezed out of the soil. Completely saturated soil does not compress, because water is incompressible and there is no air to be lost. However, these pores may be rearranged (remoulded) if the vertical force is accompanied by a horizontal force (such as the wheel slip of a tractor).

Soil pores form the living space for plant roots and soil-dwelling organisms. The space is dynamic, changing with soil moisture content and outside forces. A good soil structure consists of relatively stable, interconnected pores with a range of sizes. The range in size of different soil components is shown in Figure E2-1.

Macropores are large enough to drain at field capacity. They are sometimes called ‘transmission pores’ because of their role in transmitting air and water through the soil. They include shrinkage cracks, burrows made by soil animals and old root channels. Not only must there be sufficient macropores, but they must also be stable and vertically continuous from the surface to near the bottom of the root zone. As well as permitting rapid water entry, they allow the root zone to quickly re-aerate after rain.

Mesopores are small enough to retain water at field capacity, but large enough for the water to be available to plants. They are sometimes called ‘storage pores’ because of their role in storing water for plant roots.

THE IMPORTANCE OF SOIL WATER CONTENT

The ability of a soil to resist compaction decreases as the soil water content becomes greater (Figure E2-2). There is approximately a 100-fold difference in soil strength between field capacity and wilting point. In contrast, the range in pressures under vehicles used for cotton production is about 7-fold. This means that soil water content has a much greater influence on soil compactibility than vehicle factors.

PROCESSES ASSOCIATED WITH SOIL COMPACTION

Vehicle pressure (near-surface)

The severity of surface and sub-surface compaction is related mainly to the ground contact pressure of tyres/tracks.

Tracked vehicles generally have a ‘softer footprint’ than wheeled tractors, particularly at depth, but there can be high-pressure peaks

Figure E2-1. The range in size of different soil components (source: Kay, 1990).

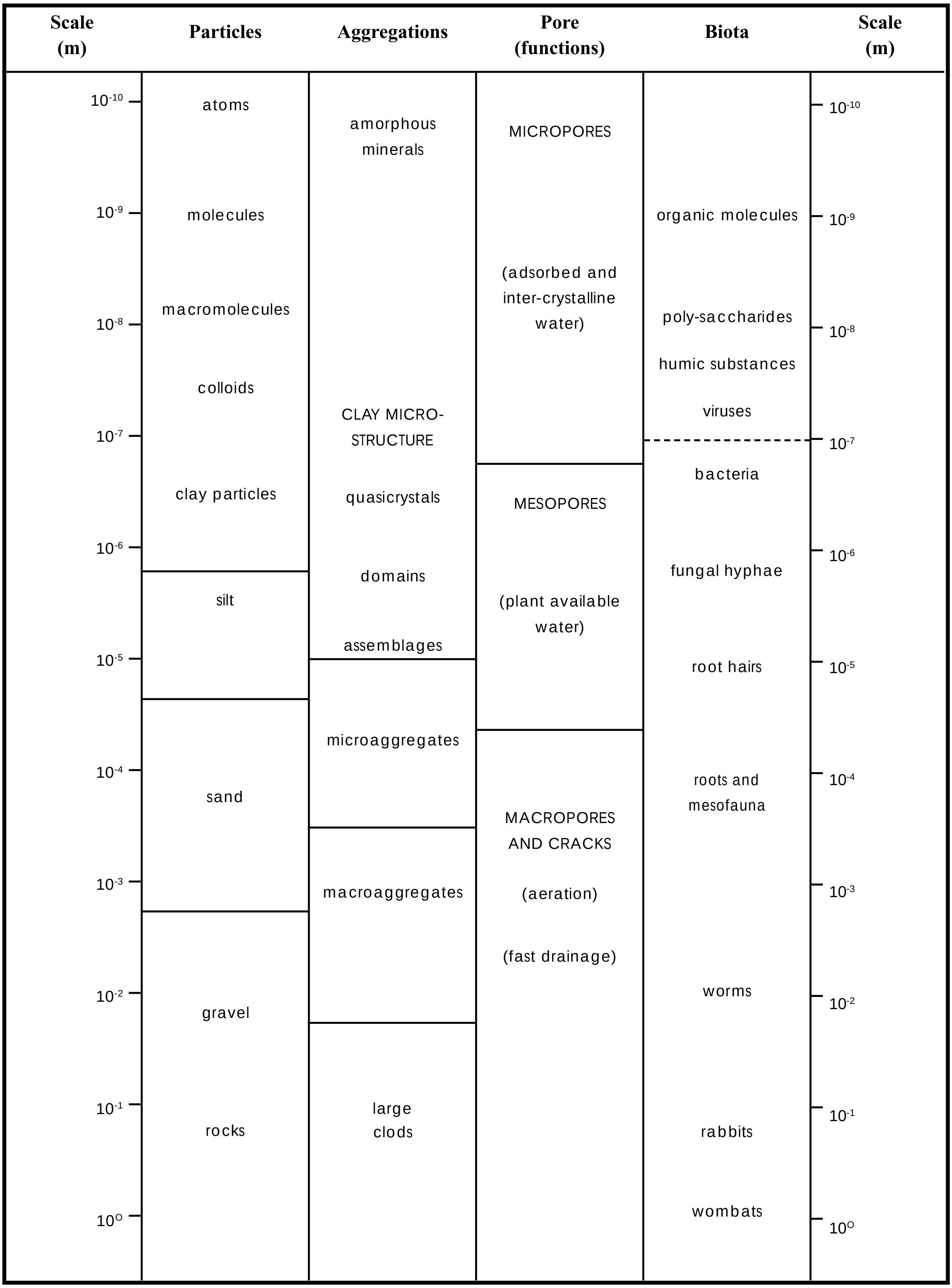
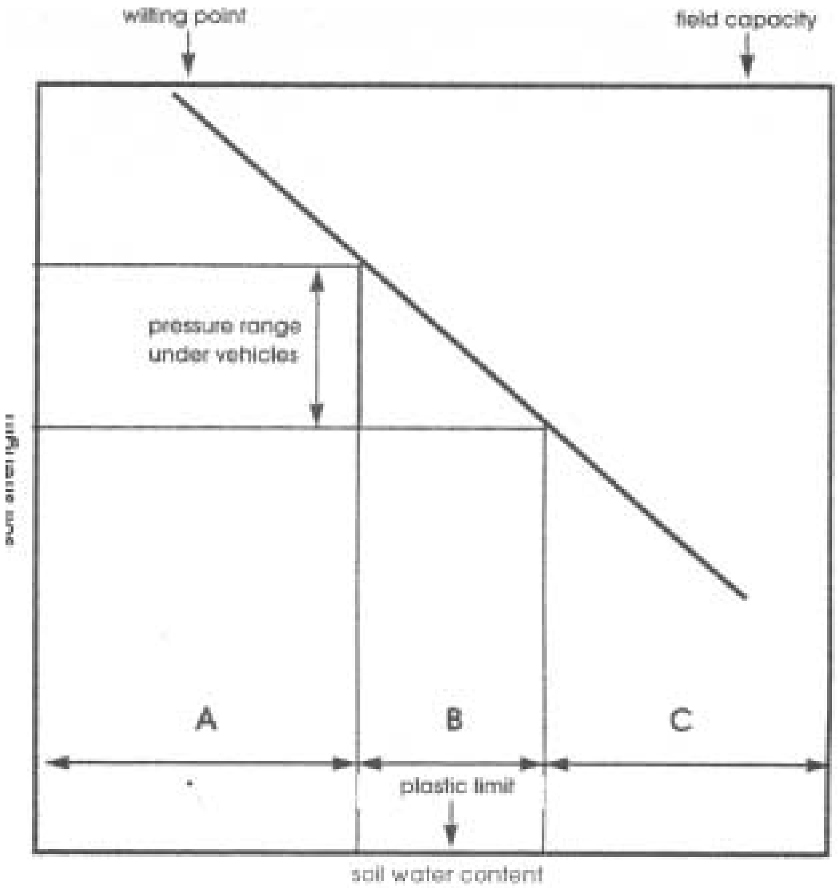


Figure E2-2. Soil strength in relation to soil water content (schematic). When cotton vehicles are driven on wet soil (zone C), compaction and/or remoulding will occur. The same vehicles on zone A soil, which is drier than about the plastic limit, will be supported without damage to the soil.



below each idler on the bogey, and there tends to be a large peak at one end of the track. The largest peak for a tracked machine tends to be lower than for an average tyred vehicle, but can be as much as two to three times the calculated average pressure under a track. The main benefit of tracks appears to be better traction, and more efficient use of engine power.

Once compaction has occurred at a given moisture content, subsequent passes of the compacting force will only marginally increase the amount of compaction; 80–90% of the damage occurs during the first pass of equipment on moist soil. However, this figure will be much lower if the first pass occurs on drier soil than the second pass. The amount of compaction tends to decrease as vehicle speed increases.

It is important that tyres or tracks be narrow enough to avoid bridging across the furrow and compression of the bed edges. Having a flat bottom in the furrow, rather than a V-shape, also reduces bed shoulder compaction.

Compaction of the topsoil and sub-surface is unavoidable—the main priority is to restrict it to narrow laneways as part of a controlled traffic farming system.

Vehicle pressure (subsoil)

Deep subsoil compaction (that is, below a depth of about 30 cm) is more a function of total axle load rather than tyre pressure and width,

particularly when the axle load is greater than about 10 t. Axle loads as great as 14 t occur under cotton pickers.

Research in Sweden has shown that machinery pressures can penetrate to as deep as 80 cm. The forces may penetrate even deeper in situations where the wheels of heavy machinery rest on ‘pillars’ of dry soil (in between large vertical shrinkage cracks) that act like pistons and push into moist soil deep in the profile. Recent studies by workers from Southern Cross University found that cotton farming near Warren had increased oven-dry bulk density (from 1.77 to 1.84 t/m^3) at a depth of 190–205 cm.

The use of dual wheels to spread the weight of heavy machinery will reduce deep subsoil compaction only when the wheels are spaced by more than about 1.5 m. A tandem arrangement of wheels is likely to be a better option for load spreading because it compacts a smaller proportion of a field than a dual arrangement.

Subsoil compaction is unavoidable—the main priority is to restrict it to ‘narrow pillars’ of soil underneath the wheeled furrows.

Deep clay movement

Clay dispersion, whereby individual clay particles separate from soil microaggregates, can occur spontaneously or be aggravated by remoulding. An example of remoulding is the rearrangement of wet soil by the wheel slip of a tractor. The dispersed clay particles block pores; on drying, the dispersed soil sets hard, with fewer large pore spaces. It has been observed that run-off water from wheel tracks contains more dispersed clay than run-off from unwheeled furrows.

Recent studies near Warren and Narrabri have shown that translocated clay does not have a major effect on soil bulk density, but coatings on clods may retard the growth of root hairs seeking water and nutrients.

Deep subsoil swelling

Deep subsoil will become more prone to swelling if sodicity increases (due, for example, to translocation of sodium from gypsum-treated topsoil), and/or if salinity decreases (due to an increase in the amount of deep drainage). An increase in the amount of swelling in a confined space is likely to decrease soil porosity under moist conditions.

Smearing (compaction in thin layers)

Smearing is the realignment of clay particles from a random to a parallel orientation, producing a hard, shiny surface overlying a thin layer with high bulk density. It results from horizontal shear forces, produced by, for example, a blunt tine moving through moist soil. Smearing may impede water and air movement and root growth, but these problems do not persist for long in a cracking clay soil, providing the soil undergoes restructuring by shrinking and swelling.

Remoulding

Remoulding refers to the rearrangement of soil pores (usually with a reduction in pore continuity) without an increase in soil bulk density. It is associated with tractor wheel slip in very wet soil.

Slumping and hardsetting

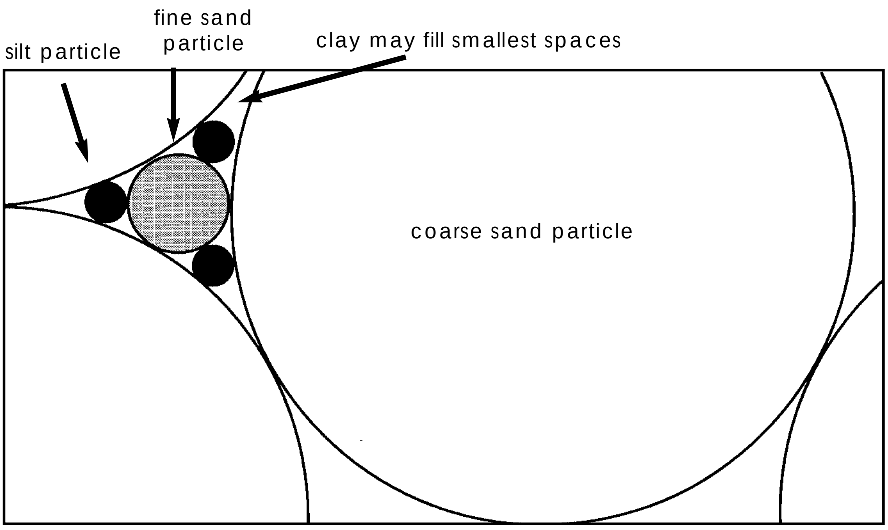
A hardsetting soil is one that becomes massive (poorly structured) or cemented throughout a significant proportion of the soil profile, due to wetting and slumping followed by drying. In hardset layers, pores may be observed, but they tend to be disconnected. Hardsetting can occur in soil that has never been cultivated. Hardset layers, although very hard when dry, are quite soft when wet.

Factors that influence the hardsetting potential of a soil include:

- particle-size distribution
- dominant clay minerals in the clay fraction
- dispersibility (sodicity and electrolyte concentration)
- the organic matter content
- the presence of cementing or stabilising materials.

The particle size distribution (amount of clay, silt and sand) in a soil has a major role in determining whether a soil will be hardsetting or not. Hardsetting is most common in soil with a high content of silt and fine sand (Figure E2-3). In a hardsetting soil, the particle size distribution is such that the individual soil particles will pack down to a high density upon wetting; it is a 'concrete-like' mixture.

Figure E2-3. Theoretical packing of spherical particles.



The clay minerals that dominate the clay fraction also determine whether a soil will have the potential to be hardsetting. If the main clay minerals are kaolinite and/or illite, hardsetting will be more likely. If the main clay mineral is smectite, and the clay content is high enough, the soil will swell and shrink and the soil will be able to regenerate itself if any hardsetting does occur. Kaolinite and illite do not swell much when they absorb water. This prevents a hardset soil from repairing itself quickly.

Hardsetting becomes worse as the amount of exchangeable sodium increases (and as the salt concentration in soil solution decreases), because there will be a greater proportion of dispersible clay. When the clay disperses it blocks pores, resulting in close packing of soil particles and very small pore sizes. The soil becomes very hard upon drying, because of the tightly packed structure.

Other factors that play a role in hardsetting are low amounts of organic matter (less than 2%) and the presence of cementing or stabilising materials (for example, aluminosilicate cements).

