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Cropping on raised beds in southern NSW

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INTRODUCTION

Irrigation in southern NSW has developed on soils that can have severe limitations to crop growth under irrigated conditions. These limitations include physical problems such as:

- poor tilth
- inadequate infiltration
- shallow hard-setting surface horizons
- crusting surface soils
- dense subsoils
- waterlogging
- soil compaction.

Chemical problems such as sodicity, salinity, and low nutrient status also occur in most soils.

Soil conditions that are conducive to high crop production are shown in Figure 1. The surface soil is aggregated and does not disperse or slake. The subsoil is not dense, and is permeable, well-aerated and does not disperse.

Most irrigated land is devoted to rice, pasture and winter cereal production on contour or border check style layouts. The current farming system based on flood irrigation, with poor grades and rigid, limited crop rotations, can lead to the following problems:

- soil degradation
- poor water management
- waterlogging
- low yields
- reduced economic returns.

If irrigation farming in southern NSW is to be sustainable, existing soil management techniques must be improved. Irrigation systems can be significantly improved by incorporating raised bed furrow irrigation techniques into a whole farm system.

Furrow irrigation provides the advantages of:

- greater flexibility in crop rotations
- more efficient water management
- improved soil structure.

This Agfact provides an overview of the important properties and problems of soils used for broadacre cropping under irrigation in southern NSW. It discusses how the use of innovative irrigation techniques can improve the productivity of irrigated crops, and how raised bed irrigation technology can provide the basis for improved crop production.

MAJOR IRRIGATED SOIL TYPES

There are three main soil types used for broadacre irrigation farming in southern NSW. They are self-mulching clay soils, red-brown earth soils and clay soils that are not self-mulching.

Self-mulching clays

The self-mulching clays (e.g. Yooroobla clay, Wunnamurra clay and Niemur clay) occur as extensive

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Figure 1. Features of an ideal soil for irrigated raised beds

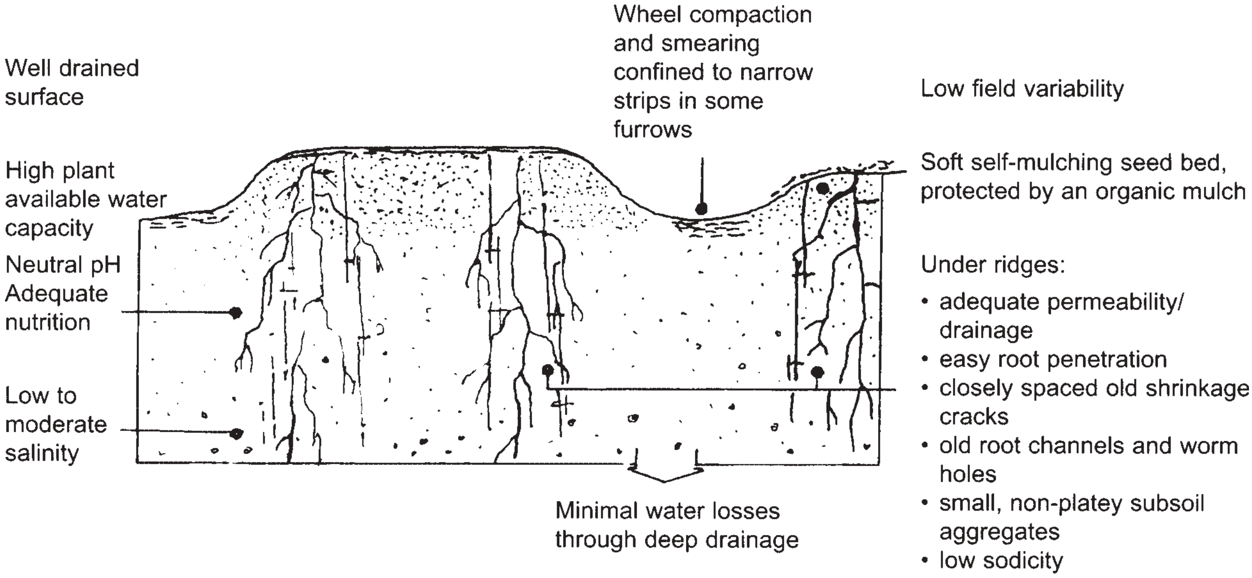
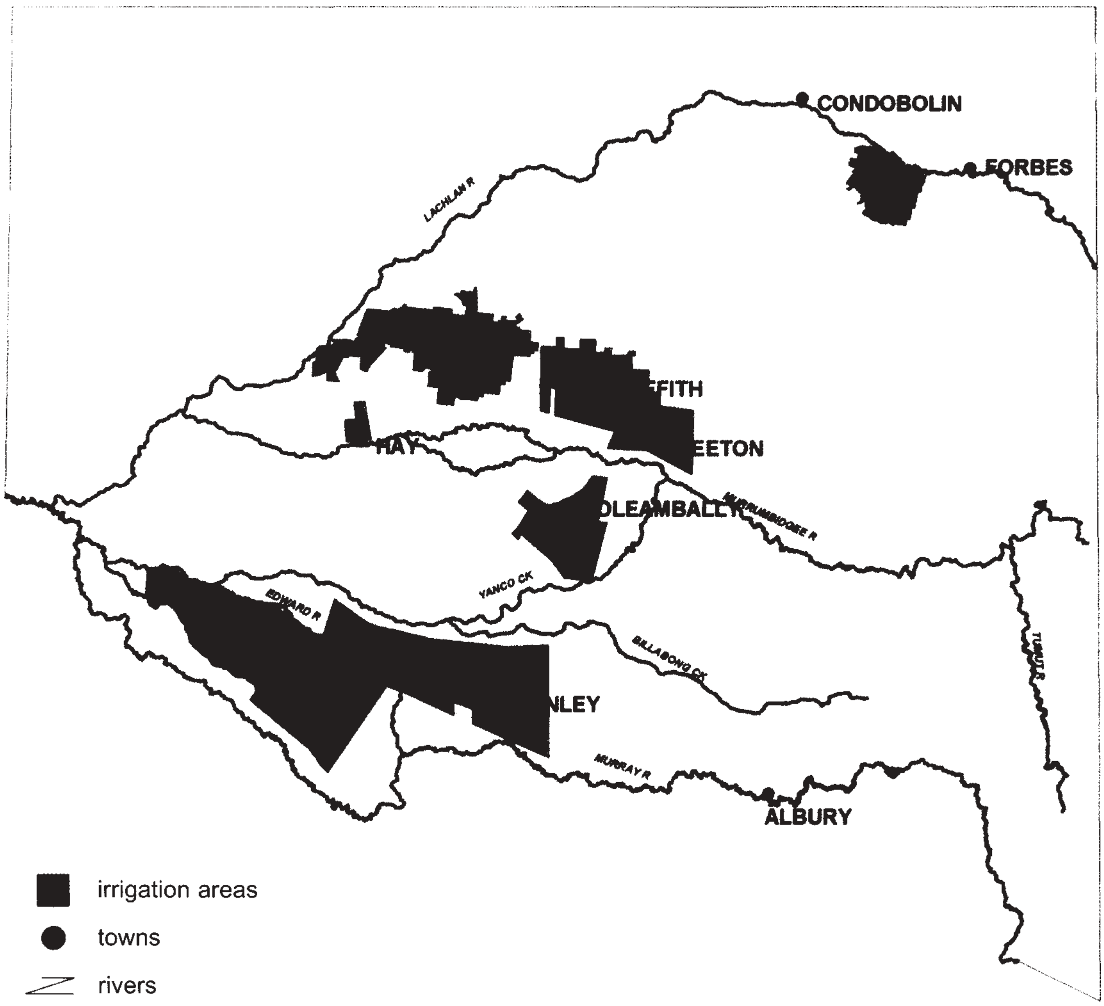


