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A MANUAL FOR

Raised Bed Farming IN WESTERN AUSTRALIA

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Contents

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Raised Bed Farming IN WESTERN AUSTRALIA

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Overview

This Manual provides a complete set of information on the nature, location, occurrence and reasons for waterlogging and how to prevent it.

The preventative technology, Raised Bed Farming, is explained in terms of

- ❖ how and why it works;
- ❖ the practical means of installing and maintaining a bedding system;
- ❖ the cropping practices and machinery adaptations needed to effectively farm Raised Beds; and
- ❖ the improved productivity and profitability that result from its adoption.

Waterlogging is explained to be the result of a lack of oxygen in the root zone of agricultural plants that results when soil is so wet as to reduce the amount of air in the soil to less than 8% of the total soil volume.

The geographic distribution of waterlogging and the frequency of its occurrence are described through computer modelling that relates surface soil texture and soil profile characteristics to rainfall and evaporation conditions over the southern half of the Western Australian agricultural area. These predictions show:

- ❖ waterlogging is primarily a consequence of the amount of winter rainfall; and
- ❖ the depth and texture of surface soils.

The insights provided by the modelling into the factors affecting waterlogging allow readers to make their own assessment of waterlogging risk, particularly in situations where there may be shallow water tables that substantially increase the likelihood of waterlogging.

The layout of paddocks of Raised Beds is explained to require sensibly located and professionally designed surface drainage structures and to be best with a north-south bed orientation.

The requirement for drains to be professionally designed and constructed is shown to be necessary for

- ❖ conducting the substantial amounts of water involved;
- ❖ controlling and safely disposing of the runoff and drainage both within and beyond property boundaries; and
- ❖ properly attending to the legal responsibilities for safe and appropriate disposal of such water.

The soil drainage and aeration conditions required to prevent waterlogging are shown to be only provided by Raised Beds in which the required conditions are deliberately created and maintained by soil and crop management practices prior to and throughout the life of permanent Raised Beds.

The management practices required to optimise soil conditions and move towards maximising crop production are explained to be:

- ❖ cultivation prior to construction at the optimum soil moisture content and a depth of 20 cm;
- ❖ regular renovation with specially designed 'blade-type' ploughs that cause no soil inversion and retain all root material;
- ❖ modification of machinery trackwidths so all machinery runs in the furrows between beds;
- ❖ adoption of the best crop rotation and management practices, including managing retained stubble.

Optimum cropping practices are justified as needing:

- ❖ no-tillage crop establishment;
- ❖ stubble retention;
- ❖ crop rotations that include broadleaf crops like canola and peas or lupins.

The types, adaptations, set-up and operation of machinery needed to farm Raised Beds for maximum production are thoroughly explained and justified. The text on machinery covers the requirements for all operations, including bed forming, bed renovation, seeding, spraying, fertilising, swathing, harvesting and managing stubble.

Finally, the economics of an investment in Raised Bed farming are explored in terms of the capacity for the extra income derived from the resulting productivity increases to repay money borrowed at commercial rates. This analysis uses actual yield data obtained by farmers and researchers.

All the information in this Manual has been obtained from farm scale work done in generally drier than normal seasons. The robustness of the positive results obtained under these conditions over a wide range of locations in the south west of Western Australia should reassure farmers that the technology is highly reliable and profitable.

Raised Bed Farming has also proven to be effective in preventing waterlogging in southern Victoria. Like the Western Australian experience, crop production and profitability have increased substantially and adoption is widespread (Raised Beds & Controlled Traffic Cropping, Southern Farming Systems ca 2001)

1. Waterlogging

How waterlogging affects plants

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore space for plant roots to be able to adequately respire.

Plants differ in their demand for oxygen. There is no universal level of soil oxygen that can identify waterlogged conditions for all plants. In addition, a plant's demand for oxygen in its root zone will vary with its stage of growth.

A usefully broad and accepted criterion for defining the presence of waterlogging is, however, when only 8% or less of a soil's total volume is air-filled.

Lack of oxygen in the root zone of plants causes their root tissues to decompose. Usually this occurs from the tips of roots, and this causes roots to appear as if they have been pruned.

The consequence is that the plant's growth and development is stalled. If the anaerobic circumstances continue for a considerable time the plant eventually dies.

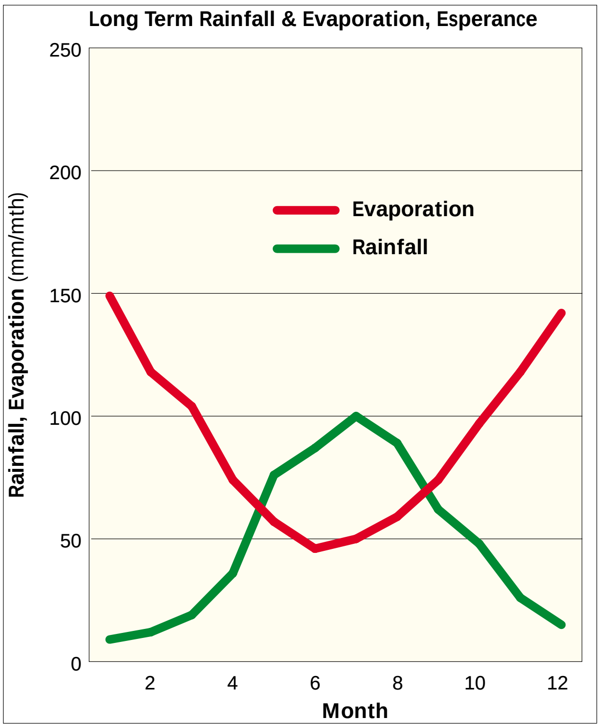
Mostly waterlogged conditions do not last long enough for the plant to die. Once a waterlogging event has passed, plants recommence respiring. As long as soil conditions are moist, the older roots close to the surface allow the plant to survive (Figure 1). However, further waterlogging-induced root pruning and/or dry conditions may weaken the plant to the extent that it will be very poorly productive and may eventually die.

Figure 1. *View of plants with roots 'pruned' by waterlogging (left) and growing healthily without suffering from waterlogging (right). Areas from which they were taken are in the background, waterlogged on the left, Raised Beds on the right.*

How, when and where waterlogging occurs

Waterlogging occurs when the soil profile or the root zone of a plant becomes saturated. In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate.

Western Australia's 'Mediterranean' climate of cool and wet winters and hot dry summers produces more rain than the atmosphere can evaporate every winter. The amount of 'excess' rain is particularly large in the higher rainfall areas of the south-west (Figures 2).



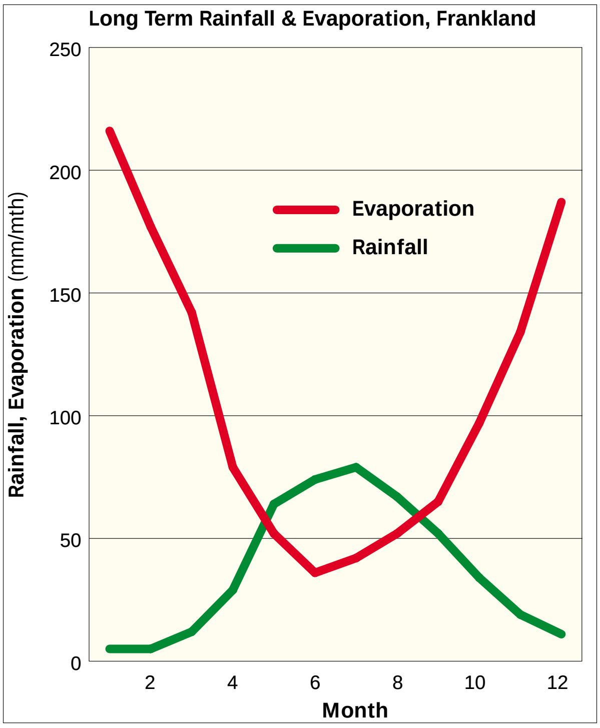


Figure 2. *Long-term monthly averages of rainfall and evaporation at Esperance, Western Australia and Frankland, Western Australia.*

Soils absorb less rain when

- water in the soil cannot quickly drain to deeper layers;
- the surface soil is shallow;
- the land slope is very low; and
- a shallow water table is present.

The climatic and soil conditions that predispose land to waterlogging explain why so much of the Western Australian agricultural area is prone to winter waterlogging. The agricultural landscape is dominated by shallow texture contrast soils (Figure 3) on lands with very low slopes and the rainfall is strongly winter dominant.

The general characteristics of the Western Australian climate that predispose the landscape to winter waterlogging are even more extreme when examined more closely. In particular, the winter rainfall arrives in many small showers – conditions that minimise evaporation and maximise wetness of the surface soil layers. For example, the average number of rain days for the month of July in many centres in the south-west is 20 days or more.

Figure 3. *Two very different Western Australian texture contrast soils highly prone to waterlogging: Cranbrook (left), and Jerramungup (above). Note the large content of gravel in the Cranbrook profile.*

Computer modelling of the factors involved with waterlogging has produced a series of maps of the frequency of daily waterlogging that show areas more or less prone to this phenomenon. These were constructed by combining a range of soil conditions with rainfall and evaporation records for 39 locations across the south-west of Western Australia (Figure 4).

Gravelly soils and waterlogging

Gravelly soils are commonly perceived to be well-drained. They are not.

In fact, when underlain by clay subsoil, as most Western Australian soils are, they are highly prone to waterlogging and rapid drying, which creates the illusion of being well-drained.

Gravel occupies space in soils, which substantially reduces their capacity to absorb rain. For example, if a soil has 60%, by volume, gravel content its capacity to absorb water is reduced by this amount. In figures, a 30cm deep gravelly sand with a potential capacity to absorb about 100mm of rain becomes equivalent to a 12cm depth of sand with an actual absorption capacity of about 36mm of rain.

Also, because they waterlog so easily they remain wet to the surface for a considerable time, which increases the rate at which water evaporates, hence creating the illusion of being well-drained.

Gravelly sands are one of the most common waterlog-affected soil types in Western Australia.

These maps provide a means of assessing the likely risk of waterlogging in a given area whenever the soil profile properties are known.

They also provide an additional insight into the requirements that must be met for waterlogging to be controlled or prevented.

For example, if deep ripping is chosen to treat land prone to waterlogging, comparing the maps for 10 cm and 30 cm deep topsoil depths illustrates the reduction in the frequency of waterlogging that would be achieved. Clearly, the effect of such a treatment would be limited where the frequency of waterlogging is greater than 50%. Furthermore, the presence of a deep loose soil condition is not permanent because the loose soil subsides over time back to its original density.

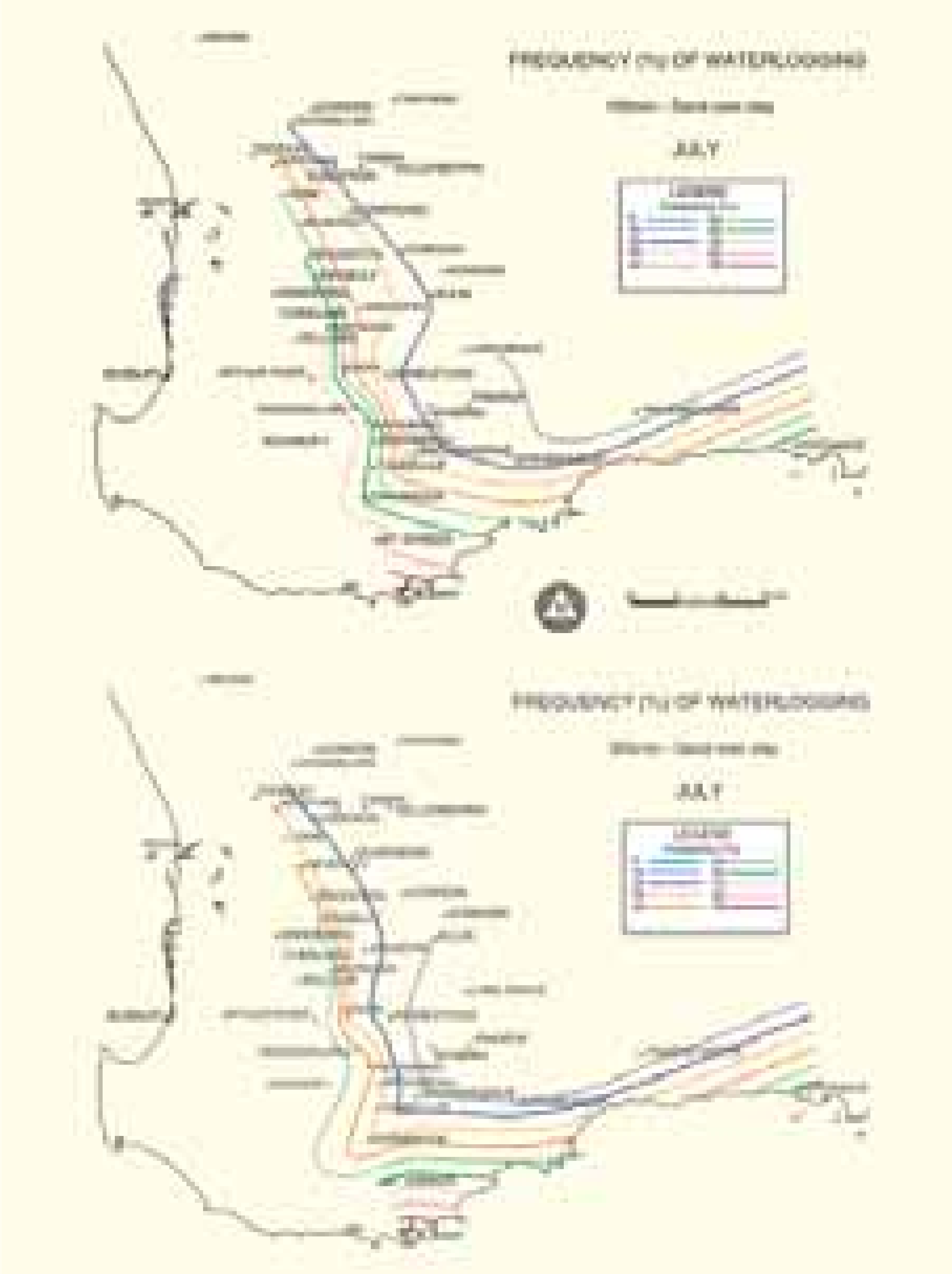


Figure 4. *Computer generated maps of predicted waterlogging frequency for 10cm and 30cm deep sand-over-clay soil and 10cm and 30cm deep loam-over-clay soils for the month of July each year.*

