2005

Managing grey clays: to maximise production and sustainability

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Contents

OVERVIEW 2

ABOUT GREY CLAY SOILS 3
  What do they look like? 3
    Topsoil 3
    Subsoil 3
  Where are they found? 4
    Location and extent 4
    Landscape position 4
    Association with vegetation 4
What makes grey clays difficult to manage 6
  Surface sealing and poor infiltration 6
  Surface ponding and waterlogging 6
  Poor traction 7
  Slumping, compaction and hardsetting 7
  Poor establishment, growth and production 8
  Interaction with rainfall 8

IMPROVED MANAGEMENT OF GREY CLAYS 11
  Symptoms and causes of poor soil conditions 11
  Strategies to improve soil conditions 11
  Management practices to improve grey clays 12
    No-tillage crop establishment 12
    Residue retention 13
    Green and brown manuring 13
    Gypsum and lime application 15
    Compaction control or prevention 15
    Loosening topsoil and subsoil 15
  Management opportunities to improve soil conditions 16
  Improvements achievable in cropping systems 17
    Combining current best management practices 17
    Exploring future management options 18
  Improvements achievable in grazing systems 23

FARMING PRACTICES FOR IMPROVING GREY CLAYS 25
  Cropping systems 25
    No-tillage crop establishment 25
    Stubble retention 26
    Rotations 27
    Gypsum and lime applications 28
    Green and brown manuring 29
    Deepened seedbed 29
    Controlled traffic 30
  Grazing systems 37
    Whole-farm grazing 37
    Mixed grazing and cropping 38

MACHINERY REQUIREMENTS FOR IMPROVING GREY CLAYS 39
  No-tillage seeding 39
  Stubble management 40
  Gypsum and lime application 40
  Green manure incorporation 41
  Deep cultivation and renovation 41
  Controlled traffic 44
    Tractors 44
    Seeders 46
    Sprayers 46
    Fertiliser spreaders 46
    Swathers 46
    Harvesters 46

ECONOMICS OF IMPROVED PRACTICES FOR GREY CLAYS 49
  Basis for comparisons 49
  Comparisons of management options 49
    Cropping systems 49
    Grazing systems 50

REFERENCES 51
Managing Grey Clays

TO MAXIMISE PRODUCTION AND SUSTAINABILITY

REVISED EDITION

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Acknowledgements

Many persons and organisations have contributed to the work that has provided the information contained in this Manual. Grateful acknowledgement is made of their assistance, support and encouragement. Their number includes farmers, commercial seed and fertiliser suppliers, machinery manufacturers, researchers and their colleagues. Specific mention is made of Graham Winfield, David McIntosh, Geoff Powell of Wemyss Estates Pastoral Company; Dan Bignell, Broomehill; Trevor Badger, Pingrup; John Hicks, Pingrup; Lyle Edmonds, Cairlocup; J Laurie, Mindarabin; T Blight, Mindarabin; W Dawson, Katanning; Campbell Brumby, Valley Seeds, Victoria; Australian Perry Agricultural Laboratories, Adelaide; Chemistry Centre WA; Lindsay Gessner, Gessner Industries, Toowoomba; John Ryan, Ausplow Ltd, Jandakot; and numerous colleagues in the Department of Agriculture Western Australia.

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The Department of Agriculture Western Australia and the Grains Research and Development Corporation will not be liable for any loss, damage, cost or expense incurred or arising by reason of any person using or relying solely on the information in this publication.
This Manual is designed to be a stand-alone reference book on the identification, understanding and management of grey clay soils in the south-west of Western Australia. It draws together knowledge gained from research funded by the Department of Agriculture and Grains and Research Development Corporation into improved management practices for grey clays, the development of Tramline Farming (or controlled traffic farming) and raised bed farming to prevent waterlogging, with the knowledge and experience of successful grey clay farmers.

Grey clay soils are described in terms of their behaviour in response to seasonal conditions, farming systems and management practices. Their general location in the agricultural area, the parts of the landscape on which they are found, their association with vegetation and their continuity at a farm scale, are all discussed.

The options that farmers have to better manage these fragile soils are shown to vary according to their choice of cropping and/or grazing enterprises, the type and frequency of changes between cropping or grazing and the level of investment they are prepared to make.

The effects the soil management practices of:
- no-tillage,
- stubble retention,
- gypsum and lime applications,
- green and brown manuring and
- deepened seedbeds
have on soil conditions and productivity are explained and illustrated by research data obtained from paddock-scale experimentation.

The soil and production data are shown to correlate well. They demonstrate that systems and practices that produce improved soil conditions also increase cropping and grazing production.

The production benefits that accompany the improvements in soil condition created by a combination of currently used improved soil management practices are likely to range from 6% to 12%. These combinations of practices increase gross margin profit by up to 12%.

Specifically, once a sound rotation is adopted, productivity progressively increases with the adoption of a) no-tillage crop establishment; b) no-tillage crop establishment plus gypsum; or c) no-tillage crop establishment plus gypsum and green manuring.

The gross margin analyses of these options favour the combination of a sound crop rotation and no-tillage crop establishment because of its substantially lower input costs. This combination is shown to increase average annual gross margin profit by 12%.

The most intensive soil management package evaluated – a deepened seedbed in a controlled traffic regime with a sound crop rotation and no-tillage crop establishment – has the potential to dramatically increase average crop productivity by about 30%. In economic terms, this translates to increased average annual gross margin profits in excess of 40%.

The productivity and profitability boost provided by the technological package of deepened seedbeds and controlled traffic should prove to be a powerful incentive for its adoption by farmers. In fact, many farmers have expressed the view that without this sort of productivity boost they would not invest in controlled traffic practices.

Grazing management options clearly show the benefits of perennial pastures and combinations of winter and summer growing perennials in phase farming systems. Phase durations of four or five years are recommended because this phase length provides the farmer with the opportunity to capture the productivity benefits of improved soil conditions that are only possible in a cropping system.

The means of how best to implement the improved soil management practices are discussed and recommendations are given on how and when they are best applied.

The attributes of the machinery required to produce the best soil and agronomic results are discussed and illustrated. Also, advice is provided on how best to lay out controlled traffic paddocks and why surface drainage should be considered as a necessary component of such practice.

Farmers should realise that although the research findings that have produced this manual originated from the need to improve the particularly fragile and difficult-to-manage grey clay soil type, the chosen management practices, and their resultant productivity increases will be appropriate for, and largely reproducible on all shallow texture contrast soils across Australia.
What do they look like?

**Topsoil**

Grey clay soils are quite distinct. Their appearance and behaviour are different from most other Western Australian soils.

As their name suggests, these soils have topsoil that is generally grey in colour. This varies with moisture content. When moist, the colour of topsoil varies between dark grey to black and when dry, the colour is pale grey to grey.

These general colours also vary according to the amount of sand a soil contains. Varying amounts of sand lighten their colour to a grey-brown when moist and dusty grey-brown when dry.

The other typical characteristic of grey clay is their surface relief. When dry their surface is smooth and often has widely spaced, large cracks connected in a polygon shape. When wet their smoothness glistens and any surface water has a “milky” appearance.

The milkiness of surface water on grey clay is caused by clay particles suspended in the water.

**Subsoil**

The subsoils of grey clays occur at a very shallow depth, generally between 5 cm to 20 cm depth. Most have subsoils around 8 cm below the surface.

The subsoils of grey clays are massive (that is, they have few cracks), clayey, and yellow or yellow-grey coloured. The yellow and grey colours often appear together in a randomly a mottled pattern.

The massive clayey subsoils are also very dense, or compact. Cracks only appear in them after they are (a) exposed, (b) relieved of the weight (overburden pressure) of the soil that is normally above them and (c) dried (Figure 1).

The presence of yellow and grey colours in subsoils indicates they are poorly drained and have spent thousands of years in a moist condition. Soils formed in locations prone to prolonged periods of wetness have been subjected to soil-forming processes that produce clayey textures, dark coloured topsoils and yellow-grey coloured subsoils.
Where are they found?

**Location and extent**

The largest areas of grey clays occur in the eastern half of the Great Southern district of Western Australia. They are also found less commonly in the Upper Great Southern, Central and Eastern districts of the Western Australian agricultural area (Figure 2). Altogether, soil surveys show they cover an estimated 1.5 M ha or 8% to 10% of the Wheatbelt.

Grey clays occur as small areas scattered across the landscape or farms. They rarely occur in areas large enough to cover whole farms.

**Landscape position**

Grey clays are found in low slope sections of the landscape, often on valley floors. However, in broad flat areas of low slope country their landscape position can be relatively high in the landscape (Figure 3).

**Association with vegetation**

Grey clays have historically been referred to as ‘Moort soils’ because of their close association with Moort trees (*Eucalyptus platypus*). This type of tree is certainly indicative of grey clays because it is rarely found on any soil other than grey clay. However, grey clay soils do extend beyond the limits of Moort trees.

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**Figure 2.** Map of texture contrast soils in the Western Australian agricultural area with special highlighting of the grey texture contrast soils. The grey clays (shown here as ‘Grey shallow loam over clay’) that are the focus of this manual dominate the areas shaded dark grey on this map. They are found on plains and broad valley floors
Figure 3. Typical landscape on which grey clay soils are found

Figure 4. Typical grey clay soil–vegetation association. Note the small, mallee-like Moort trees (foreground) and Redwood trees (background)
Other tree types found with the less clayey surfaced grey clays include Salmon Gum (*Eucalyptus salmonophloia*), and various mallee forms, such as Gimlet (*Eucalyptus salubris*), Open-fruit Mallee (*Eucalyptus annulata*), Swamp Mallee (*Eucalyptus spathulata*) and Redwood (*Eucalyptus transcontinentalis*) (Figure 4).

What makes grey clays difficult to manage?

Grey clays are a group of soils that behave differently from the vast majority of other soils in Western Australia. These differences make them tricky to manage in ways that make their potential productivity difficult to achieve.

The behaviour that makes grey clays distinct and difficult is displayed in a number of ways.

**Surface sealing and poor infiltration**

When bare grey clays are rained on, their clods and aggregates on the surface break down and form a 'crust' or seal by a process called *dispersion*. It produces a surface that appears smooth and continuous. It has few, if any, large pores.

Such seals are composed of very fine grains of soil, and the rate at which water and air can move through them is very slow.

In consequence, little rain is absorbed by the soil. Furthermore, any rain that does infiltrate the soil is absorbed slowly and does not penetrate deeply.

A consequence of shallow rainfall penetration into the soil is that it quickly evaporates back into the atmosphere, and little is available for plants as the soil dries quickly.

This phenomenon of being wet one day and dry the next has generated the colloquial description of grey clays being ‘Sunday Soils’ that are workable for only one day. The day before, they are too wet. The day after, they are too dry.

**Surface ponding and waterlogging**

Once grey clay has formed a seal or crust a millimetre or two thick, the rate at which further rain can be absorbed is very slow and rainwater quite quickly begins to pond on the surface (Figure 5).

---

*Figure 5. This grey clay is sealed, dispersed and ponded and has reduced the establishment of a pea crop*
Alternatively, if rainfall is very light but persists for several days the surface soil (which is shallow and underlain by subsoil that is dense and impermeable) will saturate and waterlog. Waterlogged soil lacks enough oxygen for plant roots to grow.