The structure collapses upon wetting and the soil hardens—without regeneration of structure—during drying. It involves:

- **slumping.** Hardset soil has not developed water-stable aggregates and so slumps when wet; the aggregates disintegrate by softening and swelling, often by slaking, and sometimes by dispersion of the clay fraction. When the soil slumps, small particles pack between larger particles.
- **uniaxial shrinkage.** The closer the particles are to one another, the greater the strength of the soil after drying.
- **hardsetting and the development of soil strength.**

Consequences of having a hardsetting layer are:

- timing of cultivation is restricted
- seedling emergence will be restricted
- root penetration will be restricted
- aeration will be limited, particularly when the soil is wet
- drainage of water through the soil profile will be reduced
- waterlogging or a perched watertable may occur
- run-off and erosion will increase.

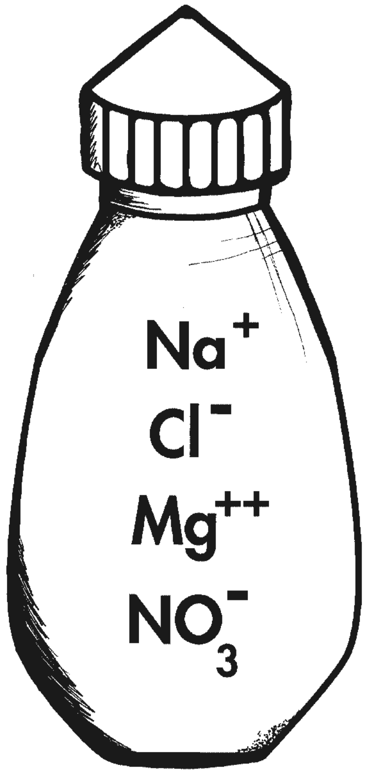
Crusting

A crust is a transient soil surface layer that is denser or more cemented (with less pore space) than the soil beneath it. Because it is denser, it will be more waterlogged when wet and stronger when dry than the more porous soil beneath it.

Crusts usually range in thickness from a few millimetres to a few centimetres. They may be separated and lifted off the soil below, which is usually loose.

Crusting of soil is a widespread problem; it usually results after rainfall on bare, cultivated soil. Crusting is more common on soil that is prone to slaking in water due to a lack of organic matter, and that has a high percentage of silt or fine sand. Instability in water is aggravated by the presence of excessive exchangeable sodium and inadequate salt concentration.

E3. Effects of sodicity and salinity on soil structure



PURPOSE OF THIS CHAPTER

This chapter explains the difference between sodicity and salinity, and describes how they interact to affect soil stability in water.

CHAPTER OVERVIEW

The following points are covered:

- sodicity
- salinity
- gypsum and lime.

Other chapters to refer to are:

- Chapter C4: ‘Structural condition’.
- Chapter C7: ‘Salinity’.
- Chapter D4: ‘Avoiding salinity problems’.
- Chapter E4: ‘Clay minerals’.

For further information, see the NSW Agriculture Agfact *Improving soil structure with gypsum and lime.*

INTRODUCTION

Sodicity refers to the proportion of exchangeable sodium cations held on the surface of clay particles. The greater the proportion of sodium in the total exchangeable cations, the more sodic the soil is. Excessive exchangeable sodium promotes clay dispersion—an undesirable condition. Excessive clay swelling and pore blockage are more of a problem when sodicity problems are confined to the subsoil.

Salinity refers to the amount of dissolved salt in the soil solution between soil particles and between soil clods. It includes both anions and cations of all salts. A large concentration of any salt gives high salinity. Increasing salinity improves soil structural stability, but it becomes more difficult for plant roots to absorb water.

SODICITY

How is sodicity measured?

A sodic soil has a strong tendency to disperse in water. The field signs are shown in Figure E3-1; note the separation of pale, fine sand from the dispersed clay.

Sodicity is determined by the exchangeable sodium percentage (ESP):

ESP = (exchangeable sodium ÷ sum of exchangeable cations) x 100

The major exchangeable cations are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}) and aluminium (Al^{3+}). Under alkaline conditions, the sum of exchangeable cations is approximately equal to the actual 'cation exchange capacity' (CEC). A sample calculation of ESP is shown below, using the values given in Table E3-1. Quantities of cations are commonly given in centimoles of positive charge per kg of soil (cmol(+)/kg).

Figure E3-1. Appearance of clods of sodic soil after wetting and drying.

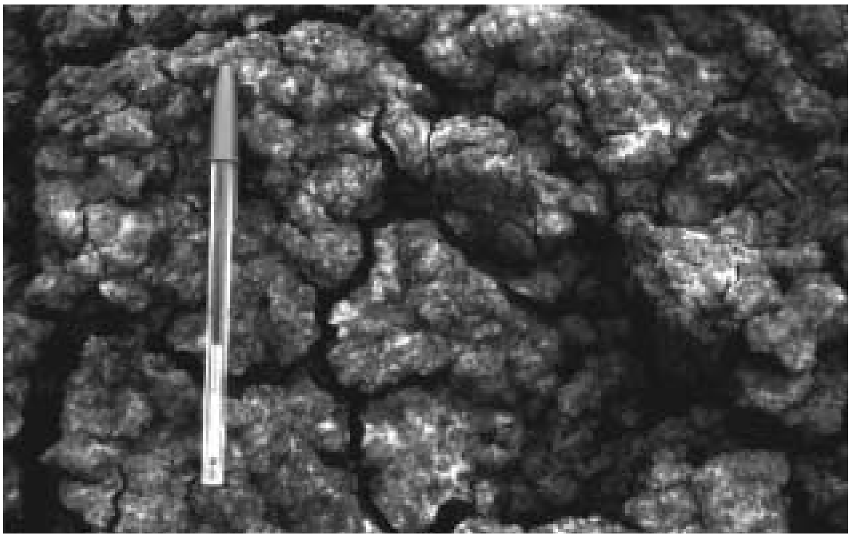


Table E3-1. Quantities of exchangeable cations found in a grey cracking clay soil near Warren at a depth of 0–10 cm.

Cation	Quantity of cation (cmol(+)/kg)
Ca^{2+}	22.6
Mg^{2+}	9.5
Na^{+}	0.4
K^{+}	2.1

Example

To find the ESP of the soil described in the above table:

Sum of exchangeable cations (cmol(+)/kg) = 22.6 + 9.5 + 0.4 + 2.1
= 34.6

ESP (%) = (exchangeable Na^+/sum of exchangeable cations) x 100
= (0.4 ÷ 34.6) x 100
= 1.1.

Critical ESP values range from 2 to 15, due mainly to differences in soil salinity. The relationship between dispersion, sodicity and salinity will be discussed later in this chapter.

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See Chapter E4 for more information on the properties of clay minerals.

Why does sodic soil disperse?

An excess of exchangeable sodium relative to other exchangeable cations causes soil to disperse because of its effect on the thickness of the diffuse double layer.

A large amount of exchangeable sodium relative to other exchangeable cations results in a fat double layer, while a large amount of exchangeable calcium relative to other exchangeable cations results in a thin double layer (Figure E3-2). A fat double layer results in dispersion, while flocculation occurs when there is a thin double layer.

A fat double layer promotes dispersion, because the negatively-charged clay surfaces are held together inadequately by the positively-charged cations that lie between them. The addition of water to the soil forces these individual clay surfaces even further apart, particularly when the cations are weakly charged.

What determines the thickness of the double layer?

The valency of exchangeable cations determines the thickness of the double layers. The higher the valency of the dominant exchangeable cation, the thinner the double layers. Sodium has a valency of 1 (Na^+) while calcium has a valency of 2 (Ca^{2+}). A soil with a high level of exchangeable aluminium will have very thin double layers because it has a valency of 3 (Al^{3+}). Al^{3+} can be pictured as a 'magnet' having 3 times the strength of a Na^+ 'magnet'.

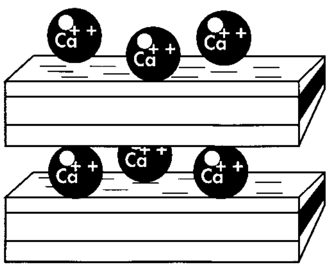
Differences in the thickness of the double layer occur even with cations with the same valency, for example, calcium and magnesium. The hydrated magnesium cation is larger than the hydrated calcium cation, which forces clay platelets apart.

Relationship between the exchangeable sodium percentage (ESP) and the sodium adsorption ratio (SAR)

The concentration of sodium in the double layer (ESP) is in equilibrium with sodium in the soil solution (SAR). This means that

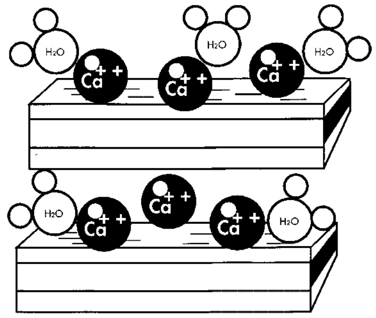
Figure E3-2. The reaction of sodic and non-sodic clay to the addition of water.

non-sodic clay

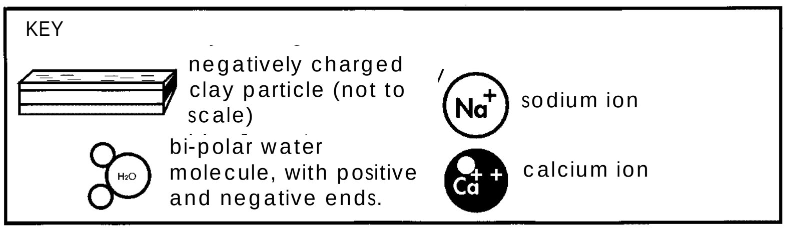


In a non-sodic soil calcium is adsorbed onto the surface of the negatively charged clay particles. This is a small ion with a strong charge.

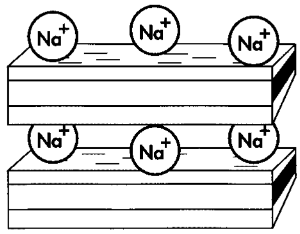
non-sodic clay and water



Water can enter between the platelets in a non-sodic soil, which leads to swelling. However, the binding forces between the particles by calcium ions are never completely overcome. The soil does not disperse.

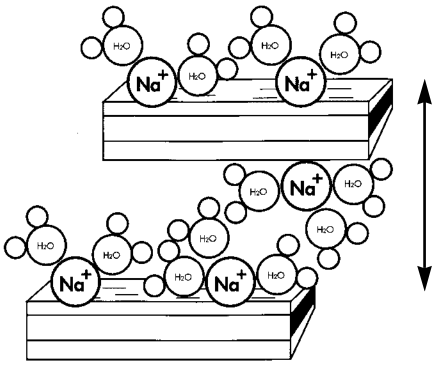


sodic clay (high ESP)



In a sodic soil, sodium, is adsorbed onto the surface of the clay. It is a large ion with a weak charge. The positive ions bind the negatively charged clay particles together.

sodic clay + water



As water is added to a sodic soil the water is attracted to the sodium. The ions hydrate, forcing the plates apart. The ions' role in binding the clay platelets is overcome, and the clay swells then disperses with water.

ESP can be estimated by measuring sodium concentration in the soil solution, in relation to calcium and magnesium, although the relationship varies from one site to another:

SAR = Na÷[-(Ca + Mg)÷2]

$$ESP = \frac{100\,(-0.0126 + 0.01475\,SAR)}{1 + (-0.0126 + 0.01475\,SAR)}$$

(this relationship is specific to Californian soil)

SALINITY

A saline soil is one that contains sufficient water-soluble salts (electrolytes) to adversely affect the growth of most plants. The water-soluble salts are mainly of sodium, calcium and magnesium, and may be chlorides, sulfates or carbonates.

Some plant species are extremely sensitive to salt, while others are extremely tolerant.

A benefit of salinity, however, is that it improves soil structure. The process is described below.

☞

See Chapter C7 for details on the salt sensitivity of different plants.

RELATIONSHIP BETWEEN SODICITY AND SALINITY

When the soil is sodic, clay dispersion declines as the salt concentration of the soil solution becomes greater.

If the soil is sodic and the salt concentration is negligible, the soil will disperse severely. This occurs when rainwater (with a low electrical conductivity—EC) falls on to a saline sodic soil. Some salt is necessary to prevent the soil dispersing. Even if a soil has an ESP as low as 2, it may disperse if the EC of the soil is negligible. It must be remembered, however, that even though high salt levels will prevent the soil dispersing, they will adversely affect crop growth.

A convenient way of expressing the relationship between sodicity and salinity is to calculate the 'electrochemical stability index' (ESI):

$$ESI = \frac{EC_{1:5}\ (dS/m)}{ESP}$$

ESI values less than 0.05 indicate soil dispersion problems.

GYPSUM AND LIME

Gypsum and lime may be used to help to overcome soil structure problems associated with sodicity.

How does gypsum improve soil structure?

There are two reasons why gypsum (calcium sulfate—$CaSO_4.2H_2O$) improves soil structure. Both require the gypsum to be dissolved so that it can enter the soil solution.

- The dispersion of sodic soil decreases as the salinity of the soil solution increases. By adding gypsum, which is a mildly soluble salt, the salinity of the soil solution increases. The effect is only short-term, because it ceases when the applied gypsum has been leached from the soil.
- The second reason why gypsum improves soil structure is that calcium entering the soil solution exchanges with sodium and magnesium on the clay.

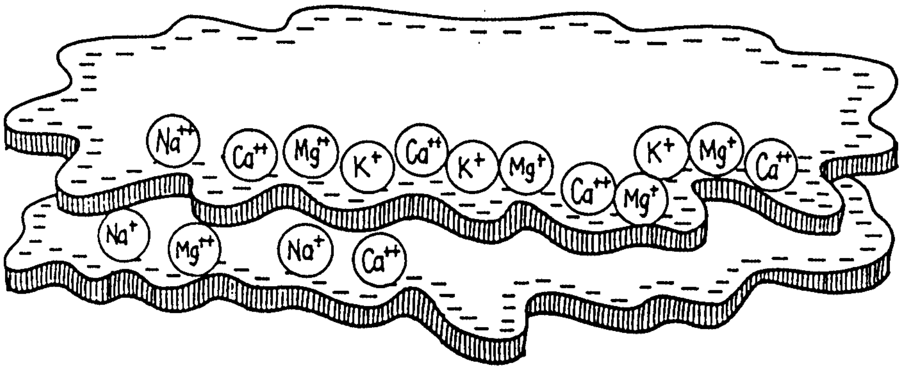
As a result of the clay becoming dominated by exchangeable calcium, clay dispersion and swelling are reduced. The sodium cations that are released into the soil solution are leached below the root zone, where their presence is less crucial than nearer the surface.

When is lime useful?

Lime (calcium carbonate—$CaCO_3$), another calcium compound, can also be used to improve soil structure, either by itself or in a mixture of lime and gypsum. Lime can be used to improve soil structural stability when the pH (in $CaCl_2$) is below about 6.5.

Lime is much less soluble in water than gypsum, but both compounds improve structure via the electrolyte and exchangeable cation effects. In some situations, lime may also act as a cementing agent.