Figure 2. Major irrigation company areas in southern NSW



Raised beds improve drainage and aeration of the rootzone following irrigation, leading to good root development of crops on grey self mulching clay (left), transitional red-brown earths (top right) and brown clay soils (lower right).

plains throughout the region. They are characterised by a heavy texture, with a uniform clay profile. The surface horizon, in the dry state, is self-mulching, being composed of easily disturbed small aggregates resulting from extensive cracking. The self-mulching soils are generally associated with gilgai formations and frequently occur in association with transitional red-brown earths. However, toward the west of the region the gilgai formations may not be present. The self-mulching clays vary in colour from reddish brown to grey. They also vary in the degree of gilgai development and in the presence of free lime (calcium carbonate) in the surface soil. Initial water infiltration into dry self-mulching soils is rapid (most of the irrigation water enters in the first 30 minutes). After this, swelling closes the large cracks, and infiltration rates are significantly lower. The self-mulching surface condition is favourable for seedling establishment. Traffic tends to compact these soils when they are wet.

Red-brown earths and transitional red-brown earths

These soils (e.g. Cobram loam, Birganbigal loam and Deniboota loam) are red-brown to grey-brown, weakly structured to massive surface horizons, and feature an abrupt boundary between topsoil and subsoil horizons. The subsoils have usually brighter brown to red clay horizons with well-developed blocky aggregates. The soil typically becomes yellow brown to yellow grey, with lime concretions present below 60 cm.

Transitional red-brown earths (e.g. Wilbriggie clay loam and Marah clay loam) are a sub-group of the red-brown earths. Transitional red-brown earths have shallow surface horizons 5–10 cm thick, with a clay-loam texture, whereas red-brown earths have loam or sandy loam textured surface horizons, typically 15–30 cm deep.

Topsoils can contain a high proportion of fine sand and silt. When the surface soil is exposed to flood irrigation or heavy rainfall, the soil aggregates (being low in clay and/or organic matter to bind them) slake to form microaggregates. Dispersion is likely if the soil is sodic (exchangeable sodium percentage [ESP] greater than 6) and non-saline. Both slaking and dispersion increase the soil bulk density, causing poor crop emergence, increased waterlogging and poor infiltration.

The subsoils are generally high in clay content and have high bulk density. The high bulk density of the

Potential soil structural problems can be identified quickly and easily using slaking and dispersion tests in the field.

AVOID FLOODING

When irrigating on contour or border check layouts with grades of 1:1500 to 1:2500, the major concerns are slaking and dispersion resulting from flooding the entire soil surface. This is especially the case with red-brown earths, transitional red-brown earths and non self-mulching clays. Slaking and dispersion affect crop emergence by prolonging waterlogged conditions. Crop emergence may also be affected by the formation of crusts as the slaked and/or dispersed soil surface dries.

subsoil impedes root growth. Zones of low hydraulic conductivity ('throttles') can occur at the interface between the topsoil and subsoil horizons, limiting water and air movement.

The pH ($CaCl_2$) of the topsoil is normally 5.5 to 6.5, and the subsoil is frequently alkaline and sodic.

Clays that are not self-mulching

The non self-mulching clays (e.g. Billabong clay and Riverina clay) occur in areas of very low grade and have the following features:

- a shallow surface crust over a blocky clay subsoil
- relatively uniform clay content throughout the profile
- low amounts of lime
- moderate amounts of gypsum (calcium sulfate) below 60 cm
- grey or brown colour
- sodicity throughout the profile.

The sodicity leads to dispersion upon irrigation, so water movement and aeration tend to be very poor. The alkaline and saline conditions that occur, particularly in the subsoil, can also restrict plant development.

FAVOURABLE SOIL CONDITIONS

Irrigated crops require a stable topsoil that provides a favourable environment for emerging seedlings and water entry, and a subsoil that transmits water and air easily, allowing unimpeded root penetration. Only then can the growth potential of the plant be achieved. The most productive soils around the world have several features in common:

- well-aggregated surface soil that does not slake or disperse
- high calcium content
- high organic matter content
- high biological activity
- low density (degree of compaction)
- a silty clay loam texture
- permeable and well-aerated subsoil
- non-sodic subsoil resulting in minimal swelling.

Most irrigation soils in southern NSW, by comparison, possess numerous limitations for plant growth. The physical (structural) nature of the soil directly affects plant growth through its influence on:

- soil resistance to root penetration
- soil water content and movement
- soil aeration
- soil temperature.

The closest soil we have to the ideal is the self-mulching clay.

WHAT ARE RAISED BEDS?