**Poor traction**
The dispersion and shallow infiltration of rain water in grey clays makes their surface soil very slippery when wet, and farm vehicles lose traction and steering control. This is a common trait of grey clays and it makes cultivation, spraying and seeding operations difficult, if not impossible.

When seasonal conditions remain wet for a considerable time the full depth of the topsoil, and perhaps the subsoil, becomes saturated. The slippery conditions of wet grey clays means they have little or no friction between soil particles, and have little or no capacity to carry or support heavy loads, and farm vehicles often become bogged.

**Slumping, compaction and hardsetting**
The dispersive nature and consequent lack of load-bearing capacity of grey clays makes them highly prone to settling or slumping under their own weight when wet. This form of subsidence transforms a loose and friable seedbed into a dense mass.

The lack of load bearing capacity that grey clays have when wet also guarantees they will compact very easily under the weight of farm vehicles and animals.

Thus, if a cultivated seedbed of grey clay becomes wet and is compacted by farm traffic it becomes very dense with few large pores to facilitate water and air movement.

The typical sealed and slumped winter condition of grey clays transforms into a very hard mass in summer that is smooth and dense, with only a few large cracks (Figure 6).

*Figure 6. This grey clay has set hard in summer with no openings other than a few widely spaced polygon-shaped cracks*
In this condition, grey clays are impossible to cultivate or seed, and such operations must await a gentle, early break to the season with low rainfall and cool temperatures if seeding is to be undertaken without difficulty, risk or delay.

**Poor establishment, growth and production**

The grey clay characteristics include:
- poor infiltration,
- sealing or crusting,
- surface ponding,
- waterlogging,
- poor traction, and
- compaction and hardsetting.

These characteristics make the seeding and establishment of crops and pastures difficult, especially when a pre-seeding cultivation is used and an abrupt break to the season occurs.

Commonly, where cultivation is undertaken and the opening of the season is wet, establishment is poor, and/or early growth is retarded as a consequence of surface ponding or waterlogging.

Equally, when the opening of the season is dry, establishment is poor because a cloddy seedbed results in poor seed–soil contact and moisture uptake by the seed and seedling.

Throughout the growing season the lack of stability in soil structure and the density and impenetrability of the subsoil causes the root zone conditions for plants to very quickly switch between too wet (waterlogging) or too dry (droughting). The result is less growth and development than is achieved on other soil types.

However, given mild conditions and in particular moist conditions in spring, the clayeyness of grey clays can allow crops to mature well, over a longer period than is possible with lighter, sandier soil types.

This ability for crops on grey clay soils to sometimes ‘hang-on’ and ‘finish’ better than crops on lighter textured soils is the basis for the belief that, properly managed, grey clay soils have the potential to be much more productive. Farmer estimates of this potential for increased productivity are commonly put at 1.0 t/ha to 1.5 t/ha of extra grain.

**Interaction with rainfall**

The generally moderate and reliable amount and winter-dominant distribution of rainfall (Table 1 and Figure 7) interacts with grey clays to increase the challenge facing farmers trying to manage them in ways that maximise production.

While there is certainty about rain falling in the growing season, the fact that it exceeds evaporation in winter (Figure 7) means that soils must have the capacity to absorb and store this excess without becoming saturated and lacking oxygen.

<table>
<thead>
<tr>
<th>Location</th>
<th>Median rainfall (mm/yr)</th>
<th>Percentile range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentile 1 (10% records lower than)</td>
<td>Percentile 9 (10% records higher than)</td>
</tr>
<tr>
<td>Beverley</td>
<td>417</td>
<td>305</td>
</tr>
<tr>
<td>Quairading</td>
<td>366</td>
<td>262</td>
</tr>
<tr>
<td>Pingelly</td>
<td>444</td>
<td>339</td>
</tr>
<tr>
<td>Kulin</td>
<td>351</td>
<td>261</td>
</tr>
<tr>
<td>Wagin</td>
<td>428</td>
<td>309</td>
</tr>
<tr>
<td>Lake Grace</td>
<td>348</td>
<td>234</td>
</tr>
<tr>
<td>Katanning</td>
<td>480</td>
<td>370</td>
</tr>
<tr>
<td>Pingrup</td>
<td>353</td>
<td>256</td>
</tr>
<tr>
<td>Tambellup</td>
<td>447</td>
<td>344</td>
</tr>
<tr>
<td>Ongerup</td>
<td>390</td>
<td>278</td>
</tr>
<tr>
<td>Jerramungup</td>
<td>421</td>
<td>277</td>
</tr>
</tbody>
</table>

Grey clays have difficulty in both absorbing and storing this excess rainfall. As the season cools and evaporation falls rapidly, the soil profile wets up at a rate faster than indicated by the atmospheric evaporation data shown in Figure 7. This is because soil, particularly when it is only just moist, evaporates moisture much more slowly than the atmospheric rate. Consequently, when rainfall exceeds atmospheric evaporation in winter, soils with limited capacities to absorb rain, like grey clay, will become waterlogged.

The interaction between grey clays and rain often causes crop establishment problems. If rain falls quickly the surfaces of grey clays will seal and excess rain will pond on the surface causing the seedbed to waterlog. If the rain comes slowly but in substantial quantities, the capacity of the topsoil and subsoil to store it is easily surpassed and profile waterlogging results. In these circumstances, crop establishment will be reduced.

Conversely, if there is a dry start to the growing season, the hard cloddiness of seed beds will not facilitate good seed–soil contact and crop germination and establishment will be restricted.

The interaction between the grey clays and rainfall in spring can also have an adverse effect on crop and pasture growth. Such late-season impacts on crop growth and production are a consequence of the density of the subsoil of grey clays. Very dense clays have a low porosity or water-holding capacity and stored water is difficult for plants to extract.
In a wet spring, when plants are actively growing, the topsoil can be unsaturated while the subsoil is waterlogged. These circumstances cause the plant to produce much fewer, if any, roots in the saturated and anaerobic subsoil and more than normal amounts of roots in the shallow topsoil. Plants growing in these circumstances suffer sub-clinical waterlogging – their roots below approximately 15 cm have been ‘pruned’ by waterlogging. In this condition the plants are very susceptible to droughting and ‘poor finishes’ as the rainfall diminishes and temperatures rise in late spring and early summer.

In a dry season, when crop demand for water to support active growth is high, grey clays have insufficient plant-available water in their compact subsoils to allow crops ‘finish’ well.

Such poor finishes on grey clays in dry seasons may seem better than they are in reality, however, because the comparison is mostly made with crops on sandy soils which have much less plant-available water and are much more prone to poor finishes.

**Figure 7.** Typical seasonal distribution of rainfall and potential evaporation. Note the excess rain over potential evaporation in the winter months. Soils need the capacity to store in excess of 100 mm of the rain that falls between May and July.
MANAGING GREY CLAYS
Symptoms and causes of poor soil conditions

Managing grey clays to maximise their productivity requires an understanding of the relationships between the symptoms and causes of poor soil conditions (Table 2).

The contents of Table 2 very clearly illustrate the critical need to stabilise the soil structure and lessen the density of the topsoil and subsoil of grey clays if their physical condition is to be improved. (Nutritionally, because of their clay content, grey clays have adequate chemical fertility.)

Strategies to improve soil conditions

There are only three courses of action that will effectively stabilise soil structure and improve the air and water movement properties of grey clays:

1. change the soil chemistry;
2. increase soil organic matter; and
3. mechanically loosen the soil.

The first two of these courses of action aim to stabilise dispersive, unstable soil structure and can therefore be used together or separately.

Changing a soil’s chemistry refers to adding extra amounts of calcium (mostly in the form of gypsum) to the soil. Calcium is held to the clay particles of soil much more strongly than sodium, and so it displaces sodium. Sodium is then moved in soil water to deeper depths in the soil profile.

Naturally dispersive, or sodic, soils have a considerable amount of sodium on their clay particles (as distinct from saline soils which have sodium in the pore space of soil). A widely acknowledged Australian standard for the amount of sodium that causes dispersion is 6% of all the other exchangeable chemical elements on the clay particles (hence the term, exchangeable sodium percentage or ESP). With levels of ESP equal to or in excess of 6% a soil’s structure will disperse once it is saturated. Dispersion does not take place when the soil is only partially wet.

Soil organic matter acts as a binding agent that sticks soil particles together. It also provides extra nutrient absorption capacity to soils and thus reduces the relative amount of exchangeable sodium in soil. This means organic matter has a secondary, indirect effect of reducing a soil’s ESP.

Once the structure of a grey clay has been stabilised by increased organic matter and/or added gypsum, its density needs to be lessened to create more space for air and water movement. Loosening very dense topsoil and subsoil will:

❖ increase the water holding capacity of soil;
❖ increase the amount of water that can be extracted from the soil by plants; and;
❖ increase the ability of plant roots to grow to greater depths in search of water and nutrients.

Other benefits accrue from a deepened, loose and stable-structured root zone. Water penetrates deeper, more quickly, and short-term evaporative losses are reduced. Roots, water and nutrients will all penetrate more deeply, and the soil becomes more drought-proof and effectively more fertile, because plants are able to extract more water and nutrients for longer, from a greater depth during a growing season.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Primary cause</th>
<th>Secondary cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor infiltration and surface sealing</td>
<td>Unstable or dispersible structure of topsoil</td>
<td>Bare, unprotected surface</td>
</tr>
<tr>
<td>Surface ponding</td>
<td>Unstable or dispersible structure of topsoil</td>
<td>Bare, sealed surface</td>
</tr>
<tr>
<td>Waterlogging</td>
<td>Unstable or dispersible structure of topsoil and low water holding capacity of topsoil</td>
<td>Poor drainage of subsoil</td>
</tr>
<tr>
<td>Slumping, compaction and hardsetting</td>
<td>Unstable or dispersible structure of topsoil</td>
<td>Penetration of rain is shallow. Wetting and drying of shallow topsoil is rapid</td>
</tr>
<tr>
<td>Poor traction</td>
<td>Unstable or dispersible structure of topsoil</td>
<td>Penetration of rain is shallow</td>
</tr>
<tr>
<td>Poor crop establishment</td>
<td>Unstable or dispersible structure of topsoil</td>
<td>Sealed or crusted surface, or poor seed–soil contact when dry and cloddy</td>
</tr>
<tr>
<td>Shallow roots, poor growth and yield</td>
<td>Unstable or dispersible soil structure of topsoil and high density of subsoil</td>
<td>Low water holding capacity, low plant available water content of topsoil and subsoil</td>
</tr>
</tbody>
</table>
Also, in a wet year the risk of waterlogging becomes very much less because the greater pore space in loosened soil increases the water holding capacity and delays the onset of saturated conditions.

Management practices to improve grey clays

There are a limited number of management practices that farmers can use to improve grey clays. They include:

❖ no-tillage crop establishment
❖ residue retention
❖ green and brown manuring
❖ gypsum and lime application
❖ compaction control or prevention; and
❖ loosening topsoil and subsoil.

The opportunities to apply these and maximise their benefits vary according to the preferred farming system that is used.

Some of the management practices that improve grey clays are complementary and some are alternatives.

They should be applied with the aim of creating and maintaining improved soil conditions. The ways in which they work are discussed below.