E4. Clay minerals



PURPOSE OF THIS CHAPTER

This chapter provides an overview of the properties of some common clay minerals found in Australian cotton soil.

CHAPTER OVERVIEW

The following topics are considered:

- the structure of clay minerals
- the effect of clay minerals on swell–shrink behaviour
- the influence of positive ions (cations) on swell–shrink behaviour
- clay as a colloid—dispersion and flocculation
- the effects of total salt concentration, pH and clay type on dispersion and flocculation.

STRUCTURE OF CLAY MINERALS

The clay fraction of the soil consists of mineral particles with a diameter less than 0.002 mm. Many chemical and physical properties of the soil depend not only on the amount of clay the soil contains, but also on the type of clay.

There are many types of clay minerals: kaolinite, smectite (montmorillonite), illite (mica), vermiculite and chlorite for example. They result from the weathering of various minerals in rock.

Clay minerals are made up of a number of crystalline sheets. There are two types of sheet: tetrahedral (silicate) and octahedral.

Tetrahedral sheets are made up of silicon (Si^{4+}) and oxygen (O^{2-}). Octahedral sheets are made up of hydroxide (OH^-) and either aluminium (Al^{3+}) or magnesium (Mg^{2+}). An octahedral sheet is referred to as dioctahedral if it contains aluminium, and trioctahedral if it contains magnesium.

The different clay minerals are made up of various combinations of tetrahedral and octahedral sheets. For example, kaolinite is made up of one tetrahedral sheet plus one octahedral sheet (1:1 layer), while smectite and illite are made up of two tetrahedral sheets and one octahedral sheet (2:1 layer) (Figure E4-1).

The space between layers (for example, two tetrahedral sheets plus one octahedral sheet) is known as the interlayer space. The interlayer space may contain positive ions known as cations (for example, potassium—K^+). Different clay minerals contain different cations in the interlayer space. The interlayer spacing of kaolin does not contain cations, because the layers are held together by hydrogen bonding.

The basal spacing of a clay mineral is the distance from the top of one layer to the top of the next layer. The basal spacing varies among clay minerals.

SWELL-SHRINK BEHAVIOUR OF CLAYS

The physical characteristics of clays change with their chemical composition. Some clay minerals swell when wet. Soil types with their clay fraction dominated by a clay mineral that swells when wet show strong swell–shrink behaviour.

Kaolinite shows little expansion on absorption of water and is therefore used for ceramics. Illite also shows little expansion on absorption of water.

Smectite, on the other hand, shows large expansion on absorption of water. Therefore clay soil types with the clay fraction dominated by smectite swell markedly when they become wet. Cracking clay soil types contain a large proportion of smectite in their clay fraction. Smectite is used in agriculture as ‘bentonite’ for sealing dams.

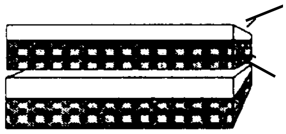
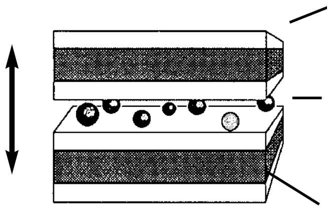
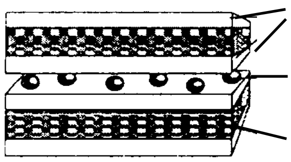
CLAY SIZE AND SURFACE AREA

Clay particles are small. Their small size means that a small volume of clay particles has a large surface area (Figure E4-2). This large surface area makes available many reactive sites of exchange of ions in a small volume of soil.

WHY IS CLAY NEGATIVELY CHARGED?

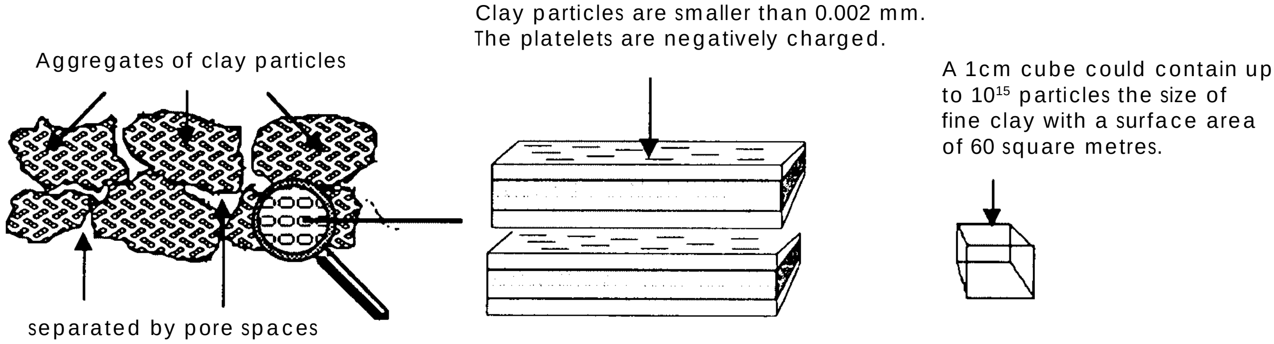
The basic building blocks of clay minerals are silicon atoms surrounded by four oxygen atoms (tetrahedra), and aluminium atoms

Figure E4-1. Structure of the three main clay minerals found in cotton soil.

Clay structure	Characteristics	Cation Exchange Capacity (CEC)*
kaolinite  	Little expansion on addition. of water. Used for ceramics.	3-20 cmol (+)/kg
Smectite (montmorillonite)  Distance between the layers varies as exchangeable ions and water enter or leave.	Swelling on absorption of water between the layers of mineral. Agricultural uses, eg. bentonite in dam sealing. This clay mineral has a major effect on the behaviour of cracking clays.	80-120 cmol(+)/kg
Illite  The potassium ions bond closely between the mineral sheets, balancing charge.	Little expansion on addition of water.	10-40 cmol(+)/kg.

*Although the charge on the surface is negative, it is measured by the number of moles of cation charge (+) adsorbed.

Figure E4-2. Clay particle size and surface area



surrounded by six hydroxide groups (dioctahedra), or magnesium atoms surrounded by six hydroxide groups (trioctahedra). These groups of atoms are arranged in sheets. The atoms in these sheets are tightly bound and are not exchangeable with other ions in the soil solution.

When the single tetrahedra and octahedra join to form sheets, the positive (Si^{4+}, Al^{3+}, Mg^{2+}) and negative charges (O^{2}-, OH^{-}) are balanced. However, oxygen atoms that are exposed on the surface of the clay are not wholly balanced by positively charged atoms. A net negative charge results. The negative surfaces of clays can attract and hold cations.

A negative layer charge can also be the result of isomorphous substitution. Isomorphous substitution is the substitution of Al^{3+} for some of the Si^{4+} in the tetrahedral sheet. This results in a negative charge. Mica has 25% of its Si^{4+} substituted by Al^{3+} in the tetrahedral sheet; the potassium cation (K^{+}) is necessary in the interlayer spacing to neutralise the negative layer charge.

THE IMPORTANCE OF NEGATIVE CHARGE

The negative charge on the surface of clay particles attracts positive ions (cations). This is important for the storage of cations that can be used by plants as nutrients. It also allows us to alter soil structural characteristics chemically by changing the cations that are adsorbed on the clay surface.

The ability of clay minerals to hold cations is called the 'cation exchange capacity' (CEC). Smectite has a much greater ability than kaolinite to hold cations. The CECs of kaolinite, smectite and illite are approximately 9, 100 and 25 cmol(+)/kg respectively.

Organic matter also contributes to CEC and has a CEC of approximately 250 cmol(+)/kg (at pH 8.5).

DISPERSION AND FLOCCULATION OF CLAY

Colloidal clay

Clay is a colloid. Colloidal particles have special properties due to their very small size. First, their large surface area in relation to their mass makes them very reactive—in clays, this reactivity is shown as an electrostatic attraction of cations. Secondly, colloids can exist in water as either suspensions (dispersed) or as gels (flocculated).

The tendency of a colloid to flocculate or disperse depends on three things:

- the nature of the colloidal particles
- the total salt concentration
- the nature of the adsorbed ions.

Nature of colloidal particles

Colloidal particles are either hydrophilic (water-loving) or hydrophobic (water-repelling). Hydrophilic colloids (for example, starch) form stable suspensions and do not readily flocculate. Hydrophobic colloids (for example, clay) form unstable suspensions and flocculate easily. The term 'unstable' here refers to the suspension, not the soil aggregates.

The nature of the colloidal clay particle (hydrophobic) means that clay will flocculate if allowed to. This is good for soil structure!

Total salt concentration

The more concentrated the salts (electrolytes) in the soil solution, the more likely it is that clay will flocculate. This is the ‘electrolyte effect’. All soluble salts have this effect, including common salt (sodium chloride), and gypsum (calcium sulfate).

When the salt concentration of the soil solution is greater than between the clay platelets, water will move from between the platelets into the soil solution (by the process of osmosis); the clay will flocculate and be very stable. In contrast, if the soil solution has a low salt concentration, water will tend to move from the soil solution into the zone between clay platelets; this will cause swelling and dispersion unless the cations there are strongly charged.

Salts such as gypsum, lime (calcium carbonate which, when dissolved, forms calcium salts with whatever anions are present), ammonium or nitrate salts in fertiliser or manure, various forms of phosphate, potassium salts, and trace elements such as zinc sulfate are all salts that are added to the soil in agriculture. Each adds to the total salt (electrolyte) concentration of the soil solution.

Nature of adsorbed ions

The type of cations adsorbed on to the negative surface of clay influences flocculation (clustering of clay particles into microaggregates). Calcium adsorbed on to the clay surface allows the clay to flocculate even when the total salt concentration is low. When sodium is adsorbed on to the clay surface the salt concentration has to be much higher for the clay to flocculate.

The effects of pH and clay type on dispersion

pH

Increasing pH results in the charge on the edges of clay layers becoming more negative. This aggravates dispersion in kaolinite, because negative edge to positive face bonding is the main factor in flocculation. In contrast, pH has only a slight effect on the dispersibility of soil dominated by smectite and illite; these clay minerals have a charge that is mainly permanent (independent of pH).

Clay type

Illite has a greater sensitivity to exchangeable sodium than smectite. This is caused by the smaller edge-to-face attractive forces in illite than in smectite, due apparently to the irregular shape of illite particles. Illite requires four times as much electrolyte to stabilise it compared with smectite, when their exchange sites are dominated by sodium.

Water: its structure and importance in swelling clays

The structure of the water molecule (Figure E4-3) is important in how it reacts with charged particles. Water is a dipolar molecule—it has a slightly positive and a slightly negative end. This allows a water molecule to be attracted to both negative and positive ions and particles, and to other water particles (‘head’ to ‘tail’).

Water surrounds cations in a shell of oriented water molecules—a hydration shell (Figure E4-4).

Figure E4-3. The dipolar water molecule.

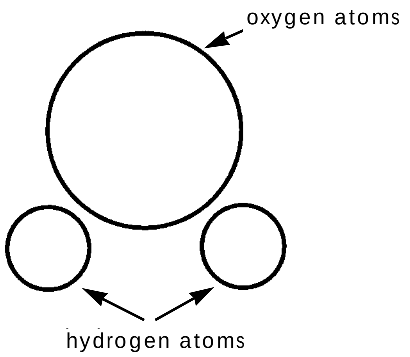
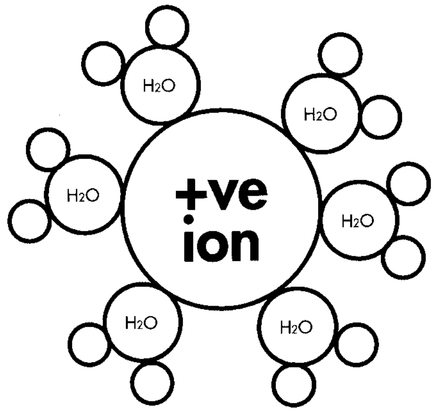


Figure E4-4. Hydration shell of water molecules clustered around a positively charged ion (cation).



The thickness of the hydration shell depends on the cation. The shell around Na^+ is bigger than that around Mg^{2+}, which is bigger than the shell around Ca^{2+}.

The diffuse double layer

The surface of a clay particle, being negatively charged, attracts positive ions. When the clay is wet, the exchangeable positive ions on the surface of the clay move into the soil solution surrounding the clay particle. They are, however, still attracted to the clay surface, and consequently swarm close to it.

This region of attracted positive ions in solution and the negatively charged surface of the clay is termed the ‘diffuse (or Stern–Gouy) double layer’. It is called ‘diffuse’, because a net positive charge of ions extends away from the surface (Figure E4-5). The further from the surface, the less is the net positive charge of the solution.

The force of attraction on the cations by the clay reduces quickly as the distance from the clay surface increases (Figure E4-5).

For one cation to leave the double layer it must be replaced by another from the soil solution. Plant roots, in order to take up cations as nutrients, give up hydrogen ions (H^+) in exchange.

Figure E4-5. The double layer at the face of a clay particle.

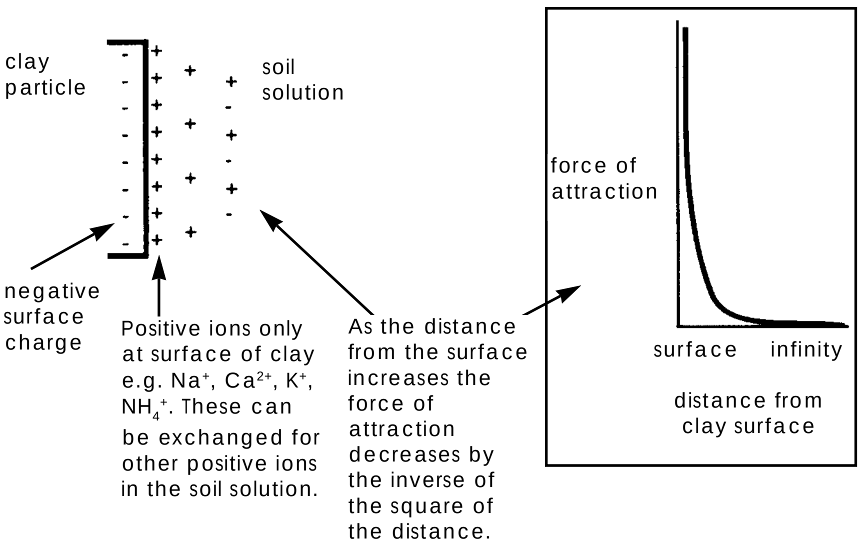
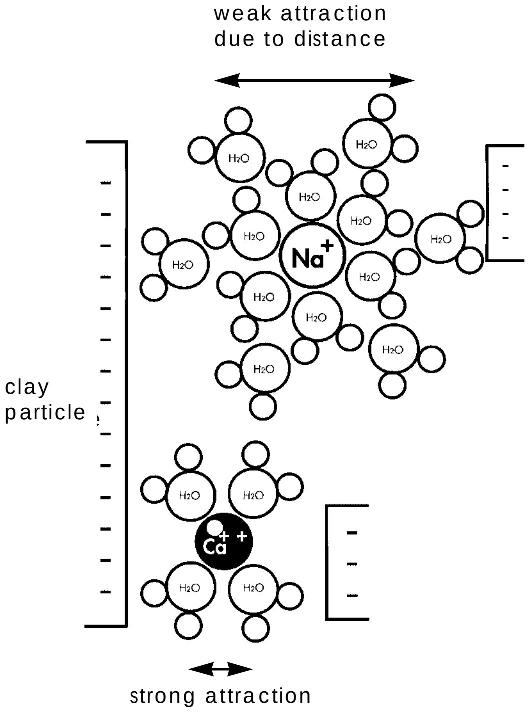


Figure E4-6. Strength of attraction of common soil cations



Na^{+}: Strongly hydrated ions such as sodium are surrounded by a shell of water which effectively increases their distance from the surface of the particle and decreases the attactive electrical force acting on the ion.

