NSW DEPARTMENT OF
PRIMARY INDUSTRIES

SOILpak – cotton growers - Readers' Note

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

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

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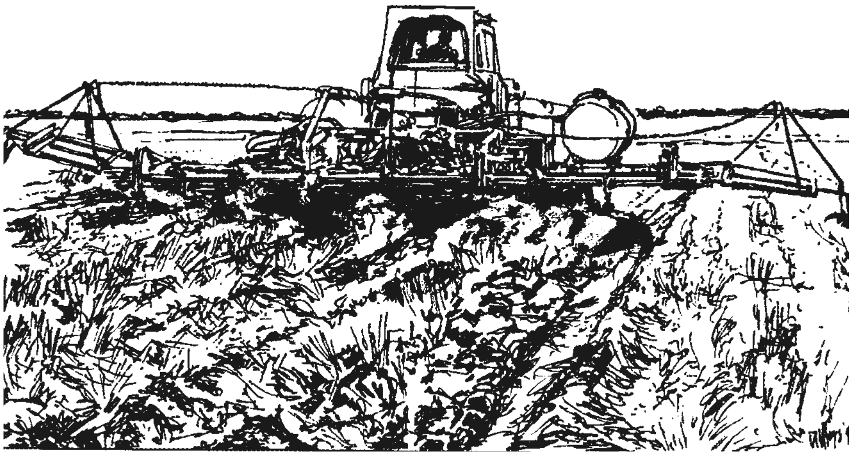
PART D. PRACTICAL SOIL MANAGEMENT: AFTER THE DIAGNOSIS

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.

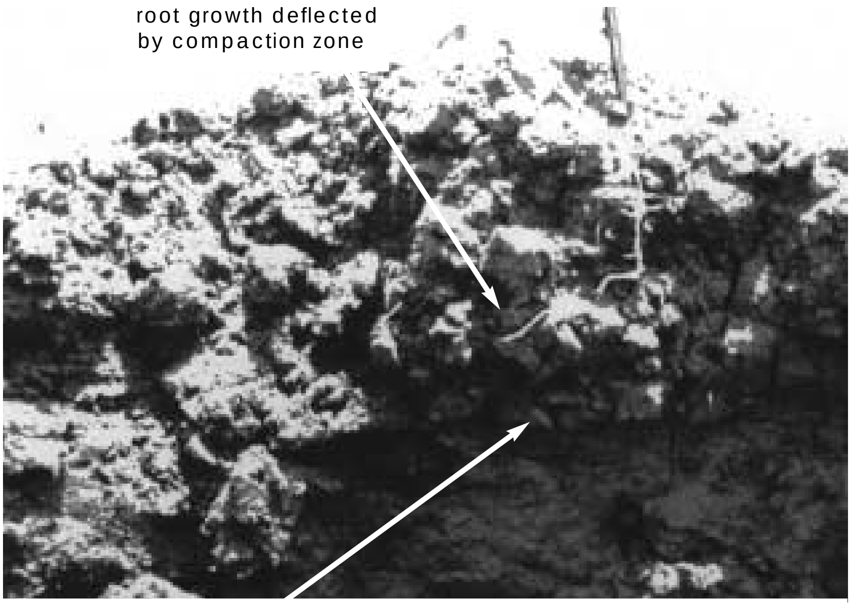
The biggest hurdle to overcome with controlled traffic is the matching of cultivation and sowing equipment with that of harvesting machinery.

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.

☞ *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.

☞ *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):

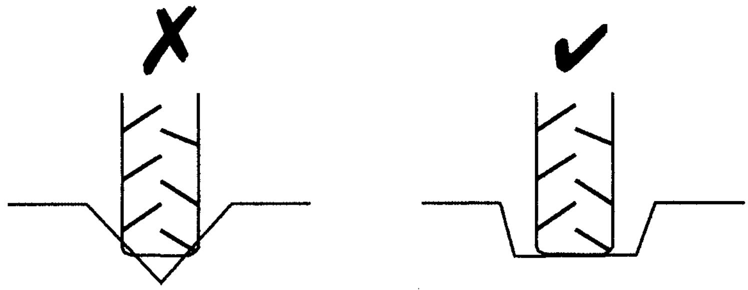
- Widen the furrows (perhaps each pair of cotton rows can be brought closer together, therefore widening the furrows between 2 m wide beds). Flattening the base of furrows will also help to reduce tyre pressure on the bed edges.
- Select wheels/tracks that are narrower.
- As a temporary measure, gas 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.

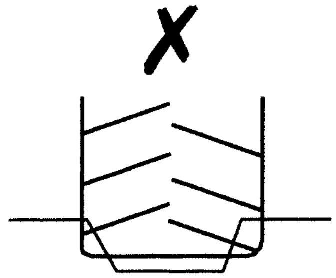
Under dryland conditions, waterlogging is a concern in some years. Therefore, raised beds have a role to play, particularly on heavy clay soil in flat areas, in rain-fed areas. Excess water is drained from the surface via the furrows. Beds also help to define the controlled traffic laneways.

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.

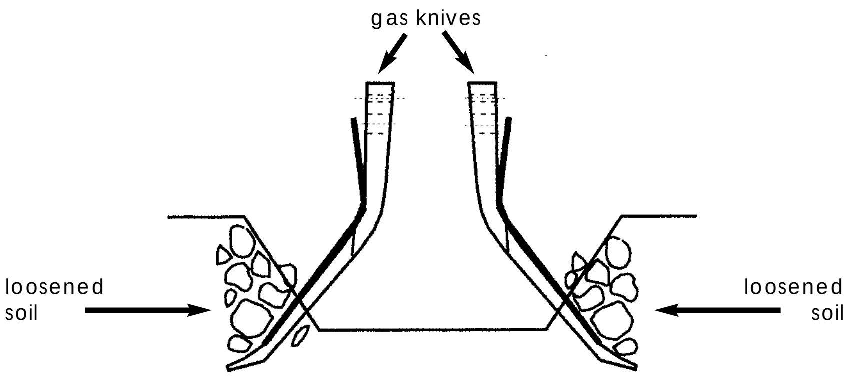
Figure D1-2. Options for dealing with bed shoulder compaction problems.