**No-tillage crop establishment**

No-tillage crop establishment practice acts in three ways to increase soil organic matter.

First, it maximises the retention of roots from previous crops by reducing soil disturbance to just the sown row, and a quite small width of sown row at that.

Second, it maximises the time for organic matter to bind soil particles into water stable aggregates.

Third, it minimises the exposure of roots and soil organisms to the sun and elements.

*Figure 8. Enhanced and deeper rainfall infiltration that occurs beneath retained stubble. The catchment effect of the stubble is complemented by better structured soil around the roots of the previous crop. The greater depth of wetting in the root zone of the previous crop conserves infiltrated rain compared to the areas between the rows of stubble where the shallower depth of infiltration evaporates more quickly.*
Residue retention

When grey clays are wet rapidly they disperse and seal, particularly if they are also subject to some force such as that exerted by impacting raindrops, moving machinery and grazing animals.

The retention of ungrazed and unincorporated stubble or pasture cover provides protection for the surface soil against raindrop impact and, to a lesser extent, against compaction from stock and machinery.

Stubble or pasture cover also harvests rain, directing it down stems to soil that has been improved by roots and the soil organisms associated with them. In consequence, water entering the soil near the base of plants infiltrates quicker, in greater quantity and penetrates deeper than water that enters the soil between plant rows (Figures 8 and 9).

Green and brown manuring

The practice of green and brown manuring aims to raise the organic matter content and improve the fertility of soils. Normally, a green or brown manure ‘crop’ will be a specific mixture of a cereal plus a legume crop or pasture plant.

The intention is to incorporate into the soil 100% of the plant mass, made up of 30% roots, 40% stem and leaves and 30% immature grain.

The off-setting factor in green and brown manuring is the requirement for a particularly vigorous inversion ploughing to incorporate the large mass of plant material (Figure 10). Such vigorous ploughing exposes large amounts of existing organic matter (roots and soil organisms) (Figure 11). The result is often a much lesser increase in soil organic matter than expected.

As well, the incorporation of such large amounts of organic material provides a flush of food for soil organisms, and populations of these organisms explode. This creates a short-term deficiency of soil nitrogen, and so the crops following a green or brown manure crop will benefit from extra applications of nitrogenous fertiliser.

Figure 9. No-tillage triple disc seeder seeding into retained stubble on a grey clay at Mndarabin. This seeder conserves existing soil organic matter by cutting existing roots with minimal soil disturbance. It also allows stubble to be retained to conserve moisture and protect the surface against raindrop impact.
Figure 10. Disc plough showing the almost complete soil inversion and exposure of existing roots and organic matter to the sun and elements.

Figure 11. Green manure crop of oats and vetch in the process of being ploughed-in. Note the soil inversion, exposure of soil and roots, and the incomplete incorporation of the green manure crop.
Gypsum and lime application

The application of gypsum and/or lime to grey clays is done to change the soil chemistry by reducing the amount of exchangeable sodium on the clay. Gypsum and lime, being calcium salts, cause the sodium in soil to be replaced by calcium, which reduces the ESP and increases the ratio of calcium-to-magnesium on the clay.

Calcium is held much more strongly by clay than sodium. This causes clay particles to bind together, making them stable to wetting, which reduces or eliminates their dispersive behaviour (Figure 12).

The challenge associated with applying ameliorants like gypsum and lime is to maximise their effect. First, the calcium salts only change the chemistry. They do not create a loose, porous soil, so these physical conditions have to be created by some form of cultivation.

Second, the sodium displaced by calcium moves into the soil pore space and is transported by water moving in the soil. If the drainage is poor, as it is with grey clays, the sodium will not move very far, and since more calcium than sodium is used by plants, the sodium can return to the topsoil after some time.

It is for these reasons that benefits of gypsum applications are often reported to be short-lived.

Hence, the maximum benefit from gypsum or lime applications will be gained when they are combined with practices that lightly loosen the soil and increase organic matter.

Compaction control or prevention

Structurally weak or dispersive soils are very prone to compaction from machinery and grazing animals when they are moist or wet. Compaction increases the density and reduces the pore space in soils. In consequence, a compact soil has a reduced infiltration capacity, a smaller amount of water that plants can extract, and conditions that roots find difficult to penetrate. The soil thus becomes more prone to waterlogging and drought, and its productivity falls.

Management practices like controlled traffic farming (or Tramline Farming) or grazing exclusion that prevent or minimise soil compaction, allow other farming practices and the natural activity of roots and soil organisms to maintain or even improve soil density, aeration and infiltration.

Loosening topsoil and subsoil

Grey clays with their dispersive and compact topsoil and subsoil are highly likely to benefit from some form of loosening.

Provided that any such loosening is practically and economically achievable (Figure 13), and that such a practice is complemented by other management practices designed to minimise any subsequent re-compaction, a number of soil conditions will improve, and these will assuredly increase productivity.

Loosening dense soil will:

- increase infiltration capacity,
- enlarge plant water availability,
- allow improved root growth and proliferation and
- reduce short-term evaporation,

all of which will make these soils less risky and more profitable to farm.

Furthermore, loose grey clay, provided its surface is protected against raindrop impact, will be less inclined to disperse because water entry and movement will occur at moisture contents well short of saturation, which is the precondition for dispersion.

Figure 12. Gypsum response test of a grey clay illustrating the effect gypsum has on a dispersive soil. Shown are jars of soil and decreasing concentrations of gypsum solution, from concentrated gypsum solution on the left, to water (no gypsum) on the right. Note how the clay flocculates and sinks to the bottom of the jar at a certain concentration of gypsum. This indicates the amount of gypsum that needs to be applied in the field.
Management opportunities to improve soil conditions

The opportunity to implement the range of management options outlined above will vary according to the farming system a landholder chooses to use. An assessment is presented in Table 3 of the relative opportunities for soil improvement in the common extensive farming systems found in the agricultural area in Western Australia.

The opportunities for improving the condition of grey clays are obviously greater in cropping systems, because cropping systems provide:

- the greatest number of operational opportunities to implement the beneficial management practices of no-tillage crop establishment, green manuring and incorporation of gypsum and lime.

Farming systems on grey clays that include grazing, while maximising the likelihood of gradual soil organic matter build-up (via root retention and the absence of cultivation), provide little scope for protecting the surface soil or preventing its compaction. Creating and maintaining a loosened soil is simply not possible in a grazing system.

Figure 13. Paraplow® being used to loosen the grey clay at Mindarabbin with zero soil inversion
Since 1996 the Grains Research and Development Corporation and the Department of Agriculture Western Australia have undertaken intensive research work to ascertain the best means of managing grey clay soils. The work was done on a near-paddock scale using farm-sized machinery in order to 1) assess the benefits of improved management options under realistic conditions, and 2) ensure the results would be transferable to actual farm-scale situations.

The information which follows was generated from five years’ experimentation with average rainfall and distribution and three years with considerably variable amounts and distributions of rainfall.

Combining current best management practices

The management practices known to improve soil conditions:
- no-tillage crop establishment practice,
- gypsum application and
- green and brown manuring

were combined in various rotations and compared against the conventional crop:graze farming system.

The combinations of cropping rotations included:
- a biologically unsustainable continuous wheat;
- a mix of broad-leaf and cereal crops with and without a green manure crop;
- a rotation of one year of cereal and one year of self-regenerating medic pasture; and
- two permanent grazing systems of winter (perennial rye and sub-clover) and summer (lucerne) growing pasture.

Crop establishment practices included both no-tillage (narrow points and presswheels) and direct drill (wide points and harrows).

Gypsum was applied over half of the treatment combinations at a rate of 2.5 t/ha. This application rate was known to be required to stabilise the surface 8 cm to 10 cm depth of grey clay soil.

The results of this research showed improvements in soil conditions and productivity that are large enough and conclusive enough to guide farmers striving to more profitably farm grey clay soils.

Soil conditions

Two very influential soil properties that illustrate the relative physical condition of soils were monitored in the various combinations of soil management practices and rotations. These were:
1. **surface soil bulk density** (which is an index of the air and water movement, water storage properties and root growth potential); and
2. **hydraulic conductivity** (a direct measure of water movement properties).

The data collected on bulk density (Figure 14) showed the density of surface soil:
- decreased as the compaction caused by grazing was generally reduced from a grazing system, to a crop:graze system, to a no-tillage cropping system and ultimately to a no-tillage cropping system that included a green manure crop; and
- was not substantially affected by the application of gypsum.

![Surface Soil Bulk Density](image-url)
However, the hydraulic conductivity data (Figure 15) showed that soil water movement:

- is markedly increased by the application of gypsum, provided the farming system does not include grazing;
- is effectively unchanged by the addition of gypsum in a crop:graze system; and
- is slowest in a permanent grazing system, presumably because of grazing-induced compaction.

Productivity

Data on the growth and productivity of crops grown with various combinations of soil management practices and rotations showed that production increased as the number of improved practices increased. Average crop establishment, weed burden and yield all improved as the amount of tillage and grazing were reduced and gypsum and green manure were added to the package of practices.

Specifically, the data showed the following:

- Crop establishment on grey clays improved with the use of presswheels (compared to harrows) through better seed–soil contact when the soil was dry and cloddy, and through more accurate seeding depth control when the soil was moist (Figure 16):
- In-crop weed populations were reduced when no-tillage crop establishment was practised, because of the lack of soil disturbance between the sown rows of crop (Figure 16).
- Average grain yields were increased by between 0.20 t/ha and 0.35 t/ha (Figure 17).

Yield increases of this magnitude would pay for most of the costs associated with the adoption of various combinations of improved practices.

Management Effects on Plant Populations in Cereals

![Management Effects on Plant Populations in Cereals](image)

Figure 16. Average cereal establishment (Cropping NT, PW was 15% more than Crop:graze DD, H) and weed burden (Cropping NT, PW was 80% less than Crop:graze DD, H) in experiments at Wemyss Estates, Mindarabin

Cropping profit would be further increased if herbicide costs could actually be reduced through the lower weed burden in no-tillage cropping systems requiring less herbicide to control weeds.

Exploring future management options

Very dense and compact soils like grey clays provide an environment that:

- is difficult for plant roots to penetrate;
- has a limited capacity to absorb water;
- has poor drainage properties; and
- holds its water in very small pores that make water uptake by plants difficult.

Therefore, loosening the dense subsoil of grey clays ought to:

- lower the density and penetration resistance properties of the root zone of crops to levels that do not restrict root growth;
- greatly improve water and air movement;
- substantially increase the infiltration capacity and reduce the risk of waterlogging; and
- conserve soil water by reducing evaporation from the soil

and thus:

- increase the amount of water used by plants.

In addition, because a loose soil would rarely, if ever, be saturated (and waterlogged) any tendency for it to disperse, seal and set hard would be minimised, provided the surface is protected from the impact of raindrops.

The good reasons for examining this type of soil management on grey clays, plus the high probability of success, prompted the research that is reported below.

Figure 15. Hydraulic conductivity of surface soil in farming systems with and without applications of gypsum
The shallow topsoil and dense and dispersible subsoil of grey clay required that it be loosened and maintained in a loose condition:

❖ by using implements that cause little or no soil inversion, like the action of a Paraplow®; and

❖ by applying a precise form of controlled traffic, to avoid re-compaction.