Mg^{2+}: Magnesium is also a highly hydrated ion like sodium, so despite its double positive charge it is held more weakly than calcium due to its distance from the surface.

Ca^{2+}: Calcium is not as strongly hydrated as sodium or magnesium; therefore, the calcium ions are held closer to the surface with consequently greater attraction. The double positive charge also leads to greater attraction.

Strength of attraction of exchangeable cations

The cations adsorbed on to the surface of the clay particles can greatly affect how the clay behaves. The cations act as a link between the clay particles. Similarly, dispersive organic matter (with negatively charged edges) can be linked strongly by positively charged cations.

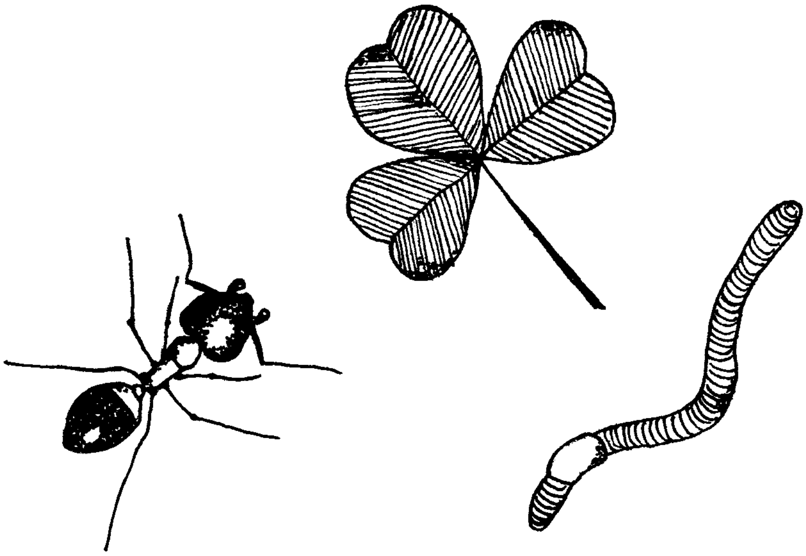
The binding force on to and between the clay plates depends on a number of factors including:

- the charge of the cations
- the size of the cations, including their hydration shell
- the thickness of the double layer outside the surface of the clay particles.

The strength of the bond depends on the cations present. Sodium ions have a single positive charge, so their clay-binding ability is poor. Calcium ions have a double positive charge, so their clay-binding ability is good. Magnesium is intermediate because, although it has a double positive charge like calcium, when hydrated it is larger than a hydrated calcium ion. This is explained in Figure E4-6.

In a dispersive soil with a large exchangeable sodium percentage and small concentrations of water-soluble salts, the weak bonding of the clay particles by sodium ions can be broken. As water enters between the clay particles it hydrates the sodium ions. This in turn forces the plates away from the ions and lowers the attractive force between the particles and the ions. The plates may move far enough apart for attraction forces to be overcome. The result is dispersion.

E5. Organic matter and soil biota



PURPOSE OF THIS CHAPTER

This chapter aims to give an understanding of the role of organic matter in the soil, and of factors that can cause an increase or decrease in organic matter levels.

CHAPTER OVERVIEW

This chapter covers the following points:

- types of organic matter
- benefits of organic matter
- problems associated with organic matter
- accumulation and destruction of organic matter
- cotton farming and organic matter.

Other chapters to refer to are:

- Chapter E4: 'Clay minerals'.

INTRODUCTION

In most soil types, organic matter is considered to be essential for maintaining soil structure, although the actual composition and amount that is required has not been clearly defined. However, the structure of cracking clay soil apparently depends less on organic matter than on other soil types; the shrink–swell nature of the clay minerals creates and maintains a desirable soil structure.

Clay particles also retain and release cations as nutrients for plants, a task that is handled by organic matter in light textured (sandy) soil. Consequently, cracking clays can have good soil structure and good nutrient status at organic matter levels that would be low enough to cause problems on non-clay soils. Loam soil used for cotton production is more reliant on organic matter for the creation and stabilisation of a desirable soil structure.

Despite these differences between soil types, organic matter in general has numerous benefits, plus several undesirable effects.

TYPES OF ORGANIC MATTER

Soil organic matter consists of living roots and organisms (including earthworms, bacteria and fungi), decomposing plant, animal and microbial residues, exudates from plant roots and microbes, and humus. Most soil organisms are understood very poorly— only a fraction have been identified. It is estimated that 80–90% of soil biological activity is carried out by bacteria and fungi.

Humus is the dark, relatively stable end-product of organic matter breakdown. It may be thousands of years old. Some carbon (as much as 50%) may be in the relatively inert form of charcoal. Figure E5-1 shows how carbon cycles through soil organic matter.

Readily oxidised (labile) organic carbon is of particular value in soil management. Unless the soil is being regularly supplied with fresh organic matter, the amount of useful (labile) material in the soil will decline. For information about the development of a ‘carbon management index’ test, based on the measurement of total and labile carbon, refer to the paper by Blair, Lefroy and Lisle in Appendix 1.

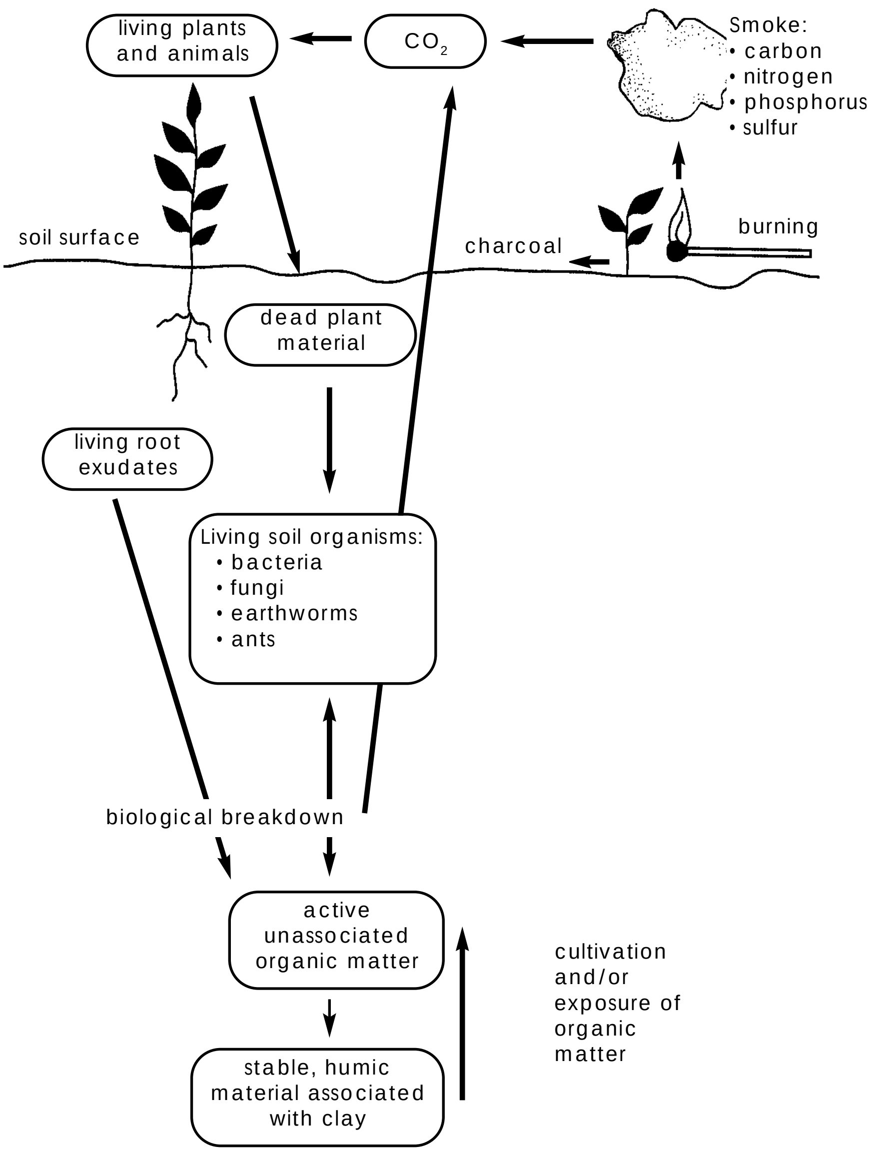
LIVING ORGANIC MATTER

Active roots. Roots force apart mineral components of the soil and leave channels for water flow and oxygen diffusion when they eventually die and decompose.

Burrowing animals such as earthworms, ants and termites create larger pores in their burrowing. Soil passed through earthworm guts ensures intimate mixing of organic and mineral matter, which can improve soil aggregation. Some of the ants in cotton fields are predacious, and may decrease pest populations. Other creatures that may be found in cotton soil include beetles, earwigs, spiders, springtails and mites. A burrowing organism that is not welcome in cotton fields is the larva/pupa of *Heliothis armigera*.

Fungi and mycorrhizae. Fungi help in the breakdown of dead plant material to its component parts. Live fungal hyphae also bind the soil into aggregates, by tangling with individual soil particles, thus improving structure, especially on lighter textured soil types. The mycorrhizal group of fungi (‘vesicular-arbuscular mycorrhizae’—VAM) live in a symbiotic relationship with plant roots. They provide, in effect, an extended root system, and help the plants to extract a

Figure E5-1. Carbon cycling in cotton soil.



number of nutrients (especially phosphorus and zinc) from the soil. In return they receive carbohydrates, amino acids and a protected habitat. In many cases the growth of plants is retarded if mycorrhizae are removed. Mycorrhizal growth is retarded by poor soil structure and waterlogging. The creation of heavily cut areas after landforming leaves bare subsoil that is depleted of mycorrhizae.

Bacteria assist in the breakdown of dead macro-organic matter and contribute to the polysaccharides found in the soil. Macro-organic matter is composed of the complex dead cells of plants and animals. The polysaccharide sugars form a part of the glue that holds aggregates together. Some bacteria damage cotton (for example, 'bacterial stunt', also known as 'Galathera syndrome' or 'early season growth disorder'); other types are beneficial.

Actinomycetes. This group of organisms has a complexity that is mid-way between the fungi and bacteria. Like the bacteria, they assist in the breakdown of organic matter. They are also more tolerant of dry hot conditions than either fungi or bacteria.

Non-living organic matter

Root exudates. Roots exude a variety of organic materials as they penetrate the soil. With the pressure from root penetration, organic matter is forced into close association with soil particles.

Decaying material. This includes material in the process of decomposition by soil microbes that was once part of living organisms, e.g. surface mulch.

Humus. This is the stable part of organic matter, made up of large organic molecules that are the result of decomposition of plant and animal cells. Humus is composed of a complex of different molecules from a number of chemical groups. It consists mainly of carbon, hydrogen and oxygen; however, large amounts of nitrogen and sulfur are also involved.

Charcoal, a relatively inert form of soil carbon, sometimes accounts for a large proportional of the carbon in a soil.

As dead plant and animal material is broken down to humus, carbon is lost in the form of carbon dioxide (CO_2) due to respiration by the soil micro-organisms.

Clay particles have a role in stabilising organic matter. Organic matter is adsorbed on to the surfaces of, and between, clay particles; this in turn makes it inaccessible to soil micro-organisms that would normally decompose the organic matter.

BENEFITS OF ORGANIC MATTER

Ion adsorption

Most humus particles have very large surface areas. They are negatively charged and act in much the same way as clay particles in the exchange of positive ions such as ammonium, calcium, sodium, magnesium, zinc, copper and iron. They make a very significant contribution to the cation exchange capacity (CEC) of a soil. For example, an organic matter content of just 2.5% in soil with a clay content of 25% accounts for approximately one-third of the CEC of the soil.

Some humus particles or parts of particles are positively charged and can adsorb and store on their surface the negative ions found in the soil solution—for example, nitrate, sulfate, phosphate and chloride.

Metal chelation

Some organic matter forms complexes with metal ions. The metal ions in these complexes are in a form that is available to plants. If these elements were not protected in these molecules, they would be readily precipitated into a form that would be unavailable to plants.

Metals that are chelated in the soil by this means include copper, iron, manganese and zinc.

Acting as a source of plant nutrients

The breakdown of organic matter by soil microbes (mineralisation) provides plant nutrients and is one of the major sources of nitrogen for plants. The ammonium form of nitrogen is the form first produced when organic matter is broken down. Plants can use this form of nitrogen as well as nitrate (a secondary microbial breakdown product of ammonium).

The breakdown of organic matter to form available nitrogen is slow, however, and may not meet the peak demand of a growing crop.

Aggregate stabilisation

Organic matter binds the aggregates of cotton soil and helps to reduce clay dispersion. The benefits for cotton growers tend to become greater as the clay content decreases. Organic matter improves soil friability.

In loam soil, it has been shown that microaggregates are stabilised by mucilages/polysaccharides. These units are held together by the action of fungal hyphae (mainly mycorrhizae) growing through the soil. Casts produced by earthworms also improve soil structural stability in water.

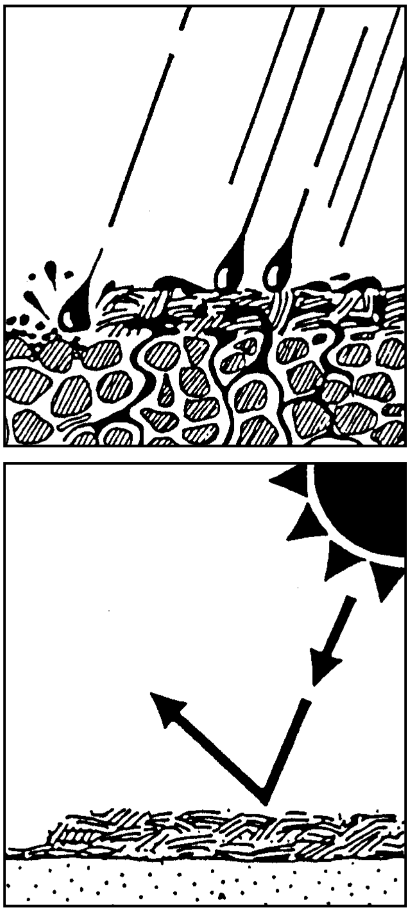
Creation of macropores

Earthworms and ants can improve soil structure by their burrowing activities. For example, *Heteroprodrilus mediterreus* (‘Myall worm’), a large (50 cm long) native earthworm found in grey cracking clay soil under Mitchell grass, builds channels that can improve water entry into the soil and maintain subsoil aeration after closure of shrinkage cracks in wet weather. Under dry conditions, they apparently reside at a depth of about 2 m.