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.

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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.

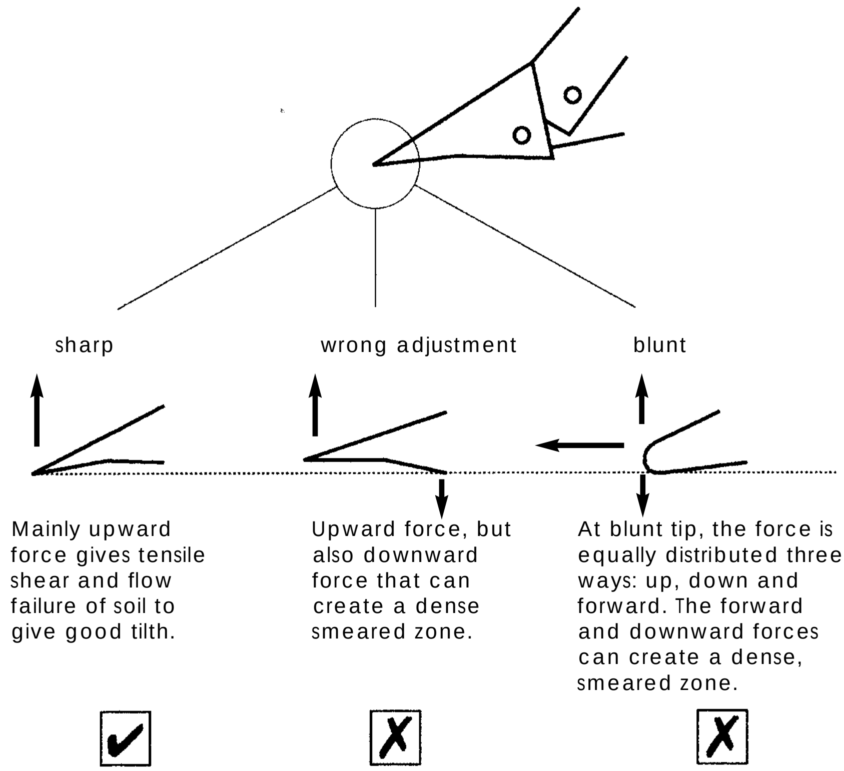
Implement adjustment and wear can also affect compaction, especially if the soil moisture level is above or near the plastic limit. As a tool wears and becomes blunt, the downward force from the tine into undisturbed soil increases (see Figure D1-3). Generally speaking, the compaction (smearing) will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



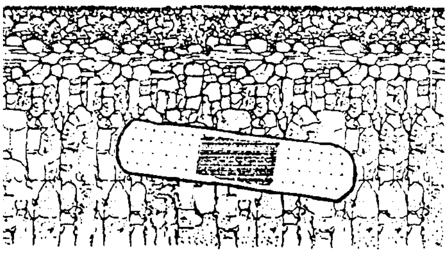
Chapter C7), counterbalance the sodium with calcium from gypsum. Soil structural decline caused by the use of sodic irrigation water can be severe enough to prevent water entry, even under drip irrigation.

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^{o}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.

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.

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

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

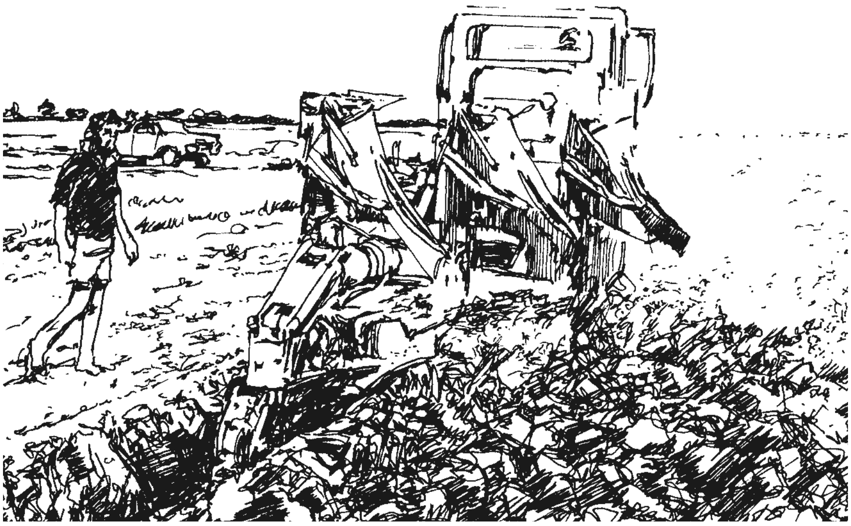


Figure D2-5. A Californian slip plough, which brings subsoil clay to the soil surface from a depth of about 1 m.

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

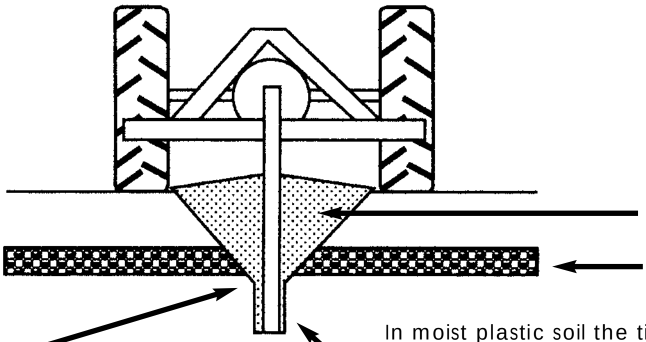
A single pass with a deep tillage implement will not loosen all soil to the working depth of the tine. A given design of tine has a critical depth, which varies with soil type and soil water content. Working deeper than the critical depth will not increase the depth of disturbed soil.