Soil conditions that prevent waterlogging

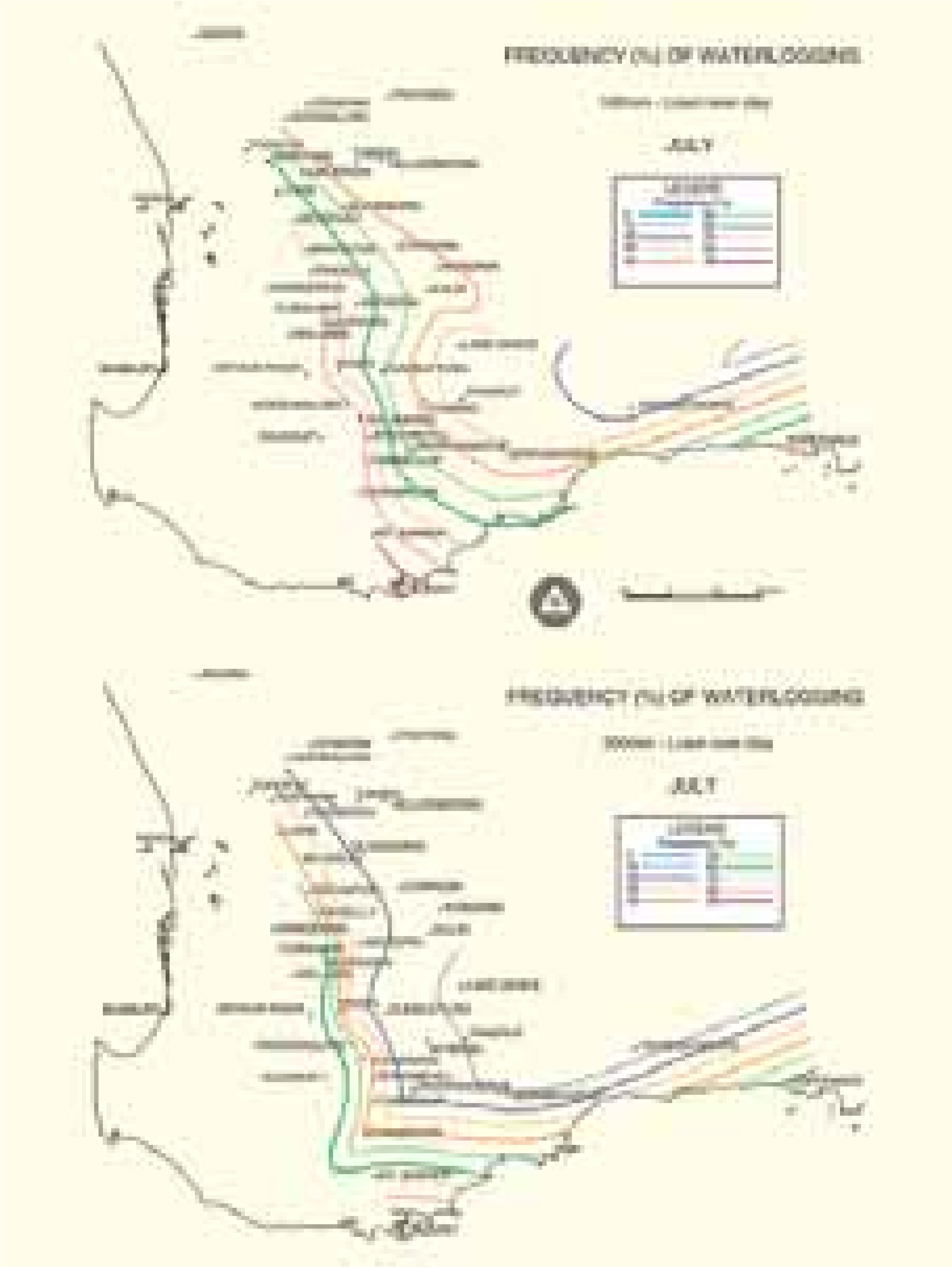
The prevention of waterlogging in soils requires the achievement of two objectives:

- ❖ draining excess water; and
- ❖ aerating the soil.

These two processes do not necessarily happen together. For example, compare the amount of air-filled space in coarse and fine sponges when they are lifted out of a basin of water. The coarse sponge will have many air-filled pores. The fine sponge will have very few air-filled pores.

When water tables are drained from soils with poor structure they have too few large pores to supply enough oxygen for the plant roots to quickly overcome the effects of waterlogging. Rapid aeration of soils only occurs when they have an adequate number of large pores.

In the shallow texture contrast soils that dominate the Western Australian agricultural area, large pores have to be created and maintained by soil management practices that enhance the growth of roots and the populations of soil organisms associated with them.



Why surface drains alone do not prevent waterlogging

Surface drains remove only surface water. They do not:

- ❖ drain the surface soil (the gradient into the drain from the soil is very small), and
- ❖ they do not create large pores and aeration.

They only remove excess surface water and thereby reduce the time over which the surface soil is inundated. On low slope country the movement of surface water into shallow drains is slow and inefficient.

Why Raised Beds are the only permanent form of prevention

Raised Beds are designed to achieve a number of objectives. These are to create and maintain:

- ❖ a deepened seedbed that is not dense and does not constrain root growth;
- ❖ a seedbed with more roots and a significant proportion of large pores for good aeration, infiltration and drainage; and
- ❖ a short distance and a reasonable height from the bed centres to the base of a furrow for a substantial hydraulic gradient to stimulate lateral drainage.

In addition, raised bed farming requires machinery to pass up and down the furrows, which creates a controlled traffic style of farming (or Tramline Farming – see Tramline Farming, A Technical Manual) operation. This means the soil in the beds is never compacted by machinery.

Furthermore, provided the furrows empty all the water that enters them the excess water draining from the beds will ensure the soil in the beds remains unsaturated and does not subside. Well-maintained beds thus tend to maintain a low density and have a low need for maintenance.

Only this form of soil and water management has these capabilities and this form of self-perpetuating function (Figure 5).

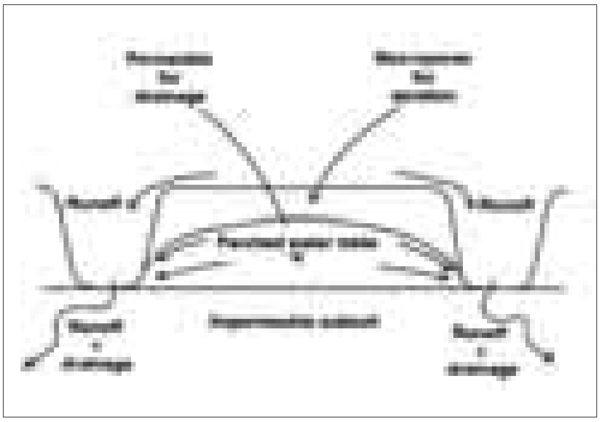


Figure 5. *Diagram of the cross-section of a raised bed and the way it operates to drain, aerate and prevent waterlogging.*

What frequency of waterlogging justifies an investment in Raised Bed Farming ?

Farmers who have tried to crop waterlog-prone areas will know from experience whether the areas concerned would benefit from Raised Bed Farming.

The potential of Raised Bed Farming will be less obvious on areas that have been traditionally used for grazing. To assist in assessing the potential for Raised Bed Farming to be profitable in such circumstances some guidance is provided here on how to interpret the waterlogging frequency maps.

The waterlogging frequency predictions presented in Figure 4 do ***not*** *provide a complete guide to waterlogging susceptibility for* ***all*** *types of land. The model used does not include the effects of shallow water tables, high gravel contents or steep slopes. Where any of these exists, however, farmers are at least likely to know the areas of their farms that are often wet during winter, and this local knowledge should be combined with the waterlogging frequency predictions made in the maps.*

Shallow water tables, like large gravel contents in soil, reduce the soil's capacity to absorb rainfall, and produce the same effect – the soil will waterlog much more frequently than is indicated by the computer generated maps.

Where hillslopes are considerable waterlogging ***may*** *not be a problem. In shallow and/or gravelly soils, however, waterlogging can occur on land with slopes > 3%.*

A reasonable, though arbitrary, guide for deciding whether an investment in Raised Beds ought be profitable is the 50% frequency line for waterlogging in July, for the soil types and depths shown in Figure 4.

Where farms are situated reasonably close to the 50% waterlogging frequency line there are three combinations of circumstances that should be interpreted as follows:

(i) Shallow sand- or loam-over-clay soils situated in areas where the waterlogging frequency on the 300mm topsoil depth maps is greater than 50%:

Raised Bed Farming on land with either of these soil types and this level waterlogging frequency will definitely be profitable.

(ii) Shallow sand- or loam-over-clay soils situated in areas where the waterlogging frequency on the 300mm topsoil depth maps is less than 50% but greater than 50% on the 100m topsoil depth maps:

Raised Bed Farming on land situated between these waterlogging frequency lines will be highly probably profitable.

(iii) Shallow sand- or loam-over-clay soils situated in areas where the waterlogging frequency on the 100mm topsoil depth maps is less than 50% but greater than 40% AND the areas have either a high gravel content or a shallow water table:

- ***a) High gravel content:*** *Raised Bed Farming on such land will be highly probably profitable.*
- ***b) Shallow water table:*** *Raised bed Farming on such land will be probably profitable,* ***BUT*** *the land is likely to be salt-affected and reclamation of the salinity is likely to be difficult.*

Farmers are advised to consult qualified professionals for a more complete and definite interpretation of the probability of profitable Raised Bed Farming on their land.

2. Design, layout and installation of Raised Beds

All Raised Bed installations ***must*** include appropriate surface drains. The amount of extra water running from Raised Beds is not trivial, and there are legal responsibilities that farmers must abide by with respect to the safe disposal of excess water from their land.

Research has shown that the extra runoff from areas of raised beds is likely to be between 5 and 10 per cent of the growing season rainfall. This is roughly equivalent to an extra 15 to 30mm of water annually, which from an area as small as 100ha amounts to between 15,000 and 30,000m^3 per year. If a 20mm rainfall event fell of an already wet field of raised beds the water shed from 100ha by this single event could amount to 4,000m^3

Whilst these amounts of water may seem large in their own right they are only 5 to 10 per cent ***more than normal***. However, the water harvesting efficiency of a system of raised beds is such that the water will run off far quicker than normal and may therefore ***seem*** to be excessive, which it is not.

The efficient disposal of this general amount of runoff ought to make a real contribution to reducing groundwater recharge and salinity. Annual amounts of recharge of between 15 and 30mm per year are about the size considered to have caused the shallow water tables and dryland salinity that is so widespread in Western Australia.

The layout of Raised Beds and their associated drains is thus important for two reasons:

- ❖ the safe and legal disposal of excess water; and
- ❖ the operational efficiency of farming operations.

Elevation surveys

The prime objective for installing Raised Beds is to drain excess water from the root zones of crops and pastures. Success requires that this be achieved with certainty to remove the risk of production and economic loss.

Most land prone to waterlogging has a low slope and shallow texture contrast soil. The presence of shallow topsoil removes the option used in irrigation farming of landplaning paddocks to ensure surface water flows in the dominant direction of the land's slope. Minor humps and hollows reverse the direction of flow of surface water and cause drainage lines to meander or to pond water on a local scale.

If these minor landscape features are not drained the water harvesting attributes of the furrows may actually increase the catchment area of such hollows and the amount of water that ponds in them. Ponded water in the furrows of Raised Beds totally negates their drainage function, causes the bed to subside and leaves any crop on them susceptible to waterlogging.

Precision contour surveys are thus ***essential*** on low slope areas. On higher slope country (slopes > 0.5%) they ***may*** not be needed because the slope direction is much less likely to be altered by minor elevation changes. An example of a precision contour survey is shown below in Figure 6.

The reasons for undertaking a precision contour survey are:

- ❖ to detect the dominant direction of slope;
- ❖ to identify humps and hollows that will change the direction of surface flows;
- ❖ to identify the need for local drains or 'Cross Drains' to remove water from small depressions; and
- ❖ to plan the orientation of Raised Beds and the best location to dispose of water from the major drains at the lower end of the Raised Beds.

Surveyors with the capability of undertaking precise elevation surveys and producing maps with 10cm contours are available in country areas. Such surveys are done rapidly with differential GPS technology. The cost of surveying and the production of maps is around $10/ha.

Practical considerations

There are five key issues that need to be considered when deciding on the layout of an area of Raised Beds. These are outlined below, in the order in which they should be considered.

Bed orientation

Orienting Raised Beds approximately north-south is best, but it may not always be possible. The north-south orientation allows for an even exposure of the bed to sunlight, which maximises the chances of uniform crop development across the full width of the bed.

Crops planted on a predominantly east-west orientation have the rows closest to the northern shoulder of the bed exposed to sunlight for most of the day. This causes greater soil evaporation from the northern shoulder and results in one or two crop rows growing less well and yielding less than the crop rows on the remainder of the bed.

Experience has shown that a ***north-south orientation is almost always achievable***. If the major direction of slope is not north-south there is usually enough side-slope for the beds to be placed on this orientation and still have the furrows run water.

Where paddocks have a long east-west axis operational efficiency considerations will favour this orientation of beds, particularly where the east-west axis is coincident with the major component of slope.

Figure 6. *An example of a high precision contour survey done for planning the layout of Raised Beds and drains at Badgingarra. The map shows 10cm contours and spot heights of grid points. This was produced by DGPS technology.*

Surface drainage

There are three types of drains that are associated with the disposal of water from fields of Raised Beds: ‘Cross Drains’, ‘Catch Drains’ and ‘Waterways’.

Cross Drains

Cross Drains are the drains installed to remove water from small areas within a field where water ponds as a consequence of rises (humps) in the ground surface that are high enough to reverse the direction of slope and surface water flow.

Cross drains usually need to extend only a short distance across-slope to the nearest point lower than the lowest part of the depression they are to drain. Their length must extend far enough across-slope for their channel to have a gradient that will cause water to flow to the nearest area with lower furrows.

Because these drains conduct water across-slope they will lie at an angle to the direction of the Raised Beds. Their beginning and end points are the furrows between the beds. At their exit point, the direction of flow becomes that of the general orientation of beds (Figure 7).

The spoil from the excavation of these drains can either be spread thinly on land either side of them or placed between a cut either side of a median strip. The first alternative is appropriate where the required capacity of the drains is small. The second alternative, which makes the structure a broad channelled ‘W’ drain, is appropriate where flows will be considerable. In such circumstances the median strip needs to be broad-based so that machinery can cross it without discomfort.