Raised bed farming is a system where the crop zone and the traffic lanes (wheel tracks or furrows) are distinctly and permanently separated. Soil is moved from the traffic lanes (or furrows) and added to the crop zone, slightly raising the surface level of the crop zone. Raised bed technology is an adaptation of the traditional hill and furrow row cropping design. Irrigation water moves laterally from the furrow through the bed by ‘subbing’ (soaking up from the furrow to the top and middle of the bed against gravity).

ADVANTAGES OF RAISED BEDS

Improved surface and internal drainage of the soil, because the entire soil surface is not flooded. The soil wets up by subbing, so the raised bed layout reduces waterlogging in both winter and summer crops. More favourable root-zone conditions exist for plant growth since there is a greater depth of surface soil, and the furrows act as drains, so rapid re-aeration of the root-zone occurs following irrigation or rainfall. Wetting of the soil by subbing reduces the incidence of surface crusting, which provides improved seed bed conditions and allows improved crop emergence.

Improved soil structure of the crop zone, because most machinery wheel compaction is confined to the furrows. Crop growth is improved, as soil conditions are maintained within favourable limits. Minimum tillage and direct drilling techniques allow soil structure to be improved through increased organic matter levels and root activity, even where stubbles are burnt.

Reduced tillage requirements, because the crop zone is not compacted by wheeled traffic. This results in reduced mechanical inputs and costs, and smaller tractors can be used for cultivating. The use of the furrows for traffic is more likely to allow cultural operations to be undertaken at the optimum time, unlike border check and contour layouts, where delays are experienced, and where the soil is looser and potentially more boggy.

Increased range of crops and pastures that can be grown in rotation. The grower can easily change crop sequences to benefit from favourable market prices. The opportunity exists to water-up some winter crops with less risk of poor establishment caused by seed burst, dispersion and crusting of the surface soil. This increases the possibility for double cropping, offering improved flexibility in crop choice and better land utilisation.

Improved financial returns. The ability to operate in a double cropping crop sequence—combined with improved root-zone conditions and fewer and more timely cultural operations—makes better profits likely.

OPTION OF PERMANENT RAISED BEDS

The conventional practice for row cropping has been to cultivate and reform hills or raised beds after the harvest of each crop. If the raised beds are adequately constructed initially, they can be left in place over a long period—at least five years. Construction of raised beds in a permanent format significantly reduces operating costs by removing the need for annual construction of the beds. It also aids the potential for double cropping since successive crops can be sown close to optimum sowing dates, avoiding delays by cultivation requirements of other systems. Reduced cultivation contributes to improvements in soil structure by maintaining or improving levels of soil organic matter.

PADDOCK SELECTION

Soil

Raised beds have been constructed by farmers on each of the three main soil types, and have performed satisfactorily. You will need to carefully assess the suitability of the soil for this technique, because increased levels of management input are required. Self-mulching soils are the most easily managed when using the raised bed system because cracking clay soils regenerate their structure by shrinking and swelling. When using red-brown earths and non self-mulching clay soils, you need to pay attention to issues such as:

- moisture content at the time of cultivation
- sodicity levels and gypsum requirements
- soil aggregate sizes
- soil crusting at seedling emergence
- water entry during irrigations.

Gypsum, if necessary, should be incorporated before the first crop after bedding up, as later incorporation may destroy soil structural improvements.

Field grades

Raised beds are most suited to flatter grades of about 1 in 1000 to 1 in 2500. Where possible, use the most even natural grades, without big cut and fill requirements, and run lengths of up to 800 m. This reduces the number of structures required to water a paddock. Flatter paddocks should have shorter run lengths.

Landforming, preferably laser-guided, is recommended. When paddocks that have not been laser-graded are laid out to raised beds, they are likely to develop problems including over-topping of the beds and waterlogging. This in turn causes soil crusting and seedling emergence problems.

Recirculation systems

Flow rates are usually adjusted to allow 8–12 hour changeover intervals. A recirculation system is essential to allow reuse of drainage water from the furrows and harvesting of rainfall runoff.

Even on slaking and dispersive soils, crops can grow well using raised beds and appropriate management.

A cross-section of a raised bed showing its dimensions and its seed bed. Wider flat beds suit well-structured soils which allow good subbing. Higher, narrower beds are best where subbing is poor or where better drainage is needed.

Wheat double cropped into burnt maize stubble. Raised beds provide increased possibilities for double cropping, allowing winter cereals to be sown directly after harvest of summer crops.

Recirculation systems should also help to retain and manage any pesticide residues on-farm.

Weeds

Permanent raised beds should be constructed in paddocks where the weed population is minimal, since the beds are intended to remain in place with minimum cultivation for some time. Use of cultivation to control weeds is not advocated, because improved soil physical condition is an objective of the use of beds. Frequent cultivation may destroy these conditions, particularly when carried out at inappropriate soil moisture contents. However, strategic cultivation may be necessary where perennial weeds cannot be adequately controlled by herbicides.

Salinity

Saline soils and shallow watertable areas can result in salt concentrating on the surface of the beds. These areas should be avoided for raised bed systems. The existing watertables and soil salinity levels should be measured at the outset and monitored over time.

Soil pH

Acid soil conditions should be avoided or ameliorated, as the potential range of crops may be limited by soil acidity. Lime, if necessary, should be incorporated before bedding up for the initial crop. Later incorporation requires knocking down of the beds, which may destroy soil structural improvements.

PADDOCK PREPARATION

Heavy machinery used for landforming can cause severe subsoil compaction if undertaken when subsoils are wet. Soil moisture content should be close to the lower plastic limit (see 'Glossary') when landforming. Growing a winter crop before landforming can assist in drying the subsoil. Landforming often leaves the soil pulverised, with fine dust particles overlying large compacted aggregates.

Permanent raised beds are intended to be in place for several crops, so good initial paddock preparation is essential.

CONSTRUCTION OF RAISED BEDS

Bed dimensions

Bed width varies with the soil type and the equipment to be used to grow the crop. Raised bed irrigation requires the water to sub up. The beds are normally 1.5–2.0 m wide, allowing a bed top width of 1.0–1.5 m (see Figure 3). This contrasts with conventional hills which are traditionally spaced at 75–100 cm centres. Favourably structured soils (e.g. self-mulching clays) are usually able to wet up well, enabling the use of a wider bed configuration of 1.8–2.0 m. Red-brown earth soils and non self-mulching clays may need narrower (1.0–1.5 m) bed configurations to ensure adequate water entry.