A disturbed area will form that at the most will be at an angle of 45^o 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^{o} (the first pass at 90^{o} to the rows). This gives extra depth, compared with crossing the paths at 90^{o}. 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^{o}).

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.

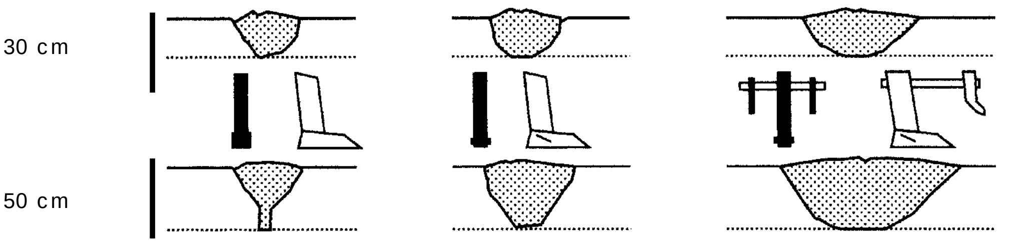
Use wings and leading tines

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).



A conventional tined implement. Note, the slot is formed when attempting to rip at depth. High moisture content of the soil will also increase the slot depth.

A winged tine increases the amount of disturbed soil and helps to prevent a slot forming.

A winged tine with shallow leading tines can also help to eliminate the tine slot.

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.

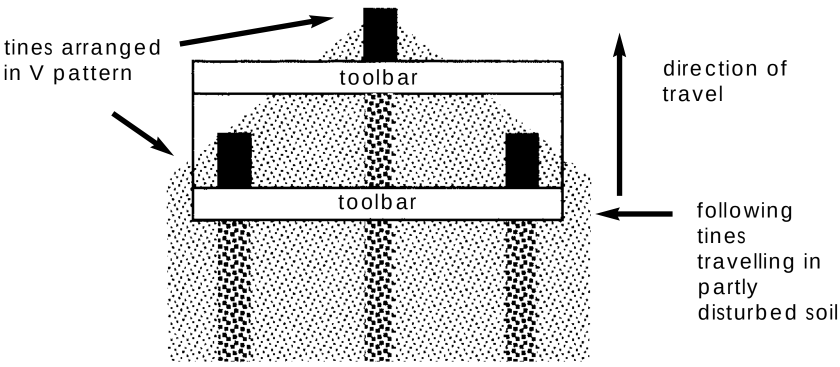
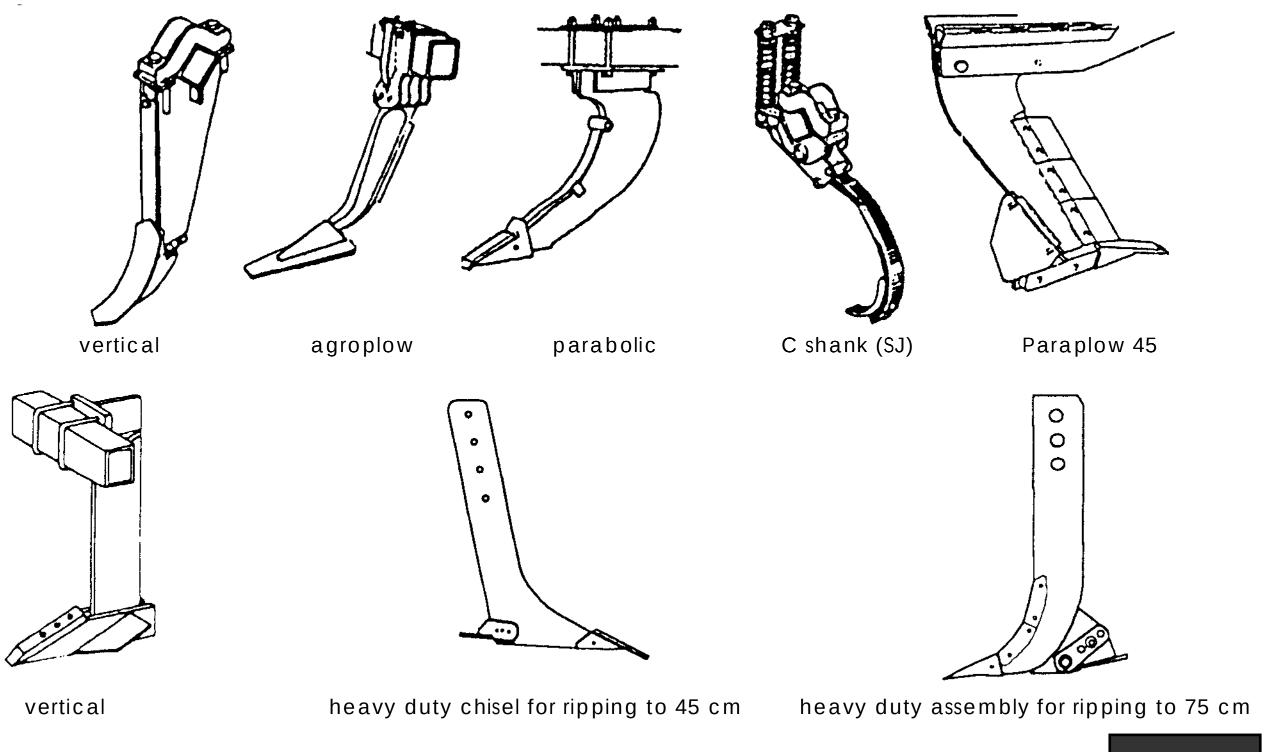


Figure D2-9. A range of tine designs for deep tillage.



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.