The optimum depth for loosening the topsoil and upper layers of the subsoil was not known, so an easily achievable and economic depth of 20 cm below a settled topsoil surface was chosen. This produced a loosened soil depth of approximately 25 cm to 27 cm, which was then protected by applying controlled traffic farming operations.

This form of soil management, which is not excessively deep, is referred to as a deepened seedbed.

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**Soil conditions**

The soil-loosening treatment produced large and dramatic changes in the top 25 cm depth of the grey clays. The large reduction in the bulk density of the surface soil of the deepened seedbed, relative to the bulk density of other soil management practices, is shown in Figure 14.

Data on Penetration resistance (PR), which is an indicator of the ability of plant roots to grow through soil, showed that the deepened seedbed compared to the no-tillage seedbed had similarly large reductions to a depth of 25 to 30 cm (Figure 18).

The generally recognised critical value of penetration resistance is 2,000 kPa. Root growth of agricultural plants is restricted at penetration resistance readings in excess of this value.

The data presented in Figure 18 therefore indicate that crops grown on deepened seedbeds should have larger and deeper root systems, grow better for longer, and suffer less from the drought (2002), or from waterlogging (2003).
The 2003 average winter water content data in the two seedbeds (Figure 19) confirmed this. There was clearly less water in the deepened seedbed, which indicated greater water use by the crop on the deepened seedbed treatment, and a root zone with more air-filled pores. More importantly, however, when the water content data are converted to assess the degree of saturation (that is, the percent of pore space filled by water), the no-tillage seedbed was shown to be saturated below about 15 cm depth for the whole of the winter period.

Saturated conditions at a depth of about 15 cm means that plants can grow in the cooler season from roots confined to the surface layer without visible signs of waterlogging. Over this time, however, the plants will in fact be suffering from sub-clinical waterlogging, that is, waterlogging without symptoms.

In such soil conditions plants in a no-tillage seedbed face two challenges in spring when plant growth becomes rapid. First, their roots will need to grow deeper in search of water in conditions that restrict root growth; and second, the plants will have difficulty in extracting water from very compact soil. Thus, both root growth and the availability of water will be restricted.

**Productivity**

The challenge of the deepened seedbed form of soil management is for crops on such seedbeds to actually

- produce more growth;
- have deeper and larger root systems; and
- ‘finish’ better and produce larger yields.

Furthermore, crops on deepened seedbeds need to be able to reproduce these benefits in dry and wet years, with less seasonal variation in yield than would occur in a no-tillage seedbed (Figures 20 and 21).

Plant growth data on the deepened seedbeds on grey clays have shown that root growth was, in fact

- about 14% greater and
- the bulk of roots was 10 cm to 15 cm deeper than occurs in a no-tillage seedbed.

More importantly, the grain yield data for deepened seedbeds (Figure 17) illustrate that this treatment does in fact produce substantial yield improvements across variable seasons.

The seasonal conditions over this period were:

- **2001**: Very little rainfall fell in the first half of the season and above average rain fell in the second half (10% less rain than long term median for the growing season)
- **2002**: The season was very dry in the first half and sparingly dry in the second half (20% less rain than the long term median for the growing season)
- **2003**: Above average rain fell throughout the season (64% more rain than the long term growing season median).

The yield increases from these seasons were:

- **2001** Barley 0.41 t/ha (29% increase)
- **2002** Canola 0.53 t/ha (62% increase)
- **2003** Wheat 0.40 t/ha (13% increase).

Farmers wanting to maximise grain production and improved reliability of grain production on grey clay soils should adopt deepened seedbeds.

However, the farming practices for creating and maintaining the improved physical conditions and productivity on a deepened seedbed must include a combination of precise controlled traffic and the best agronomic practices. The practical aspects of improved management practices for grey clays are discussed in the next chapters.
Figure 20. Contrast of the mid-season growth of wheat on normal (left) and deepened (right) seedbeds in September 2003.

Figure 21. Contrast of the mid-season growth of wheat on normal (left) and deepened (right) seedbeds in October 2003.
Should One Invest in Raising Calcium:Magnesium Ratios?

Over the last few years there has been considerable publicity focused on the apparent value of raising the Calcium: Magnesium (Ca:Mg) ratio of soils to values greater than 5.0. The promotion of this form of soil management has been largely based on the assertion that soils with Ca:Mg ratios greater than 5.0 are well-structured with better water and air movement and root proliferation properties than soils with ratios less than 5.0. This promotion has also been accompanied by recommendations to apply liberal dressings of gypsum and/or lime (even to non-acid soils) and to increase the application rates of traditional fertilisers and add trace elements.

Substantial research effort was invested in large field experiments on grey clay soils at Pingrup, Gnowangerup and Mindarabin to assess the validity of these claims on Western Australian soils. The soils at these sites all had low Ca:Mg ratios and high ESP values, and should have been responsive to such management. Over three years the soil chemical and grain yield responses were monitored. Soil analyses were done by the proponents and the Chemistry Centre WA (Figure 22).

In addition to normal fertiliser dressings, lime was applied for two of the three seasons at all sites, at rates of 1.5 t/ha to 2.5 t/ha each year, as were the trace elements copper and zinc. At one site boron and manganese were also applied, and at another, 0.5 t/ha gypsum was applied.

After the addition of up to 5.0 t/ha of lime, the Ca:Mg ratios increased at all sites, but remained at less than 5.0, the minimum value acceptable to the proponents of this form of soil management. Even the most pH responsive site, Gnowangerup, remained well short of this Ca:Mg value.

On the other hand, the exchangeable sodium percentage, which is an indicator of the stability of soil structure, fell to values less than 4.0, substantially less than the value of 6.0 that is used to identify dispersive behaviour in soils. Values of pH at all sites were raised, but by less than 0.5 pH unit at Mindarabin and Pingrup and 1.0 pH unit at Gnowangerup.

Yield responses to the dressings of lime and additional plant nutrients at all three sites were consistently small to negligible over the three seasons (Figure 23).

At all three sites the extra costs associated with buying and spreading the lime and additional fertilisers did not generate any extra income and so the gross margins for the investments were reduced accordingly. The total gross margins reductions over the three seasons were Mindarabin $207/ha, Gnowangerup $284/ha and Pingrup $146/ha.

Recommendation

Without clear evidence of financial return, farmers should not invest in practices promoted on the basis of raising the Ca:Mg ratio of soils.
Improvements achievable in grazing systems

Soil conditions

The naturally dispersive nature of grey clays makes them highly susceptible to compaction from grazing animals, particularly when moist or wet. This applies equally to summer and winter growing pastures, as indicated by the surface soil bulk density data presented in Figure 14.

While the worst extent of compaction can be avoided by a management practice of removing stock to less dispersive and better drained soils in the cooler, wetter months of winter, compaction of these soils cannot be avoided in grazing systems. Small amounts of rain and moist soil conditions will always occur during a grazing phase.

The fact that the topsoil is cultivated for cropping every second year in a 1-year:1-year crop:graze system does not reduce its susceptibility for, or the extent of, re-compaction during its grazing year. Figure 24 shows that the topsoil density in this farming system returns to levels typical of permanent pastures within a year.

The longer term trends in topsoil bulk density shown in Figure 24 illustrate the clear differences in surface soil condition between farming systems, and the beneficial effect on surface soil density that occurs when grazing is removed from farming systems.

High surface soil density will make the germination and regeneration of pasture problematic and will eventually result in a reduced sward density of desirable pasture species.

With no other opportunity for moderating the physical properties of soil in grazing systems, the subsoil will have the same properties as that in conventional cropping systems, but the topsoil will be denser. This will mean even less water will infiltrate (see Figure 15), and the susceptibility of pastures to surface ponding and droughting will be greater than that which crops experience.

Productivity

Permanent pastures comprised of mixes of perennial ryegrass and sub-clover, or lucerne, can be used to increase the grazing productivity of grey clays. Their use as a permanent stand or as a phase of three to five years’ duration is a matter of choice by farmers.

Both these pasture types provide a substantial increase in grazing capacity on grey clays compared to the conventional self-regenerating medic or sub-clover-based pastures in the 1:1 crop:graze rotation. Pastures in crop:graze systems have to re-establish a sward every alternate year before they can be grazed.

Production measurements on two perennial pastures – ryegrass and sub-clover, and lucerne – on grey clays at Mindarabin (Figure 25) showed the ryegrass-dominant pasture produced twice the dry matter and carried four times the stock of a lucerne pasture.

These pastures are not alternatives, however. Their different growing seasons should be used to complement one another, with the lucerne providing quality feed in the late summer–autumn feed gap left by winter-growing pastures.

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**Figure 24.** Trends in surface soil bulk density in a range of farming systems. Grazing systems have higher bulk densities than cropping systems, even the 1:1 crop:graze (GM = green manure crop).

**Figure 25.** Average annual dry matter production and carrying capacity for perennial summer (lucerne) and winter (ryegrass and sub-clover) pastures on grey clay soil at Mindarabin.
Lucerne pasture, being a summer-growing perennial legume, has the potential to:

a) draw more water from the root zone soil than annual crops and pastures and so provide a buffer against the onset of winter waterlogging and perhaps groundwater recharge; and

b) increase soil nitrogen and boost the yields of following crops.

Experimental measurements have confirmed that lucerne draws more water from soil profiles over twelve months than perennial ryegrass pasture and crops (Figure 26). Most of this extra water use occurs in late spring and early summer.

The comparatively greater amount of water stored at the end of summer in cropping and ryegrass pasture systems means that the drier soil profile beneath a lucerne pasture will experience winter waterlogging, if any, a month or two later than crops and ryegrass pastures.

However, because the profile water storage beneath lucerne at the end of the growing season is less than that under winter-growing crops and pastures, lucerne pastures require sizable summer rains if they are to provide reasonable quantities of stock feed over the summer.

Importantly, the information in Figure 26 also shows that the drier soil profile under lucerne (which creates a buffer against winter waterlogging) is entirely re-filled after only one year once it is returned to a cropping phase.

Studies of the ability of lucerne pastures to supplement soil nitrogen levels and boost the yield of succeeding cereal crops for a year or two indicate that expectations of achieving a yield boost must be realistic. These studies show that getting a yield increase is very dependent on growing season rainfall in the first two seasons following the lucerne pasture.

There seem to be two distinct responses:

- If rainfall in the first one or two years of a cropping phase after lucerne is above average, grain yield increases of about 20% can occur.
- If, however, the following season has below average rainfall, grain yields can be about 20% less than the yields from crops in a cropping rotation.
Cropping systems

The annual cycle of operations required for cropping grey clays provides the opportunity to apply the full range of management practices that create and maintain improved soil conditions and greater productivity. The contents of this chapter capture the knowledge and experience gained by researchers and farmers who have been applying these practices for some time. Recommendations are made as to which practices should be used and how they should be applied.

No-tillage crop establishment

Since the research on grey clays began in 1996, the use of no-tillage crop establishment has been shown to be essential for improving these types of soils.

The use of no-tillage crop establishment practices allows both operational and soil management objectives to be met. The operational objectives are:

- improved timeliness of seeding: Herbicide spraying and a single pass seeding operation require less time which greatly improves the chances of seeding in near-ideal soil moisture conditions at the near-ideal seeding time.