For summer cropping alone there is no major advantage of wider flat-topped beds over hills. However, if the crop sequence is to include winter cropping, then the use of wider flat-topped beds is more appropriate, because more rows can be placed on the bed.

Bed height can be 15–20 cm. Uniformity of bed heights allows the use of fixed rather than floating row crop equipment.

Bed height depends on soil type and paddock grade. For the flatter grades and longer runs, bed heights need to be greater to reduce waterlogging. For red-brown earths and non self-mulching clays which do not sub easily, the bed height needs to be more shallow.

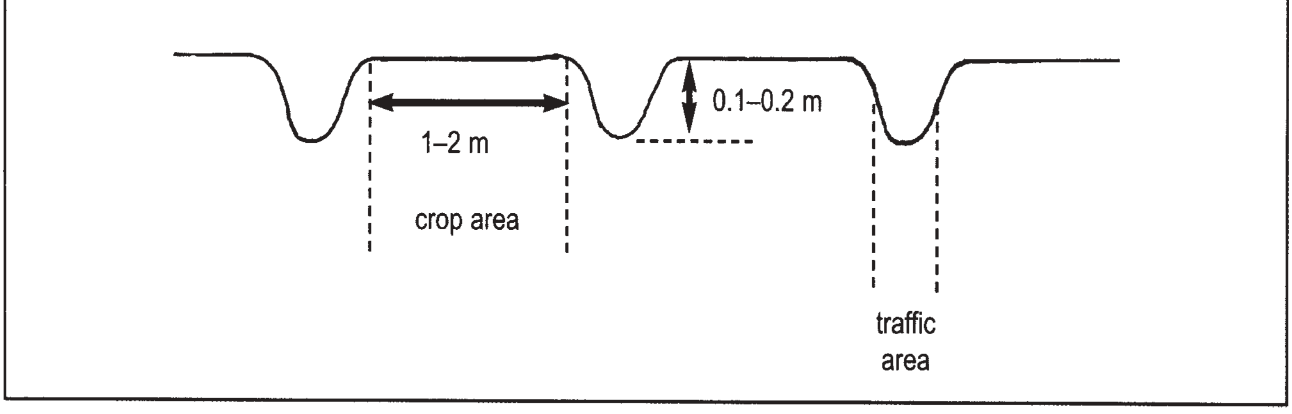
Hilling up

The soil should be cross-worked with deep tillage before hilling up, so that the soil is loose to below the anticipated furrow depth. This depth of cultivated soil allows accurate and straight furrowing and hilling.

Two techniques are most commonly used to construct beds:

- removing every second lister from a toolbar and connecting the remaining pairs of lister shanks with

Figure 3. Irrigated raised beds showing the dimensions of segregated traffic and crop areas



The height and width of raised beds is influenced by soil type, and available tillage and sowing equipment.

heavy bed-forming chains

- listing up hills as for normal furrow irrigation, and then placing a bed shaper over two adjacent hills to form a bed.

In some cases, rotary hoes are used in association with listers and bed shapers to form the raised beds.

Once the beds have been constructed they may have a rough appearance, with a mixture of fine powdery soil and large clods. It is better to leave them in this condition than to try to work them down to a finer condition wetting by rain and drying will usually allow weathering of the larger clods. Pre-watering and further cultivations (during herbicide incorporation and sowing) accelerate the weathering process and assist seedbed preparation.

Red-brown earths, transitional red-brown earths and non self-mulching clay soils have sodic horizons and are generally low in organic matter. Raised beds on these soils require special management and a narrower bed width (1.0–1.5 m) to help with subbing, especially after excessive working or landforming. More time and patience is often required to allow these soils to improve their structure, in order to improve subbing. This may require a number of crops to successfully improve soil structure. Beds on these soils are often fallowed over winter before a summer crop, or, alternatively, winter cereals can be grown. The winter cereal crop can be established after rainfall, and it has a fibrous root system that improves the soil structure of the beds before more expensive summer cropping is attempted.

The approach developed at Tatura, Victoria, to manage the problem of poor water entry—especially in red-brown earth soils—has been to hill up the beds and then cultivate the soil to a good tilth. This cultivation, referred to as 'aggresizing', involves tilling the bed at close to the lower plastic limit, using a spring-tined cultivator. The loam surface soil of a red-brown earth forms aggregates 0.1–0.4 cm in diameter—which, once dried, are stable to rewetting. By cultivating at this moisture content there is very little dust formed, reducing the hard-setting soil condition. Substantial improvements in water infiltration have been achieved using the aggresizing technique.

Where initial subbing is anticipated to be a major problem due to soil type and condition, some growers have opted to construct narrower hills. These hills, half the size of the planned final bed-width, are used to grow the first crop in the problem soil. When the soil structure has improved, the hills are converted to the wider bed format (0.9-1.8 m) after harvest.

With the raised bed system, productivity can be maintained at a high level on the better soil types, and dramatically improved on poorer soil types, particularly if attention is paid to soil structure.

Time of bed construction

Raised beds can be constructed at any time, provided soil conditions are suitable. If the paddock is to be landformed before permanent bed construction, it is preferable to grow a winter crop to dry the soil profile. This will reduce the chance of landforming equipment contributing to subsoil compaction.

Autumn construction of raised beds allows a choice of:

- Fallowing the beds during winter. This allows the beds to consolidate, and may improve soil structure.

It can also increase your chances of sowing on time in spring, if rainfall is high during the winter.

- Sowing the beds immediately with a winter cereal crop. This is usually done under conditions created by rainfall, without irrigation, and allows the development of fibrous root systems to bind the soil aggregates.

In the rice farming system, if the paddock has been previously levelled, raised beds can be prepared after removal of the rice stubble, allowing a summer crop to be grown. In this case, most of the soil preparation would occur in late winter and early spring, provided it is not too wet.

Run lengths

The length of run depends upon the soil type and the slope of the land used. On lighter soils, shorter run lengths are preferred so that the top end is not over-watered. On heavy soils, run lengths of up to 800 m have been successfully used in southern NSW, providing that satisfactory laser grading has been achieved.

