SOIL MANAGEMENT OPTIONS FOR COTTON-BASED FARMING SYSTEMS IN SWELLING AND NON-SWELLING SOILS

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Abstract

The yield of cotton lint in Australia has increased greatly over the last 15 years. This improvement is due partly to the development of soil management systems that are based on the objective measurement of soil structure in individual fields. Average yields now exceed those of other major producers elsewhere in the world. Grey swelling clays (Vertisols) dominate, but hard-setting red duplex soils with non-swelling surfaces (Alfisols) are also important for cotton in some areas. On these soils mechanical compaction and instability in water are soil structural problems that can cause major yield declines if managed incorrectly. Most Australian cotton is grown on ridges and is furrow irrigated.

Available methods for overcoming natural and man-induced soil structural problems include shrinkage crack formation (created by drought-stressed rotation crops; particularly useful for Vertisols), biopore formation and organic matter accumulation (due to decomposing roots, and soil fauna such as earthworms and ants; particularly useful for the topsoil of Alfisols), low draft deep tillage, and the use of gypsum and lime. Extra water and nitrogen fertiliser can be used to obtain high yields on degraded soils, but such an approach tends to be inefficient and may cause off-site pollution. Where the soil has favourable conditions for cotton root growth and water movement, 'controlled traffic - reduced tillage' systems are recommended to minimise costs.

In the future it is necessary to provide soil structure assessment procedures that are more objective and many of the procedures for improving and living with degraded soils need to be refined. Also, better farm machinery should be developed for controlled traffic systems under cotton; vital are engineering and soil mechanics inputs to optimise axle loadings, and tyre and tool dimensions and configurations, on soils with different water contents and pre-stress conditions.

Introduction

This review focuses on systems of land preparation systems for irrigated cotton (*Gossypium hirsutum* L.) in Australia, where large increases in average lint yield have occurred over the last decade. General accounts of land preparation systems for irrigated and rainfed cotton elsewhere in the world have been written by Berger (1969) and Waddle (1984).

Early Developments in the Australian Cotton Industry

In 1960-62 the average cotton lint yield in Australia of 130.5 kg ha^{-1} (over 13,457 ha) was approximately 1/3 that of the USA (Basinski, 1963). In the 40 years previous to that, Australian yields had hardly changed whilst North American yields increased 3-fold. Most of the Australian cotton was rainfed, and grown with the help of a Commonwealth Government price guarantee in the 1960s scheme. In the five years up to 1963 only about 8% of Australia's cotton was grown with irrigation. Irrigated crop yields were poor, although they were about double those grown under dryland conditions.

During the 20 years that followed the area planted in cotton expanded rapidly, particularly in the newly developed irrigation districts of northern New South Wales, and yields improved greatly. Most of the soils brought into cultivation for cotton were uniformly-textured grey swelling clays (*Vertisols*), although hard-setting red duplex soils with non-swelling loams overlying clay-rich subsoils (*Alfisols*) are important in some districts (McKenzie *et al*., 1992). Land preparation techniques were based mainly on ideas from western USA, so until the mid-1980s most Australian cotton growers prepared their land for cotton by annual disc ploughing, followed by ridging and anhydrous ammonia application using listing equipment.

Soil Structural Problems that Retarded the Growth of High-yielding Cotton

The imported procedures used in cotton production often led to compaction and smearing in Vertisols that were too wet for cultivation (McGarry, 1987), which led to poor root growth and a decline in lint yield as a consequence of excessive waterlogging (Hodgson *et al*., 1986; McKenzie *et al*., 1990). New ridges sometimes were inadvertently built over old wheel tracks (McGarry, 1990). Also, large areas of land were deep ripped at great expense prior to discing without objective assessment of the degree of compaction, even though some fields did not require this disturbance. Sodicity is an associated structural problem in some areas, especially when subsoils are exposed by land forming (McKenzie *et al*., 1993). L. Sullivan (pers. comm.) is investigating the possibility of deep subsoil densification due to the translocation of dispersed clay.

With the Alfisols there is an inherent susceptibility to structural collapse, due mainly to low amounts of clay minerals that swell and shrink, inadequate organic matter and low electrolyte concentrations. Additionally, cultivation at water contents less than the plastic limit creates excessive dust whereas cultivation above the plastic limit causes remoulding (Mullins *et al*., 1990). The subsequent development of hardset surfaces as the soil dries sometimes severely restricts cotton seedling emergence and root growth, and the infiltration of water (Harrison *et al*., 1992).