- improved weed control: Herbicide control of weeds is more efficient when combined with minimal disturbance of soil in the seedbed.

The soil management objectives of using no-tillage crop establishment practices are:

- to maximise the retention of roots and above-ground plant material to build up soil organic matter in order to stabilise the weak or dispersible soil structure (Figure 27);

- to retain the large pores created by roots and soil organisms in order to enhance rapid infiltration and aeration of the root zone (Figure 28);

- to retain the roots as ‘reinforcing rods’ in order to minimise subsidence of the deepened seedbeds; and

- to minimise weed establishment, particularly in the inter-row spaces.

Figure 27. No-tillage seeder operating in a heavy stubble cover on the grey clay at Mindarabbin
Although minimising soil disturbance at seeding is desirable to achieve these soil management objectives, there are good reasons to ensure some soil disturbance. Soil disturbance is required:

❖ to control diseases like Rhizoctonia bare patch, some of the Septoria diseases, Black spot in peas, Ascochyta in faba beans and Blackleg in canola (Farmnote 68/96);
❖ to reduce weed populations by minimising inter-row soil disturbance;
❖ to incorporate root-active herbicides like trifuralin (Farmnotes 66/96 and 67/96); and
❖ to mix fertiliser with soil close to the seed and minimise the risk of ‘fertiliser toxicity’ damage to germinating seeds (Farmnote 72/96).

Recommendation

No-tillage crop establishment practices should be used on grey clays because of their ability to build up soil organic matter (mainly through the retention of roots) and because the efficiency of their operations maximises the chances of seeding in the short time when soil moisture conditions are ideal.

Stubble retention

The objectives for retaining stubble on grey clay soils are clear cut. These are:

❖ to protect the soil surface from raindrop impact to minimise dispersion, sealing and crusting of the surface soil;
❖ to maintain and increase of soil organic matter levels;
❖ to facilitate deeper penetration of rain and conservation of soil moisture; and
❖ to control of wind and water erosion.

Retention of stubble does not come without management challenges, however, such as:

❖ retaining a bank of weed seeds and adding to weed control challenges in succeeding crops;
❖ achieving clear passage of seeders without blockages;
❖ achieving good seed–soil contact in sown crops so that establishment is not reduced;
❖ shading weeds from herbicide sprays and reducing spray effectiveness; and
❖ harbouring some diseases and pests.

Figure 28. Enhanced and deeper rainfall infiltration that occurs beneath retained stubble. The catchment effect of the stubble is complemented by better structured soil around the roots of the previous crop. Stubble cover plus the greater depth of wetting conserves infiltrated rain compared to the areas with shallow infiltration depth between the rows of stubble.
In controlled traffic regimes there is an additional management challenge – preventing or minimising the build-up of stubble in traffic lanes. Stubble on the tracks can obstruct water flow, and ponding of tracks can cause waterlogging in the adjacent seedbeds.

Effective management of stubbles is largely achieved by employing the practices outlined in Farmnote 66/96. Specifically, these are:

❖ harvesting the crop high and subsequently harvesting stubble for straw, leaving erect stubble about 5 cm to 10 cm high;
❖ harvesting the crop low, leaving erect stubble about 15 cm high and using a highly efficient straw storm on the harvester to spread small pieces of straw and chaff evenly;
❖ trailing a chaff bin behind the harvester to avoid leaving a trail of chaff and straw;
❖ leaving a harvester trail of chaff and straw that is subsequently baled or burnt late in autumn;
❖ grazing stubbles after harvesting them low; and
❖ using a seeder with large spaces between seeding units.

Another practice that helps overcome the challenge of clearing stubble during seeding is to use wide row spacings and to seed in the inter-row space of the preceding crop. Most seeders sold these days have seeder units spaced at 26 cm (or 10 inches), which is wide enough to allow seeding in the inter-row space of previous crops.

If one or a combination of these management options fails to allow trouble-free seeding, a late autumn ‘cold’ burn can be done.

**Recommendation**

Stubble retention should be practised on grey clay soils because of the need to build up organic matter, protect the surface soil from raindrop impact and enhance the deep penetration and conservation of soil water.

**Rotations**

The choice of a particular rotation of crops, or crops and pastures, is usually very much a farmer’s preference. There are five factors that ought to be considered in choosing a rotation suited to grey clay soils. These are:

1. weed control;
2. disease control;
3. insect control;
4. nutrition; and
5. grain price.

**Weed control**

Crops sown with no-tillage seeders rely almost entirely on herbicides and crop-weed competition to control weeds. This reliance is somewhat offset, however, by the research data (Figure 16) and farmer experience that report smaller weed populations in no-tillage crops, particularly those sown with presswheels (that is, without the soil disturbance of harrows). This phenomenon results from the lack of inter-row soil disturbance, the hardset condition of inter-row soil and the preferential infiltration of rain in the sown rows, all of which combine to retard the establishment of weeds in the soil between the rows of sown crop.

Nevertheless, the reliance on herbicides to control weeds in no-tillage systems, and the associated risk of developing herbicide-resistant weeds, requires the use of any practice that will increase the range of weed control options.

Crop rotations certainly broaden the range of weed control options. These additional options follow:

❖ The inclusion of broadleaf oilseed and pulse crops allows the use of a range of herbicide types. This avoids relying on a single or small number of herbicide types and diminishes the risk of developing herbicide resistance.
❖ Pasture phases allow the options of minimising the seed set of weeds through grazing, hay baling, spray-topping, and green manuring (crop or pasture).
❖ Herbicide-resistant crops such as triazine-tolerant canola and Basta® resistant lupins allow greater use of broad spectrum herbicides (Farmnote 69/96), which result in much greater control of grass weeds and a much reduced establishment of them in following cereal crops.

**Disease control**

Rotations provide the best and most effective means of controlling airborne and soil-borne crop diseases (Farmnote 68/96). Rotations remove host plants and residue that allow the carry-over of viable spores from one crop to the next.

For instance, rotations with botanically different crops such as oilseeds and pulses can control:

❖ in wheat: Septoria, Yellow spot, Take-all and Cereal cyst nematode
❖ in barley: Scald, Net blotch, Take-all and Cereal cyst nematode
❖ in oats: Septoria
❖ in lupins: Pleiochaeta root rot, Brown spot
❖ in peas: Black spot
❖ in faba beans; Ascochyta and Chocolate spot
❖ in canola: Blackleg.

Research in South Australia has shown that rotations in a no-tillage regime can also control Rhizoctonia bare patch. There is some anecdotal evidence from no-tillage farmers in Western Australia that supports the South Australian findings, particularly after eight to 10 years’ no-tillage practice.
Insect control
Cropping practices that retain stubble and grass over the summer–autumn period provide food and shelter for insects and predispose the next crop to increased risk of damage from most insects.

Crop and crop–pasture rotations that reduce or change the amount and type of summer–autumn ground cover reduce the risk of insect damage to following crops. However, even when crop rotation is practised, farmers are advised to use appropriate seed dressings and sprays to ensure a high level of insect control (Farmnote 73/96).

Nutrition
Including a pulse crop in a rotation has long been advocated as a way to build up soil nitrogen reserves for a following cereal or oilseed crop. The extra yield from cereals following a pulse crop can be considerable, for example, a 40% increase in wheat yield following peas (Farmnote 3/99) and lupins (Lupins as Crop Plants Commonwealth Agricultural Bureau 1998).

Grain price
The choice of a rotation crop is always a balance between:
- the need to pursue the management objectives of the factors outlined above; and
- the desire to maximise income.

The prices for the different types of grain and the likely yields (or gross margin returns) will always exert a major and perhaps final influence on the choice of rotation crops.

However, as the harvesting difficulty decreases and the yield potential increases with new varieties of legume and oilseed crops, the influence of grain price on the use of rotations and the selection of crop types will lessen.

Notwithstanding the influence of grain price on the choice of rotation crop, farmers should be aware that the effectiveness of rotating crops to improve weed, disease and insect control is greater when two consecutive broadleaf crops are grown between cereal crops, for example, canola and peas or lupin.

Recommendations
1. Crop rotation using a sequence of two broadleaf crops between two cereal crops should be practised in a no-tillage cropping system on grey clays. (This recommendation is subject to the proviso of reliable yields and prices for the broadleaf oilseed and legume crops.)

2. If a crop–pasture rotation is preferred, phase farming with a phase length of greater than or equal to four years for crops and pasture is recommended, and the pasture phases should, if possible, include both perennial ryegrass–sub-clover and lucerne pastures.

Gypsum and lime applications
Gypsum will always be an appropriate management option for grey clays. Lime will not. On grey clay soils the only circumstances in which lime is appropriate is where the soil is a sandier type of grey clay that has acid topsoil. All grey clays have neutral to alkaline subsoil.

When gypsum is judged to be worth spreading in an effort to rapidly improve the soil structure of a grey clay soil, there are a number of issues farmers should consider:
- for gypsum or lime to give rapid physical effect to its ability to stabilise soil structure or neutralize pH, it needs to be cultivated into the soil;
- every time a soil is cultivated, organic matter (which also stabilises soil structure) is broken down and the structure is weakened;
- while gypsum and lime change the soil chemistry their impact in terms of improving soil density, infiltration of rain and productivity is marginal and short-lived.

If gypsum and/or lime are to be added to a soil, the best time for the application is at the beginning of a cropping rotation that employs no-tillage crop establishment practices and good crop rotations.

Many gypsum requirement tests on grey clays have produced the same rate of application to stabilise the structure: 2.0 t/ha to 2.5 t/ha. This quantity will stabilise the surface 8 cm to 10 cm depth of soil.

The amount of gypsum to stabilise grey clay to the depth of 20 cm is, to a reasonable level of accuracy, twice this amount: or approximately 5 t/ha. If the intention is to stabilise the soil to this depth, the cultivation to incorporate it also needs to be this deep.

Currently, applications of gypsum (or lime) are achieved by first applying the chemical to the surface and then incorporating it by cultivating to the required depth. Some experimental work has incorporated gypsum at depth by injecting the gypsum at the rear and towards the base of ripper shanks. However, machinery with this capability is not commercially available and the productivity improvements are not dramatic enough for this technique to be recommended.

Recommendations
1. Regard gypsum applications as only a short-term means of improving the stability of soil structure.

2. Apply gypsum at a rate that stabilises the structure of the topsoil to a depth of 8 cm to 10 cm. This rate will be close to 2.5 t/ha.

3. Incorporate the gypsum with a thorough cultivation.

4. If gypsum is applied, farmers should adopt and continuously practise soil management practices that increase the organic matter content of soil, that is, no-tillage crop establishment using presswheels (rather than harrows), stubble retention, a biologically sound crop rotation, and minimal or zero grazing.

5. Do not apply lime unless the topsoil is known to have a pH less than or equal to 4.5 in calcium chloride solution.
Green and brown manuring

Green and brown manuring is used for the sole purpose of rapidly improving soil structure stability by adding a large amount of organic matter to the soil. Manure crops mostly include a legume to boost soil nitrogen supplies, because whenever large amounts of organic matter are added to the soil the amount of nitrogen available to plants is reduced.

A common green manure crop is oats and vetch.