Cut areas

Areas of fields heavily cut by landforming are frequently characterised by the exposure of sodic subsoil horizons which are low in plant nutrients and which frequently have higher soil pH levels that affect plant nutrient availability. Cut areas require special attention in regard to fertiliser and gypsum applications. (Animal manures are also being applied by growers as a soil amendment to cut areas.)

It is important that the permanent raised beds are constructed in good condition, as there may not be the opportunity for later cultivation to rectify any problems. The furrows should be as straight as possible, otherwise later cultivation operations will modify bed dimensions.

MAINTENANCE OF PERMANENT BEDS

Major maintenance

The paddocks may require additional landforming every three to seven years. Possible reasons for this include:

- poor initial landforming
- soil movement due to soil swelling and gilgai effects
- wet harvesting, particularly of late summer crops, damaging bed dimensions and soil condition.

Minor maintenance

Furrow spinners are used to repair the furrow and reshape the edge of the beds. Soil and stubble material is removed from the furrow and moved to the sowing line on the top of the raised bed. Once beds are up and subbing, there are usually no further problems, other than furrow tyre compaction on the edge of the bed which may need cultivating occasionally. This can be achieved by using cultivating knives at the appropriate moisture content (lower plastic limit) followed by re-furrowing with listers.

IRRIGATION MANAGEMENT

Irrigation methods

Small hand syphons (5.0–7.5 cm), with one or two per furrow, are the most flexible way to irrigate. Control of water in individual furrows is possible, regulating the rate of advance down each furrow. Some furrows, especially trafficked furrows, tend to water quickly and finish before untrafficked furrows. Irrigation of these quick watering furrows needs to be cut off earlier, unless the recirculation system can handle the drainage flows.

Alternative systems of pipes through the channel banks, or large moveable syphons over the bank, have been used to irrigate several furrows at once. No flow control within the group of furrows is then possible, so recirculation systems must be available to handle increased drainage flows. These systems are more expensive but reduce labour requirements, as water control is then managed in groups of furrows.

Pre-watering

Pre-watering (irrigating before sowing) is the preferred technique on unconsolidated beds, or where the soils are prone to crusting or hard setting. It is particularly useful for summer crops, as sowing into unconsolidated beds and watering up can result in poor crop emergence due to bed and seed subsidence during irrigation. Prewatering avoids sudden reductions in soil temperatures and subsequent effects on seed germination that may result when watering up. In addition, the survival of seed inoculant for legume crops (such as soybeans) is enhanced, as the inoculant is placed directly into moist soil.

Pre-watering for winter crops can also be carried out confidently later in the season than on flat layouts due to better general field drainage.

Watering up

Summer crops should only be watered up on well-consolidated beds (e.g. double cropped beds). Where unconsolidated beds are being used, pre-irrigation is preferable to help consolidate the beds.

Raised beds should be uniformly high so that all of the seed line is above the furrow water levels, especially for soybeans.

Hilling up conventional hills for later conversion to raised beds.

Rotary hoes can be used after listing, to form beds.

Raised bed shapers can be placed over two adjacent conventional hills to form raised beds.

Listers with heavy connecting chains can be used to form raised beds.

Watering up of raised beds presents a much lower risk of waterlogging than with flat layouts, due to better field drainage down the furrows.

Therefore, most crops can be watered up on time, avoiding the need to wait for rain, as is the case on the flat.

Watering duration

Crops grown in furrow irrigation are more tolerant of excessive watering duration than those irrigated on flat layouts, due to the better re-aeration of the soil in the beds after drainage of the furrow.

However, watering times should be kept to 12 hours or less for most crops, as waterlogging can still occur in the raised beds with long watering times. Long watering times have significantly reduced yields in some grain legume crops grown on hills (e.g. mung beans).

Raised beds on red-brown earth soils can present problems in maintaining adequate infiltration, due to slaking and dispersion of soil in the furrow. In this case, water may not sub entirely across the width of the permanent beds, leaving a dry 'bone' section in the centre of the bed. Irrigation and stubble management may need to be modified to allow adequate moisture to infiltrate the beds. Methods of overcoming this problem include:

- run water at a high level in the furrows (without flooding the beds) to increase the wetted surface of the furrow
- leave stubble in the furrow to slow the rate of wetting of the soil surface, hence decreasing the rate of slaking and dispersion
- establish a continuous flow down the furrows using small-diameter syphons (saturated soil culture).

Saturated soil culture

For some hard-setting soils the use of saturated soil culture (continuous flow furrows) may be necessary. In this system, small diameter syphons (e.g. 2.0 cm) may be used in each alternate furrow to reduce the potential for moisture stress affecting yield. The approach is suitable for soils which have very poor infiltration and subbing characteristics. Soybean is the only crop with which it can be successfully used. In these situations good weed control is necessary at the outset.

Need for recycling facilities

The use of furrow irrigation requires that a drainage recirculation and storage facility be available to reuse tail water and rainfall runoff.

Irrigation scheduling

Moisture stress at critical times can significantly affect grain yield in all irrigated crops. Growers need to be able to predict when irrigation of a crop is necessary. Irrigation can be scheduled by using neutron probes to estimate soil water content, or with climate-based scheduling services such as *Water Watch* provided by NSW Agriculture. Details of the service are available from district agronomists.

FERTILISER REQUIREMENTS

Soil testing

Soil physical and chemical testing is recommended on all fields before contemplating the use of raised beds.

Soil pH. Measuring soil pH is important, as both alkaline (high pH) or acidic (low pH) soils can result in nutrient deficiencies.

Subsoils exposed during landforming frequently have a pH greater than 7.0 ($CaCl_2$) and are usually deficient in zinc. Crops vary in their tolerance to acidic soil conditions. Where acid soil conditions exist, applying lime to raise the soil pH to 5.5 allows the full range of crops to be grown. Molybdenum, essential for successful nodulation of legume crops, is less available below pH 5.5 and should be applied if soil conditions are acidic.

Landformed cut areas are likely to require extra phosphorus (P) (40-50 kg/ha), and zinc (Zn) (l0 kg/ ha. A soil test before bedding up will indicate whether there are any nutrient deficiencies. Further recommendations on liming are available in Agfact AC. 19 *Soil acidity and liming*.