Ants provide similar benefits. In hardsetting soil, they can improve surface structure by bringing up well-structured subsoil.

Cotton crops with very high yields (>12.5 bales per hectare) have been associated with soil containing plenty of earthworms.

Figure E5-2. The benefits of mulch.



Protection of the surface soil from raindrop impact and rapid drying

Mulch protects the soil from raindrop impact, and reduces evaporation of water from the soil (Figure E5-2). The extra moisture under mulches can promote root growth in the topsoil, where nutrients are concentrated. It allows cotton crops that otherwise would have been adversely affected by ‘bacterial stunt’ to grow strongly. If dense enough, mulches can also reduce weed emergence, although excessive coolness in the topsoil may be a problem in spring. Mulches also protect cotton seedlings from wind-blast damage during windy weather.

Acting as an anti-compaction agent

The effects of compaction are less pronounced in soil that is rich in organic matter. The theory behind organic matter being an anti-compaction agent is that the long-chain carbon bonds found in organic matter are more flexible than the bonds formed between clay particles. This gives the particles joined by organic matter more freedom to move, while still being attached in aggregates.

Soil reinforcement is also gained by the effect of living and dead plant fibres, such as fungal hyphae and plant roots, within macroaggregates and microaggregates.

Acting as a source of nutrients for beneficial soil organisms

Biological activity is likely to be helped by the nutrients contained within the more labile organic residues. The carbon in organic matter is a vital energy source for soil biota.

Water retention

As the soil organic matter content increases, the soil water holding capacity becomes greater. This effect is most marked in light-textured soil.

Acceleration of the biodegradation of pesticide residues

Organic matter helps with pesticide decomposition, although detailed information is not available.

Fixation of carbon dioxide, a 'greenhouse gas'

Accumulation of soil organic matter (particularly as humus) reduces the amount of carbon dioxide (CO_2) gas in the atmosphere. This makes a small but important contribution to a slowing of global warming, which is caused by 'greenhouse gas' emission.

Reduction of soil alkalinity

Most of the material in organic matter is eventually converted to carbon dioxide gas (CO_2) and water, with heat as a by-product (this is why composting straw feels warm). Some of the CO_2 dissolves in the soil solution, which forms carbonic acid (H_2CO_3). This mild acid lowers soil pH—a desirable process in alkaline clay. Respiring roots also emit CO_2.

PROBLEMS ASSOCIATED WITH ORGANIC MATTER

Mechanical problems

Large amounts of plant residue can be difficult to handle mechanically—either when incorporating them into the soil or when planting through stubble.

Possible negative effects on weed control

Surface mulch can reduce weed growth by shading the soil, and by producing leachates which inhibit weed emergence. However, stubble tends to reduce herbicide–soil contact and limit the mechanical incorporation of herbicides.

Nitrogen tie-up

Organic matter with a high C:N ratio (high carbon content and a low nitrogen content, for example, straw) can tie up nitrogen in the short term. This is because the material acts as a food source for soil microbes, which increase in number. The microbes need nitrogen to form their body proteins, and they use up the available nitrate in the soil. Later, when the food source is used up and the majority of microbes die, their bodies decompose and the nitrogen returns to the available pool.

Phytotoxin production

The breakdown of plant material can produce phytotoxins that adversely affect crop growth in the short term (allelopathy).

Water repellence

In some sandy soil types, coatings on sand grains of organic materials produced by micro-organisms can cause water repellence.

Encouraging disease

Plant residues may be a repository for plant diseases. This is the main method of survival for cotton diseases, including bacterial blight, verticillium wilt, seedling diseases, fusarium wilt, phytophthora boll rot and alternaria leaf spot.

If cotton is to follow cotton in a crop sequence, dispose of suspect plant residues by incorporation. An exception is for fusarium, where cotton crop residues need to be left on the surface; burial aggravates the problem. Early incorporation followed by moist soil conditions will speed the complete breakdown of macro-organic matter and its associated disease organisms, as well as returning plant nutrients to the soil.

However, as the web of 'predator–prey' relationships in the soil becomes more stable, suppression of harmful organisms tends to become greater.

Aggravation of soil dispersion problems

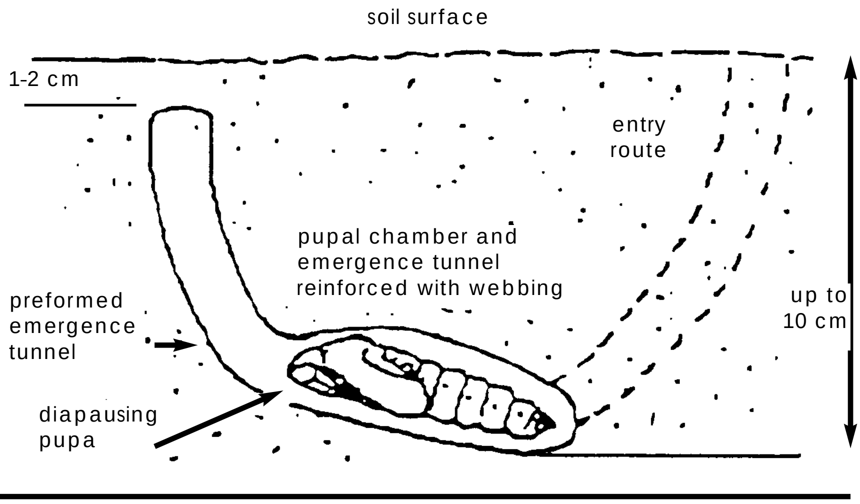
In soil aggregates where organic molecules have a negative charge, and the positively charged cations linking these molecules and negatively charged clay are only weakly attractive (for example, sodium ions), disruption of the bonds by tillage will make the soil become dispersive. As the amount of negatively charged organic matter becomes greater in such a situation, the dispersion problem will become worse. Adding calcium ions will help to address such problems.

Heliothis pupae

Over-wintering pupae of *Heliothis armigera* lie in the soil to a depth of about 10 cm. They are highly resistant to insecticides, and must be destroyed within a few months of cotton harvest—the end of the following August is the deadline.

An illustration of pupal position in the soil (burrow morphology) is shown in Figure E5-3. At present, the only feasible control measure is thorough cultivation of the topsoil (0–10 cm). Clod diameter after tillage needs to be less than 5 cm.

Figure E5-3. Position of Heliothis pupa in the soil.



FACTORS THAT CAN INCREASE SOIL ORGANIC MATTER CONTENT

Rainfall and irrigation

The growth of plants that eventually break down to soil organic matter depends on soil moisture. Increasing soil moisture through rainfall or irrigation stimulates plant growth, and consequently provides a greater input of organic matter to the soil. However, soil moisture also increases the rate of breakdown of organic matter. For organic matter levels to increase, other factors must be favourable.

Increased soil fertility

Fertile soil in general has higher levels of stable organic matter, reflecting the greater amount of plant growth.

Relatively high clay content

Clay particles form stable associations with organic matter and protect it from attack and consequent breakdown by soil organisms. Very sandy soil is unable to retain much organic matter, because it has only a small amount of clay available to protect the humus.

In general, smectite clays have more organic matter than kaolinite clays. This is due to the greater number of sites available for bonding.

High numbers of soil organisms

The greater the activity of soil organisms, the faster the conversion of organic residues to stable humus. Low temperatures, acidity and low aeration inhibit microbial activity; organic residues may break down only partly and form peat under such conditions. For example, various forms of peat occur in peat bogs (cool, waterlogged and acid), in swamps (waterlogged), in tundra (cold) and even as thatch under acid pasture or lawn turf.

Acidity also inhibits earthworm proliferation, and consequently reduces the natural incorporation of organic residues into the soil, where they can decompose more fully (although ants may take the place of earthworms).

Appropriate land use

Until now, the best form of agricultural land use for increasing organic matter levels is pasture. Organic matter is supplied constantly to the soil through dead leaves and roots, root exudates and the droppings of grazing animals. The lack of tillage helps to maintain the organic matter.

On cropland, reduced tillage will help to keep organic matter at higher levels. Permanent beds and minimum tillage retain more organic matter than ‘maximum tillage’ systems.

Manure application

Green manure crops (especially nitrogen-fixing legumes) and animal manure can be added to soil. However, tillage to incorporate the manure decreases soil organic matter (and may disrupt soil macropores), so very large quantities of either of these manures are required to have a significant beneficial effect. In the first year, three-quarters of the added carbon disappears as carbon dioxide from the

respiration of soil organisms. After three years, as little as 10% of the original organic carbon remains.

Other materials to consider include composted gin trash and synthetic polymers.

FACTORS THAT CAN DECREASE SOIL ORGANIC MATTER CONTENT

Tillage

Organic matter, especially the smaller stable humus fraction, is protected from biological attack by being located within very small pores in the soil (even between clay particles). Tillage disturbs these small pores, exposing the organic matter to decomposition. More reactive parts of the organic matter that formerly may have been attached to clay particles may also be exposed.

Pesticides

Herbicides appear to have few (if any) adverse effects on soil biological processes. Fungicides are more damaging, but are rarely used by cotton growers. Insecticides may disrupt beneficial soil biota, such as predacious ants. The introduction of transgenic cotton varieties is likely to reduce pesticide use in the Australian cotton industry, so it should be possible to make better use of soil-borne fauna in the future.

Burning

Burning destroys above-ground organic matter. Smoke carries away elements such as nitrogen and sulfur. However, under permanent beds, the roots of the previous crop and the stable organic matter will remain in the soil despite the burning of the upper parts of the plant. Burning may, in fact, destroy less organic matter than tillage, especially when there is little stubble to incorporate.

If the elements lost in smoke are replaced by fertilisers, a stable and profitable farming system can result. The ash (rich in phosphorus, potassium, zinc and calcium) that remains after burning may provide a beneficial electrolyte effect when dissolved in water.

Nevertheless, burning should be considered only as a ‘last resort’ by cotton managers—for example, in very wet winters when soil disturbance by tillage needs to be minimised. It is a practice that wastes valuable nutrients and soil organic matter, and makes the distribution of P, K and Zn less uniform due to the raking of stalks into windrows.

COTTON FARMING AND ORGANIC MATTER

Cotton crops are poor returners of organic matter to the soil. The stems are hard and lignified and contain only small (albeit useful) amounts of nitrogen, and so decompose slowly. They take up to two years to decompose, although it may be possible to accelerate this process by spraying the stalks with sulfuric acid. The roots make up only 10–30% of the mass of the plant. In some agricultural crops, up to two-thirds of the mass is in the roots. Nevertheless, cotton residues contain enough nutrients and useful organic matter to justify retention rather than burning under most circumstances. Experiments at Narrabri have shown that N fertiliser recovery is improved by 10% where cotton stalks are retained rather than burnt.

If alternative crops such as wheat are grown in rotation with cotton to increase organic matter levels, it is important to reduce tillage to a minimum to preserve the organic matter that is produced. A permanent bed system is the best way of achieving this goal. On hardsetting soil types such as red-brown earths, retaining a mulch is very important for the protection of the fragile surface structure from raindrop impact. Mulches also encourage root growth in the nutrient-rich topsoil—this zone is usually too dry for root function where the soil is left bare.

Mulches make weed control more difficult, but practical solutions have been developed. Weed management under mulches is likely to become easier when herbicide-tolerant cotton varieties are released. They will allow ‘over the top’ applications of herbicides that previously could not safely be applied to cotton.

Incorporating stubble or ‘green manure’ may not necessarily increase organic matter levels. Unless the volumes of stubble are large, soil organic matter content may decrease through the process of cultivation to incorporate fresh unstable organic matter.

Most cotton growers place a lot of emphasis on the return of organic matter, but are not sure why. There is uncertainty about the value of organic matter in old roots versus surface residues, and from various rotation crops. We do not have ‘critical values’ of total and labile carbon for optimal cotton growth on the different soil types used to produce cotton in Australia.

Future research is likely to answer these questions.

E6. How soil structure and temperature affect plant growth

PURPOSE OF THIS CHAPTER

This chapter explains how cotton roots and seedlings respond to different soil structural conditions.

CHAPTER OVERVIEW

The following points are covered:

- the physiology of cotton roots
- root growth and the ‘non-limiting water range’
- root activity in relation to soil temperature.

INTRODUCTION

Cotton has considerable flexibility in its response to environmental conditions because of its bud and boll shedding ability and growth indeterminacy. If conditions are less favourable than usual, greater than average shedding occurs, but if conditions become more favourable a higher proportion of bolls is retained, and this at least partly compensates for previous losses. The cotton plant, therefore, adjusts to environmental fluctuations by altering its fruiting pattern. Nevertheless, cotton productivity usually is well short of potential, due to the limiting effects of soil physical conditions and the interacting effects of climate on cotton root growth and function.

Root systems are particularly important. They anchor plants, absorb water and nutrients, act as storage organs, and are the site of production of growth-controlling substances. To fulfil these functions, roots need to elongate and expand to explore the soil during and after seedling establishment. Poor subsoil aeration and excessive soil strength are the main problems; they are aggravated by soil compaction, remoulding and/or hardsetting.

Crusting and/or hardsetting of the soil can be a problem for emerging seedlings—particularly where the seedbed is sodic and/or is prone to hardsetting—but most Australian cotton soil does not have this problem. Excessively low or high temperatures and the presence of soil-borne diseases of cotton tend to be the main seedling establishment problems.

THE PHYSIOLOGY OF COTTON ROOTS

Cotton roots have the following features, which should be appreciated by soil managers:

- Cotton can tap soil moisture from as far as 3 m below the surface.
- Deep roots are as effective as shallow roots in water extraction, although cotton taproot dominance generally wanes with depth.
- Rates of cotton taproot elongation as great as 80 mm/day have been recorded in the laboratory, but elongation rates are generally slower in the field.
- Cotton taproot length reaches a maximum between first bloom and just before the appearance of mature bolls.
- Developing bolls out-compete roots for carbohydrates, so root system development must occur early in the season.
- The addition of N stimulates vegetative growth and increases auxin production, which depresses root growth further.
- Cotton has been shown in laboratory experiments to have the ability to move water via its roots from wet to dry soil during periods of low evaporative demand. This may be a survival mechanism under certain circumstances, allowing plants to lift water passively from deep, relatively moist soil layers during the night, thus allowing continued uptake of nutrients in the surface soil, which otherwise would be too dry .
- Cotton has a poor tolerance of waterlogging. It has been shown that the elongation of cotton taproots at 30^{O}C ceases completely within two to three minutes of oxygen removal from the soil, but returns to normal shortly after the return of 21% oxygen to the system, provided the period without oxygen does not exceed 30 minutes. Most of the roots die after three hours without oxygen.