Where a low ridge extends across the full width of an area to be bedded, Cross Drains need to extend the full distance and empty either in to a ‘Waterway’ drain or onto a well-grassed surface of an adjacent area that is not bedded. In this special case these drains become ‘Catch Drains’.

Catch drains

Catch Drains collect the water flowing from the end of all the furrows in a field or section of a field that is separated by other Catch Drains. Their purpose is to carry all the runoff and drainage water from the furthest point of the catchment of beds across-slope to a safe disposal area. The safe disposal area may be a constructed ‘Waterway’ or natural watercourse.

The capacity and trafficability of Catch Drains are crucial issues. The capacity must be sufficient to carry the ***Peak Flow***, which is that volume of flow when runoff from the furthest part of a catchment combines with all other flow at the exit point.

Figure 7. *View of typical 'Cross Drain' at a Sustainable Grazing on Saline Land (SGSL) funded demonstration at Badgingarra, Western Australia. Note the rise just beyond the Cross Drain and the angle of the drain relative to the direction of the beds.*

Catch Drains must collect and conduct water from the full width of an area of Raised Beds to ensure the water is removed from the field and placed back into the natural drainage line or creek. They do not need to have a single exit point, but all exits must safely dispose of the runoff ***within*** the catchment of origin.

Catch Drains will have a wide channel to ensure they have the capacity to carry all the flow at a shallow depth and therefore slow velocity. However, the channel must also possess a firm base to allow farm machinery to cross it at the end of their run up and down the beds.

The channel of Catch Drains will always need to be excavated because the base ***must*** be level with or below the furrows that drain into them. In addition, they must have a cross-slope gradient that will cause their contents to flow towards the disposal point(s).

Farm machinery must pass through these drains to turn and undertake another run of each operation. The drains must function properly and efficiently so that water does not lie in them and create conditions that put machinery in danger of leaving deep wheel ruts in the channel or even bogging.

Figure 8. *View of a properly constructed and functioning Catch Drain at Woodanilling.*

Consistent with the need for farm machinery to turn at the end of their runs, the spoil from the excavated channel should be used to form a broad-based bank on the downstream side of drains. The use of spoil for this purpose provides an elevated all-weather access area on which to turn or park farm machinery (Figure 8.).

Waterways

Waterways are broad-channelled, large capacity drains that carry water from upstream past and/or from an area of Raised Beds back to the natural drainage course. They are excavated to provide a smooth, broad channel (to maintain low depth and therefore reasonably low velocity flows) and to ensure their gradient is consistently in the downslope direction (Figure 9).

Because Waterways function as a main conduit for catchment water they need to have all-weather crossings built into them.

Access

There are a number of practical issues concerning access that should be taken into account before the layout of a paddock for Raised Beds is decided. For example, access will be required for:

- delivering seed and fertiliser when sowing;
- removing grain during harvest
- directing the movement of stock out of the Raised Beds when managing pasture; and
- fighting fires, should the need arise.

Access considerations only become important when the area to be bedded is large. A useful guide is that for every 600m length of beds 'W' Catch Drains should be installed across beds and the broad-based median strip of the drain used for access. Also, if the paddock is wide, the same distance (600m) should be used to leave a normal (flat) seedbed as a traffic lane up-and-down the slope, parallel to the beds.

Matching machinery

Like controlled traffic (or Tramline Farming – See Tramline Farming A Technical Manual), the layout of Raised Beds should consider how the widths of sprayers, seeders, fertiliser spreaders, swathers and harvesters fit the total width of the Raised Bed area. Although an exact fit is not essential, it is certainly desirable.

Preferably, the number of passes for each piece of machinery will be a whole number. It is worth spending time planning the layout in terms of the number of machinery passes, because whole numbers of passes for all machinery will greatly facilitate paddock operations and compatibility with normal farming operations on unbedded paddocks.

Sidelands with a normal seedbed can be used as an area whose width is flexible and can therefore be widened or narrowed to accommodate whole numbers of machinery passes in the beds.

Drain orientation and operations

Although not absolutely necessary, the preferred orientation of drains should be as close as possible to a right angle with the direction of the beds. The wider the machinery, the more important this becomes.

The right angle orientation of drains assures easy, comfortable and efficient operation of machinery whose height above the ground surface is important, that is, the bed-former, seeder, swather and harvester.

Figure 9. *View of a Waterway Drain under construction at Woodanilling. This drain will carry water from an unbedded upslope catchment and from a midslope Catch Drain that completely crosses an area of Raised Beds.*

If the orientation of the drains has to be at a considerable angle with the beds, as a machine exits the beds some parts of it will have gauge wheels 10 to 15 cm lower than the base of the furrows, while the remainder will have its gauge wheels at the correct height for the beds.

Also, an angled exit and entry creates a ‘pitch and roll’ effect, which wears the machinery and causes some discomfort for the operator.

If a drain has to be at an angle to the direction of the beds the drain must have a channel width of at least as wide as the ***diagonal*** wheel base of the power unit, that is tractors, self-propelled sprayers, fertiliser bars and harvesters.

Wide drain channels minimise ‘pitch’ and ‘roll’ stresses and strains on machines and operators, and provide improved performance of operations where depth or height control are important.

Capacity of Catch Drains

The capacity of Catch Drains is determined by the total number of, and the rate of discharge from, the furrows that discharge into them. This volume of flow can be considerable.

However, because the capacity of Catch Drains ***must*** be large enough to safely handle ***all*** the runoff and drainage from Raised Beds, a limit ***has*** to be imposed on the size of the area of beds draining into them. Layout designs that limit the area of beds will ensure the required dimensions of Catch Drains are constrained and thus practical and not too costly.

The amount and rate at which runoff water discharges from a furrow is controlled by particular combinations of:

- land slope;
- depth of water in the furrow;
- rainfall intensity; and
- length of furrow.

When these factors are combined with the ***maximum permissible velocity*** of flow (that is, a velocity below which erosion will not occur) they produce a maximum length of furrow for a range of slopes.

The theoretical maximum length of furrow on a 3% slope is about 600 m. Longer furrows build up depths of water to levels where flow velocities become erosive. On lower slopes this theoretical maximum length increases, and practical considerations relating to the capacity of Catch Drains and the disposal of their drainage water become more important, as do the considerations discussed in the section on ***Access***. These also act to limit furrow length.

Once the maximum length of furrow is decided, the required capacity of the main Catch Drains can be determined.

The volume of flow entering main Catch Drains can be considerable (see Figures 10 and 11).

Whilst furrow runoff, bed drainage and practical management considerations limit the area of beds shedding water into a particular Catch Drain, it is essential that the required capacity be properly calculated.

Figure 10. *View of water flowing from furrows and the quantity of flow in the Catch Drain (foreground). This runoff occurred at Woodanilling in early July 2000 from an intense storm of about 20 minutes duration. The length of furrow is about 300 m and the slope is about 1.5%.*

Like furrows, the velocity of flow in Catch Drains needs to be limited to a maximum permissible velocity that will not cause erosion. The control of flow velocity in Catch Drains (Figure 11) is achieved by:

- limiting the total discharge of water entering from furrows (by controlling the length of furrows and the number of furrows entering the drain); and
- controlling the depth of flow in the Catch Drain at full capacity (by widening the channel).

A wider channel will ensure Catch Drain discharge flows at a shallow depth and, therefore, a slow velocity. However, the velocity of flow is also strongly influenced by the slope of the floor of the Catch Drains.

Because Raised Beds will be mostly aligned up-and-down the slope, Catch Drains will most often be required to move water ***across*** the slope. The natural gradient in their channel is thus always likely to be small, and small gradients produce slow flow velocities. However, slow flow velocities mean the channels of catch drains have to be wide for them to have the capacity to carry the required volume of water.

Where possible and desirable therefore, the channel slope should be excavated to produce a slope that will ensure water flows at a velocity sufficient to guarantee the drain empties as quickly as possible at a non-erosive velocity.

Having drains empty promptly and completely guarantees they will not become too wet and difficult to drive through. Catch Drains with sections of their channels that pond water will be soft and result in deep wheel ruts which will diminish the efficiency of the drain.

Figure 11. *Catch Drain with a full capacity of runoff flow. Note the need for a wide cross-section on these drains to handle the volume of flow. This flow was accumulated from Raised Beds in the same event shown in Figure 10.*

Slope limits for furrows and drains

There are two important factors that affect the velocity (and erosivity) of runoff flows that need to be considered. These are:

(i) the slope of the furrows; and

(ii) the slope of the furrow entering Cross or Catch Drains.

The theory used for predicting the velocity of flow in furrows suggests Raised Beds with the furrow dimensions that match a 45 cm (18") tractor tyre can be safely installed on slopes of up to 3%, ***provided*** the length of furrow does not exceed 600m.

Furrow flow velocities on slopes >3% are likely to cause erosion problems in the both the furrows and the Catch Drains, and are not recommended for Raised Beds.

Where channels of Cross or Catch Drains have to be excavated to obtain the desired flow direction and velocity, the slope of furrows as they enter the drains will increase substantially. An increase in flow velocity at this point can cause erosion, which may alter the height of the bed above the furrow base and cause difficulties with seeding and harvesting.

Slopes at the point of furrow entry into Cross or Catch Drains should be made as low as possible and should not exceed a gradient of 1:6 vertical to horizontal distance. Attention to this detail will not only control erosion – it will provide comfortable entry and exit conditions for machinery.

Drain design specifications

The important factors in drain design are the:

❖ width required of the channel (to control flow velocities); and

❖ slope of the sides of the drain.

Both are derived from theoretical calculations of flow quantities which combine flow and erosion control considerations. However, these need to be compatible with comfortable entry and exit conditions for the operation of machinery.

The order in which these matters should be considered is:

❖ first, specifications for the control of flows; and

❖ second, matching the hydraulic design specifications with the requirements for operational comfort and efficiency of machinery.

The convention used for the design of erosion control earthworks is that the maximum slope of the sides (or batters) of drains is one vertical to six horizontal units - a slope of 1:6.

Figure 12. *A broad channel of a main Catch Drain and a broad-based bank suitable for turning large machinery comfortably without damaging the channel floor, at Badgingarra.*

This grade on the batters must be regarded as a maximum for the entry of furrows into drains. A slope of 1:6 represents a slope of about 17%, which is about six times greater than the maximum permissible slope for furrows.

This batter grade is also a comfortable grade for machinery entry and exit from a drain.

Cross Drains will generally have a much smaller catchment and therefore a much smaller required capacity to handle maximum flows. In these circumstances, if the design channel width for a Cross Drain is less than the wheel base of a tractor, sprayer, or harvester the minimum width should be that of the diagonal wheel base of the largest machine that will traverse the drain.

Almost always the required flow capacity of main Catch Drains will require the channel width to be larger than the wheel base of a tractor. Although the largest machine wheel base criterion should still be considered, it needs to be combined with the other practical needs of turning the tractor plus trailing equipment.

The width of the channel floor of main Catch Drains and their broad-based banks, which are made from with the excavation spoil from the drain, should allow sufficient space for comfortable turning of all the machinery ***on the bank, not the drain channel*** (Figure 12).

Preventing erosion of drain channels

Preventing erosion of the channel of Catch Drains and Waterways is a major challenge for sustainable Raised Bed Farming. This is particularly so on sandy soils that are highly erodible.

Solutions to this challenge ***must*** be found. The quantity and velocity of flow in Catch Drains and Waterways can be considerable and hence the potential for erosion can be high.

The most important requirement for preventing erosion of the channels of drains is to have a good cover of vegetation at the time when flows are going to be largest and most frequent. In a winter dominant rainfall regime this time is in June and July.

Meeting this challenge in cropping systems that rely on herbicides for weed control makes the task even greater. There are two possible solutions to this challenge:

- vegetate the channels of Catch Drains and Waterways with a mixture of a prostrate perennial grass and an annual legume; or
- vegetate the channels with a particularly hard-seeded variety of subterranean clover.

The former option will involve grasses like Kikuyu or Couch and clovers like Balansa or a suitable variety of subterranean clover. Maintenance of a sward of this type presents major operational challenges if herbicides are not to kill it. Crop rotations and the passage of sprayers using both grass and broadleaf herbicides will mean the sward will be subject to spray applications that will kill both types of plant.

Such potentially lethal applications of herbicide will occur no matter how careful and conscientious an operator is in turning off and on the sprayer as it enters and leaves a drain channel. Hence, if this option is chosen there will be an on-going management requirement to maintain such a sward.

Another significant drawback with this option is the risk of grasses like couch and kikuyu invading the cropping area of the beds. Farmers will be unenthusiastic about creating such a potential weed problem in their cropping program.

The second alternative of using a hard-seeded sub clover is likely to be much less of an operational challenge and far less of a potential weed problem in crops. Hard seeded annuals like sub clover have the capacity to survive some herbicide damage because of the reserve they create of hard seed in the ground. Furthermore, because they will remain ungrazed throughout the growing season they will be always be able to flower and set seed, and thus increase the reserve of hard seed over time.

Sub clover has an additional trait that increases its potential as a good erosion preventative cover for drains in paddocks of Raised beds. Its habit of burying seed increases its potential to persist for long periods, and the growth habit of anchoring a mat of vine to soil over summer will provide good protection against erosion.

Establishing vegetation in drain channels

Despite the best time for the construction of drains and beds being the spring before the first crop, most farmers will want to do this work in the summer-autumn period between crops. Such a works program will mean drains will be sown in the same season as the first crop on beds. If this situation applies the better operational alternative is to seed the drains after some rain as ***early*** as sensibly possible to enhance pasture establishment ***before*** the crop seeding program.

Further, because of the need to have a reserve of hard seed in the ground to achieve sward survival through the weed spraying program, the seeding rate is recommended to be ***up to twice*** the rate recommended for normal pasture establishment.

Indemnity against liability for the disposal of drainage water

Professional assistance should be sought for the design and specifications of drains, particularly the main Catch Drains, if legal liability for any possible damage caused by runoff flows is to be properly avoided.

3. Soil management for Raised Beds

The objectives of managing soils in Raised Beds are to create and maintain:

- ❖ a stable soil structure;
- ❖ a porous and permeable soil; and
- ❖ a deeper than normal seedbed.

The desired outcomes from these management objectives are to ensure the Raised Beds function properly, that is, they:

- ❖ drain and aerate freely, and thus prevent waterlogging;
- ❖ increase root growth and proliferation, and thereby reinforce the loose structure, minimise subsidence and increase soil organic matter; and
- ❖ increase plant water use, and thereby increase production and reduce deep drainage and water table recharge.