Gypsum requirement. Sodic surfaces, either naturally occurring or exposed by landforming, are difficult to manage, and gypsum application will be required. Application rates of 2.5-5.0 t/ha are commonly used and applications can be targeted toward the exposed subsoil areas in the paddock.

Fertiliser type and placement

Fertiliser application and placement varies between crops. Details are provided in Agfacts about specific crops.

Strategies for permanent raised beds. On permanent raised beds, particularly in the double cropped or minimum tillage situations, fertiliser management needs to be considered in a longer time frame, particularly for less mobile nutrients such as phosphorus. It is preferable to apply nutrients such as phosphorus, sulfur, zinc and molybdenum in sufficient quantities to provide for the requirements of a number of successive crops. This avoids major soil disturbance often associated with deep fertiliser placement in the bed, and subsequent poor seed bed condition.

CROP ESTABLISHMENT

The first crop is usually planted into a conventionally prepared seed bed following construction of the bed. Depending on the time of construction, either a winter or summer crop can be grown.

Row spacing

A range of row spacings can be used on raised beds.

Summer crops are usually established with two rows per bed top, with each row next to the furrow. This position generally waters up well and reduces establishment problems especially where infiltration into the middle of the bed is considered to be poor.

For some crops (e.g. soybeans or mung beans), three to six rows can be spaced across the bed. The increased number of plant rows allows earlier closure of the crop canopy and better suppression of weeds. This configuration is only appropriate where good subbing to the bed centre occurs. Narrower row spacings are also preferred where sowing is delayed beyond the optimum date.

Winter crops can be established on the bed tops with 15–18 cm spacing, as for conventional combine spacings. In some cases, small-seeded crops (e.g. canola) may be broadcast and then lightly harrowed for seed burial.

Sowing rates

The sowing rates used for raised beds are the same as those used for conventional layouts. Sowing rates may need to be increased to compensate for reduced seedling emergence when using direct drilling or minimum tillage practices.

HARVEST

Compaction should be minimised by the harvester wheels tracking in the furrows. Header wheel configurations do not generally fit with furrow spacings, so you will need to consider modifying the header wheel spacings.

Winter crops are usually harvested when soils are dry, and compaction will be minimal. However, harvesting of summer crops is more likely to coincide with wet soil conditions, and harvester wheels will compact soil within the bed. Where possible, avoid harvesting under wet soil conditions.

If the harvest must proceed under these conditions, use narrow harvester tyres to minimise soil compaction. Harvester grain bins should be emptied as often as possible, reducing axle loads and consequent soil compaction. Similarly, it is preferable to keep tractors and field bin traffic on the paddock margins.

STUBBLE MANAGEMENT

Winter crop

The stubble residue of irrigated winter cereal crops can be bulky and can hamper the establishment of

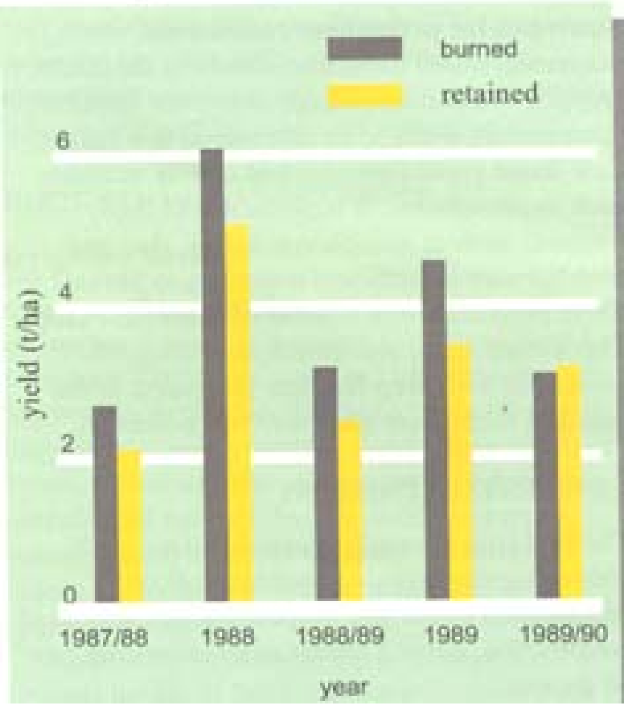


Figure 4. The effect of stubble management treatments on the yields of crops in an irrigated double cropping trial at Leeton Field Station

following double cropped summer crops, because the stubble may be too thick to handle with existing sowing equipment. Summer crops can be successfully established into either slashed or standing cereal stubble by use of a fluted disc coulter in front of the sowing tine to cut through the cereal straw.

Other options include burning the stubble or slashing the stubble and directing the slashed residue toward the centre of the beds away from the summer crop sowing lines at the bed edge.

The stubble of winter legume and oilseed crops does not impede the sowing of following summer crops.

Summer crop

Although less bulky than winter cereal stubble, the stubble residue of summer crops can pose a problem for double cropping. The most common approach to removing this stubble is raking and burning.

All crops

Alternative methods of removing stubble include slashing and mulching, incorporation and grazing by livestock. In double cropped situations, retaining stubble often reduces dry matter production and grain yields (see Figure 4) and delays maturity of succeeding crops. Delayed maturity may lead to delayed sowing of any following crop. Also, more fertiliser is needed when stubble is retained, rather than removed.

Overall, to achieve high yields, the best management approach is to remove crop stubble wherever possible. The most suitable method has been burning, especially in the double crop system. Burning stubble also plays a significant role in improving crop hygiene by reducing the population of weeds, crop insect pests and potential disease sources.

WEED CONTROL

Weeds reduce crop yields by competing for moisture, nutrients and light and can result in reduced grain prices due to dockage for contamination. They can also act as an alternative host for diseases, and cause harvesting and machinery problems.

Ideally, new beds should be constructed on land with a low weed burden. Crop selection should be based in part on an assessment of the weeds in the paddock. Growing crops with different seasonal or herbicide requirements is a technique that can be used to effectively manage weed infestations.

Annual grass weeds

Pre-emergent herbicides can be incorporated before sowing the first crop that follows bedding up (e.g. control of barnyard grass in soybeans and maize; and control of ryegrass, wild oats or phalaris in wheat or barley).