- Cotton roots can, themselves, modify the aeration status of a soil. It has been shown that cotton lateral roots at a depth of 0.8 m shrink in the middle of the day to about 60% of their maximum diameter; shrinkage occurs when roots lose water faster (due to transpiration) than they absorb it. The resultant gaps apparently allow movement of gases in the soil.

There is evidence to suggest that the degree of Bt expression in transgenic cotton varieties is reduced by waterlogging stress. This makes Heliothis control particularly difficult.

ROOT GROWTH AND THE 'NON-LIMITING WATER RANGE'

As a soil becomes more compact, there is an increase in the range of water contents over which root growth is restricted by poor aeration and excessive soil strength.

Good soil structure prevents the 'non-limiting water range' (NLWR) for cotton growth becoming less than the available water range. If the soil is compacted (low NLWR), cotton growth can be restricted by a lack of oxygen when the soil is wet and by high soil strength when the soil is dry. The water content at which hardness of the soil starts to become limiting corresponds to the 'refill point'. The 'partially-limiting water range' (PLWR) indicates the zone where between 10% and 90% of the soil has adequate aeration and freedom from strength limitations.

These effects are illustrated in Figure E6-1. It shows the water content range that needs to be maintained in the soil to avoid aeration problems at high water contents, and to avoid strength limitations when the soil is dry, for various degrees of compaction as measured by the SOILpak score.

Note:
1. Compaction severity becomes worse as one moves towards the top of the diagram.
2. Cotton farmers should aim to maintain their soil water contents within a range that coincides with the Non-Limiting Water Range (NLWR).

The cotton root symptoms associated with contrasting degrees of compaction are shown in Figure E6-2. Restriction of root growth limits the volume of soil that can be utilised by plants.

COMPACTION, ROOT GROWTH AND CROP YIELD

Impeded root systems will exploit a smaller soil volume for plant nutrients and water than root systems that are unrestricted. Retarding the growth of new roots means that existing roots have to maintain a greater than normal uptake rate of water and nutrients per unit root length in order to keep pace with demand. Plants confined to a restricted soil volume, therefore, are more susceptible to water or nutrient stress.

Good crop yields are difficult to achieve on compacted soil. However, soil compaction does not always reduce crop yield. University of Queensland researchers, working on a cracking clay with and without irrigation, found that pigeonpea growth restrictions resulting from compaction were related mainly to reduced water uptake resulting from decreased infiltration and storage of water, and restricted root growth. Seasonal conditions—in particular, the distribution of rainfall—exerted a strong influence on plant response. Yield reductions resulting from compaction varied from 100% in a dry

Figure E6-1. The range of soil water contents (schematic) over which soil strength (S) and soil aeration (A) effects are not limiting to root growth (non-limiting water range; NLWR) or partly limiting to root growth (partially-limiting water range; PLWR) as the severity of soil compaction becomes worse. The PLWR indicates the zone where between 10% and 90% of the soil has adequate aeration and freedom from strength limitations.

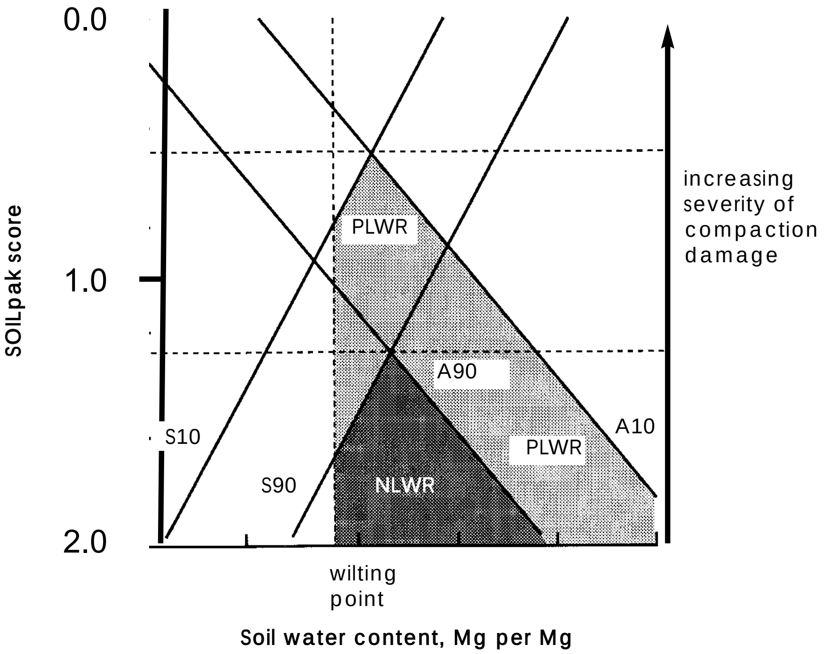
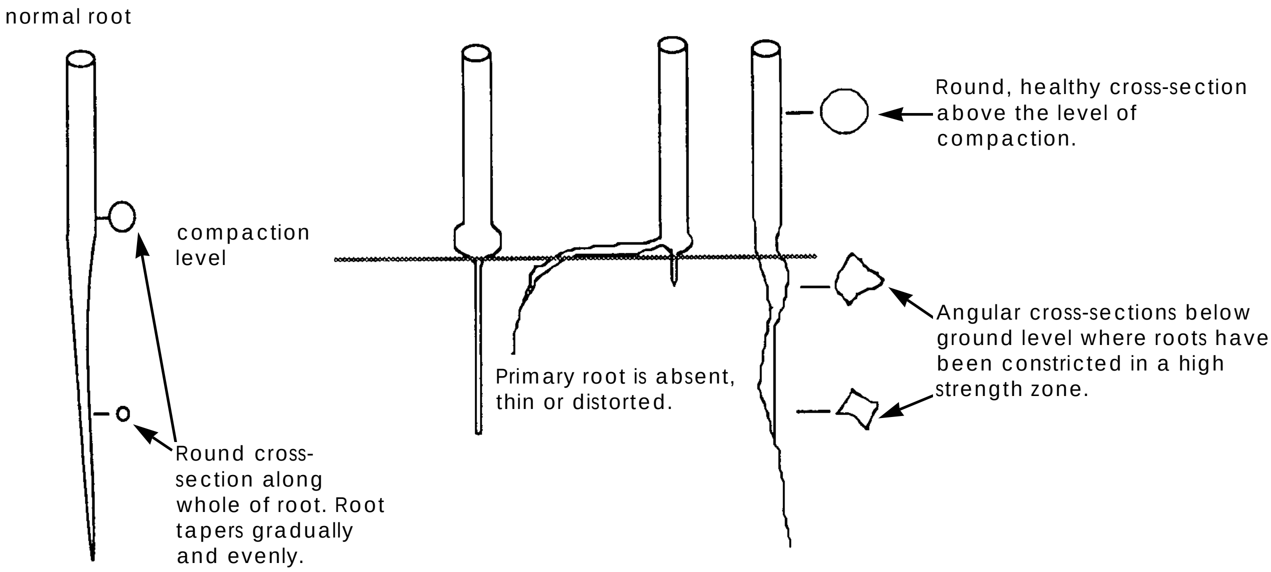


Figure E6-2. Cotton root symptoms following compaction, The left-hand damaged root is referred to as a 'nub' root.



season to 0% in a wet season, so it is difficult to nominate a critical level of compaction when ameliorative measures might be required.

Researchers at Narrabri and Trangie have shown that the adverse effects of soil compaction on cotton root growth can be offset by irrigating more frequently, and by adding extra nitrogen to replace that lost by denitrification.

ROOT ACTIVITY IN RELATION TO SOIL TEMPERATURE

Cotton originated in the tropics, and becomes inactive at low temperatures. Maximum temperatures between 27ºC and 35ºC and minimum temperatures between 15ºC and 20ºC constitute the optimum range for productivity, although the temperature optimum for both the primary roots and hypocotyls of cotton shifts with time and stage of growth. Experiments at Narrabri have shown that cotton development ceases below 11.4ºC.

Wet soil warms much more slowly than dry soil, so effective field drainage is important for seedling survival under cool conditions. Mulches can insulate the surface soil from extremes of temperature in winter and summer.

An associated limitation is that caused by a reduction in light intensity. On dark, foggy days, lateral roots became more dominant than the taproots, even when the temperature is suitable for root growth.

High soil temperature can be a problem in some cotton growing districts. The surface of dark soil can reach a temperature as great as 75^{o}C, which is not conducive to root growth. Irrigation water and/or rain cools the soil surface, particularly in summer.

Temperature interacts strongly with the effects of mechanical impedance on root growth. The soil strength at which roots are restricted becomes greater as temperature increases.

Seed size also is important. The rate of root elongation for a broad range of plants is positively correlated with seed size; the relationship becomes stronger as temperature decreases.

E7. Water movement

PURPOSE OF THIS CHAPTER

This chapter describes the key parts of the hydrologic cycle that need to be understood clearly by cotton soil managers.

CHAPTER OVERVIEW

This chapter covers the following points:

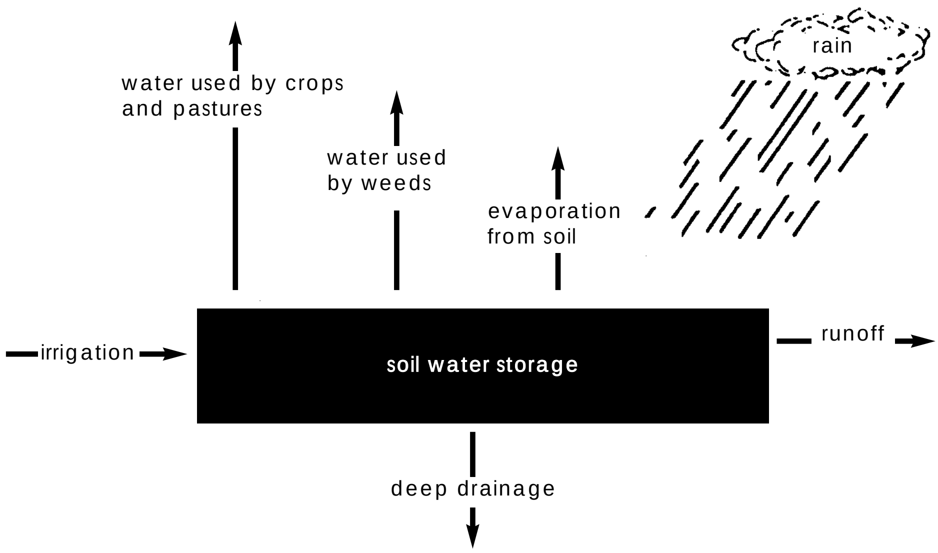
- movement of surface water in cotton fields
  - —water entry
  - —waterlogging
  - —soil movement
- movement of water within the root zone of cotton
- deep drainage below cotton fields.

INTRODUCTION

The most important process to be understood by the managers of cotton soil is the hydrologic cycle. It drives aeration and strength (the main soil structural factors influencing root growth), provides water for nutrient transport and plant growth, erodes soil, transports salt, and determines the trafficability of farm machinery.

The cycle is shown schematically in Figure E7-1. Computer models are available to simulate hydrological processes; contact a soil scientist or your local advisory officer for further information.

Figure E7-1. The hydrologic cycle



MOVEMENT OF SURFACE WATER IN COTTON FIELDS

Water entry

Water entry into cracking clays is rapid and deep when the soil profile has been dried and shrinkage cracks are present. However, if the surface soil has been slowly wet by, for example, light showers of rain, the cracks will close up and water entry will be much slower than where deep cracks extend to the soil surface.

Where irrigation water is applied via furrows (as is done for most of the Australian cotton crop), its penetration into the root zone may be restricted by bed shoulder compaction (that is, poor ‘subbing’). This damage is caused by poor matching of furrow shape and tyre width.

Loam soil, particularly if prone to hardsetting, needs to be maintained in excellent structural condition because of its very slow self-repair potential. The macropores in the water entry zone should be protected.

With the introduction of very accurate tractor guidance systems, it may become possible to separate the traffic laneways and water application zones by driving along the middle of 2 m wide beds.

Waterlogging

In flat cotton fields with heavy clay soil, waterlogging (lack of oxygen in the root zone) is a potential hazard. It does not necessarily mean that the entire root zone of the soil is poorly structured. For example, if a well structured topsoil overlies a poorly-drained subsoil,

too much water may be allowed into the profile if water application is not carefully controlled.

Compacted soil will have waterlogging problems due to temporary perching of water near the soil surface.

One approach to waterlogging management is to steepen the irrigation fields. This will not be feasible, though, if large areas of poorly structured subsoil are to be exposed.

The other way of dealing with poor surface drainage is to build raised beds. Their architecture needs to be matched with soil resilience (shrink–swell potential), slope, type of farm machinery, and water application method. Unfortunately, very little ‘hard data’ are available to provide such designs for growers; until further research is carried out, ‘trial and error’ is necessary.

Soil movement

The problem of soil loss from cotton fields becomes worse as:

- rainfall intensity and amount become greater
- surface cover becomes lower
- slope becomes steeper
- the distance between contour banks becomes greater
- run-off water becomes concentrated rather than spread out
- soil wetness becomes greater.

MOVEMENT AND STORAGE OF WATER WITHIN THE ROOT ZONE OF COTTON

As discussed in Chapter A2, soil within the root zone needs to be able to store as much water as possible. However, even more important (particularly for irrigators) is to redistribute water quickly within the root zone so that adequate aeration is re-established.

It is inevitable that some of the interiors of clods in the soil profile will be anaerobic just after irrigation; the challenge is to keep aggregate diameter in the range 2 to 4 mm, so that roots still have access to a large area of well-aerated clod surfaces.

Water losses via evaporation can be minimised by encouraging storage of water in the sub-surface and subsoil, rather than in the topsoil.

DEEP DRAINAGE BELOW COTTON FIELDS

It is crucial that excessive deep drainage be avoided when growing cotton. It can be justified only if salt that has entered fields via the irrigation water has to be leached to below the root zone. Loss of water as deep drainage leads to problems such as rising water tables, and inefficient use of a scarce resource.

In horticultural areas, permanent drains are installed to reduce waterlogging and to intercept deep drainage. Generally, the cost is too great for cotton producers. Another (much cheaper) option is to install mole drains. However, the need to have a non-sodic subsoil that does not cause collapse of the cavity means that much of the cotton soil in Australia appears to be unsuitable for this technology.

Deep subsoil compaction caused by heavy machinery apparently is a desirable process in terms of restricting the deep movement of water.

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Appendix 3. More case studies are needed

This *SOILpak for cotton growers* manual provides you with options for overcoming soil-related problems under irrigated and dryland cotton. It is your responsibility to select an option (or series of options) that is appropriate to your operation.

Fine-tuning of your soil management program to maximise profitability is likely to take several years. You will need to do strip trials of the various options at different rates and settings.

Often this fine-tuning process will be of great value to subsequent managers, and to other growers in the district. Therefore, it is important that you document these case studies.

District cotton grower associations have provided an excellent lead with the documentation of on-farm case studies. Cooperating growers and their consultants ensure that the various treatments under consideration are properly replicated. Otherwise, it is not possible to prove whether or not an improvement in performance was a real one.