To be effective in the short term, green manure crops are incorporated into the soil by a plough that inverts the soil and buries the crop (Figures 10 and 11).

By inverting the soil to incorporate the crop, such ploughings very effectively accelerate the breakdown of existing soil organic matter.

Farmers contemplating adding a green manure crop to their soils should have a proper perspective of:
- the amount of organic matter already in the soil,
- the amount of organic matter that will be added as crop, as well as
- the amount of organic matter broken down when green manure is incorporated.

The following facts are relevant:

1. Organic carbon represents about 70% by weight of the organic matter in soils, which means that an organic carbon content of 1.4% represents about 2.0% organic matter.
2. A topsoil with a common bulk density of 1.5 g/cm$^3$, (or 1,500 t/ha of soil to a depth of 10 cm) will have approximately 30 t/ha (dry weight) of organic matter if the organic matter content is 2.0%.
3. The amount of organic matter added to the soil by a green manure crop will be about 7 t/ha dry weight.
4. Inversion ploughing will cause about 0.3% of total organic carbon to be broken down, which represents about 21% (or 6.3 t/ha) of the current soil organic matter.

Hence, ploughing in a green manure crop will add little or no extra organic matter to the soil. At best, the type of organic matter will change, which may improve a soil's nutritional status.

Research on grey clays substantiated these calculations. It failed to detect any increase in organic carbon in the green manure treatment, and there were only slight improvements in bulk density and productivity.

Recommendations

1. Farmers should not invest in green manuring unless they are prepared to suffer the loss of one year's input costs and gross margin income for very little gain in productivity (research experiments detected 3% or less increase in grain production per annum over a 5-year period).
2. If a farmer chooses to incorporate a green manure crop, soil management practices that increase the organic matter content of soil (that is, no-tillage crop establishment using presswheels, stubble retention, a biologically sound crop rotation, and minimal or zero grazing) should be simultaneously adopted and continuously practised.

Deepened seedbed

Farming deepened seedbeds must be undertaken with the objective of creating and maintaining loose soil conditions always uppermost in the minds of operators.

Initial working

Given the importance of organic matter in moderating the dispersive behaviour of grey clays, the loosening operation should strive for minimal soil inversion.

A preferred mode of action that minimises soil inversion is provided by the Paraplow®. Mixing of topsoil and subsoil, and therefore dilution of topsoil organic matter content, is virtually zero with this type of machine. It has shanks mounted at 45 degrees from the vertical that lift and drop the soil back in place (Figure 29).

Most commercially-available rippers are much more aggressive. Their near-vertical ripper shanks lift and shatter soil causing a reasonable amount of topsoil–subsoil mixing. If ripping machines with an action like that of a Paraplow® are not available the more common type of ripper can be used, provided it is operated at a slow speed to minimise mixing of topsoil and subsoil.

Renovation

Loosened soil, as farmers well know, subsides or re-consolidates over time. This re-consolidation is a natural process that is driven by the low strength and weight of wet soil (or overburden pressure). A naturally dispersive soil like grey clay hastens the re-consolidation process, and 60% to 80% of the reconsolidation process can occur in one growing season.

Without some form of regular renovation, loosened soils will re-consolidate. The rate of re-consolidation will depend largely on the wetness of the season. Regular loosening is required to maintain the loose condition. This is best done every year between harvest and seeding.

The maintenance of a deepened seedbed presents four management challenges:

1. zero soil inversion, and minimal mixing of topsoil and subsoil;
2. retention of as much undisturbed root material as possible;
3. assured trafficability, particularly for in-crop operations in winter; and
4. low cost operations.

The first and second of these challenges can be successfully overcome by using equipment developed specifically to minimise capillary rise of salt into raised beds on saltland. This equipment consists of steeply raked, flat and wide-spanned mulch sweeps mounted at the base of rippers (Figure 30).

The mulch sweeps cut through the seedbed at its base, forcing the soil to pass over the mulch sweep in the same way as air passes over the top of an aeroplane wing. This
lifts the soil about 1 cm to 2 cm vertically, causing it to break open before it falls back in place. No soil inversion occurs, and roots are cut and remain in place.

So effectively does this machinery operate that it can pass beneath growing plants and leave their roots so undisturbed that the plants cannot be pulled from the soil, and they continue to grow (Figure 31).

The lack of soil inversion has been confirmed by organic carbon measurements that were identical in deepened and normal seedbeds. In addition, the maintenance of the loose condition has been confirmed by bulk density measurements that have not varied from year to year (Figure 24).

The only way the third of these challenges can be overcome, and to a large extent the fourth, is through the adoption of controlled traffic operations or Tramline Farming. Fortunately, precision guidance or steering technology and farmer experience with controlled traffic operations (with and without ‘high-tech’ differential global positioning satellite technology) are now available. The reader is referred to DAWA Bulletin 4607, Tramline Farming Systems and DAWA Bulletin 4646, A Manual for Raised Bed Farming in Western Australia.

**Controlled traffic**

Combining controlled traffic farming and deepened seedbed soil management requires the most used traffic lanes (that is, those of the tractor) to remain unloosened, compacted and unsown (Figure 32). There are three reasons for this:

1. The looseness of the seedbed will not be maintained if it is subject to compaction by traffic.
2. Traffic-induced compaction will make the renovation of deepened seedbeds to maintain their looseness more difficult and costly.
3. The risk of bogging in wet conditions will be too high.

When applying a controlled traffic regime the area of deepened seedbed should be maximised and the area of unsown and compacted traffic lanes should be minimised. The most efficient and economical way to achieve these objectives is to match track widths and tyre widths.
Figure 30. Three-point linkage bar used to renovate deepened seedbeds and raised beds. Note the wavy coulters and wide, steeply-raked mulch sweeps. The furrowers are removed for deepened seedbed renovation.

Figure 31. Renovation of a deepened seedbed on the grey clay at Mindarabin. Note the capability of the renovation tools to leave plants effectively undisturbed while thoroughly loosening the soil.
Track width and tyre width matching

By taking the time and effort to match the track widths and the tyre widths of all major pieces of machinery, all operations can take place on a set of narrow tracks with no overlap onto the deepened seedbed area by wide tyres and/or machines with different track widths.

With medium-sized machinery (for example, the maximum width of an 11 m boomspray), by matching track widths to 1.83 m (6 feet) and tyre size to less than or equal to 0.45 m (Figure 33), the area of a paddock subject to machine-induced compaction can be reduced to just 8% at seeding and 12% at harvest.

By using machinery with a larger span, the proportion of a paddock that will be compacted by machinery will be reduced further, provided the increased draught requirement of wider machines does not require a larger tyre width or dual wheels.

The machinery-induced compaction illustrated in Figure 34 is obvious in both normal and deepened seedbeds, and demonstrates the very substantial benefits in soil condition that result from a deepened seedbed-controlled traffic practice. In this particular case, the peaks in penetration resistance correspond to the permanent traffic lanes that are constrained to track widths of 1.83 m, or multiples of this width, and tyre sizes of 0.45 m width. From left to right, the peaks in both seedbeds have the following causes:

1st peak: Seeder and renovator gauge wheels – two passes
2nd and 3rd peaks: Tractor wheels for renovating, spraying (2) and seeding, and the left-hand harvester wheel – five passes
4th peak: Tractor wheel for spraying and right-hand wheel for harvester – three passes
5th peak: Tractor wheel for renovating and seeding – two passes.

The data in Figure 34 show that even traffic lanes that receive lighter traffic and fewer passes than others still suffer obvious compaction. This evidence further emphasises the value of investing time and money to match the track widths and tyre widths of all machinery.

Pattern of working and paddock layout

Having decided to adopt controlled traffic operations, and committed to matching track widths and tyre widths, the next step is to choose the pattern of working and the paddock layout that will produce the simplest and most efficient operation.

There are five issues concerning the operation of working paddocks on a controlled traffic basis that should be considered:

1. ease and precision of maintaining the definition between traffic lanes and deepened seedbed, and rows and inter-row spaces;
2. efficiency and precision of turning boomsprays, seeders and harvesters at the end of straight runs or in paddock corners;
3. ease and efficiency of operating and loading boomsprays and seeders, and unloading harvesters at the end, part way along runs, or in paddock corners.
4. assured access in wet conditions; and
5. control and disposal of runoff in wet conditions (Figure 35).

Readers are referred to Tramline Farming Systems (DAWA Bulletin 4607) and A Manual for Raised Bed Farming in Western Australia (DAWA Bulletin 4646) for more detailed information on these issues.

**Recommendations**

1. Straight ‘up and back’ working is recommended for:
   - precise definition between traffic lanes and deepened seedbeds, as well as between crop rows, which will facilitate inter-row operations;
   - easy and efficient turning at the end of runs. This can be accomplished simply by using the so-called ‘Rip skip’ method (see Tramline Farming Systems) of missing one or a number of machinery pass widths and filling-in these by return passes (moving back across the paddock), or by cycling passes as the operator moves across the paddock;
   - the simplicity of providing operational access and for controlling and disposing of runoff (see A Manual for Raised Bed Farming in Western Australia, DAWA Bulletin 4646).

2. Paddock layout of traffic lanes and direction of working is best up-and-down the slope, with access tracks that act as catch drains spaced at operationally appropriate distances across the slope (that is, to allow sprayers, seeders, harvesters to be re-filled or unloaded).
Figure 34. Cross-section of the average penetration resistance (PR) of 0 to 250 mm depth of soil in deepened and normal seedbeds on a grey clay at Mindarabin. Peaks in PR correspond to permanent traffic lanes in a matched tyre size and track width controlled traffic regime.

Figure 35. Freshly loosened seedbed in a controlled traffic layout.
Choosing Trackwidths and Matching Tyre Size for Controlled Traffic Farming

The choice of a standard trackwidth and tyre size for farm machinery to operate controlled traffic farming (or Tramline) or raised bed farming depends on:

- the difficulty and cost of adaptations;
- the versatility of adapted machinery;
- the return on the investment of time and effort; and
- the re-sale value of adapted machinery.

The following text outlines the reasons why 1.83 m (6 ft) trackwidth and 0.45 m (18 inch) tyre size were chosen for raised bed farming and for deepened seedbeds with controlled traffic farming.

**Trackwidth**

All the manufacturers of tractors, harvesters, swathers and sprayers are overseas-based and most of the machinery is made in the United States of America or by US-owned companies in Europe. All this machinery continues to be made from designs and plant based on Imperial measures, despite its metric description in sales brochures. Thus, conversion of the trackwidth to whole metric numbers, such as 2 m centres or multiples of this figure, will not be easy or cheap.

- **Wheel Tractors**
  - Standard trackwidth is 1.83 m. 2 m conversion is simple. Either move the wheels on the axle, or reverse the hubs. Conversion to 3 m requires costly, factory-certified axle extensions.

- **Sprayers**
  - Track width on self-propelled types is continuously adjustable. Trailing tank-type sprayers can have their axles easily and cheaply extended.

- **Swathers**
  - Newer self-propelled types have wheel frames that can be adapted. Trailing types need to have their wheels and opening re-aligned to match the tracks.

- **Harvesters**
  - Easily adapted to 3.66 m by moving the mounting disc inside a narrow rim. Adaptation to 4 m requires costly, factory certified extension of axle and housing.