Recent Improvements in Soil Management for Irrigated Cotton

Over the last five years, growers have been encouraged to objectively assess soil physical fertility in each field before selecting appropriate soil management techniques via the SOILpak manual-based decision support system for Vertisols (Daniells and Larsen, 1991). These techniques, which are described in the next section, were developed mainly by leading growers and their advisers, and have helped to stabilise lint yields at a high level. Large regional yield declines no longer occur after wet harvests.

Australian cotton growers now are unsubsidised and over 257,200 ha (1992-3) achieved an average lint yield of 1,417 kg ha^{-1}, which is greater than that of other major world producers (Dowling, 1993).

Soil Management Options for Vertisols

Most cotton in Australia is on Vertisols, and is grown on ridges 1 m apart and approximately 0.15 m high. Ridging is needed to direct the irrigation water, and to minimise near-surface waterlogging. Some of the furrows are also used as wheel tracks. However there is increasing interest in the use of 2 m wide beds rather than 1 m wide ridges. Approximately 20,000 ha i.e. 8%, of the Australian crop is estimated to be on 2 m wide beds (Anthony, 1992). Most of the remaining area is under refained ridges. Ridges and beds usually are installed as far as possible in advance of planting so that they have time to develop a friable seedbed.

However, before ridges or beds are built many growers inspect the physical condition of their soil to determine if any other operations are needed to overcome restrictions to cotton growth. They are guided by the semi-objective SOILpak scoring scheme of Daniells and Larsen (1991). Efforts to develop more objective structural assessment procedures are described by Greenhalgh *et al.* (these proceedings) and Larsen (1994), and are continuing at The University of Sydney (A.B. McBratney and A.J. Koppi, pers. comm.).

Even with retained ridge or bed systems, it is possible to have situations where poorly structured, root-restricting, layers of soil exist under the plant lines. This may arise from operations such as land levelling under wet conditions. There are two choices in dealing with such scenarios:

1. Live with poor structure. In the short term it is economically feasible to boost cotton yields in compacted soil by irrigating more frequently (Roth and Cull, 1991), and by adding extra nitrogen (N) to replace that lost by denitrification under the waterlogged conditions (Constable *et al.*, 1992). Increasing the ridge height (Tisdall and Hodgson 1990), if feasible, is also likely to alleviate the symptoms of waterlogging in compacted soil. Hearn (1986) and Constable *et al.* (1992) have shown, though, that no amount of extra N fertiliser will completely return cotton crops to full production on compacted Vertisols. Also the risks of causing atmospheric pollution due to nitrous oxide emission from waterlogged soil, and of lowering the efficiency of use of water, are increased when growers choose to live with compaction rather than correct it.
2. Repair the damage. The following longer term options are available to decompact and/or stabilise physically degraded Vertisols (Hodgson *et al.*, 1986; McKenzie *et al.*, 1990, 1992, 1993).

   (a) *'Biological deep ripping'* using well fertilised, but drought stressed, rotation crops such as wheat and safflower. The shrinkage cracks that form after water extraction by these crops provide lines of weakness for root growth through compacted layers, and all of the soil tends to become more friable after several wetting and drying cycles.

   (b) If the 'biological ripping' has not adequately disrupted the compacted layers, *mechanical deep tillage* using parabolic tines is recommended to shatter and loosen the soil whilst it is in a dry condition. The use of shallow leading tines can increase the amount of soil disturbance without increasing implement draft (Kirby and Palmer, 1992). Tillage under moist conditions is likely to aggrevate subsoil compaction (McGarry, 1987; Koppi *et al.*, 1994). Further research is required, on compacted soils with contrasting shrink/swell potential, to compare the economic consequences of a single drying cycle followed by deep tillage vs. repeated drying and wetting with a rotation crop.

   (c) If soils are sodic, i.e. prone to excessive swelling and dispersion in water due to an excess of exchangeable sodium and inadequate soil solution electrolyte level, the application of *gypsum and/or lime* is likely to increase stability, and reduce the risk of pore blockage by clay particles. Organic matter, particularly when added in combination with these ameliorants, may also improve soil stability in water.

Once severe impediments to root growth and water movement have been removed, the main aim of soil management for irrigated cotton is to minimise tillage and trafficking of the soil when its water content is greater than the plastic limit. However, because it is not always possible to avoid driving on wet soil, it is necessary to develop controlled traffic systems, preferably using newly developed guidance systems for tractors (Billingsley and Schoenfisch, these proceedings), that restrict wheel compaction to narrow strips, and protect soil under the plant lines within ridges and beds from further damage. We still have much to learn about optimal bed/furrow architecture for different types of Vertisol, and about appropriate axle loads, wheel/track pressures, and tyre/tool configurations under farm machinery. Some relevant aspects of soil mechanics theory that provide the foundation for such work are discussed by Kirby (1991).