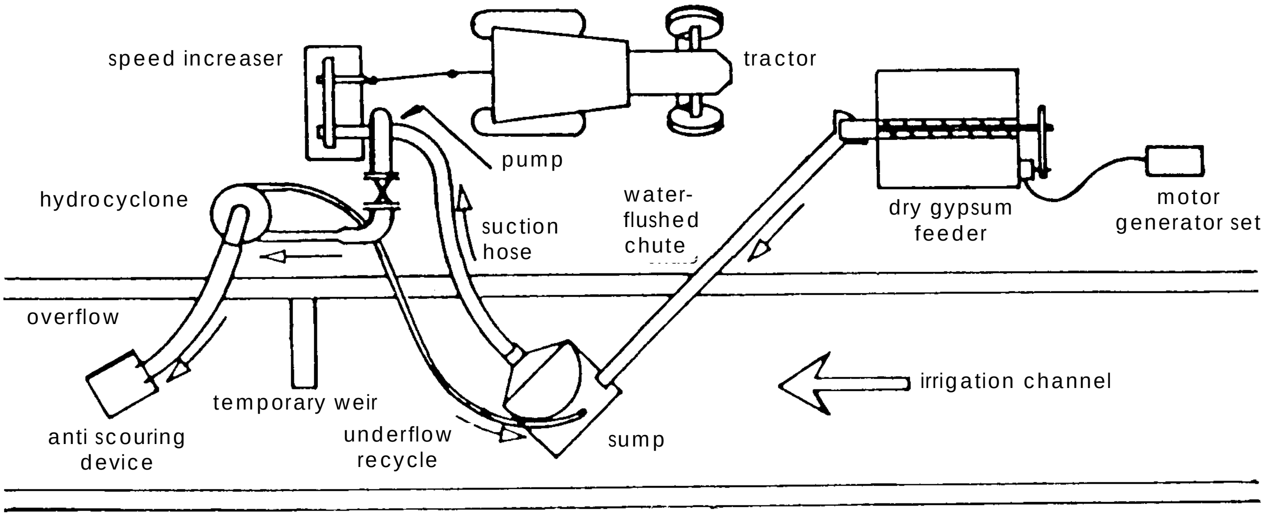
Where a field has been cut and filled or has variable soil types, it may pay to treat the areas individually with increased or decreased rates. Accurate soil mapping allows you to locate the areas.

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.*

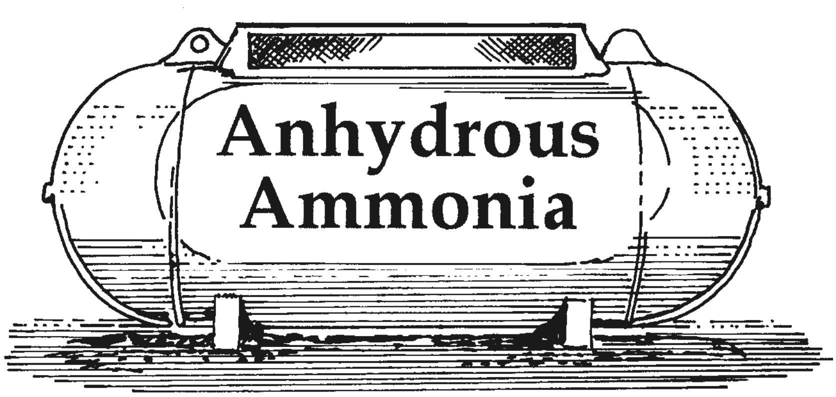
☞

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).

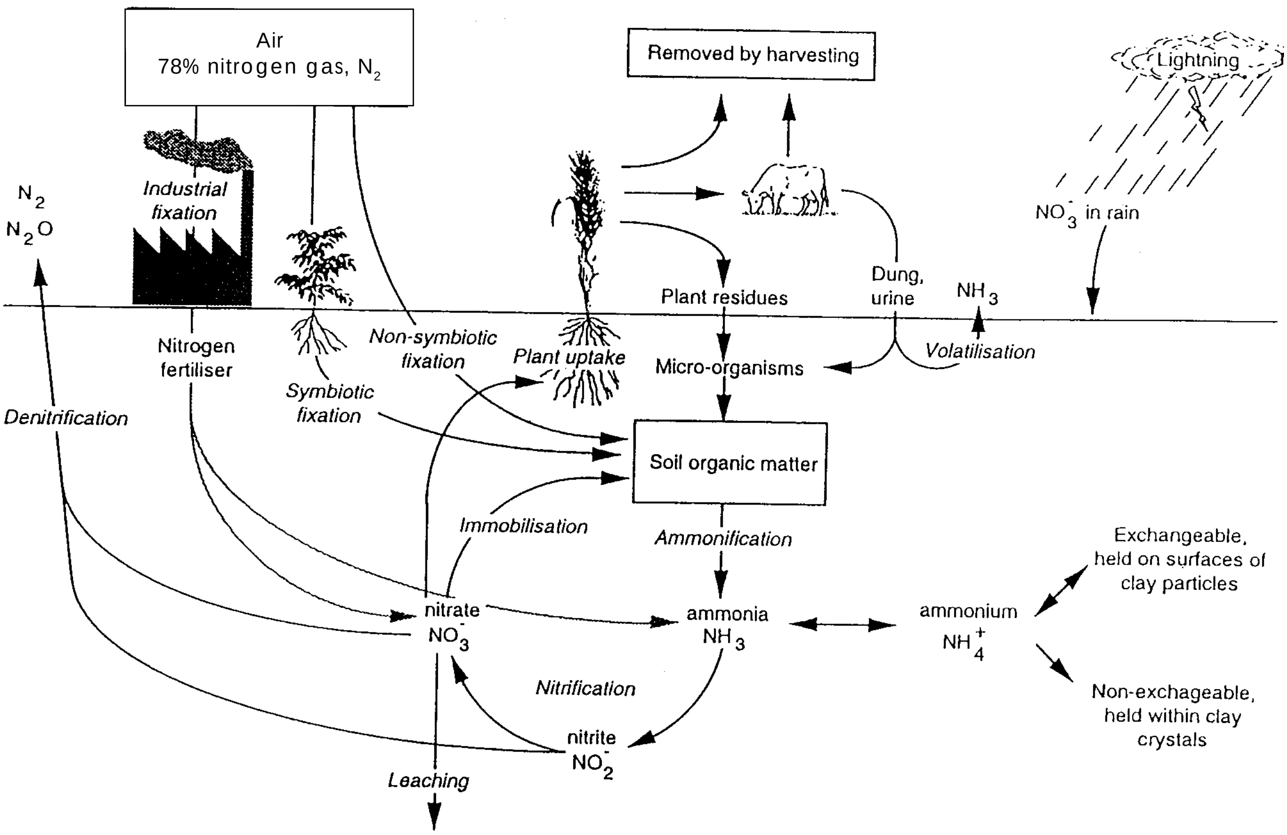
Major nutrients	Removal in lint + seed (kg/ha)	Total uptake (kg/ha)
Nitrogen	135	255
Phosphorus	30	45
Potassium	42	138
Calcium	6	102
Magnesium	12	39
Sulfur	6	N/A