Conclusion: A trackwidth 1.83 m, or multiples of this figure, compared to 3 m or 2 m trackwidths, involves no adaptation to tractors and self-propelled sprayers, and only simple and relatively inexpensive adaptations to trailing sprayers, swathers and harvesters.

**Tyre size**

The two major factors to consider when choosing a tyre width are the maximum load the machine has to carry and the flotation required in soft soil conditions. The machine with the greatest load to carry is the harvester, which when full weighs in excess of 20 tonnes. Tyres and rims of 0.45 m width (18 inches) are common on tractors, sprayers and swathers. They are also common on dump trucks that carry upwards of 40 tonnes.

**Conclusion:** Dump truck tyres and rims of 0.45 m width have more than enough load carrying capacity for harvesters and are easily fitted to them. With lessened pressure they have sufficient flotation to avoid bogging in soft soils.

**Summary**

The 1.83 m trackwidth and 0.45 m tyre width require no factory approval to retain their warranty and are the best against all the criteria below:

- **Difficulty and cost of adaptations**
  - Simplest and cheapest

- **Versatility of adapted machinery**
  - Retains full versatility for all farm conditions

- **Return on the investment of time and effort**
  - Returns are high from deepened seedbeds and raised beds

- **Re-sale value of adapted machinery**
  - Unaffected. Wheels can be changed back to originals.
Managing Traffic Lane Runoff

Traffic lanes will shed water because of their compact state and bareness. If this water is unable to run downslope and off the paddock in a controlled manner it will accumulate and create excessively wet, waterlogged and perhaps eroded areas that will be a significant hazard to all cropping operations (Figure 35).

Planning the layout of a paddock must include provisions to control and dispose of runoff if the full benefits of farming deepened seedbeds are to be gained. The issues to consider include the following:

❖ Most if not all of the runoff will be generated by the area of unsown traffic lanes. (The looseness of a deepened seedbed combined with the improved soil structure resulting from other soil management practices, including residue to protect the surface of grey clays from raindrop impact, will ensure the infiltration capacity of the deepened seedbeds is rarely, if ever, surpassed by rainfall.)

❖ Once the tracks are moist in winter, probably 50% to 80% of the rain that falls on the tracks will run off.

❖ Track runoff should always be directed downslope. If the machinery passes are oriented across the slope, water will either pond on the track or move sideways into the deepened seedbed, causing in-crop operations to have a high risk of sliding off the track and bogging in the deepened seedbed.

❖ The need to handle runoff water should be viewed as a water harvesting opportunity. The amount of water that will run off is not trivial. In wet conditions in winter as much as 2,000 m$^3$ of water could run off from a 20 mm rainfall event in a 100 ha paddock with unsown traffic lanes occupying 12% of the area.

❖ A surface drainage system needs to ensure that furrows drain to access tracks and that access tracks drain to a waterway or headland that, in turn, drain to a water storage or safe disposal point.

❖ Consult a properly qualified professional to ensure surface water control measures are competently designed and constructed, and the disposal of water is legal and does not cause downstream damage.

Figure 36. Tractor traffic lanes that have ponded runoff where surface drainage was not allowed for in the direction of working or in the layout of the paddock and access tracks. This caused waterlogging and subsidence of the deepened seedbed. Note the area of affected crop.
Grazing systems

If a farmer chooses to invest in grazing as part of the enterprise mix for the farm business the options to manage grey clays to improve their productivity are more limited than they are for cropping.

Management objectives for maximising the productivity of grey clays used for grazing should aim to maintain the soil in the best possible condition by:
- minimising compaction and puddling damage to the surface soil;
- maximising protection of the surface soil; and
- maximising organic matter build-up in the soil.

The practices that can be employed to achieve these objectives also vary with the proportion of the grazing enterprise in the farm business.

**Whole-farm grazing**

Whole-farm grazing farmers have only three options to achieve these objectives on their grey clay soils:
- stock removal strategy;
- summer-growing pastures; or
- winter-growing pastures.

**Stock removal strategy**

A stock removal strategy is a viable management practice only where a farm has other soils that are less susceptible to structural damage, for example, sands or well-structured and well-drained red soils, both of which will normally be found on higher sections of the landscape. Stock can be moved to these less fragile soils in periods of prolonged wetness or dryness.

The objects of a stock removal strategy are to minimise soil structure degradation by
- avoiding compaction and puddling damage in wet times; and
- retaining enough pasture cover to avoid raindrop impact-induced dispersion and sealing in wet seasons, or pulverisation in dry conditions.

Although there are no research data to demonstrate the productivity benefits of employing this management strategy, it will maintain better soil conditions which ought to result in improved plant growth, pasture re-generation and hence productivity.

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*Figure 37. Perennial rye grass (dominant) and sub-clover pasture on a grey clay soil at Mindarabin*
Summer- or winter-growing pastures
There are very clear data that show a perennial ryegrass-based pasture is far more productive than a perennial summer-growing lucerne pasture.

However, there are clear-cut data that also show a lucerne pasture (Figure 36) provides high quality feed in the summer–autumn feed gap period and that this pasture dries the profile more than any other herbaceous pasture.

Perennial ryegrass and lucerne pastures are therefore complementary, not alternatives. Farmers would be well advised to have both types on their grey clay soils.

Notwithstanding the dependence of lucerne production on summer rain, having both types of pastures will provide the opportunity to employ the stock removal strategy on perennial ryegrass pastures (Figure 37) for short periods in late summer and autumn. In this way the farmer should be able to maximise the likelihood of retaining a cover of ryegrass without over-grazing the lucerne, which would then be able to dry its soil profile and diminish the likelihood of waterlogging during winter.

Of course, such a combination of pasture types also provides the farmer with the opportunity to graze the lucerne pasture during winter and spring and thereby help to maintain the ryegrass pasture in good condition.

Maintaining both types of permanent pasture in good condition should maximise their productivity, and in turn increase soil organic matter and improve soil structure stability and fertility.

Recommendations
Where a farm with grey clays consists solely of a grazing enterprise, the soils will be best managed by:
❖ ensuring both winter- and summer-growing perennial pastures are available for grazing; and
❖ removing stock to other pastures on less fragile soils when conditions are too wet in winter or too dry in summer.

Mixed grazing and cropping
There are two ways in which pastures and cropping can be combined – a ‘one year in, one year out’ 1:1 crop:graze rotation, or phase farming where cropping and grazing are alternately practised.

The 1:1 crop:graze rotation commonly uses a medic- or sub-clover-based, self-regenerating pasture in which the pasture species is determined by the pH of the surface soil – alkaline, medic or acid, sub-clover. The crop in this type of rotation is usually wheat or barley.

Farmer experience and research data have shown the 1:1 crop:graze rotation to be poorly productive and not sustainable. The compaction caused by grazing requires that the seedbed for the succeeding crop receives a complete cultivation, which causes soil conditions and productivity to decline. Also, pasture regeneration is slow and grazing is limited and late in the pasture phase. This is the least profitable farming option for grey clays.

On the other hand, phase farming represents the best of both worlds for managing grey clays in mixed farming enterprises. It allows the farmer the opportunity to employ all the better forms of soil management and crop rotations and to use both winter-and summer-growing perennial pastures.

Phase farming is a relatively new way of combining grazing and cropping enterprises. There are no data or a significant body of farmer experience on which to base advice as to what is an optimum duration of phase. However, the time required to establish good quality pastures and for benefits to flow from better soil, crop and pasture management practices indicates that the phase length needs to exceed three years, and extend to at least four, preferably, five years.

Recommendations
1 Where a grazing enterprise is combined with cropping, phase farming should be adopted.
2 The duration of pasture and crop phases should be four to five years.
3 The pasture phase should comprise separate winter- and summer-growing perennial pastures to capture the benefit of a quality stock feed supply for the summer–autumn feed gap and to avoid the soil degradation of overgrazed, bare pasture paddocks during this period.
4 Grazing management should include the stock exclusion strategy of removing stock to paddocks with less fragile soils when the grey clay soil is either too wet (to avoid compaction and puddling) or too dry (to avoid pulverization, poor surface cover and wind erosion).
No-tillage seeding

A reliable no-tillage seeder has the following attributes:

❖ It cultivates a minimal width of soil into which the seed and fertiliser are placed.
❖ It places fertiliser close to the seed (but not with the seed) and mixes the fertiliser with soil.
❖ It places the seed accurately at the correct depth.
❖ It covers the seed with soil and provides good seed-soil contact.

Additional attributes are required of such a seeder if it is to improve grey clay soils. These are that:

❖ It penetrates hard soil.
❖ It cuts, rather than tears soil, stubble and the roots from previous crops or pasture.
❖ It covers the seed with a presswheel (with adjustable pressure settings) that ensures good seed-soil contact in wet and dry seeding conditions.

❖ It clears heavy amounts of stubble with little fall-off in the quality of seeding depth and seed-soil contact.

There is no single brand of seeder that has all these attributes, and compromises have to be made when the purchasing commercial seeders. A popular and versatile seeder that is used on grey clays and other soils is the Auseeder® (Figure 38).

During the course of this research a hybrid seeder was developed to better meet the performance criteria outlined above.

The hybrid seeder (Figure 39) combines Walker® disc coulters and Auseeder® presswheel assemblies. It was designed specifically to maximise the retention of roots through its cutting action and to improve seed placement and seed-soil contact in difficult soil moisture conditions. The version shown in Figure 39 has difficulty adequately penetrating the soil in dry, hard seedbeds. Heavier duty springs are needed to overcome this inadequacy.
Stubble management

Stubble management begins at harvest, and should have a number of objectives in mind:

❖ protecting the soil surface from raindrop impact and wind erosion, conserving soil water and increasing soil organic matter;
❖ avoiding stubble blockages when seeding the next crop; and
❖ minimising weed seed populations.

The first of these objectives requires maximising the amount of stubble retained. The second and third objectives require minimising the amount of stubble retained.

In striving to improve the condition and productivity of grey clays, major emphasis should be placed on the first objective with just enough attention paid the second and third objectives to ensure production of the next crop in not impaired.

Hence, knowledge of the straw clearance capabilities of the seeder, particularly in moist soil conditions, should determine the maximum length of retained stubble. Remember, with improved soil management, grey clays will become softer, and seeders with coulters will not be able to be relied on to cut stubble.

Successful stubble management on grey clays must therefore always involve practices that avoid the accumulation of straw and chaff. There are a number of ways in which this can be accomplished:

❖ straw storms on harvesters that chop straw and chaff into short pieces and spread it widely (Figure 40);
❖ trailing chaff carts that collect chaff and transport it off site for disposal; or
❖ windrowing the chaff and straw for a ‘cold’ burn in late autumn or early winter prior to seeding.

Also, in a controlled traffic regime, a degree of stubble avoidance is possible by re-aligning the seeder to operate in the inter-row space of the previous crop. This can be done by either:

❖ moving the seeder units on the seeder bar to align them with the inter-row spaces (Figure 39 above); or
❖ adjusting the hitch point at the rear of the tractor to displace the whole seeder bar one half a row spacing to either side.

Both of these adaptations can work with or without precision steering systems.