Creating desired soil conditions

Deep cultivation

There are six reasons why a deep cultivation is recommended ***prior*** to bed formation. These are:

(i) to remove the compact traffic pan that exists in all agricultural soils between the depths of 8cm and 18cm;

(ii) to facilitate the excavation of furrows to a depth of 20cm below the normal ground surface;

(iii) to incorporate the top of the B-horizon soil in the tilth and make the transition to the B-horizon less abrupt;

(iv) to improve the water holding capacity of the beds in shallow sand over clay soils through the inclusion of some of the clayey B-horizon in the tilth;

(v) to increase the infiltration capacity and make waterlogging less likely; and

(vi) to increase the amount of water that is easily available to plants.

This deep cultivation should, if possible, be done when the soil moisture content is at the ***Lower Plastic Limit***, (the moisture content at which the soil ***just*** becomes plastic and is able to be moulded). At this moisture content, cultivation creates the largest amount of aggregates with the most uniform size distribution. Damage to soil structure by way of pulverisation (when the soil is too dry) or compaction (when the soil is too wet), are avoided.

(Note that this requirement ***does not*** apply to sands.)

Assessing the Lower Plastic Limit of Soil

The assessment of whether or not the soil moisture content is at or close to the Lower Plastic Limit can be done simply in the field.

Take a handful of soil from about 20cm depth and roll it into a rod. The moisture content is correct if the soil can be rolled into rod of about 1 cm diameter. If it can be rolled to a smaller diameter, the soil is too wet. If it cannot be rolled into a rod of diameter about 1 cm, it is too dry.

The depth of cultivation should, if possible, be 20cm below the surface of undisturbed soil. This becomes equivalent to a depth of about 27cm of disturbed soil (Figure 13).

Figure 13. *View of deep cultivation being undertaken prior to constructing Raised Beds at Beverley.*

The deep cultivation should be done ‘up-and-back’ in the ***same direction*** that the Raised Beds will run.

The best time at which to do this cultivation is in the spring, when soil moisture conditions will be close to optimum (that is, the Lower Plastic Limit). Spring is also often a time when there is less pressure of other farm work.

Gypsum application

Many Western Australian soils are sodic, which predisposes them to dispersion whenever they are wet rapidly or cultivated when too wet.

Dispersion is a process in which the clay component of soil disintegrates into very fine particles. These fine particles are transported in quite slow moving soil-water and block pores and form crusts on the surface of soil.

The results of dispersion are a soil surface which seals and reduces the infiltration rate and total amount of rainfall that enters soil, and a soil that has very poor permeability, drainage and aeration.

Figure 14. *Gypsum response test on the soil from a Raised Bed site at Toolibin. Soil is mixed with distilled water (right) and progressively increased gypsum solutions (left). The concentration of gypsum solution at which clay flocculates (suspension settles) is converted to tonnes of gypsum/ha/depth of soil.*

Gypsum is a chemical that is commonly used to flocculate soil and prevent dispersion. There is no doubt that it works. A large amount of research data demonstrates the capacity of gypsum to stabilise sodic soils. Other GRDC-funded research on grey clay soils recently demonstrated the capacity of gypsum to decrease the bulk density and increase the infiltration rate of surface soil.

The amount of gypsum required to stabilise a sodic soil can be determined by a gypsum response test (Figure 14).

The amount of gypsum commonly required to stabilise the surface 8-10cm depth of soil is in the vicinity of 2.0 to 2.5 t/ha.

The amount of gypsum required to stabilise twice this depth of soil, that is, the depth of soil incorporated into Raised Beds is about twice the normal application rate because twice the depth of soil needs to be treated.

Organic matter build-up

An alternative to investing in gypsum is the adoption of practices that will build up soil organic matter. Organic matter stabilises all soils, including sodic soils, by

- acting as a cementing agent, binding soil particles together; and
- increasing the population size and activity of soil organisms and thereby facilitating their ability to bind soil particles together and to create macropores and aerate the soil.

Practices such as no-till crop establishment and stubble retention provide an alternative to gypsum. These practices maximise the retention of above and below ground plant material between crops and thereby build up soil organic matter.

No-till crop establishment practices, in particular, have been shown by researchers and farmers to increase the soil organic carbon content by about 1% over four to five years.

Does applying gypsum return a profit ?

A decision to invest in gypsum ought to be taken only after consideration of the costs and benefits of applying it are compared with the costs and benefits of alternative ways to stabilise soil structure.

The cost of gypsum delivered and spread on the paddock is commonly around $40/t/ha.

The cost of applying gypsum at rates of 2.0 to 2.5 t/ha to stabilise soil structure to a depth of about 100mm is therefore going to be about $80-$100/ha. To stabilise the full depth of soil in raised beds (200mm of undisturbed soil) will require rates of 4.0-5.0t/ha and will thus cost about $160-$200/ha.

Gaining a return on the cost of applying just 2.0 to 2.5t/ha of gypsum by way of grain yield increases has proved to be difficult, however. Careful experimentation over five years with good growing seasons produced only a 3% increase in production, which, for a 3.0t/ha wheat crop, amounted to about $20/ha/yr.

Hence, the economic return from gypsum should be regarded, at best, as a long-term investment.

Adopting practices that increase soil organic matter are likely to be more economic and effective.

An increase in organic carbon of 1% adds a very much greater weight of material to soil than is added by even the heaviest gypsum application, for example, an increase in organic matter of 1% by weight is equivalent to 15t/ha.

Constructing Raised Beds

Raised Beds are constructed with a special-purpose implement called a bed-former. These machines come in 3-point linkage and trailing models. Some makes have the versatility of moving their components to change the width of beds.

Figure 15. *Freshly constructed beds and bed-former at Katanning. Note the grader blades set up has produced square shouldered flat topped beds.*

The bed-formers specially adapted for the fragile structure of WA's coarse textured surface soils have furrowers and grader blades. The furrowers are set at the spacing to be used (the centre-to-centre distance between beds), and the grader blades trail behind the rear edge of the furrowers. The furrowers excavate soil to the depth of the deep cultivation and push the spoil to the left and right.

The grader blades then gently spread the spoil evenly across the soil that passes between the furrowers.

The furrowers leave a trench about 45cm (18") wide, and these are set in line with tractor wheels fitted with 45cm (18") tyres.

The grader blades are best set at a rake angle of 35 degrees from the direction of travel. This angle gives the best soil flow and spreading efficiency for all soil textures and moisture conditions.

Properly set up, bed formers should produce beds with a square profile. The scour pattern on the furrowers and blades, as well as the appearance of the beds, will indicate the quality of a bed-former's set-up (Figures 15 and 16).

The best soil moisture conditions in which to construct beds is the same as that for deep cultivation, the Lower Plastic Limit moisture content.

The bed-former needs to have a marker arm on each side, to mark the centre of the next pass. Each pass makes three complete beds and two half-beds. Each successive pass completes the half-bed constructed on the outside of the beds built by the previous pass.

Figure 16. *View of bed-former showing the scour paffern produced on the furrowers and grader blades indicating the machine has been properly set up.*

The first pass with bed-former must be marked manually. Marker pegs are measured from a reference line, such as a fence. The distance from the reference line to the centre line of the first pass of the bed-former is one half the width of four beds – 3.66m for 1.83m wide beds (or 4.0m for 2.0m wide beds). Of course, allowance needs to be made for any sideland or access track alongside a fence.

When making beds from a specially deep-cultivated soil there is value in passing over the freshly made beds a second time. The second pass will tidy up the beds but, more importantly, compact the base of the furrows. The base of furrows in a field of newly constructed beds may well be less compact than is desirable. If furrow drainage is less than perfect and some water ponds in them, there will be a risk of the tractor bogging while seeding or spraying in the first year.

Traffic that takes place during the first season's crop should compact the furrows and prevent bogging thereafter.

Maintaining the desired soil conditions

Properly constructed and functional Raised Beds have physical conditions that do not deteriorate quickly. This is because they drain excess water and do not become saturated. The wettest part of a Raised Bed is its base at the centre of the bed (see Figure 5).

The natural tendency for loose soils to subside into a dense, less permeable condition is substantially reduced in Raised Beds. Drained beds, combined with no-tillage crop establishment (which maximises the retention of root matter) and a totally controlled traffic regime, respectively maximise internal friction between soil particles, provide reinforcing rods in the form of roots, and remove traffic-induced compaction.

The consequence is that improved infiltration and density conditions are retained for a considerable time (Figures 17 and 18).

The data presented in Figures 17 and 18 do not mean there is no need to periodically renovate Raised Beds. Wetting and drying of the soil in the beds, some compaction from grazing stock and a less than a perfect match of machinery track widths and tyre widths, plus the possibility of some ponding in parts of furrows are some of the reasons why it may be necessary or desirable to renovate Raised Beds.

Machinery components have been devised and tested to renovate beds with minimal disturbance and destruction of root material. The aim when renovating beds is to return beds to their initial condition without reducing the organic matter and soil organism populations built up through no-tillage crop establishment practices.

The renovation tools consist of wide, sharply raked, flat blades that are mounted at the base of narrow ripper shanks. Two pairs of the blades are mounted on two ripper shanks per bed. These gently cut, lift and break open the soil in beds from their base, level with the floor of the furrow (Figure 19).

The passage of these renovation tools leaves plants in the beds with enough soil-root contact to prevent the plants from being pulled out by hand (Figures 20 and 21.).

Also, suspended from the rear of the bed-former bar in its re-configured, renovation-mode are gangs of disc harrows. These gently break any crust on the soil surface and maximise infiltration properties.

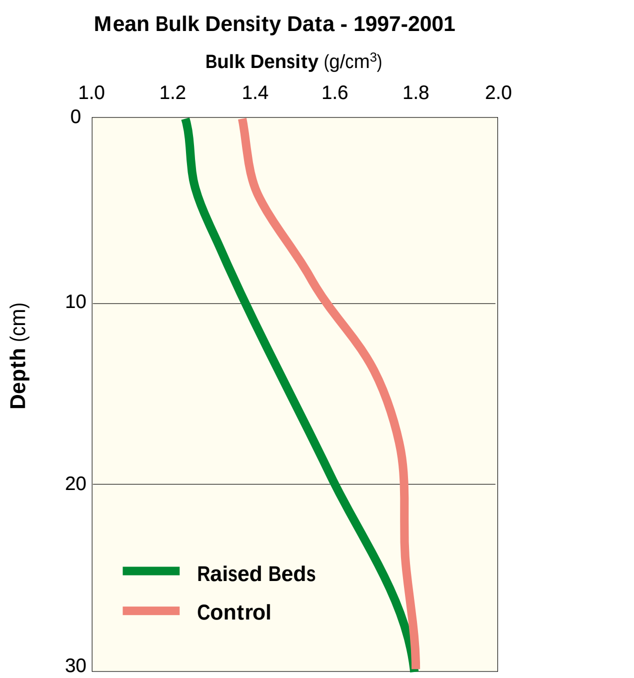


Figure 17. *Mean bulk density profiles of the 0 to 30cm depth of soil in Raised Beds and a normal (Control) seedbed over five years in the GRDC 'Raised Bed'project'.*

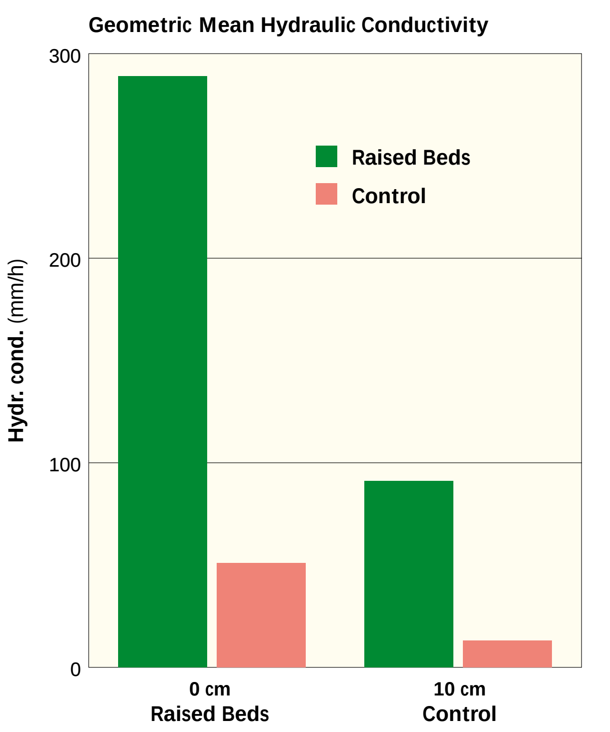


Figure 18. *Five-year mean hydraulic conductivity data for surface and 10cm depth of soil in Raised Beds and Control treatments of the GRDC 'Raised Bed'project.*

Figure 19. *View of renovation tools - wavy coulters, ripper shanks with mulch sweeps - designed to renovate beds with minimal disturbance and maximum root retention.*

The breaking of any surface crust and the retention of plant tops and roots ensures water will move relatively rapidly in beds at moisture contents considerably less than saturation. Unsaturated soil conditions limit or even prevent dispersion of sodic soil, which only occurs at saturated moisture contents.

There is no clear-cut recommendation on the regularity with which Raised Beds should be renovated. The need really depends on their condition, which should be monitored.

The objective for managing Raised Beds is to maintain their condition as a reasonably loose, permeable and aerated seedbed. If they are allowed to return to a compact (dense and less permeable) condition they will lose the ability to aerate and prevent waterlogging.

The condition of beds will depend on the amount of rainfall, traffic and grazing they receive and whether they have been subject to waterlogging (and subsidence) because of ponding in the furrows.

Where farms with Raised Beds have sheep and the Raised Beds are grazed over summer, bed renovation every second year is likely to be beneficial. It may even be beneficial every year, prior to seeding.

Figure 20. *Freshly renovated Raised Beds. Note the plants are apparently undisturbed and the sufface crust has been broken. These plants continued to grow through to maturity affer the renovation.*

Figure 21. *Freshly renovated beds of a previous barley crop at Woodanilling. Note the looseness of the soil and the shape of the beds and furrows, and the retention of the stubble cover.*

4. Cropping practices for Raised Beds

Cropping Raised Beds is little different from cropping normal seedbeds. There are, however, some minor changes required in approach and practice. This Chapter presents the knowledge and experience gained by the researchers and farmers who have been cropping Raised Beds since 1997.