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.

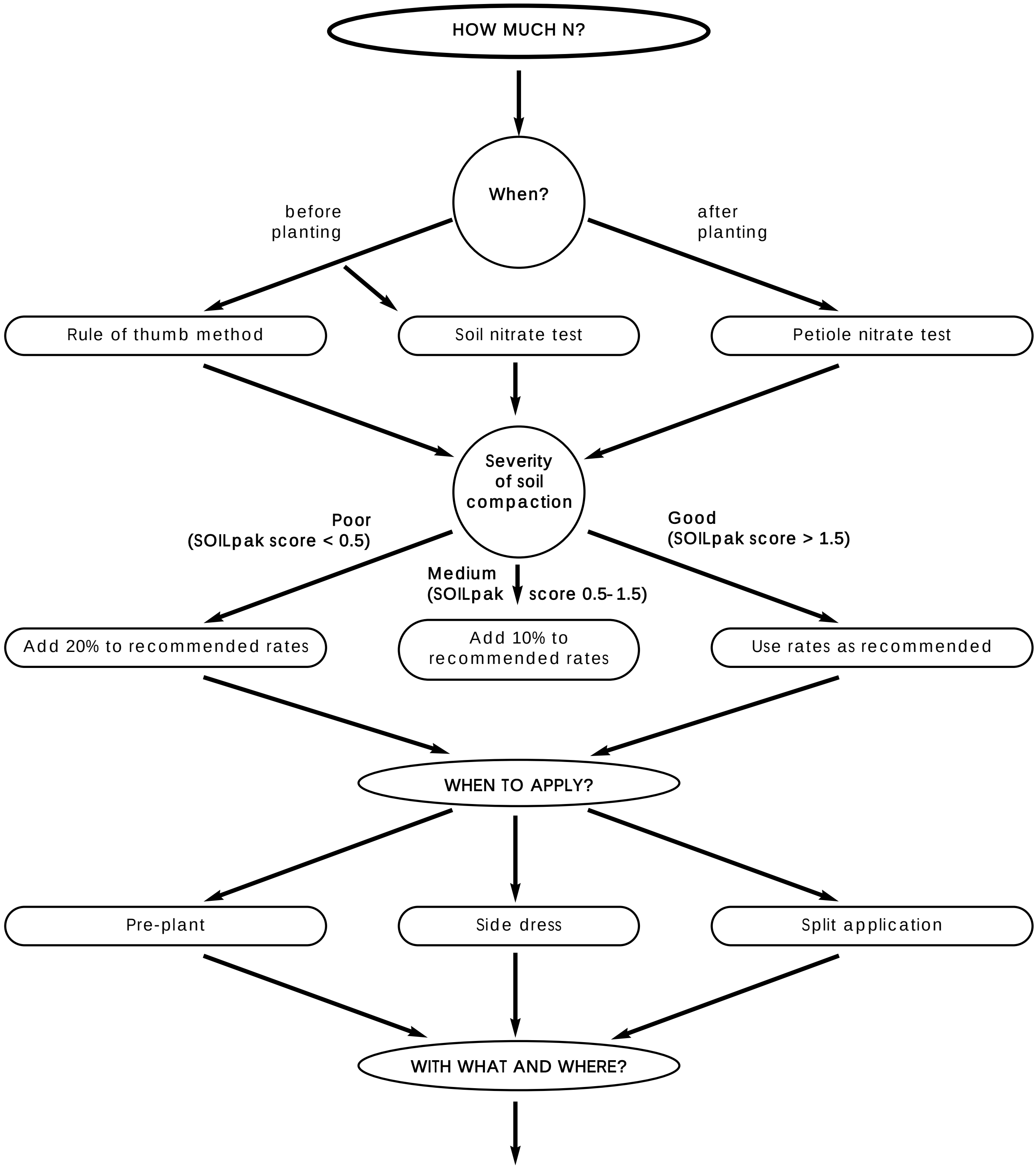
When the soil is very wet, use water-run urea to avoid smearing. If N must be injected into moist hills, use the sides rather than the middle of the hills. Because the variation in the output of anhydrous ammonia into each hill can be as great as 50%, ‘striping’ of crops is a widespread problem. Agricultural 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.

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.

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 E7 for more information on the field water balance.*

☞ *See Chapter E3 for more information on the effects of salinity on soil structure.*

☞ *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.