It is hoped that engineers in machinery companies will respond to these challenges and provide lighter, more mobile equipment that can carry out all field operations associated with both rotation crops and cotton using the same wheel tracks. The financial benefits of reduced tillage systems for irrigated cotton on well structured Vertisols have been demonstrated by Hulme (1987). Problems with the use of 'permanent ridges/beds', i.e. disposal of crop residues, and the control of soil-borne insects, diseases and weeds, have occurred in some areas, but they do not appear to be insurmountable.

Land Preparation Options for Alfisols

The management strategies for Vertisols are also relevant to Alfisols, particularly where it is possible to initially increase the clay content of the surface by deep mouldboard ploughing (Harrison *et al.*, 1992), but the following modifications are recommended (*McKenzie et al.*, 1992; Hall *et al.*, 1994). A detailed version of SOILpak for Australian cotton soils with non-swelling surfaces (Alfisols and related soil types) is not yet available.

- Living with poor soil structure generally is not an option because of poor water penetration in compacted Alfisols (unlike compacted Vertisols, where water transmission still occurs, under dry conditions, via large widely spaced cracks)
- In contrast to Vertisols, which initially accept large amounts of applied water but then have very low infiltration rates once swelling closes the shrinkage cracks, well structured Alfisols tend to have low to moderate infiltration rates even when wet; therefore Alfisols are more prone to losses of water by deep drainage, which may cause saline watertables to rise
- Waterlogging is less of a problem on Alfisols than on heavily textured Vertisols, so high ridges are not as essential
- Lateral movement of water from the furrows into ridges is relatively slow, so the use of beds wider than 1 m wide is rare; furrow-side compaction can aggravate the problem
- If deep tillage is required to disrupt dense layers, it should be carried out at a water content just below the plastic limit to avoid smearing (if the soil is too wet) or excessive dust formation (if the soil is too dry)
- Organic matter is particularly useful for improving the stability in water and friability of hardsetting surfaces, so its rate of oxidation needs to be minimised and input maximised; gypsum application may also reduce the severity of hardsetting
- Every effort should be made to create continuous vertical macropores by encouraging soil fauna, e.g. earthworms and ants, and plant roots; they allow water and new roots to bypass zones with poor structure

Discussion and Future R & D Priorities

During the 1980s, the Australian cotton industry developed distinct land preparation systems for swelling and non-swelling soils (Vertisols and Alfisols, respectively) that rely upon the assessment of soil structural form and stability prior to technique selection. Together with improvements in other aspects of cotton management, e.g. better varieties and more effective pest management, improved soil management has allowed average lint yield to stabilise at a level which is high by world standards.

Common to both soil types is the need to overcome structural problems before entering a controlled traffic management phase, where strenuous efforts are made to prevent repetition of the damage. If Vertisols are badly degraded it is possible, in the short term, to produce irrigated cotton profitably by adding extra N and water, but this approach tends to be wasteful and may cause off-site pollution. Repair strategies rely mainly on the use of rotation crops to extract water and crack the soil, which often is followed by deep tillage under dry conditions to further disrupt layers of soil that restrict root growth and function. Raised ridges/beds are vital for the control of near-surface waterlogging in vertisols, although optimal architecture and the degree of consolidation have not yet been defined in terms of water intake, aeration, spring soil temperatures, sediment transport, pesticide movement/degradation and salinity hazard. With degraded Alfisols, where poor water penetration and excessive strength when dry are more of a problem than waterlogging, repair strategies rely upon deep tillage at a water content just below the plastic limit, organic matter accumulation and the formation of stable vertical biopores

At present the minimum sized management unit is the field, with a size rarely less than about 50 ha. If more than one soil type occurs within a field, it rarely is possible to provide optimal soil management in all parts of it. Because field boundaries usually cannot easily be moved, there is a need to develop techniques that allow soil-specific farming within a field (Robert, 1993).

Other topics that deserve more attention in the future are:

- development of more appropriate farm machinery for controlled traffic farming, based upon a sound knowledge of soil mechanics (particularly soil deformation behaviour with different water contents and pre-stress conditions), cotton root biology, and near-surface hydrology
- refinement of most of the procedures for improving and living with degraded soils; in particular we need to learn more about the processes, and practical problems, associated with aggregate instability in water, and about optimizing crop management so that desirable cracking patterns and/or stable biopores are provided rapidly.

New information about the assessment and modification of soil structure needs to continue to be given to land managers as soon as possible via updates of SOILpak (Daniells and Larsen, 1991), the manual-based decision support system for irrigated cotton soil management. This will allow producers of irrigated cotton to develop and maintain a sustainable and profitable system of soil management.

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