Crop productivity on Raised Beds in Western Australia

The costs of installing a system of Raised Beds will be most quickly and assuredly recovered through a cropping program. Pastures take time to establish and the return from them is less than from cropping, particularly in the short term.

Substantial increases in grain production (Figure 22) have been achieved from paddock-scale research sites located over a wide area and range of soil types in the south west of Western Australia. These sites ranged from Beverley to Esperance, and included soils that ranged from grey loam over clay, to gravelly sand over clay, to sand over clay.

The average increase in grain yield from the research sites over the period 1996-2001 and over a range of crops (oats, wheat, peas, lupin and canola) was 0.47t/ha.

Importantly, these production increases were achieved in drier than normal seasons and from some areas where the long-term frequency of daily waterlogging in July is predicted to be less than 50%.

Farmers who have adopted Raised Bed Farming have obtained similar but larger yield increases from

- a narrower range of soil types (sand over clay and gravelly sand over clay)
- seasons that were generally normal to slightly wetter than normal.
- a range of crops that included barley, wheat, canola and lupin.

The grain production increases obtained by farmers averaged 0.87t/ha (Figure 23).

The yield increases shown in Figure 23 are dominated by data from farmers in the Esperance District. Three of the four growing seasons between 1998 and 2001 in the Esperance District received more than long-term median rainfall and the fourth (2000) received about 130mm less than the long-term median.

The Esperance farmers have led the adoption of Raised Bed Farming and have installed Raised Beds over large areas. At the end of 2001, surveys put this area at 15,000ha. More recent estimates indicate this area has increased to approximately 30,000ha.

There are good reasons for the adoption of Raised Beds in the Esperance district. The soils and rainfall conditions in this district cause frequent waterlogging and its impact is extensive and severe. Computer predictions of the daily frequency of waterlogging in July in this area, on the sand over clay soil type are close to 80% (refer to Figures 4 a,b,c,d.).

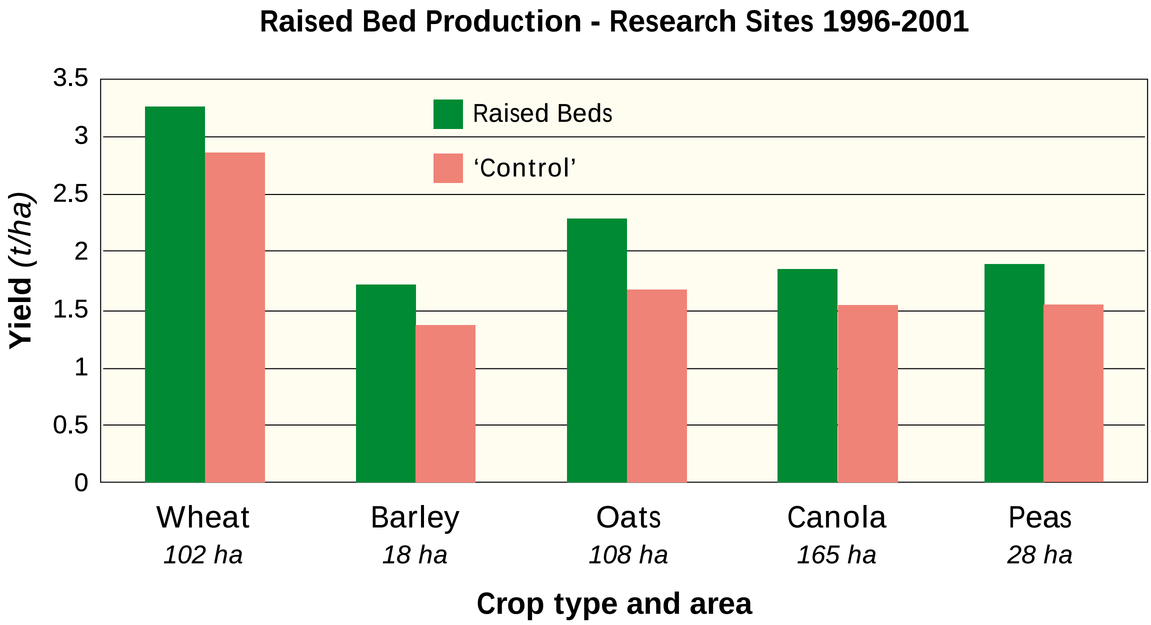


Figure 22. *Average crop yield increases obtained from paddock-scale experimental sites from Beverley to Esperance over the period 1997-2001.*

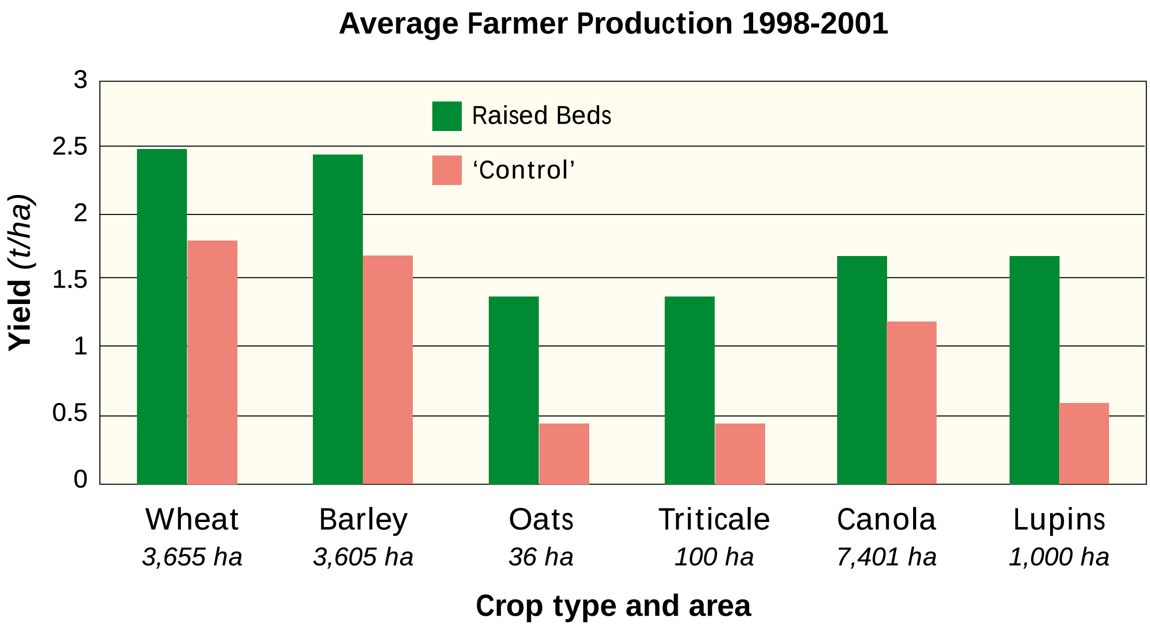


Figure 23. *Average crop yield increases obtained by Raised Bed farmers for a range of crops over the period 1998~2001.*

No-till crop establishment

The use of no-tillage crop establishment practice is essential for farming Raised Beds. There are five soil management objectives that require the use of no-till crop establishment practices on Raised Beds. These are:

(i) to maximise the retention and build-up of the organic matter of roots and their associated soil organisms to stabilise weak or dispersible soil structure (Figure 24);

(ii) to retain the large pores created by roots and their associated organisms to enhance rapid infiltration and aeration of the root zone (Figure 25);

(iii) to retain the roots as 'reinforcing rods' to minimise or prevent subsidence of the Raised Beds in wet conditions;

(iv) to minimise disturbance and 'spray' of soil during cultivation and seeding to avoid the need to re-shape beds to restore their original height and width (Figure 26); and

(v) to aid the control of weeds by minimising inter-row soil disturbance (and germination).

Whilst minimising soil disturbance at seeding is desirable, there are good reasons to ensure ***some*** disturbance occurs around the seed placement zone.

These reasons are:

❖ 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 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 (Farmnotes 71/96 and 72/96).

Furrows

People unfamiliar with Raised Beds become concerned with the proportion of land occupied by furrows. Unseeded furrows are ***perceived*** to be a loss of productive land and therefore of potential productivity.

The area occupied by 0.45m wide furrows in a field of Raised Beds with centres at 1.83m is about 25%. *(In a field with beds at 2.00m centres furrows occupy about 22.5% of the total area.)*

Virtually all the data on increased grain yield from Raised Beds (Figures 22 and 23) has been obtained from crops that were sown only on the beds, whilst ***all yield response data*** are based on the ***total*** area of the paddocks, including beds and furrows.

Early in the development of this technology the furrows were sown in the belief that some plants were required in the furrows to maximise production and to prevent erosion in the furrows. Neither concern proved to be substantial.

Water flowing in furrows did not cause erosion.

More importantly, the yield from the furrows was very poor, probably because the floors and walls are compact and wet for protracted periods of time. Data collected to assess the level of production from the furrows revealed that two out of seven rows (or 29%) of the crop inputs placed in the furrows were producing only about 10% of the yield.

Furthermore, oilseed or legumes crops sown in the furrows had a high probability of being killed because their stems were damaged by tractor wheels during mid-season applications of fertiliser, herbicide or insecticide (Figure 27).

Figure 24. *Contrasting growth of canola plants and roots from a waterlogged normal seedbed (left) and second-year Raised Beds (right). Note the mass, size and depth of roots on the plant grown on Raised Beds.*

Figure 25. *Rainfall infiltration is greater in amount and depth in the root zone of previous crops.*

Accounting for 10% of the total grain yield from a paddock of Raised Beds coming from crop in the furrows means any yield increase from the total area is dominated by a considerably larger increase from the 75% of the area occupied by beds.

The seed and fertiliser inputs that may be placed in furrows are thus very clearly capable of returning much more grain and income if they are placed in the improved root zone environment of the beds.

Consequently, the standard recommendation is that furrows should not be seeded and the seed and fertiliser inputs that would be normally placed there should be placed in the beds.

Row spacing

There are two alternatives for using the seed and fertiliser that would otherwise be placed in the furrows:

(i) increase the seed and fertiliser rates that the rows on the beds receive without altering their spacing (that is, the five rows on the beds at 26cm spacing receive the seed and fertiliser normally supplied to seven rows at that spacing); or

(ii) increase the number of rows on the beds to seven by reducing their spacing to 20cm (that is, each row receives the same amount of seed and fertiliser).

Both combinations have been tried with no production advantage for either.

Some farmers prefer to have as many rows as possible on the beds to create as wide a crop canopy as possible across the bed and over the edge of the furrows.

There are, however, practical difficulties with seeding seven rows on the beds spaced at 1.83m. The space between rows has to reduce to 20cm (or on 2.0m spaced beds, 22cm). Such narrow row spacings make seed depth control highly dependent on the speed of seeding. At speeds greater than 8 km per hour, soil can be thrown by the trailing opener over the adjacent row, burying seed much deeper than intended. The operator needs to remain aware of this likelihood and pay special attention to maintaining a speed that does not deposit soil on adjacent rows.

The other difficulty is the much reduced stubble clearance of seeders with rows spaced at 20cm compared to 26cm.

Relative Productivity of the Soil in Raised Beds

Given that area of the tops of Raised Beds spaced at 1.83m centres with 0.45m wide furrows occupies 75% of the total area installed to beds, any yield increase means the soil in the beds must have a much greater productivity than a normal seedbed.

For example, a grain yield from beds that is equal to the grain yield from a normal seedbed indicates the productivity of the improved root zone conditions in the beds is 33% more productive than a normal seedbed, e.g.

(i) Normal seedbed and Raised Bed yield = 2.0t/ha: % relative increase of Raised Beds = zero%

Productivity of Raised Beds relative to a normal seedbed is

2.0(t/ha)/0.75 = 2.67t/ha, and the % relative productivity increase is

= [(2.67 – 2.0)/2.0] x 100 = 33%

(ii) Normal seedbed yield = 2.0 t/ha; Raised Bed yield = 2.5 t/ha; % increase of Raised Beds = 25%.

Relative productivity of Raised Beds is

2.5 t/ha/0.75 = 3.33 t/ha, and the % relative productivity increase is

= [(3.33 – 2.0)/2.0]x 100 = 67%

Conclusion: *Placing all seed and fertiliser in the deliberately engineered, improved soil conditions in Raised Beds (rather than placing a proportion in the furrows) produces a much greater return on the investment in crop inputs.*

Figure 26. *View of freshly sown Raised Beds. Note the disturbance is limited and the shape of the bed shoulders is retained.*

Recommendation

Leave the row spacing on the beds as wide as possible. Five or a maximum of six rows on the beds are much less risky than seven. Five or six rows on beds do not compromise seeding depth control or stubble clearance.

Rotations

The choice of a particular rotation of crops or crops and pastures is usually very much a farmer's preference. There is, however, a number of factors that ought to be considered in choosing a rotation:

- ❖ weed control;
- ❖ disease control;
- ❖ insect control;
- ❖ nutrition; and
- ❖ grain price.

Weed control

Crops sown with no-tillage seeders (that is, with minimal soil disturbance in the seeded row and none in the inter-row space) rely on herbicides and competition from the crop to control weeds.

However, the lack of inter-row disturbance in no-tillage seeding operations also contributes to weed control by restricting the germination of weed seeds in between the sown rows of crop.

In a no-tillage crop establishment regime, notwithstanding the likelihood of a lessened weed burden because of little or no inter-row cultivation, the possibility of herbicide resistant weeds developing is greater because of the sole reliance on herbicides to control weeds.

Rotations offer some advantages in controlling weeds by way of:

- ❖ the inclusion of broad leaf oilseed and pulse crops requires a wide range of herbicides to be used, thereby avoiding reliance on a single or small number of herbicides, and thus diminishing the risk of herbicide resistance developing;
- ❖ pasture phases allow the options of hard grazing, hay baling, spray topping or green manuring of either crop or pasture to reduce weed seed burdens; and
- ❖ the use of herbicide resistant crops such as triazine tolerant canola and Basta® resistant lupins allows greater use of broad spectrum herbicides (Farmnote 69/96).

Figure 27. *View of poorly productive canola growing in the furrows at South Stirlings in 2000. Note the furrow to the right has lost most of its plants because of traffic, and the furrow on the left has substantially poorer growth than the crop on beds.*

Disease control

Rotations provide the best and most effective means of controlling airborne and soil-borne crop diseases (Farmnote 68/96).

Crop rotations that include 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; and
- 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-till 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.

Management practices that reduce the amount and change the type of summer–autumn ground cover, by way of crop rotations and grazing, reduce the risk of insect damage to following crops.