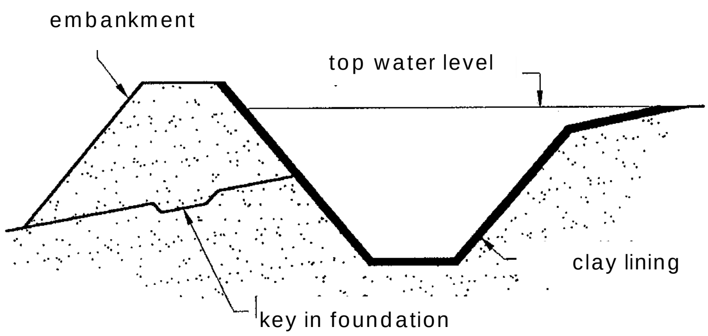
Large seepage losses (typically 1.5 mm/day) also may occur from earthen storages. Occasionally, above-ground storages burst due to embankment failure, caused by ‘tunnelling’ through soil that is structurally unstable. Tunnelling involves dispersion of soil from the sides of macropores that transmit water 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.

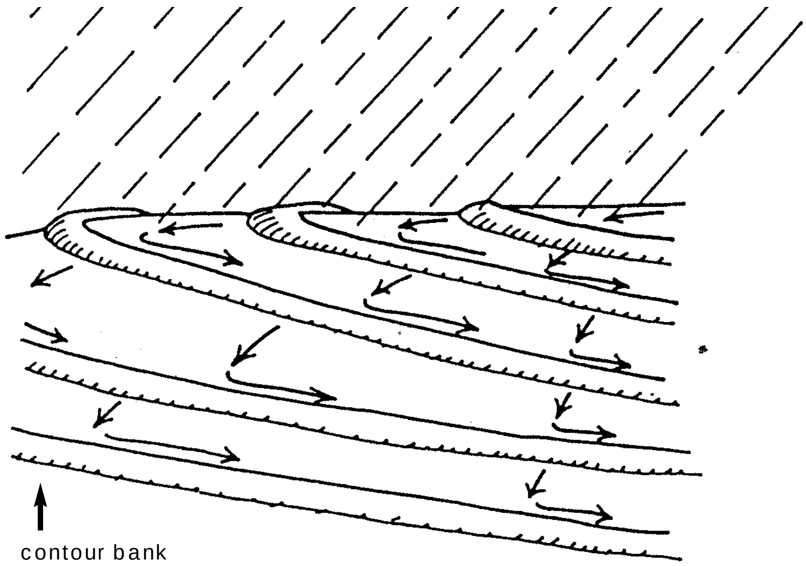
QDNR Indooroopilly has developed some very useful models (for example, ‘Sodium-SaLF’) to describe salinisation processes. Your local Landcare group will also have helpful information about this topic.

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.

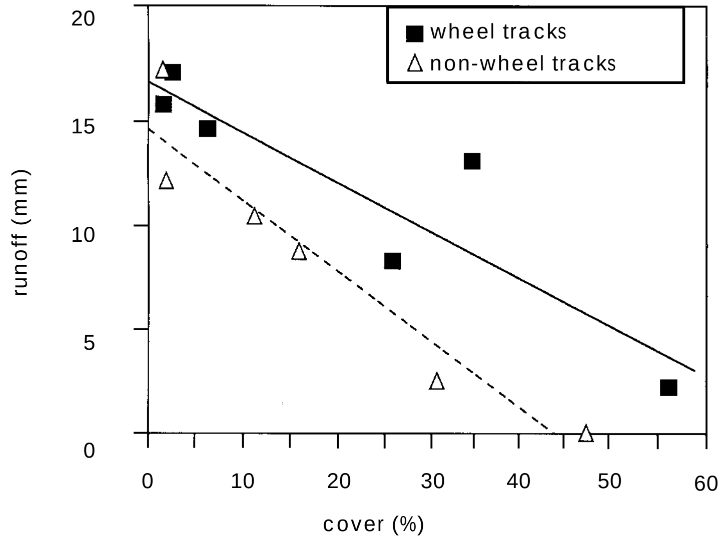
Surface cover protects the soil surface from raindrop impact, slows run-off water, traps sediment and encourages the activity of earthworms and ants, which improve infiltration. Its value is demonstrated in Figure D5-1. It has been shown near Emerald that between the harvest of one cotton crop and the 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.

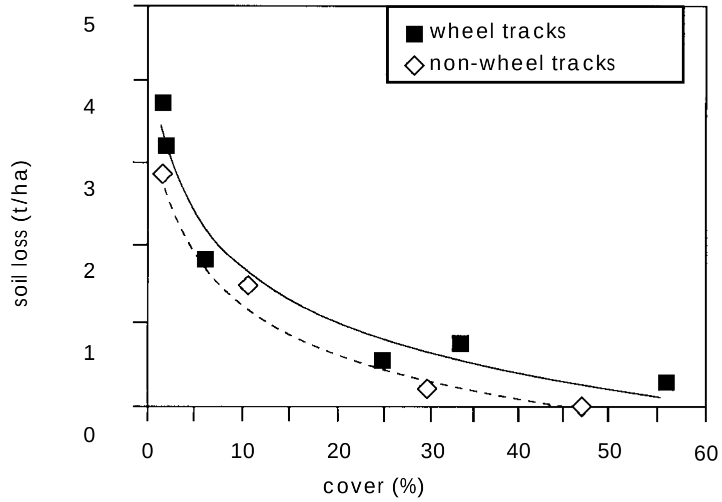
Healthy mature crops usually provide good protection, although some (such as sorghum) are better than others (such as sunflower). The residues remaining after wheat persist for longer than those produced by legumes. Cotton stubble provides poor surface protection.

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.*

☞ *See Chapter E7 for more information about water movement.*

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.

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%.

$$IE = \frac{\text{evapotranspiration (ML) x 100}}{\text{water input to the farm via irrigation and rainfall (ML)}}$$

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.

☞ *See Chapter D10 for more information on fallow efficiency.*

Crop water use efficiency (CWUE), which is the amount of lint produced per ML of water used in evapotranspiration, is calculated as follows:

$$CWUE = \frac{\text{(lint yield in bales/ha)}}{\text{evapotranspiration (ML)}}$$

Water measurements in mm can be converted to megalitres (ML) by dividing by 100.