Perennial weeds

A build-up of perennial weeds (e.g. dock and Johnson grass) is a significant potential problem with direct drilled permanent beds. Perennial weed populations should be monitored and controlled while infestations are small.

Appropriate crop sequences should be used to give a range of weed control options.

Cultivation methods

Weeds can be cultivated in the furrows. Shallow inter-row cultivation is possible between the widely spaced rows of summer crops.

Herbicides

In direct drilled and double cropped situations, herbicides are an essential tool in controlling weed infestations on raised beds. In-crop herbicides to control weeds are necessary, as is the use of pre-emergent knockdown herbicides.

The use of soil residual herbicides needs to be recorded so that plant-back periods are observed. Some herbicides may restrict the range of crops that can be sown for 12 months or more following their use (e.g. Glean® or trifluralin).

Further information on plant-back recommendations is available in the NSW Agriculture publications *Weed control in winter crops* and *Weed control in summer crops.*

CROP ROTATIONS

A healthy crop rotation is a sequence of crops that allows the grower to maintain control of the management options available for efficient crop production through the following aspects:

Weed control. The three main considerations in chemical weed control are to:

- maintain the range of effective herbicides that are currently available, by minimising the risk of herbicide resistance developing in weed populations
- minimise the potential for chemical pollution due to excessive use of herbicides
- reduce waste due to the poor use of herbicides.

Alternating between cereal and broadleaf types of crops allows more effective post-emergence weed control. Alternating between chemical groups, integration with preemergent herbicides and strategic cultivation can help to avoid or delay development of weed resistance.

Nutritional benefits. Legume crops or pastures may build up residual nitrogen in the soil that will reduce the nitrogen fertiliser requirements for the next phase of the crop sequence.

Disease control. Growing crops with different disease susceptibilities reduces the build-up of disease levels. Table indicates those plant diseases that affect particular crops. Recommendations on host-free periods (crop and/or weed) to reduce the incidence of plant disease may be obtained from Agfacts on specific crops. Good crop husbandry and rotation practices are necessary for disease control, especially when double cropping (using short rotations).

The raised bed system is ideally suited to a flexible, alternating crop sequence. Raised beds can be used in several cropping sequences—either for a single annual crop each year or in a double cropped situation, or in a combination of the two. Double cropping is a satisfactory cropping option; however, it can delay sowing from the optimum dates, particularly for the summer crop phase. Attention needs to be focussed on the appropriate crop type and cultivar to be sown at any particular time, and on weed and disease problems. A wide choice and selection of crops and pasture can be grown successfully on such a system.

The choice of crop or pasture depends on the paddock history; markets; disease, weed and insect burdens; and future rotation requirements for the paddock. If the optimum dates are used for sowing, the harvest dates can be predicted. With adequate water, machinery and labour available, the most profitable of the available crops can be slotted into time frames over a given period, weather permitting.

Raised beds allow growers to successfully grow crops in sequence, if the crop rotation principles previously outlined are observed.

EQUIPMENT REQUIREMENTS

With the raised bed farming system, the tractor and heavy machinery requirements are reduced compared to conventional farming practices. Once the initial development stage of levelling and hilling up has been undertaken, reduced soil compaction, improved soil structure and better furrow trafficability decrease the draft requirement of tillage implements by up to 60%. As a result, tillage operations can be undertaken with smaller and narrower wheeled row crop tractors (range 50–150 kW), which fit the 1.5–2.0 m bed configuration. This can reduce the capital requirements for farm machinery and the variable costs of tractor use.

Hilling up (listing up)

Hills or beds are hilled up from the flat using toolbar mounted listers or shovels at appropriate spacings. See the section in this Agfact on construction of beds.

Planting

Conventional combines can be adapted to the raised beds. Combines wide enough to straddle three beds are usually selected. The normal undercarriage can be used to sow small-seeded crops at row spacings of 15 cm. Those boots sowing to the furrows can be excluded or seed can be allowed to fall into the furrow. When sowing soybeans and other crops, the combine undercarriage can be modified to allow the sowing tines to be altered to the desired row spacing.

Sowing equipment needs to handle as much trash as possible and be able to sow all kinds of seed sizes and rates. Individual sowing tines or discs with floating depth control, such as a parallelogram, are ideal to handle uneven bed heights. The ability to sow into moisture, with press wheels, is ideal but not essential.

Specialised summer crop planters are required for crops such as maize or sunflowers where the spacing between plants within rows is important.

Fertilising

Most growers use ‘fertiliser rigs’ to band nitrogen and phosphorus fertiliser. Fertiliser rigs consist of fertiliser boxes mounted on toolbars with delivery tubes to disc openers or narrow shanks. Metering devices vary in

Power harrows can be used to renovate raised beds.

their degree of complexity; some are ground driven, others are driven from the tractor.

Deep application of anhydrous ammonia gas requires specialised equipment and high powered tractors.

Inter-row cultivation

Inter-row cultivation is carried out using a toolbar on which a range of implements can be attached including knives, discs, tines or shovels. Frequently the tool bars are set up with the implements mounted in tandem, with sweeps at the rear to clean the furrow.

Furrow cleaning

Furrow cleaning can be successfully undertaken using Alabama sweeps or furrow spinners. Frequently, knives are used to loosen soil at the bed edge and furrow base before furrow cleaning.

Bed maintenance

Significant work is needed only when beds are damaged during wet harvests. Deeper tines or discs are needed to disrupt the compaction zones and reshape and/or re-form the beds. Where damage is caused by header wheels during a wet harvest, raised beds can be repaired by using minimal strategic tillage with tined implements.

Techniques, for example middle busting (at appropriate soil moisture contents), are becoming available to repair beds damaged by compaction without knocking them down. Where beds are middle busted, a toolbar-mounted shank with a pyramidal foot is used down the centre of the bed. Subsequent cultivation with rolling cultivators or power harrows may be necessary.

Stubble management

A stubble mulcher and/or slasher is also helpful to assist in burning or incorporating stubble.

Pesticide application

Insecticides and fungicides. Insecticides and fungicides are usually applied aerially. The use of band booms is also an option. It reduces costs by reducing the amount of pesticide used, and can significantly reduce pesticide drift.

Shielded sprayers can be used for spraying furrows or between plant rows on raised beds.