Even when crop rotation is practised, appropriate seed dressings and sprays should still be used to ensure a high level of insect control (Farmnote 73/96).

Nutrition

The inclusion of a pulse crop in a crop rotation has long been advocated as a means of building 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) or lupins (Ch 10, p322 IN "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 briefly 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 probably always exert a major and perhaps final influence on the choice of rotation crops

During the term of the GRDC-funded WA Raised Bed project, crop choices were based on the need to meet the soil management objectives as well as obtaining a positive (not a maximum) gross margin income. Oats was chosen as a first crop to maximise root matter retention in freshly made beds. With the hindsight of a high level of confidence in the Raised Bed technology, this choice was probably unnecessary.

Crop fertilising

With the facility of an efficient surface water drainage system and the presence of compacted, water shedding furrows as traffic lanes, Raised Beds provide greatly improved all-weather access. This dramatically improves the opportunity for farmers to apply mid-season fertiliser applications at the optimum time.

This same facility plus the controlled traffic nature of the beds and furrows also offers the opportunity of:

- applying mid-season fertiliser dressings precisely on the sown rows of crop on the beds; and importantly,
- minimising fertiliser placement in the furrows.

Fertiliser that lands in furrows is unlikely to be used by the crop and is very likely to be transported off-site and become a nutrient pollutant to streams and rivers.

Spraying

Spraying programs for the control of weeds, diseases and insects in crops on Raised Beds are the same as those for crops grown on normal seedbeds.

The operational advantages that derive from the greatly improved access provided by compact furrows offer the opportunity for timing applications for maximum effectiveness and efficiency, as mentioned in the preceding text.

Swathing and harvesting

Harvesting crops on Raised Beds differs from harvesting on normal seedbeds ***only*** in terms of the constraints imposed by tracking the harvesting equipment in furrows.

For direct harvesting, these constraints impact only on the access to stationary or mobile grain bins or trucks. Only mobile grain bins with wheel track widths and tyre sizes that match the spacing and width of furrows are able to travel with the harvester. Stationary bins have to be placed on specially constructed access tracks, cross-drains, or at the end of the field on the headland or catch drain.

Crops that do not remain erect or which are harvested from swaths require some pre-harvest planning regarding:

- the timing of harvesting; and
- the placement and width of swaths.

Examples of crops that require specific harvest plans are peas and swathed canola and barley crops.

Peas

Pea crop harvest must be undertaken at a time when the condition of the crop facilitates the pick-up of vine. This will be as soon as the grain is at or slightly above the maximum allowable moisture content. At or slightly above this moisture content the stems retain some pliability and a pick-up harvest front can lift and capture any vine that has slumped into the furrows.

If harvest is attempted after the crop has passed this stage the stems will have dried to an extent that makes them brittle. A pick-up harvester front cannot lift pea vine in this condition. The stems break when lift is attempted and a considerable loss of grain can result from crop that has slumped into the furrows.

The use of a crop desiccant can provide some operational flexibility to manage the condition of the crop at harvest (Farmnote 3/99).

Swathed canola and barley

Effective swathing on Raised Beds requires a swather that places the swath on the top of a bed. This can be arranged by adapting the swather's opening to match the top of a bed. If a swath is not located squarely on top of a bed, some of it will fall into the furrows.

A swath that overhangs the furrows is unlikely to present a problem to lift and harvest ***provided*** it is harvested at the optimum time when seed moisture content is at or slightly above the limit and the straw is still a little pliable, as with peas.

If the swath placement is not wholly on top of a bed and the straw is too wet or too dry, its pick-up and threshing will be inefficient and harvest loss will be experienced.

Other options can be implemented where farmers have a large enough commitment to make them work. For example, one farmer in the Esperance district has configured his bed-former to build a 2.5m wide bed among beds that are 2.0m wide specifically to carry a swath and facilitate the harvest of barley.

Stubble management

Retaining stubble has some advantages and disadvantages. The advantages are:

- control of wind and water erosion;
- protection of the soil surface from raindrop impact;
- protection of emerging crops from sandblasting;
- conservation of soil moisture; and
- maintenance of soil organic matter levels.

The disadvantages, which represent management challenges, are:

- 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 and reducing spray effectiveness; and
- harbouring some diseases and pests.

In Raised Beds there is an additional management challenge – preventing or minimising the build-up of stubble in furrows. Stubble in the furrows of Raised Beds will impede water flow. Ponded water in furrows creates waterlogged conditions in adjacent beds, causing them to subside and lose their improved infiltration and aeration properties. In large storms furrow blockages may cause water to cover the beds and erode beds and channels.

Effective management of stubbles in Raised Beds is largely achieved by employing the same practices that are effective for cropping normal seedbeds (Farmnote 66/96).

Specifically, stubble is best managed in Raised Beds by:

- harvesting the crop high and subsequently harvesting stubble for straw, leaving erect stubble about 5cm high;
- harvesting crops low, leaving erect stubble about 15cm 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;
- leaving a harvester trail that is subsequently baled or burnt; and
- grazing stubbles after harvesting them low.

If, despite employing one or a combination of these management options, stubble build-up occurs in the furrows of Raised Beds, clearing them with a furrower, either as a separate operation or at seeding, will be required. The latter can be achieved by mounting furrowers on the rear of a seeder bar.

5. Machinery requirements for Raised Bed Farming

The machinery needed to crop Raised Beds requires ***only*** one additional, specialised implement. This is a bed-former, which also converts to a bed-renovator. The remaining machinery is exactly the same as that needed to crop normal seedbeds, except for some minor adaptations to allow it to track in furrows and operate on Raised Beds.

Machinery that is adapted for bed farming retains all the capabilities needed to crop normal seedbeds. Every implement is inter-changeable. At most, minor adjustment may be needed e.g. re-alignment of seeding units for crop row spacing that does not allow for unseeded furrows.

The text that follows refers to the commonly used size of machinery to illustrate the best design features, set-up and operation. Machinery size and method of hitch to the tractor are not critical and can be easily adapted according to the scale of operation, type of farming and existing machinery on any farm.

Track width and tyre size choice

The objective of Raised Bed Farming is to create and maintain soil conditions that will allow soils to drain and aerate and so prevent waterlogging. The operation of farm machinery must be consistent with this objective if the investment of time, effort and dollars put into Raised Beds is to gain maximum return.

The single most influential change in management to achieve this objective is a commitment to adapting the trackwidth and tyre size of machinery, as this will ensure absolutely no traffic compaction is imposed on the soil in the beds. A 100% controlled traffic regime is a pre-requisite to maximising the performance of, and return from, Raised Beds.

There is no single best track width and tyre size (that is, bed spacing and furrow widths) ***provided*** soil conditions in the beds are created that ensure they will drain and aerate. The choice can and should be made on the basis of practicalities and cost.

The choice of a standard trackwidth and tyre size for machinery used for Raised Bed Farming depends on:

(i) the difficulty and cost of adaptations;

(ii) the versatility of adapted machinery;

(iii) the return on the investment of time and effort; and

(iv) the re-sale value of adapted machinery.

The following text outlines the reasons why a 1.83m (6ft) trackwidth and 0.45m (18inch) tyre size are the preferred choice for Raised Bed 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 2.0m centres or multiples of this figure, will not be easy or cheap, e.g.

Wheel Tractors: The standard trackwidth is 1.83m. Conversion to 2.0m is simple. Either move the wheels on the axle, or reverse the hubs. Conversion to 3.0m requires costly, factory certified axle extensions.

Sprayers: The wheel trackwidth on self-propelled machines is continuously adjustable. Trailing tank-type sprayers can have their axles easily and cheaply extended.

Swathers: Newer self-propelled models may have their trackwidth adjusted. Trailing power take-off models can have their tractor hitch adjusted and their guage wheels re-aligned

Harvesters: Adjusting the trackwidth of harvesters to span two 1.83m beds or 3.66m is easily achieved by moving the mounting disc inside a narrow rim. Adaptation to 4.0m requires costly, factory certified extensions of axles and their housing.

Conclusion: The choice of a Raised Bed width of 1.83m and machinery trackwidths to match this dimension or multiples of it (compared to trackwidth choices of 3.0m or 2.0m) involves no modifications to tractors and self-propelled sprayers, and only simple and relatively inexpensive adaptations to harvesters and trailing sprayers and swathers.

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 tonne. Tyres and rims of ≤ 0.45m width (18") 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 0.45m width have more than enough load carrying capacity for harvesters and are easily fitted to them. With lessened pressure they have adequate flotation on soft soils.

Summary

The choice of trackwidths of 1.83m and multiples of this width and 0.45m tyre width require no factory approval to retain the manufacturer's warranty and are the best against all of the criteria:

- *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 raised beds
- *Re-sale value of adapted machinery:* Unaffected. Wheels can be changed back to originals.

A bed spacing of 1.83m (or 6ft) and a furrow width of 0.45m (or 18") are the most practical and economic choices. They require less complicated and much cheaper adaptations to farm machinery.

Bed-forming and renovation

Cost

Bed-formers can be supplied as three-point linkage or trailing models. New machines will cost between $30,000 and $40,000, depending on the variety of detachable components purchased to add to its versatility.

Some farmers have made their own bed-formers by converting old rippers/deep cultivators. These often have hydraulic stump-jump rams on their ripper shanks. Mostly they are trailing machines and the cost of a second hand ripper and its conversion to a bed former is about $12,000 to $15,000.

The old rippers that have been converted to bed-formers lack the versatility of the specially made machines. In particular, their framework limits options for rearranging components to allow the machine to renovate existing beds.

Specifications

The most common size of bed-former is one that is 7.32m wide. A machine of this width makes three full beds and two half-beds. It has four ripper shanks, each of which has left- and right-hand listers bolted on to them to make furrowers. The two half-beds are outside the first and fourth furrowers, on the outside of the left and right ends of the bar (Figure 28).

This configuration maximises the number of beds made with each pass of the machine. The returning adjacent pass of the bed-former adds the second half to the half-bed made on the previous pass.

Grader blades are mounted at a 35 degrees angle to the direction of travel and positioned behind both sides of the furrowers. These gently spread soil excavated by the furrowers across half the intervening soil that becomes the raised bed. The spoil excavated into the space between adjacent furrowers is graded to the centre of the bed by opposing grader blades.

The depth of the furrowers and height and rake angle of the trailing grader blades are all adjustable. In addition, the position of the furrowers and grader blades on the bar are adjustable sideways, in case the spacing of the furrowers or the grader blades needs to be changed.

The machines also come with gauge wheels and adjustable marker arms (Figure 29).

Set-up and operation for bed-forming

Adjustments need to be made to the gauge wheels and the height and rake angle of the grader blades when setting up the bed-former for operation.

Figure 28. *Rear view of a 3-point linkage bed-former. Note the gauge wheels, bracketed attachments, grader blades, half beds at either extremity of the bar, marker arms and square shoulders of the beds.*

The gauge wheel setting determines the height of the beds and depth of the furrows. The gauge wheels need to have their setting determined when the machine is in the ground for a position to be selected that ensures the furrowers excavate to the base of the cultivation.

When operating, the bed-former should be horizontal from front to back, and this is controlled by the three-point linkage setting relative to the gauge wheel depth. Once the gauge wheel depth is set and the machine levelled, the height and rake angle of the grader blades can be adjusted.

The setting of these needs to ensure:

❖ the leading edge of the blades is close to and inside the outer edge of the furrower;

❖ the height above the base of the furrowers allows the blades to comfortably carry the volume of soil excavated without the soil overflowing the blade or running out of soil in the centre of the beds;

❖ the rake angle allows easy flow with a minimum of bulldozing (a rake angle of 35 degrees from the direction of travel will suit most soil types and moisture conditions);

❖ the gap between the trailing ends of blades pushing soil from both sides of the bed is about 15cm to allow excess soil to pass; and

❖ the trailing ends are set about 50mm higher than the leading end to build a small crown in the centre of the beds.

The grader blades settings are best arranged to leave a trail (or windrow) of excess soil to ensure there is no hollow in the centre of the beds.

Most farmers drag a length of 75 to 80mm diameter galvanised pipe behind the bed-former as a final smoothing tool. This is attached by short lengths of chain, and knocks down any windrow of soil leaving the top of the beds flat.

The marker arms ***must*** be set very accurately. Attention to this detail ensures the beds on the outside of the machine (which are made from two halves by adjacent passes of the bed-former) are the same width as the three beds made by the centre of the bed-former.

The furrow gouged by the disc on the marker arm should be ***exactly*** four bed widths from the centre line of the bed-former bar (7.32m for 1.83m wide beds). This distance needs to be measured and set when the bed-former and marker arms are working at the chosen depth, with the full draught of soil on the arm.

To set the marker arms to leave a gouge in the soil exactly four bed widths (7.32m) from the centre of the bed-former, make an initial adjustment to both arms and test their setting by doing a short bed-forming run with both arms operating. At the end of this run, say 100m, lift both arms and the machine out of the ground, turn around and return along the same tracks with both arms again in the ground. If the settings are correct, the gouge lines made by both arms on the return run will coincide with those made on the first run and be ***exactly*** 7.32m either side of the tractor's centre and 14.64m apart.

A second pass with the bed-former is often desirable when constructing beds. This ensures all the beds have the same depth and fullness and the base of the furrows is reasonably compact.

Figure 29. *Side view of bed-former showing the positioning of components and scour pafferns on furrowers and grader blades indicative of a properly set up machine.*

Remember that Raised Beds are virtually permanent, and well-constructed beds mean fewer operational problems, which means greater productivity and profit.

When doing a second pass or renovating beds for the first time, the three-point linkage height will need to be adjusted. This is because this working, unlike the construction pass, will be done with the tractor wheels on the same level as the gauge wheels. *(When constructing beds the tractor wheels run on the unbedded, loose tilth, and the furrowers must excavate to a greater depth - the base of the prepared soil, approximately 27cm.)*

Renovation objective

Loosened soil, as farmers well know, subsides or re-consolidates over time. This re-consolidation is a natural process driven by the low strength of wet soil and the weight of wet soil (or overburden pressure).

The rate of re-consolidation is dependent on soil texture, drainage of the soil and wetness of the season. In some soils and seasons re-consolidation can occur rapidly, for example, 60% to 80% reconsolidation can occur in one growing season.

Without some form of regular renovation all loosened soils will reconsolidate. Regular loosening is required to maintain the loose conditions. This may not be needed every year, but is best done every year between harvest and seeding.