Where soil management trials are established, aim to record more than just crop yield and quality.

Record:

- all costs and benefits associated with the various options
- the weather conditions under which the observations were made
- changes in soil condition, for example, the severity of soil compaction under the cotton plant lines.

Your information can then be incorporated into the next edition of *SOILpak for cotton growers.*

Appendix 4. Unit conversion

Table 1. Conversion factors that allow the electrical conductivity of saturated paste extracts (EC_e) to be calculated from the electrical conductivity of 1:5 soil:water suspensions ($EC_{1:5}$) and texture (source: Slavich & Petterson, 1993).

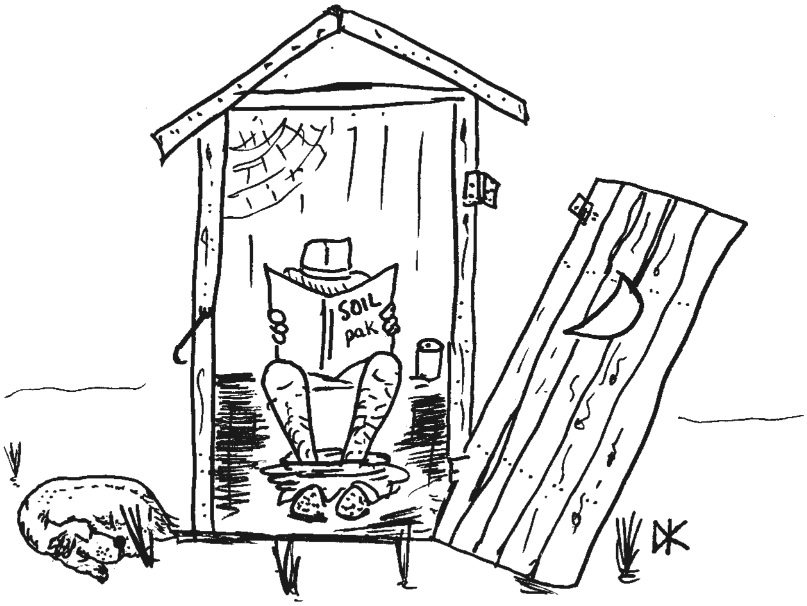
Texture grades (Northcote, 1979)	**Conversion factor**
Sand (S), loamy sand (LS), clayey sand (CLS)	22.7
Sandy loam (SL), fine sandy loam (FSL), light sandy clay loam (SCL)	13.8
Loam (L), loam fine sandy (Lfsy), silt loam (SiL), sandy clay loam (SCL)	9.5
Clay loam (CL), silty clay loam (SiCL), fine sandy clay loam (FSCL), sandy clay (SC), silty clay (SiC), light clay (LC), light medium clay (LMC)	8.6
Medium clay (MC)	7.5
Heavy clay (HC)	5.8

Table 2. Conversions between electrical conductivity units and approximations to salt concentration (source: Shaw, 1985).

To / From (multiply by)	**S m^{-1}**	**dS m^{-1}**	**mS m^{-1}**	**µS m^{-1}**	**mS cm^{-1}**	**µS cm^{-1}**	**TDI mg L^{-1}**	**m.equiv L^{-1}**
S m^{-1}	1	10	10^3	10^6	10	10^4	2/3x10^4	100
dS m^{-1}	0.1	1	100	10^5	1	10^3	2/3x10^3	10
mS m^{-1}	10^{-3}	0.01	1	10^3	0.01	10	20/3	0.1
µS m^{-1}	10^{-6}	10^{-5}	10^{-3}	1	10^{-5}	0.01	2/3x10^{-2}	10^{-4}
mS cm^{-1}	0.1	1	100	10^5	1	10^3	2/3x10^3	10
µS cm^{-1}	10^{-4}	10^{-3}	0.1	100	10^{-3}	1	2/3	0.01
TDI, mg L^{-1}	1.5x10^{-4}	1.5x10^{-3}	1.5x10^{-1}	1.5x10^2	1.5x10^{-3}	1.5	1	1.5x10^{-2}
m.equiv, L^{-1}	0.01	0.1	10	10^4	0.1	100	2/3x10^2	1

Example: 1 µS m^{-1} = 10^{-5} dS m^{-1}

Appendix 5. Glossary - soil management terminology



A, A1, A2 horizon: See: *soil profile.*

access tube: Small diameter tube (typically 50 mm) inserted vertically through soil in the root zone to provide access for a neutron or capacitance probe. This allows estimation of the volumetric soil water content.

acid soil: Soil with a pH value < (less than) 7.0.

adsorbed: Held on a surface; in soil, *cations* are held on clay surfaces due to a difference in charge between the cations and the surfaces (similar to the attraction of oppositely charged ends of two magnets).

aerobic: Soil conditions in which there is sufficient oxygen for plant roots and (generally) soil organisms that carry out processes beneficial to plant nutrition and soil structure.

aggregate: A natural unit of soil that contains groups of peds; the peds within the aggregate are held together more firmly than the aggregate holds to other aggregates (therefore the aggregate is recognisable as a unit).

aggresize: Creation of 1–4 mm diameter clods in loam soil under moist conditions that, once dried, are stable on re-wetting.

air-filled porosity: The fraction of the bulk volume of soil that is filled with air at the time of measurement.

Alfisol: Loam soil with a clay-rich subsoil (U.S. terminology).

alkaline soil: Soil with a pH value > (greater than) 7.0.

allelopathy: Production of a substance by one organism that inhibits the growth of one or more other organisms.

alley farming: Production of crops between regularly spaced, parallel strips where trees and/or perennial shrubs and grasses are grown.

alluvial soil: A soil developed from recently deposited *alluvium*; usually too young to show the effects of soil forming processes: any layers in the soil profile are successive deposits rather than soil horizons.

alluvium: Unconsolidated gravel, sand, silt and clay deposited by water flow—typical of floodplains.

ameliorate: To make or become better.

anaerobic: Soil conditions in which there is a lack of oxygen, usually because water has replaced soil air (the soil is waterlogged); substances harmful to plants (such as hydrogen sulfide) may accumulate.

anion: An *ion* with negative charge.

apedal: Soil materials without peds, that is, structureless.

aquifer: A water-bearing geologic unit of sediment or rock capable of yielding useful quantities of water to bores or springs.

ASC: See: *Australian soil classification*

ASWAT test: A measure of soil dispersion in water (**A**ggregate **S**tability in **WAT**er) that takes between 2 and 4 hours to complete. The ASWAT test is a simplified version of the 'Loveday and Pyle' dispersion test.

Australian soil classification (ASC): The system now used to classify soil in Australia; it replaces 'Great Soil Groups' and 'The Factual Key'.

available water capacity: See: *plant available water capacity.*

B horizon: See: *soil profile*.

back-to-back cotton: Planting of a cotton crop (around October) in a field where cotton was grown the previous season (usually harvested in April).

bed: A raised pair of ridges of soil (usually 2 m wide, furrow to furrow, and sometimes flat on top) into which a row crop is planted; see: *hill*

biological drilling: Using tap-rooted plants to penetrate through a hard layer of soil or into a hard subsoil; when the plants die, the root channels are available for use by subsequent crops.

biological fertility: See: *fertility*.

biological ripping: Using plants to dry and crack the soil; cycles of swelling and shrinking improve soil structure in cracking clays.

biopore: A macropore created by biological activity in the soil, for example, old root channels, or chambers created by earthworms and ants.

bleached: A pale colour (for example, of an A2 horizon); see*: Soil profile*.

bolus: A ball of moist soil which is kneaded to determine soil texture.

bulk density: A measure of compactness; the more compact a soil is, the more solids in a given volume. Bulk density is calculated as the weight of oven-dry soil divided by the field volume of the sample.

Ca:Mg ratio: Ratio of exchangeable calcium to exchangeable magnesium.

calcareous: A soil containing significant amounts of naturally occurring calcium carbonate ($CaCO_3$)(lime), which fizzes when dilute acid is added.

calcium: A *cation* that promotes *flocculation*; an essential plant nutrient.

capacitance probe: A sensor that estimates volumetric soil water content by measuring the dielectric properties of soil surrounding a PVC tube.

cation exchange capacity (CEC): See: *exchange capacity* and *exchangeable cations.*

capillary rise: The upward movement of water caused by the molecular attraction between soil particles and water; capillary rise causes the wetting of soil above a watertable.

cation: An *ion* with a positive charge.

CEC: See: *exchange capacity* and *exchangeable cations.*

chemical fertility: See: *fertility*.

chisel ploughing: Deep tillage at depths < 40 cm.

Chromosol: A soil with a *duplex* texture profile and in which the major part of the upper 0.2 m of the B2 horizon is not *strongly acid*.

clay:	Soil particles with a diameter smaller than 0.002 millimetres that are involved in swelling and shrinking of soil, and hold water and exchangeable cations. The term 'clay' also refers to soil with sufficient clay (greater than 35%) to exhibit clay behaviour.
clod:	A human-modified unit of soil that often contains smaller component clods; see: *aggregate* and *ped*.
coefficient of linear extensibility (COLE):	The percentage shrinkage in one dimension of a moulded soil between two water contents.
COLE:	See: *coefficient of linear extensibility.*
colloid:	Material consisting of very finely divided particles. It has a large surface area per unit volume, so it is very reactive; *clay* and *humus* are colloids.
compaction:	Compression of soil into a smaller volume so that bulk density is increased and air-filled porosity is decreased; see: *smearing*, *remoulding* and *pulverisation.*
conchoidal:	'Ball and socket' morphology associated with severely compacted and remoulded soil.
controlled traffic:	The confinement of traffic over a field to the same wheel tracks, the position of which is fixed for several years.
conventional tillage:	Describes traditional systems where mechanical tillage is the main method used for seedbed preparation and weed control; normally involves 3 to 6 tillage operations.
cracking clays:	Black, grey or brown (occasionally, but rarely, red) clay soil that is distinguished by seasonal cracking and a lack of distinct horizons; see *Vertisol*.
crop water use:	The water used by a crop from planting to harvest. It includes transpiration (through the crop) and evaporation (directly from the soil), and is usually expressed in mm.
crop water use efficiency (CWUE):	See: *Water use efficiency.*
crusting:	Occurs when the soil surface 'melts' together when wet, and then sets hard and impermeable when dried. If a thin (up to 10 mm deep) surface layer is affected, and cannot be readily separated from and lifted off the underlying soil, the problem is called crusting; if thicker (particularly when the whole topsoil is affected) it is called hardsetting; see: *hardsetting* and *flaking*.
deep percolation:	Drainage of water below the root zone.
deep ripping:	Deep tillage at depths > 40 cm.
deep tillage:	Any tillage deeper than that needed to produce loose soil for a bed/hill or seedbed; its usual purpose is to loosen a compacted subsoil.
denitrification:	The processes by which soil microbes convert soil nitrate to nitrogen gas and nitrous oxide gas, which are unavailable to plants.
discharge area:	An area where underground water is discharged at the soil surface.
dispersion:	Disintegration of microaggregates into individual clay, silt and sand grains; it is the opposite of flocculation.
dryland salinity:	Symptoms of salinity associated with dryland agriculture.

duplex soil: A soil that shows a sharp change in soil texture between the A and B horizons; for example, a loam topsoil overlying a clay subsoil; red-brown earths are duplex.

$EC_{1:5}$: The electrical conductivity of a 1:5 soil:water extract.

EC_e: The electrical conductivity of a saturated soil paste.

electrical conductivity (EC): Conductivity of electricity through water or an extract of water, commonly used to establish the soluble salt content.

electrochemical stability index (ESI): Soil electrical conductivity (dS/m) (1:5 soil:water extract) divided by exchangeable sodium percentage; it is a measure of soil stability in water.

electrolyte: Salty solution.

EM instruments: Electromagnetic induction devices that estimate soil salinity.

Entisol: Loam without a clay-rich subsoil (U.S. terminology).

erosion: The wearing away of the land surface by rain, irrigation water or wind, causing soil movement from one point to another.

ESI: See: *electrochemical stability index.*

ESP: See: *exchangeable sodium percentage*.

evapotranspiration: The sum of direct evaporation from the soil surface and transpiration, by which process plants give off water vapour through their leaves.

exchange capacity: Ability of the clay and humus in the soil to hold ions on charged surfaces. Negatively charged surfaces (cation exchange sites) hold cations; positively charged surfaces (anion exchange sites) hold anions. For cations, the capacity (cation exchange capacity; CEC) is expressed as centimoles of positive charge per kilogram of soil (cmol (+) kg^{-1}); for anions, the capacity is expressed as centimoles of negative charge per kilogram of soil (cmol (-) kg^{-1}); both are numerically equal to milliequivalents per 100 g of soil (meq/100g); see: *ion*.

exchangeable cations: Positively charged *ions* held loosely on negatively charged soil particles, and readily exchanged with other ions in the soil solution. This mechanism reduces the leaching of some plant-available nutrients.

exchangeable sodium percentage (ESP): The number of exchangeable sodium ions as a percentage of all exchangeable cations held by a soil. The critical ESP value above which dispersion occurs ranges from 2 to 15, depending on the amount of electrolyte in soil solution.

fallow efficiency: The percentage of rainfall received during the fallow that is stored in the soil; soil management can alter fallow efficiency.

fertility: The capacity of a soil to support plant growth. It is has three components—chemical, biological and physical fertility.

Chemical fertility is the ability of a soil to supply plants with an adequate and balanced supply of nutrients.

Biological fertility refers to the nature and diversity of soil organisms, and their activity in the soil.

Physical fertility is the ability of a soil to supply plants with enough water and oxygen, to protect their roots from temperature stress, and to allow unrestricted root penetration and shoot emergence; it depends largely upon soil texture and structure.

field capacity: The content of water, on a mass or volume basis, remaining in a soil after free drainage has become negligible (corresponds to a soil water potential of –10 kPa).

flaking: Structural condition of topsoil in which the surface layer, usually less than 10 mm thick, is hard and brittle when dry and can be readily separated from and lifted off the underlying soil; see: *crusting*.

flocculation: Clustering of clay particles into microaggregates; the opposite of dispersion.

friability: The ease with which a soil sample can be crumbled.

geographic information system (GIS): A method (usually computer based) of overlaying and comparing large volumes of geographic data of different kinds.

gilgai: A natural surface feature of humps and depressions found in some types of cracking clay.

GIS: See: *geographic information system.*

global positioning system (GPS): A network of satellites controlled by the US Department of Defence that is designed to determine a radio receivers position in latitude, longitude and altitude. Differential GPS (DGPS) improves accuracy of the information via the use of a local base station.

'go-devil': Triple-disc ridge cultivator.

GPS: See: *global positioning system.*

gravimetric water content: The water content of the soil on a per weight basis; grams of water per gram of soil (also referred to as wetness).

ground truthing: Verification of the accuracy of data by actual field investigation of areas that have been remotely sensed.