Gypsum and lime application

The objective of spreading gypsum is to change the soil chemistry to make the soil structure more stable. For spreading lime the objective is to change the soil chemistry to make the supply of plant nutrients more balanced and to avoid toxic concentrations of some elements, particularly aluminium.

The effectiveness of both is greatly enhanced by cultivation, which maximises contact between the chemical and the soil.
Gypsum and lime spreaders either drop or spin-out the chemical onto surface soil. Incorporation is either done by a special cultivation or by way of a seeding operation. The latter alternative in a no-tillage regime is limited to the sown rows and is therefore quite incomplete.

The former alternative results in considerable breakdown of soil organic matter, which in the case of gypsum applications for structure improvement, somewhat defeats the purpose.

Research efforts are underway to inject gypsum and lime into the soil in a no-tillage regime to increase effectiveness and reduce the costs, but these are well short of commercial reality.

**Green manure incorporation**

Incorporating green manure ensures a large amount of new organic material is added to the soil. This objective, however, requires the use of a plough that inverts the soil (Figure 41). The break-down of existing soil organic matter that such ploughing entails means the net addition of organic matter is much less than the amount added.

**Deep cultivation and renovation**

Deepening a seedbed in a grey clay soil should only ever be done with the very clear objective in mind of improving the soil without causing any degradation in the process. For this reason the loosening of the soil to a depth of 20 cm to 25 cm must be done with as near to zero soil inversion as possible.

Implement that operate in ways similar to a Paraplow® are preferred. This plough slices through soil, lifting it outwards and upwards about 3 cm (Figure 42), and so loosens the soil without any soil inversion (Figure 30).

If a Paraplow® is not available other commercially available rippers can be used.

Once the deepened seedbed is laid out on an ‘up and back’ controlled traffic layout, it can be renovated annually using the traffic lanes of the tractor, which are best left unsown.

Renovating deepened seedbeds is best done with an implement like that shown in Figures 43, 44 and 45. This has mulch sweeps at the base of ripper shanks. These blades cut through soil and roots causing zero soil inversion.

Fully configured, the renovation bar should also have wavy coulters in front of the ripper shanks and suspended disc harrows that have an adjustable rake on the rear of the bar. The coulters cut through any trash, preventing vegetation build-up on the shanks. The suspended disc harrows lightly break any surface crust without inverting soil.
Figure 41. Disc plough used for the incorporation of a green manure crop. Note the inversion and exposure of soil and plant material.

Figure 42. Paraplow® showing the inclined tines and adjustable lift blades on the rear edge of the tines.
Figure 43. The wavy coulters, ripper shanks and steeply raked, flat mulch sweeps that act as blades ploughs. The shanks and mulch sweeps are assembled to cut through the full width of seedbed between each tractor traffic line. This unit is set up to renovate raised beds. For deepened seedbeds on grey clays the furrowers are removed.

Figure 44. Rear view of the renovator working in raised beds. Notice that the whole bed is loosened and the disc harrows suspended on the rear of the bar are breaking the crust without inverting soil.
Controlled traffic

Tractors

Tractors working in a controlled traffic regime with compact traffic lanes and ungrazed and loosened soil between the tracks do not require a large power output because the draught of working soils in this condition is not large.

This assessment of the power requirements of tractors is based on the work done at a realistic scale (100 ha) on deepened seedbeds in grey clays and on raised beds. As well, the assessment is based on large farms in the eastern states that operate thousands of hectares in controlled traffic regimes.

Single wheeled tractors of about 200 HP capacity with a tyre size of about 0.45 m width are common in controlled traffic regimes (for example, see Figure 46), and furthermore, most of the implements are three-point linkage.

The track width of the machine in Figure 47 can be easily expanded to 2 m. However, its expansion to 3 m, as recommended by some people for controlled traffic farming, requires factory-approved, specially manufactured axle extensions, which are quite expensive.
Figure 47. A tractor-mounted air seeder and three-point linkage seeder bar used for controlled traffic, deepened seedbed work on grey clays. Note that here the gauge wheels of the bar have rows sown immediately inside their track so that on the return run the next sown row (26 cm spacing) causes the tyre track to be obscured by sown crop.

Figure 48. A self-propelled sprayer with continuously adjustable track width. Its booms are being folded away.
**Seeders**

The adaptation of the track widths of air seeders and seeder bars is worthwhile. It involves little effort and expense and produces a precise and minimal area of compacted soil, which improves the condition and productivity of soil between traffic lanes. These adaptations can be easily done to air seeders and seeder bars. They involve only axle extensions and perhaps matching tyre width to equal or less than the width of tractor tyres (Figure 47). If the cropping area is not large, the air seeder can be mounted on the tractor.

**Sprayers**

Self-propelled sprayers with changeable track widths are compatible with controlled traffic tracks that are at multiples of 1.83 m (or 6 ft). Confirmation of the possible expansion of their trackwidth to 4 m, however, (that is, to multiples of 2 m) needs to be obtained from the manufacturers (Figure 48).

Less expensive towed tank sprayers are easily adapted to a track width of 1.83 m or 2 m, by extending the axle on the spray tank to match the track width (Figure 49).

**Fertiliser spreaders**

The assured trafficability of properly drained, unsown tracks in a controlled traffic regime makes mid-season fertiliser applications an almost risk-free operation that can be done on time, irrespective of soil moisture conditions. Properly drained traffic lanes require, of course, a layout that ensures runoff water will drain from them and be safely disposed off-paddock.

The application of fertiliser can also be done accurately with almost all fertiliser granules placed on sown rows, and few, if any, placed on the traffic lanes. Fertiliser applicators can be easily manufactured in the farm workshop and mounted on the rear of the tractor (Figure 50). Alternatively, soluble fertilisers can be applied using towed or self-propelled sprayers.

The accuracy achieved with the placement of urea granules by the bar shown in Figure 51 was very good. Nearly 95% of urea granules were placed on the seedbed between the tracks, and 75% of these lodged in the rows of the sown crop.

**Swathers**

Self-propelled late-model swathers that have their wheels mounted outside their wheel frame can have their track width easily adapted to match the chosen track width of controlled traffic tracks.

Swaths can be aligned to fall between the harvester tracks to facilitate pick-up of the the crop when harvesting (Figure 51).

**Harvesters**

The choice of track widths of 1.83 m and multiples of this figure for track lanes in a controlled traffic regime makes the adaptation of harvesters simple and relatively inexpensive (Figure 52). Dump truck tyres 0.45 m wide with dump truck rims of the same size can be made to fit 3.66 m track width by welding the mounting disc in the rim in the correct position. Most if not all modern harvesters have hub-hub widths that allow this adaptation.
Figure 50. A farm manufactured fertiliser bar mounted on the rear of a tractor on which the air seeder is mounted on the front. This is suited to raised beds, controlled traffic and normal farm traffic operations.

Figure 51. A harvester raising a canola swath in a controlled traffic system where the swaths were dropped between the traffic lanes.
Using new tyres and new rims for this conversion will cost about $12,000.

One farmer has used second-hand rims and tyres from the mining industry and converted his harvester for about $1,800.

Furthermore, the industrial quality of the rubber in these tyres means they will never need repairing or replacing.

Motor Registry approval and manufacturer approval (if one wants absolute guarantees of lack of liability) is assured.

The narrow tyres and rims do not compromise the ability of a harvester to harvest all farm land. In soft sandy conditions the pressure in the tyres may need to be reduced.
Decisions to invest in the adoption of improved soil management practices should include an economic evaluation of their capacity to increase profit and/or the capital value of assets. Ideally, any extra costs associated with new technology should deliver:

❖ increased productivity; and/or
❖ increased sustainability (that is, less variable productivity and increased capital value of the land).

Basis for comparisons

The economics of the various combinations of improved management practices discussed in this Manual have been examined by gross margin analyses. These were calculated over a 5 year period on the following basis:

❖ Average percentage yield increases for each of the treatment combinations in the research experiments were used to remove the effect of varying seasonal conditions.
❖ Average yields for the Great Southern Region were used as the base (or control) yields.
❖ Routine crop input costs from the Gross Margins Guide 2003 (DAWA Misc. Pub. 18/2002) were used for each crop.
❖ Extra input costs specific to each combination of the improved practices packages were averaged over the five year period.
❖ Gross margins were averaged over a crop rotation of wheat, canola, barley, peas and wheat using 2003 ‘on-farm’ commodity prices.

The improved practices packages used in these analyses were:

❖ Direct drill with harrows (DD,H) – the “control”
❖ No-tillage with presswheels (NTPW)
❖ No-tillage with presswheels and gypsum (NTPW, gypsum) No-tillage with presswheels , gypsum and green manure (NTPW, gypsum, and green manure)
❖ No-tillage with presswheels, in a deepened seedbed with controlled traffic.

The averaged extra input costs used were:

❖ gypsum at 2.5 t/ha: $100 delivered and spread - $20/ha/yr
❖ green manure average gross margin for one year ($317) plus gypsum ($100) and ploughing for incorporation ($50) - $93/ha/yr; and
❖ initial ripping and annual renovation of the deepened seedbed - $50/ha/yr.

The capital investments necessary for the adoption of the various management packages have not been included in the gross margin analyses. These are likely to be farm specific, and farmers are left to make their own judgement on how to incorporate such costs in to their machinery replacement programs and their whole-farm financial analysis.

Comparisons of management options

Cropping systems

The results of these analyses (Figure 53) clearly reflect the effects of additional costs relative to the measured yield increases.

The small but consistent and significant yield increases from the combinations of current improved practices increased the 5-year average gross margin profit in all but the green manuring combination. The most profitable of these combinations of practices is clearly the low-cost combination of no-tillage crop establishment with press-wheels and nothing else. This produced an annual average gross margin profit increase of 12%.

The large yield improvement from the application of the improved practice package of a deepened seedbed, controlled traffic and no-tillage crop establishment is shown to easily carry the extra input cost of an annual renovation of the deepened seedbed.

This combination of practices produced an increase in the annual average gross margin profit of 42%!

Notwithstanding the exclusion of capital costs from these analyses, the magnitude of the extra profit associated with particular management packages provides clear evidence on the capability of each combination to finance the purchase of machinery adaptations or replacement.

Recommendations

To maximise the return on investment in improved soil management practices for cropping grey clays, farmers should either:

❖ adopt a no-tillage crop rotation (with no investment in gypsum or green manuring); or
❖ adopt a no-tillage crop rotation in a deepened seedbed-controlled traffic regime.

The latter alternative has the capacity to make cropping less risky and more productive and to substantially increase profit to a level that would provide a positive return on an investment in precision steering technology.
Grazing systems

A gross margin analysis similar to that used for cropping practices was not possible for the limited data collected on grazing production. However, the complementary grazing productivity of winter-growing, perennial-based pasture and a summer-growing lucerne pasture has been used to illustrate their impact in terms of removing the need for supplementary late summer-autumn feeding. Assuming that both types of pasture were adopted, the need for supplementary feeding would be almost completely removed. If this was the case, the average grazing gross margin for wool-producing sheep would increase from

- an average gross margin from ‘normal’ pastures of $184/ha/yr; to
- an average gross margin for improved winter- and summer-growing pasture of $202/ha/yr.

This very conservative assessment represents a minimal annual average increase of 9% in gross margin profit for such a grazing enterprise.
References


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