The renovation of Raised Beds presents four management challenges:

- ❖ zero soil inversion, or no mixing of topsoil and subsoil;
- ❖ retention of roots, stems and leaves with as little disturbance as possible;
- ❖ cleaning and compacting furrows to ensure they empty all water and retain trafficability for in-crop operations during the next winter; and
- ❖ meeting the above challenges with a low cost operation.

The first and second of these challenges can be successfully overcome by using equipment that was developed specifically to minimize 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 loosened 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 vertically about 1cm to 2cm causing it to break open before it falls back in place. No soil inversion occurs, and any roots are cut and remain in place.

The wavy coulters mounted in front of the ripper shanks cut any straw or vine, preventing build-up of vegetation on the shanks. These coulters also reduce soil heave upwards from the point of the rippers and reduce the draught on the shanks.

Figure 30. *View of bed-former set up with renovation tools - wavy coulters and ripper shanks with mulch sweeps.*

Suspended disc harrows mounted on the rear of the bar have adjustable height and rake. They are set to lightly break any surface crust on the soil and clear to one side any prostrate stubble prior to seeding the next crop (Figure 31 and 32).

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 (see Figure 20).

The maintenance of the loose condition has been confirmed by bulk density measurements that have not varied from year to year (Figure 25).

Renovation also cleans and reshapes the furrows, ensuring the flow of drainage and runoff water remains reliable and efficient.

Renovation is necessary whenever:

- ❖ the beds have been damaged by traffic or grazing and have lost their flat-top, square-shoulder appearance;
- ❖ when they have subsided and become compact; and
- ❖ when the furrows have lost their depth and/or have accumulated soil and trash that impedes the flow of water.

Set-up and operation for bed renovation

The preferred method of renovating beds is to loosen the full width of soil in the bed as deeply as possible, that is, to a depth level with the base of the furrowers, which remain on the bar for the renovation.

To set up the bed former bar for renovation the grader blades are removed and two narrow ripper shanks per bed are mounted on the front bar 36cm either side of the centre line in each bed. These rippers are set to the same working depth as the furrowers.

Left- and right-handed sharply raked mulch sweeps are mounted at the base of each ripper. These have a rake angle of 35 degrees and no tilt from mount-to-tip or from front to back edges (Figure 30).

The mulch sweeps act as very gentle blade ploughs, cutting roots and lifting the soil by only about 2cm as it passes over the blades.

These components cause no soil inversion, and the loosening that results from the soil being lifted and dropped extends to the surface.

Field testing of this device has revealed the soil contact with roots remains so good that plants cannot be pulled out by hand. Indeed, when used beneath a maturing oats crop there appeared to be no adverse effect on the crop as it continued through to maturity and harvest without any signs of setback.

Two additional components are, therefore, preferably attached to the bed-former bar in renovation mode:

- ❖ wavy coulters in front of the ripper shanks; and

Figure 31. *Rear view of a bed-former renovating beds. Note suspended disc harrows breaking the soil crust and the looseness of the beds from shoulder to shoulder*

- gangs of suspended disc harrows on the rear of the bar.

The wavy coulters are mounted in front of the ripper shanks. Eight sets of disc harrows (two sets per bed) are suspended on the rear of the tool bar (Figure 31).

The suspended gangs of disc harrows should be set to:

- have very little or no angle;
- have only a shallow penetration of about 2cm; and
- track in the inter-row space of the previous crop.

Seeding

Seeding crops or pasture on Raised Beds presents different operational challenges to those experienced on normal seedbeds. These occur because Raised Beds are:

- elevated;
- soft;
- sometimes uneven if damaged or poorly made; and
- stubble covered.

These conditions make greater than normal demands of seeder design and performance. Much less penetration capability is required of the seeder, but seed placement and depth control mechanisms have to more precise. The seeding units, on soft soil with little load bearing capacity, must respond ***rapidly*** to larger than normal changes in elevation. As well, seeders need to be able to clear stubble without any reduction in their seed placement capabilities.

Preferably, a Raised Bed seeder will have the following attributes:

- gauge wheels that fit in furrows spaced at multiples of 1.83m (or 6ft);
- gauge wheels with the capability to raise the openers 30cm to 40cm above the base of furrows;
- openers that spray enough soil to incorporate pre-emergent herbicides;
- fertiliser delivery mechanisms that place fertiliser away from the seed, and mix it with soil, to avoid fertiliser toxicity effects on young plants;
- seed delivery mechanisms that have variable press wheel pressure settings and flotation that responds rapidly to changes in the elevation of soft seedbeds.

In addition, the seeder must not disturb soil to the extent that:

- roots from previous crops are torn out;
- bed shape is modified; or
- soil is thrown into furrows.

As with most agricultural machinery, no one machine has all these specific capabilities plus the versatility to move from Raised Beds to normal seedbeds with only minor adjustments to its set-up. Management skill has to overcome any shortcomings.

Usually, the management choices made to overcome inadequacies in the capabilities of seeders used on Raised Beds come from one or a combination of:

- reducing stubble or pasture prior to seeding (by grazing, raking and burning or baling);
- seeding in the inter-row space of the previous crop;

Figure 32. *Renovated beds at Woodanilling, showing the retention of stubble and the reshaping of the beds and furrows, in additioin to the loosening of the soil in the beds.*

- ❖ choosing optimum moisture conditions at seeding;
- ❖ adjusting the speed of seeding;
- ❖ adjusting press wheel pressures to suit the soil moisture conditions;
- ❖ changing the mechanism used to cover the seed; or
- ❖ running the seeder gauge wheels on top of the beds.

Using the first and last of these management options will damage the shape and condition of the beds and increase the need for renovation. They are ***not*** recommended.

The operational choices that contribute most to improving the efficiency of seeding Raised Bed crops are those that minimise damage to beds and maximise stubble clearance, specifically:

- ❖ changing the track width of the air seeder and seeder bar to match the spacing of furrows so that ***all*** wheels track in the furrows;
- ❖ adjusting the position of the openers so they track in the inter-row space of the previous crop;
- ❖ choosing soil moisture conditions at which stubble will break and/or slide off rather than stick to machinery; and
- ❖ operating at a speed that does not throw excessive amounts of soil.

Consequences of poor seeder choices

The consequences of poor seeder adaptation or operation can produce quite substantial reductions in crop production from Raised Beds.

The smallest impact comes from damage caused by tracking on the beds.

Machinery inadequacies or poor operation can cause substantial reductions in crop establishment through poor seed placement and inadequate seed-soil contact that may extend the entire length of a run. Such consequences can occur where, for example:

- ❖ slumped or compacted bed surfaces are at the lower extremity of opener travel;
- ❖ openers slide off the top of the beds onto the shoulders; or
- ❖ stubble prevents closure of the sown row and causes poor seed-soil contact and establishment.

Just one row per bed will reduce establishment by one-seventh in a 7-row bed, and this can translate directly to a yield loss of this magnitude.

Our choice of seeder

Our seeder has evolved through the experience gained in farming Raised Beds and observing farmer approaches and experiences (Figure 33 and 34).

Figure 33. *View of our hybrid seeder specially set up for seeding Raised Beds. Note the wavy coulters and parallelogram seed placement and press wheel assembly.*

Figure 34. *The hybrid seeder operating in raised beds at Woodanilling. Note the retention of the shoulder during seeding.*

Figure 35. *A farmer's Raised Bed seeder. The bar was specially built to fit the beds. It has triple disc seeder units. The air-seeder has not been adapted to fit the furrows. It tracks on top of the beds.*

The general properties of our seeder are:

- ❖ a bar on which the openers are easily moved;
- ❖ gauge wheels that track in the furrows;
- ❖ wavy coulter openers that are angled at about 5 degrees to the direction of travel;
- ❖ a fertiliser delivery mechanism that drops the fertiliser into the trench cut by the wavy coulter;
- ❖ a parallelogram seed delivery-press wheel assembly that closes the trench, places seed above the fertiliser and presses soil on top of the seed; and
- ❖ a parallelogram that has a rapid and large vertical movement and adjustable press wheel pressure.

These capabilities make the seeder versatile and efficient in a wide range of soil conditions. Avoiding sticky moisture conditions to minimise soil build-up on the wavy coulter is not a problem in beds that are loose and well drained because the 'sticky point' moisture condition is short-lived.

Stubble clearance remains the most problematic operational concern because the beds are soft, and stubble is very difficult, if not impossible, to cut in soft soils.

Farmer experience

Most farmers who have adopted Raised Bed farming use triple disc or no-till disc seeders (Figure 35) and have adjusted the position of gauge wheels so they track in the furrows.

Some use tined seeders and operate at a relatively slow speed.

Moving openers to sow in the inter-row space of the previous crop is also common.

Spraying

There are only two issues about spraying crops on Raised Beds that require some adjustment in practice from those used on normal seedbeds. These are

- ❖ matching the track widths of spray vehicles to furrows and
- ❖ matching boom widths to whole numbers of beds in each pass of the boomspray.

Self-propelled boomsprays generally have narrow tyres that fit 0.45m (18") wide furrows and track widths that can be easily adjusted to 3.66m (12ft) (Figure 36).

Smaller towed spray units (Figure 37) may require track adjustments to both the vehicle and the spray tank. This is relatively simple and pays substantial dividends in terms of operator comfort and efficiency. The adjustments are not costly and result in improved weed and disease control.

Boomspray matching has two issues that need to be taken into account by operators.

- ❖ Avoiding overlaps and misses: The spray boom width should be adjusted to spray a ***whole number*** of beds, including furrows, with each pass. This width should cover the same number of whole beds on both sides of the track width of the sprayer;
- ❖ Marking the track for each pass: The ***centreline*** of the sprayer's trackwidth should be marked so the driver passes over this mark secure in the knowledge that the end of the boom on one pass coincides with the end of the boom on the next pass.

Figure 36. *View of a self-propelled sprayer in Raised Beds. Note that the track width of this 90ft boom spans two beds and has 6 beds on one side and 7 beds on the other. Six feet (one bed width) of the boom was shut-off so the boom covered 6 beds each side of the tank and cabin.*

Figure 37. *A towed spray tank in beds at Woodanilling. Its trackwidth is compatible with the 1.83m bed spacing.*

- ❖ Knowing the whole number of boomspray passes for each area of Raised Beds: If possible, farmers should adjust the length of the boom to ensure there is a whole number of full boom width passes across each area of beds. If this is not possible the boom length must be adjusted for the last pass.

Fertilising

Applying mid-season fertilizers in the precise controlled traffic regime of Raised Beds becomes a risk-free operation that can be done on time, virtually irrespective of soil moisture conditions, because of the assured trafficability of the unsown furrows.

The application of fertiliser can also be done accurately with a very large percentage of granules placed in the sown rows, especially when compared with the distribution achieved by the common spinner-type spreader. Air seeder powered fertiliser applicator booms can be easily manufactured in the farm workshop and mounted on the rear of the tractor (Figure 38). Alternatively, soluble fertilizers can be applied using towed or self-propelled sprayers.

Applying mid-season fertiliser dressings to a field of Raised Beds using either an air-seeder boom or a boomspray offers some very significant gains in operational efficiencies:

- ❖ timing of applications can be optimised because access onto fields in mid-winter is assured by compacted, drained and trafficable of furrows;
- ❖ fertiliser is placed ***only*** on the beds which virtually eliminates the off-site transport of nutrients in runoff water; and
- ❖ a very high percentage of fertiliser granules are placed in the sown rows, greatly increasing plant utilisation of the fertiliser.

Swathing

Ideally the trackwidth of swathers should be adjusted to match the spacing of Raised Bed furrows. Early model self-propelled swathers are impossible to adapt because their wheels are mounted ***inside*** their frame. The latest self-propelled models have their wheels mounted ***outside*** their frame and can thus be easily adapted. Power take-off swathers require the alignment of the tractor and swather wheels, but this is not difficult.

Another option that is acceptable because of the light-weight of swathers is to drive them on top of the beds. However, damage will be done if the soil in the beds is wet.

Of more practical significance and cost if not done properly is the alignment of swaths. The swath must be placed as near as possible on the top of a bed or beds (Figure 39). This alignment needs to be compatible with the alignment of the pick-up front on harvesters whose track width spans two beds.

Figure 38. *View of a fertiliser bar that makes use of the air seeder (tractor mounted in this case) for applying mid-season fertiliser dressings with high precision in Raised Bed crops.*

Figure 39. *Canola swath placed on top of a Raised Bed.*

Figure 40. *Fitting 18" dump truck wheels to a John Deere 9600 harvester in the paddock. Note the position of the mounting disc inside the rim and the alignment of the driving and steering wheels.*

Swaths placed on top of beds are easily and completely picked up by efficient pick-up fronts provided the crop and swath are not too heavy and the moisture content is near optimum.

Harvesting

Need for adaptation

Today's harvesters are bigger than ever. When empty they weigh about 10 to 12 tonnes. When full with grain they weigh 20 to 24 tonnes. They are by far the heaviest piece of machinery to traffic agricultural soils.

Even when soils are dry and have a relatively large load bearing capacity, the compaction caused by harvesters is considerable.

Running a harvester on Raised Beds, whose soft and porous condition has been deliberately engineered to enhance drainage and aeration, has two deleterious consequences:

(i) the shape of the bed and shoulders is considerably dented, making the surface uneven, predisposing it to crop establishment problems and consequent possible loss of yield; and

(ii) the internal drainage and aeration properties of the beds are reduced substantially, which diminishes their capacity to avoid waterlogging.

Track width alignment

Harvesters are relatively simply adapted to a trackwidth of 3.66m (two bedwidths) with 0.45m wide tyres. Almost all harvesters are manufactured in the USA and have imperial measurements of feet and inches as the basic design and manufacturing dimensions. Consequently, the hub-to-hub width of their drive wheels does not vary greatly between models and makes. Most modern harvesters have hub-to-hub widths of 3.2 to 3.4m or 10.5 to 11ft.

These dimensions provide scope to move the mounting disc to one side of centre of even narrow rims and so widen the track width to 3.66m or 12ft.

Note: Where beds of 2.0m width are chosen, increasing the track width of harvesters to 4.0m, to span two beds, is much more difficult and expensive. Extensions to axles and axle housings are required.

Tyre width matching

The mining industry has many pieces of very heavy machinery that use narrow rims and tyres and is an obvious source of rims and tyres to carry the weight of a fully laden harvester on narrow tyres.

Dump truck tyres and rims that are 0.45m (18") wide can be obtained from the mining industry, either new or second-hand, to convert harvester track widths and tyres sizes.