'guess row': A row at the outside edge of the cultivation implement; the distance between successive runs of the bed-forming implement has to be 'guessed' to some extent by the tractor driver—hence the name.

gypsum: Calcium sulfate ($CaSO_4.2H_2O$), used to reduce swelling and dispersion in sodic soil; it is either a naturally mined substance or a by-product of fertiliser manufacture.

hardsetting: Occurs when a layer of soil, not necessarily at the surface, 'melts' together when wet, and then sets to be hard and impermeable when dried. Hardset layers generally are thicker than a crust, and often contain a disconnected series of small air-filled pores that resemble honeycomb. Hardsetting often occurs in soil with insufficient swelling clay and organic matter; see: *crusting*.

'head ditch': Channel, carrying water to the high end of a field, from which water flows into furrows via siphons.

***Heliothis armigera*:** A species of moth (also referred to as *Helicoverpa armigera*)— its larvae damage cotton and many other crops. Some individuals are resistant to the pesticides endosulfan and pyrethroids.

hill: A ridge of soil (usually 1 m wide, furrow to furrow) into which a row crop is planted; see: *bed.*

horizon: A layer of soil in the soil profile, different from layers above or below due to differences in colour, texture and/or structure. Horizons are formed by soil-forming

processes, as distinct from strata due to successive deposition, or modification caused by the passage of farming machinery; see: *alluvium*, *soil profile*.

humus: Stable, large organic molecules produced by the decomposition of once-living organisms.

hydraulic conductivity: The rate of flow of water per unit gradient of hydraulic potential.

illite: A type of clay mineral.

impermeable: Transmits no water or air.

infiltration: Movement of water into a soil.

infrared: Referring to the portion of the electromagnetic spectrum with wavelengths just beyond the red end of the visible spectrum.

ion: Atomic or molecular particle carrying an electrical charge.

irrigation efficiency (IE): See: *water use efficiency*

Kandosol: A soil that has a well-developed B2 horizon in which the major part is *massive* or has only a weak grade of structure, and has a maximum clay content in some part of the B2 horizon that exceeds 15%.

kaolinite: Variable-charged clay mineral with a 1:1 layer structure.

Kurosol: A soil with a *duplex* texture profile and in which the major part of the upper 0.2 m of the B2 horizon is *strongly acid*.

landforming: An earthmoving operation that creates a desirable field slope.

leaching: Downward movement of dissolved materials.

levee: Recently deposited alluvium beside a river; a levee is higher than the surrounding plains.

'lilleston': Rolling cultivator for shallow tillage of soil surface. It is used for inter-row cultivation after cotton has been planted

lime: Calcium carbonate ($CaCO_3$), occurring in rocks as limestone or chalk, and in some soil as fine particles or small nodules; finely-ground limestone ('aglime') is used to raise soil pH and/or overcome sodicity; other forms of lime are hydrated lime (calcium hydroxide) and burnt lime (quicklime, calcium oxide).

listing: A tillage and landforming operation using a tool that splits the soil and turns two furrows laterally in opposite directions, leading to a ridge and furrow soil configuration.

lower plastic limit (LPL): Old name for the *plastic limit*.

macropore: Large (>0.03 mm diameter) soil pore that is drained and aerated at *field capacity*. It may be a biopore or an old crack line; see: *mesopore, minipore*.

magnesium: A cation that promotes dispersion, but less so than sodium; an essential plant nutrient.

massive: A coherent or solid mass of soil, largely devoid of natural lines of weakness.

meander plain:	An alluvial area built up by sediment from a slow moving and winding river.
mesopore:	Soil pore with a diameter 0.2 µm to 0.03 mm; able to store plant available water (1000 µm = 1 mm).
microaggregates:	Units of soil (smaller than 0.25 mm) that contain particles ranging in size from clay (smallest) through silt to fine sand.
micropore:	Soil pore with a diameter less than 0.2 µm; responsible for the storage of unavailable water in a soil.
'middle busting':	Deep tillage of soil, confined to areas under the plant lines so that wheel tracks remain intact.
mineralisation:	The processes by which soil microbes convert organic nitrogen to ammonium; see *nitrification*.
minimum tillage:	Also referred to as 'reduced tillage'; describes farming practices that reduce the number of tillage operations compared with conventional tillage; weeds in the fallow are controlled by herbicides, and some tillage.
moisture potential:	See: *soil water potential*
moisture seeking:	Refers to planting implements that penetrate dry soil and place seed where there is sufficient moisture for germination.
mole drain:	A tubular drain formed beneath the soil surface by pulling an expanding plug through wet soil.
montmorillonite:	See: *smectite*
mottled:	Having blotches of soil with a different colour; indicative of past periods of intermittent waterlogging.
Munsell colour system:	A colour designation system that specifies the relative degrees of the variables of colour: hue, value and chroma.
mycorrhiza:	A fungus that attaches itself to plant roots, giving mutual benefits; also referred to as 'vesicular-arbuscular mycorrhizae' (VAM).
neutron probe:	A radioactive moisture sensor that is lowered down an aluminium access tube. It estimates volumetric soil water content through measurement of neutrons that are scattered by hydrogen atoms in soil water.
NFR:	See: *nitrogen fertiliser recovery.*
nitrification:	The processes by which soil microbes convert ammonium to plant-available nitrate.
nitrogen fertiliser recovery:	The proportion of applied fertiliser nitrogen that is taken up by the cotton plant.
nitrogen fixation:	The process of converting atmospheric nitrogen into compounds that eventually become available to plants. One such process is the fixation of nitrogen by Rhizobium bacteria associated with the roots of legumes; free-living soil organisms also fix nitrogen.
nodule:	An accumulation of a soil material as a discreet, small lump; may be composed of iron or manganese compounds, or calcium carbonate (lime); a swelling on the roots of legumes, containing symbiotic Rhizobium bacteria.

non-limiting water range (NLWR):	The region bounded by the upper and lower soil water contents over which water availability, oxygen and mechanical resistance to root growth is not limiting to plant growth.
organic carbon:	One of the chemical elements making up organic matter. Organic matter is often expressed as organic carbon because it is carbon that is measured in the laboratory; organic carbon multiplied by 1.75 gives an estimate of organic matter (soil organic matter is approximately 57% carbon).
organic matter:	Plant and animal material, living and dead.
pan:	A hard soil layer, which may restrict the entry of water, air and roots; if caused by repeated tillage at the same depth it is referred to as a plough pan.
PAWC:	See: *plant available water capacity*.
ped:	An individual natural soil aggregate consisting of a cluster of primary particles and separated from adjoining clusters by surfaces of weakness that are recognisable as being natural.
pedal:	Applied to soil materials consisting mostly of peds.
percolation:	Movement of water through the soil.
permanent beds:	A tillage system where the beds and furrows (wheel tracks) are left in the same place for a number of crops; see: *controlled traffic*.
permanent wilting point:	The largest water content of a soil at which indicator plants, growing in that soil, wilt and fail to recover when placed in a humid environment (corresponds to a soil water potential of –1500 kPa).
permeability:	Ability of a soil to transmit water and gases.
pH:	The acidity or alkalinity of a soil is measured as pH, which is an indication of the concentration of hydrogen ions in soil solution. The pH values increase as the concentration of hydrogen ions decreases.
pH buffering capacity:	The ability of a soil to resist changes in pH. It increases as the clay and organic matter content become greater.
physical fertility:	see: *fertility*.
picker row (PR):	Plant row adjacent to a furrow wheeled only by cotton pickers; see: *tractor row*.
PR:	See: *picker row.*
piezometer:	A non-pumping shallow bore, of small diameter, to measure the pressure level of groundwater.
PL:	See: *plastic limit*
plant available water capacity (PAWC):	The maximum amount of water that a soil can hold in the root zone and later release to plant roots. Water held between ‘field capacity’ and ‘refill point’ is referred to as being readily available.
plastic limit (PL):	The water content of a soil above which it can be remoulded (is plastic) and below which it cannot be remoulded (is brittle).
plastic:	Capable of being moulded.
platy clods:	Soil aggregates with horizontal dimensions greater than vertical dimensions.
pore:	Channel or cavity in a soil.

porosity:	The degree to which a soil is permeated with pores; the term refers not only to the fraction of the soil volume made up of pores, but also to the size and shape of the pores and the degree of connection between them.
profile:	See: *soil profile*.
pulverisation:	Mechanical destruction of soil aggregates, usually when in a dry condition; see: *compaction*, *smearing*, *remoulding*.
recharge area:	A zone where surface water from rain, irrigation or streams infiltrates the soil and adds water to the groundwater system.
red-brown earth:	A soil with a loamy topsoil (sometimes hardsetting) overlying a red clay-rich subsoil.
refill point:	The soil water content at which the rate of extraction of soil water by a crop declines due to a lack of soil water.
remote sensing:	Detection and/or identification of landscape features without having the sensor in direct contact with the object.
remoulding:	Reorganising pore space and natural clay orientation (without an increase in bulk density) by disturbing a soil when it is wet; see: *compaction*, *smearing*, *pulverisation.*
rill erosion:	An erosion process on sloping land in which numerous and randomly occurring small channels only several centimetres deep are formed.
root zone:	That part of a soil where the majority of live plant roots are located.
saline seep:	Bare, damp, salt affected area resulting from the seepage of saline groundwater.
salinity:	An excess of water-soluble salts (dominantly sodium chloride in Australia) that restricts plant growth.
sand:	Soil particles with a diameter between 0.02 mm and 2 mm; fine sand is 0.02–0.2 mm, coarse sand is 0.2–2 mm.
SAR:	See: *sodium adsorption ratio.*
sediments:	Particles of clay, silt and sand carried by water or wind before deposition.
self-mulching:	Refers to the topsoil of cracking clay that develops a crumbly layer of loose, small aggregates after a series of wetting and drying cycles.
shrink-swell behaviour:	Ability of a soil to shrink when dried and swell when rewetted.
silt:	Soil particles with a diameter between 0.002 mm and 0.02 mm; intermediate between clay and sand.
slaking:	Collapse of aggregates in water to form microaggregates, due to the breakage of bonds formed, for example, by organic matter.
slickenside:	Shiny, striated stress surface found on clay-rich aggregates, formed by one mass of soil sliding past another during swelling and shrinking cycles.
smearing:	Aligning of clay particles when mechanically disturbed under moist conditions, producing a shiny, impenetrable surface overlying a thin layer with high bulk density; see: *compaction*, *remoulding*, *pulverisation.*
smectite:	Negatively charged clay mineral with a 2:1 layer structure.

sodicity: An excess of exchangeable sodium, causing dispersion to occur.

sodium adsorption ratio: The concentration of sodium ions in water (meq/L), divided by the square root of [(concentration of calcium + concentration of magnesium) ÷ 2].

Sodosol: A soil with a *duplex* texture profile and in which the major part of the upper 0.2 m of the B2 horizon is *sodic* and is not strongly *subplastic*.

soil profile: The vertical sequence of layers (horizons) in the soil.

The *A horizon* is the zone with greatest amount of leaching; it may consist of an A1 horizon (‘true topsoil’—higher in organic matter, darker and richer in biological activity than other horizons) and an A2 horizon (similar to A1 but paler, poorer in structure, lower in clay content and less fertile); the A2 horizon does not always occur;

The *B horizon* is the zone of accumulation of materials from above—clay, iron, aluminium and organic matter (although the organic matter content is never as high as in the A horizon); structure is different from that of A or C horizons and colour is typically stronger;

The *C horizon* consists of weathered rock, little affected by soil forming processes; soil that has developed on alluvium does not have a C horizon—the rock below is not related to the soil and would be termed the D horizon.

soil structure: The combination or arrangement of primary soil particles into secondary units or peds. Naturally-formed peds (aggregates) are referred to as clods when the soil has been disturbed by the activities of humans; see: *structural form, structural resilience, structural stability.*

soil water: Water stored in the soil, or moving through it via drainage.

soil water potential: The amount of ‘suction’ that must be applied by plant roots at a particular soil water content for water uptake to commence.

SOILpak score: A semi-objective rating (on a scale of 0.0 to 2.0) of soil structural form.

SOLICON: A computer-based image analysis system for the assessment of soil structural form.

solonetz: An old term describing a soil with a thin, friable surface soil overlying a hard, columnar subsoil that may be very alkaline.

stubble retention: Soil preparation procedures that maximise the amount of stubble retained on the soil surface for soil and water conservation.

structural form: A description of soil structural units (peds or aggregates) and the pore spaces between; it includes the shape and size of peds, the nature of their faces and their porosity (also referred to as ‘soil architecture’ and ‘compaction severity’).

structural resiliency: Ability of a soil to regain structural form by natural processes, for example, swelling and shrinking, after the removal of disruptive stresses such as compaction by farm machinery.

structural stability: The ability of a soil to retain its structural form under the influence of disruption caused by: a. immersion in water; b. compaction, remoulding and smearing.

subbing: The rate of lateral flow of water from furrows into raised beds or hills.

subplastic: Soil material that has an apparent increase in clay content as a bolus continues to be manipulated.

sub-surface soil: Soil between the depths 10–30 cm.

subsoil: Soil between the depths 30–120 cm. It is subdivided into Upper subsoil (30–60 cm), Mid subsoil (60–90 cm) and Lower subsoil (90–120 cm).

surface sealing: The deposition by water, and/or packing, of a thin layer of fine soil particles on the immediate surface of a soil, greatly reducing its permeability.

tensiometer: A device for measuring soil water potential, via a permeable ceramic cup inserted into the soil.

texture: The relative proportions of sand, silt and clay in a soil sample. It can either be estimated by hand, or measured in the laboratory using particle size analysis (PSA).

TDR: See: *time domain reflectometer.*

texture contrast: See: *duplex soil.*

time domain reflectometer (TDR): A device that uses the timing of wave reflections along steel rods to determine the properties of various materials, for example the dielectric constant of soil as an indication of soil water content.

topsoil: Soil between the depths 0–10 cm.

TR: See: *tractor row.*

tractor row (TR): Plant row next to furrow driven along by tractors pulling planting and cultivation equipment (‘main’ wheel track); see: *picker row*.

transpiration: See: *evapotranspiration.*

VAM: See: *mycorrhiza*

Vertisol: Cracking clay (U.S. terminology); see: V*ertosol*

Vertosol: Australian term used to describe a soil which ‘turns’ (tills) itself (Latin *verto*—to turn). Vertosols have more than 35% clay throughout the profile, cracks greater than 5 mm at some time of the year, and the presence of slickensides. Vertosols lack distinct horizons.

volumetric water content: The water content of the soil on a per volume basis (cm^3 of water per cm^3 of soil); it is equal to the gravimetric water content multiplied by the soil bulk density.

water potential: See: *soil water potential.*

watertable: Upper surface of groundwater, below which the layers of soil, rock, sand or gravel are saturated with water.

waterlogging: Saturation of a soil with water, causing air to be displaced to the point where there is insufficient oxygen for unrestricted root activity; see: *anaerobic*.

water use efficiency: A measure of the efficiency of conversion of water into plant products. For cotton, *crop water use efficiency* (CWUE) is a measure of lint yield per millimetre of water obtained from stored reserves in the soil, irrigation and rain. Calculation of *irrigation efficiency* (IE) is similar, but it takes into account water losses in the storage and distribution system.

wilting point: See: *permanent wilting point*