Herbicides. Herbicide application is normally made with a boom spray and a range of machinery used for incorporation. On raised beds, incorporation can be achieved effectively by several implements including power harrows, rotary hoes, tines or rolling cultivators and prickle chain harrows.

If band spraying is required, the boom spray is usually mounted on a toolbar on which spray shields may also be fitted.

Harvesting

Conventional harvesting equipment is used. Wherever possible, the header wheels should travel in the furrows, to reduce soil compaction.

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FURTHER INFORMATION

Further information is available from NSW Agriculture's web site www.agric.nsw.gov.au

Artwork by John Hoye and E. Roberts
Photographs by staff of NSW Agriculture
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With the improved surface and internal drainage, and root-zone aeration provided by raised beds, many crops can be grown under irrigation on a range of soils.

Clockwise from left:

- safflower
- canola
- chickpeas
- sheep grazing lucerne established on raised beds
- wheat established after a summer crop on raised beds.

Field peas and barley growing successfully on raised beds.

Sunflowers and soybeans.

Table 1. The crops that are susceptible to common diseases

The possibility of carry over of disease should be considered when planning crop rotations, particularly for double cropping.

	Sclerotinia			*Macrophomina*	*Sclerotium*	*Verticillium*	*Phytopthora*			*Gaeumannomyces*	*Fusarium*
	sclerotiorum	*minor*	*trifolium*	*phaseolina*	*rolfsii*	*sp.*	*megasperma* fsp. *medicaginis*	*megasperma /nicotianae* fsp. *glycinea*	*cinnamomi*	*graminis*	*graminearum*
Barley											
Canola											
Chickpeas											
Clovers											
Faba beans											
Fieldpeas											
Lucerne											
Lupins											
Maize											
Mung beans											
Navy beans											
Oats											
Onions											
Safflower											
Sorghum											
Soybean											
Sub. clover											
Sunflowers											
Tomatoes											
Triticale											
Wheat											

GLOSSARY

aggregate	A unit of soil (clod) that contains groups of microaggregates.
bed	A raised ridge of soil for planting row crops; up to 2 m wide.
calcium	A cation that promotes flocculation.
cations	Ions with a positive charge.
cation exchange capacity (CEC)	The ability of a soil to hold cations on its clay and organic matter surfaces.
chemical fertility	The ability of a soil to supply nutrients to plants without hindering growth.
clay	Soil particles smaller than 0.002 mm. These particles are involved in swelling and shrinking of soils, and hold exchangeable cations.
compaction	The application of a force that increases the density of soil. The movement of soil particles closer together by external forces (e.g. by water drops, animals, machines and humans). Closer packing results in less pore space within the soil and leads to poorer internal drainage and aeration.
crusting	This occurs when the soil surface 'melts' together when wet, and then sets hard when dried. A layer forms on the surface of the soil, ranging in thickness up to perhaps as much as 25 mm. When dry, it is more compact, hard and brittle than the material immediately beneath it. The surface layer can be separated and lifted off the soil below.
deep tillage	Any tillage deeper than is needed to produce loose soil for sweeping into a bed; so deep tillage goes below the depth of furrow bottoms.
dispersion	The disintegration of micro-aggregates into individual clay, silt and sand grains; it is the opposite of flocculation. To break up soil aggregates into the individual component particles. A dispersive soil is one where the particles spontaneously disperse when immersed in water.
double cropping	Growing two successive crops on the same area of land in the same year

exchangeable sodium percentage (ESP)	The number of sodium ions as a percentage of all cations held by a soil. Sodium promotes dispersion. The critical ESP value above which dispersion occurs, ranges from 2 to 15 depending on the amount of electrolyte in the soil solution.
exchangeable cations	Positively charged ions held loosely enough on the negatively charged soil particles to be easily exchanged with other ions in the soil solution.
flocculation	Clustering of clay particles into microaggregates.
gilgai	Humps and possibly depressions found in the surfaces of some cracking clays (e.g. Yooroobla, Wunnamurra).
hard setting	A process that occurs when a layer of soil, not necessarily at the surface, 'melts' together when wet, and then sets hard when dried. A compact, hard, apparently massive condition that forms on drying. A soil surface not disturbed or indented by pressure of the forefinger. A surface seal of crust is not necessarily associated with hard setting.
impermeable	Not able to transmit water and/or air.
lower plastic limit	The minimum moisture percentage by weight at which a small sample of soil material can be deformed without rupture. A clay soil at this moisture content will form a crumbly ball but will not make a 3 mm diameter rod.
macroporosity	The air filled porosity corresponding to a soil water content of 0.1 bars. As macropores become interconnected in a better structured soil, their ability to contribute to improved infiltration, drainage and aeration of the soil increases.
massive	Soil where the individual aggregates are very large; and the natural lines of weakness between small particles have been lost.
microaggregates	0.1 mm diameter units of soil that mainly contain solid particles ranging in size from clay (smallest) through silt to fine and coarse sand.
organic matter	Residue of dead plant and animal material.
pan	A hard soil layer, just below the maximum depth of cultivation, that may restrict the entry of water, air and roots.
ped	An individual natural soil aggregate consisting of a cluster of primary particles and separated from adjoining particles by surfaces of weakness that are recognisable as being natural.
permanent beds	A tillage system where the bed and furrow is left in the same place for a number of crops.
physical fertility	The ability of a soil to supply plants with enough water and oxygen, and freedom from temperature stress, to allow uninterrupted growth.

ridge tillage	A method of land preparation whereby the topsoil is scraped and concentrated in a defined region to raise the seed bed above the natural land surface.
root zone	The parts of a soil where living plant roots are located.
self-mulching	A soft and crumbly condition that occurs after wetting and drying of cracking clay surfaces. A soil in which the surface layer becomes so well aggregated that it does not crust or seal under the impact of rain, but instead serves as a surface mulch upon drying.
slaking	Collapse of aggregates in water to form microaggregates due to the breakage of bonds created, for example, by organic materials.
smearing	Disruption of clay-rich aggregates under moist conditions to produce shiny, impenetrable surfaces. Remoulding in a thin layer, for example, at the bottom of a rotary hoe cut.
sodicity	An excess of sodium (ESP greater than 6), causing dispersion to occur.
soil structure	An arrangement of the soil material into aggregates within which the primary materials are held together by ties stronger than the ties between aggregates.