Hub-to-hub dimensions of harvesters must be known to make this conversion, because the mounting disc for the 0.45m rim must be welded in the correct position to ensure the centre-to-centre width of the tyres when mounted on the harvester is 3.66m.

When wheels with these rim and tyre sizes are available they can be placed on harvesters quickly and simply (Figure 40).

> ***Liability and Warranty Concerns***
>
> *Approval for these conversions was sought from Motor Registry authority and the manufacturer to ensure the responsible authorities regarded them as legally acceptable and did not void manufacturer warranty conditions. Both approved of the adaptations. John Deere was the relevant manufacturer in our case.*

The rear steering wheels of most, if not all, harvesters are 0.45m wide and the axles are extendable making their adjustment to fit furrows 3.66m apart straightforward.

Cost

Using new tyres and rims for this conversion cost $12,000. One farmer has used second-hand rims and tyres from the mining industry and converted a John Deere CTS harvester for a total cost of about $1,800.

Harvest operations

Once converted, harvesters are operated normally in Raised Beds, and they can handle a wide variety of crop types (Figures 41 and 42). However, there are two harvest related issues to be considered when laying out the beds and drains. These are:

(i) the length of beds and the capacity of the harvester grain bin; and

(ii) access for field bins and trucks for harvesters to off-load.

Bed length should not be so long that there is a high probability a harvester will fill up midway along a run. Also, Cross Drains should have broad-based mounds in their centres to provide access for field bins or trucks and space for harvesters to off-load.

Figure 41. *View of converted harvester operating in a cereal crop at North Stirlings.*

Figure 42. *Converted harvester in a pea crop at Woodanilling. Note that the pea vine is being easily lifted.*

6. Economics of Raised Bed Farming in Western Australia

Conditions for an economic analysis

Raised Bed Farming is demonstrably successful in eliminating waterlogging. It removes the risk of very substantial income losses from crop yields diminished by waterlogging. In areas that are highly prone to waterlogging these losses are often real, not just less profit, but negative gross margins or actual dollar losses.

Farmers seeking to decide whether to adopt Raised Bed Farming should be concerned about the ability of this technology to pay for itself, particularly if monies have to be borrowed to make the change.

For these reasons, and because:

- Raised Bed Farming is a very different way of integrating soil and water conservation into a farming system; and
- it requires a considerable level of planning and capital investment,

an investment analysis approach has been used to assess the economic wisdom of adopting Raised Bed Farming on land prone to waterlogging.

This analysis examines the ability of an investment in Raised Beds to generate enough ***extra*** income to repay all the costs associated with their installation and operation, that is, the costs ***over and above those normally incurred*** with cropping the area where the beds are to be installed.

The additional costs associated with Raised Bed Farming include:

- purchasing a specialised bed-former;
- installing Raised Beds and associated drains (surveying, ripping, cultivating, bed forming and drain construction); and
- adapting the track width and rim and tyre sizes of tractor, seeder, sprayer, swather and harvester to match the spacing and width of furrows.

Associated costs include the interest bill on monies borrowed to pay for the machinery and the installation of beds and drains.

The analysis used to evaluate the economics of Raised Bed Farming assumes that a $50,000 loan with a 10% interest rate is borrowed to fund all aspects of adopting this technology.

The costings are based on the experience of the research team and early adopting farmers. They are:

- surveying (if necessary), preparing the soil and constructing the Raised Beds: $50/ha; and
- installing drains: $2,000/100 ha, or $20/ha, although this amount is very site dependent.

Other conditions of the analysis are deliberately chosen to be conservative.

- Loan repayments (principal and interest) are made ***only*** from the ***extra*** income above the gross margin from crops grown on ‘normal’ seedbeds. ‘Normal’ gross margin profits are assumed to be used elsewhere.
- A continuous crop rotation of *canola, barley, peas* or *lupins*, and *wheat* is imposed.
- The extra income from Raised Bed Farming is calculated from ***actual yield*** increases for specific crops obtained by the research team and farmers.
- The research data are drawn from experiments undertaken from 1996 to 2001 at Beverley, Toolibin, Woodanilling, Badgebup, Cranbrook, Mt Barker, South Stirlings and Esperance. The soils of these sites include fine sandy clay loam over clay (grey clay), sandy loam over clay, gravelly sand over clay, and a water-repellent sand over clay.
- The farmer data are from crops grown between 1998 and 2001. The majority come from the Esperance district, which has a sand-over-clay soil type. Other data come from Green Range, Scott River, Tambellup and Woodanilling where the soil types are sand-over-clay, gravelly sand and sandy loam over clay.
- Commodity prices for each crop type are taken from the *2001 Farm Budget Guide*, and are assumed to remain constant for the 10-year duration of the analysis.

Scenarios

The investment potential of Raised Bed Farming is calculated from the cashflow generated from three rates of expansion in the area of Raised Beds over a 10-year period.

One analysis uses production increases generated by research sites. Another uses production increases obtained by farmers.

Two maximum areas and three annual rates of expansion in the areas of Raised Beds are used:

- 500 ha with a 50 ha/yr-expansion rate;
- 1,000 ha with an expansion rate of 100 ha/yr; and
- 1,000 ha with an expansion rate of 200 ha/yr.

Costing Details

Machinery

Bed-former	$ 30,000
Tractor adaptations	$ 3,000
Seeder, sprayer adaptations	$ 5,000
Harvester adaptations	$ 12,000
Total	**$ 50,000**

Raised Bed installation

Surveying and bed construction	$ 50/ha
Drain construction	$ 20/ha
Total	**$ 70/ha**

The extra income from crops grown on Raised Beds repays the principal and interest on the $50,000 loan, ***plus*** the costs of each annual increment of expansion in the area of Raised Beds.

Results

Production Data

The average yield increase data used in this analysis are presented in Figure 43 (research data) and Figure 44 (farmer data). The research sites had replicated areas of Raised Beds and normal seedbeds (Controls). The research data do not include data from sites where agronomic problems occurred. They reflect the benefits attributable only to the imposed soil and surface water management practices. The farmers' average paddock yields are from records kept of grain harvested from areas of Raised Beds and normal seedbeds surrounding the beds, that is, headlands and 'sidelands'.

Raised Bed Production - Research Sites 1996-2001

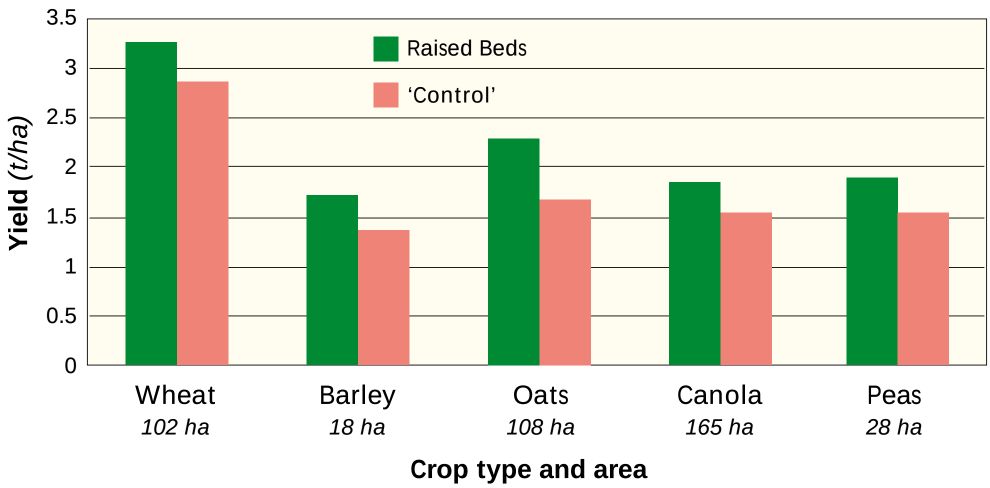


Figure 43. *Average grain yields of crops grown on research sites. The overall average yield increase was 0.47 t/ha.*

Average Farmer Production 1998-2001

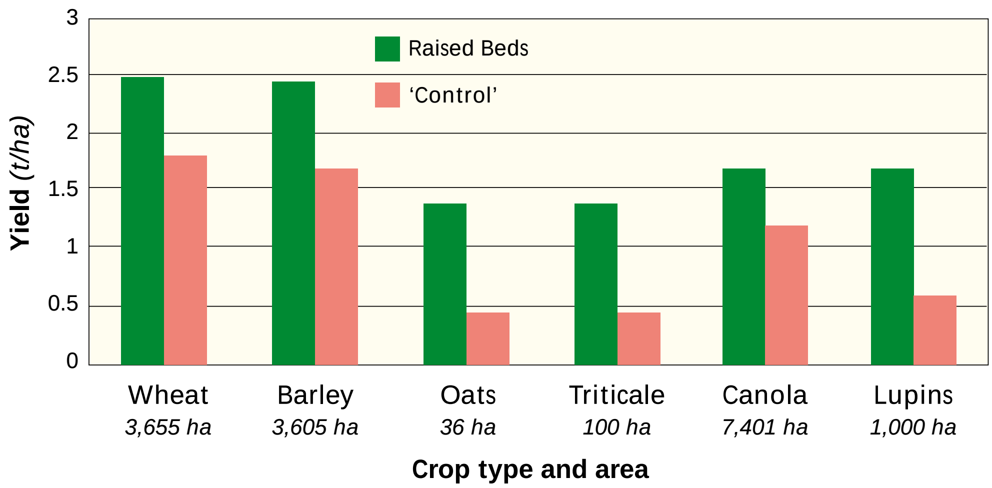


Figure 44. *Average grain yield of crops grown on farmers'properties. The overall average yield increase was 0.87 t/ha.*

Extra income per hectare

The average yield increases for each crop type from the research and farmers' data sets are converted into ***extra income per hectare*** using grain prices quoted in the 2001 Farm Budget Guide (Figure 45). These dollar values are used in the cashflow analyses. The average amount of extra income from Raised Beds using the research data is about $104/ha. The average extra income calculated from the farmers' data is approximately $183/ha.

Cashflow analyses

Annual cashflows are generated for the three rates of expansion of Raised Beds using the research and farmers' data sets. These are used to calculate the Internal Rates of Return on investment over 10 years for the circumstances of each scenario (Table 1).

Table 1. *Internal rates of return (IRR) for Raised Bed adoption scenarios*

Adoption scenarios	IRR
Research data	
a) 500 ha Raised Beds at 50 ha/yr	-1%
b) 1,000 ha Raised Beds at 100 ha/yr	20%
c) 1,000 ha Raised Beds at 200 ha/yr	42%
Farmer data	
a) 500 ha Raised Beds at 50 ha/yr	26%
b) 1,000 ha Raised Beds at 100 ha/yr	56%
c) 1,000 ha Raised Beds at 200 ha/yr	105%

As all the cashflow examples start with the same assumed borrowings and costings, the Internal Rates of Return (IRR) in Table 1 illustrate the value of installing larger areas of Raised Beds sooner rather than later. This generates larger amounts of additional income sooner, allowing the loan to be repaid sooner. As a result the interest bill is smaller and farm profits are larger.

A rapid rate of expansion in the area of Raised Beds is particularly financially beneficial, or even necessary, if the total area for which they are required is relatively small.

Facts to consider

The conditions used for these analyses that make the results conservative are worth remembering.

- Only the ***extra*** income from increased grain production on Raised Beds was used to repay the loan that financed the adoption of Raised Bed Farming. Income from other farm profits was not used.
- Installing Raised Beds on land prone to waterlogging ***returns*** that land to a profitably productive state and enlarges the area of cropping programs. The financial benefits from an enlarged cropping program are not included in the analysis.
- The extra profit that comes from land that was previously degraded and generated little or no profit causes;
  - the value of the previously waterlog-prone land to increase; ***and***
  - the technology prevents future expansion of waterlogging and associated forms of land degradation.

(These positive consequences of adopting Raised Bed Farming ***are not*** *included in the analyses.)*

- The research data probably represent a lower limit for improved productivity and profitability expectations. The farmer data probably represent an upper boundary to increased productivity and profitability expectations. These were dominated by results from the Esperance district, which experienced a larger number of wetter-than-average than drier-than-average seasons.

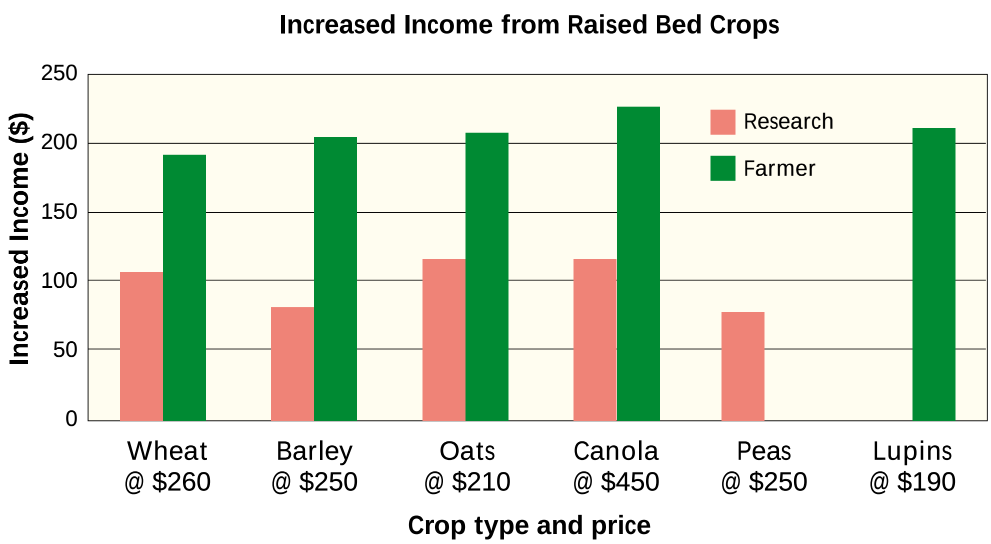


Figure 45. *Extra income from yield increases on the research sites and farmers' Raised Beds. Commodity prices were obtained from the 2001 Farm Budget Guide.*

Conclusions

1. Raised Bed Farming prevents waterlogging and substantially increases the productivity of land previously prone to waterlogging. Crop yields are more reliable and yield and profit are increased.
2. The profitability of Raised Bed Farming makes the capital investment necessary for its adoption profitable even when the necessary finance is borrowed.
3. Where land is suited to Raised Bed Farming and loans are required to purchase and modify machinery, larger returns on investments will be gained by maximising the rate of installation ***and*** the total area installed to Raised Beds.

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