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.

Figure D6-1. Surface (furrow) irrigation using hand siphons is the dominant watering system in the Australian cotton industry.

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 D6-2. 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

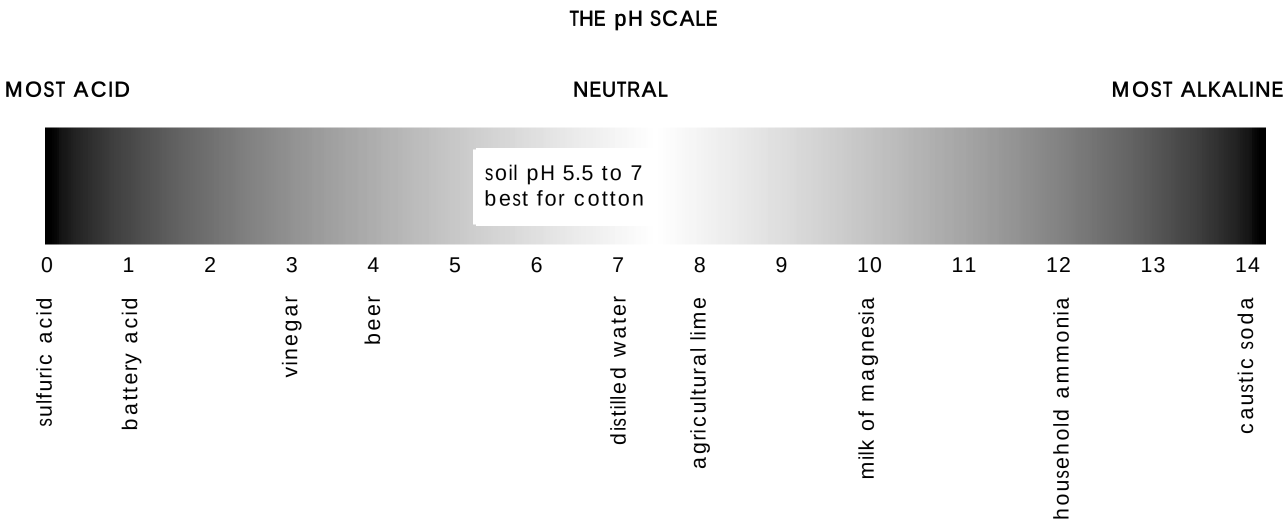
Control of weeds is critical during a fallow. It prevents the loss of valuable stored water. Weed control is also important during crop growth to reduce further wastage of water.

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

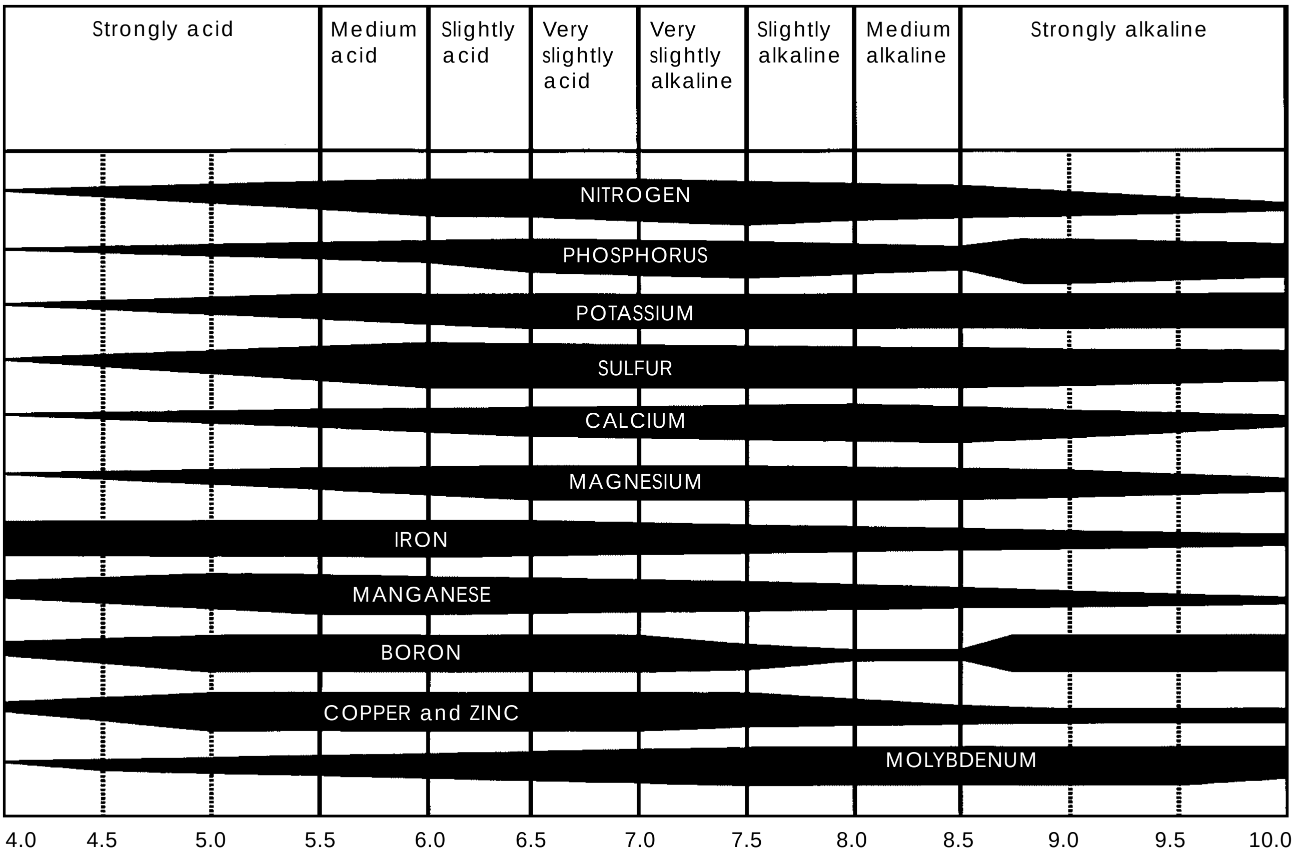
Cotton prefers a pH (measured in 0.01M $CaCl_2$) in the range 5.5 to 7.0. Wheat, the main rotation crop grown with cotton, has the same requirement. Above and below the optimum pH range, certain plant nutrients become unavailable to the plant (see Figure D7-1) or are released in toxic quantities (for 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.

☞

See Chapter D2 for more information on adding lime.

Lime application may also improve soil structural stability by adding calcium to the soil.

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.

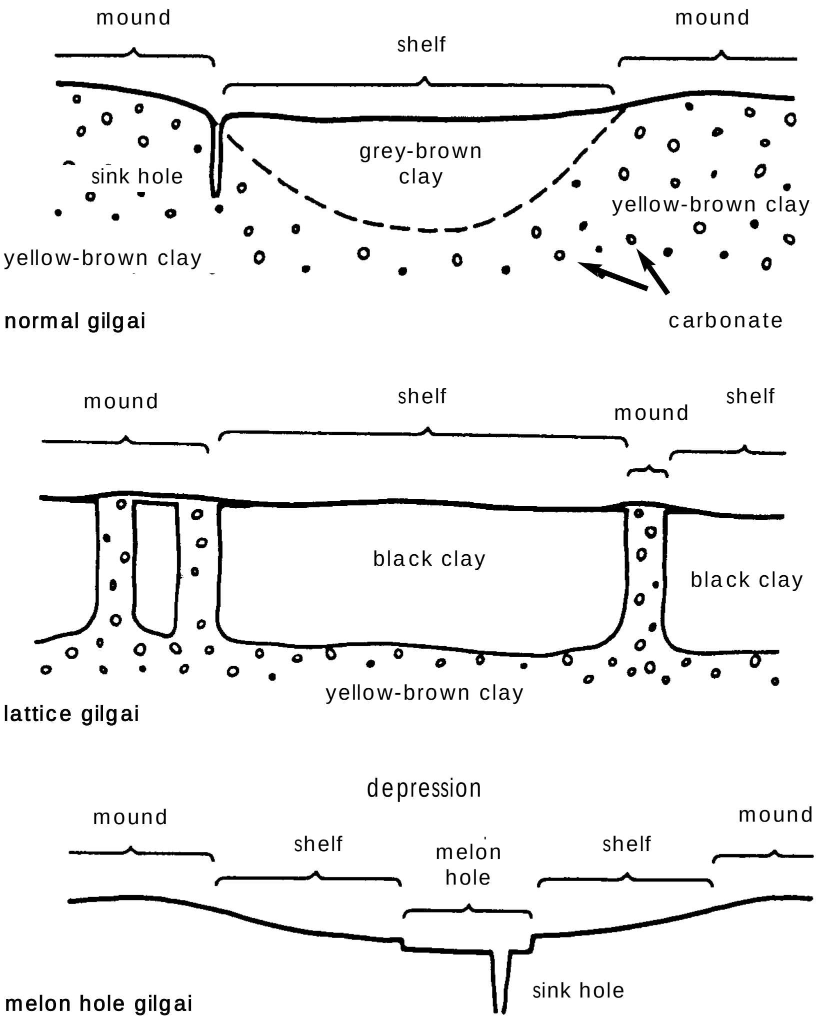
FEATURES OF GILGAIS

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.

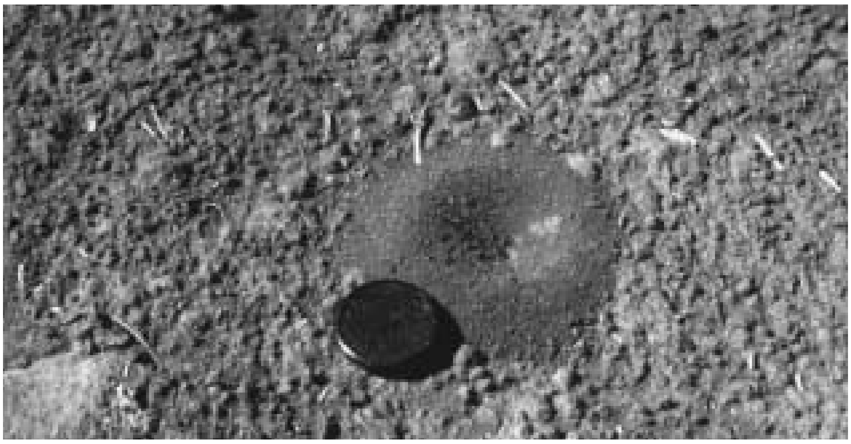
Where the cereal stubble is retained in the furrows, substantial increases in water uptake following irrigation have been found for subsequent summer crops. The increases are believed to be due to the stubble slowing down the rate of water movement and hence increasing the time water remains in the furrows 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.

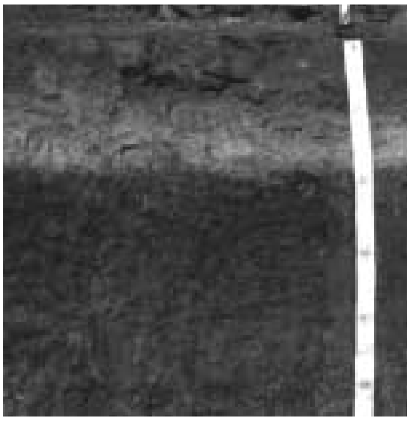
Mouldboard ploughing is also likely to be successful where thin layers of recent alluvium overlie cracking clays.

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.

☞

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.