Permanent raised bed cropping in southern Australia: practical guidelines for implementation

B. Wightman, R. Peries, C. Bluett and T. Johnston

Department of Primary Industries, PO Box 103, Geelong Vic. 3220, Australia; email: renick.peries@dpi.vic.gov.au

Abstract

When Southern Farming Systems (SFS) (a partnership between farmers, agribusiness and the research and development workers of the Victorian Government) began in southern Victoria in 1995, its primary aims were to develop a system of farming that would both reduce the prevalence of waterlogged crops and improve soil structure in crop paddocks. After many years of trying to grow crops in southwestern Victoria, it became evident that consistently good crops could only be achieved on paddocks with well-drained and well-structured soil. By addressing these issues SFS were confident they could improve yields and substantially reduce the risks associated with crop production in this region.

After some preliminary demonstrations and commercial work using various drainage techniques, including wide (20 m) raised beds and underground systems, the SFS decided to concentrate their efforts on a narrow raised bed cropping system incorporating controlled traffic to help drain the soil and improve its structure.

Permanent raised beds, by their very nature, encourage the concept of controlled traffic, where all vehicle wheels travel along the furrows between beds, thus limiting compaction on the majority of the paddock. Extensive research throughout Australia has shown significant soil structure improvements by removing vehicle compaction from the soil where the crop is grown.

Since 1995 SFS has developed various techniques to successfully install raised-bed controlled traffic programs. These techniques include contour surveying, waterway construction, soil cultivation, bed forming, crop sowing, crop spraying, windrowing and harvesting. Techniques to accurately apply fertiliser only to the top of beds have also been developed. Two concept farms (400 ha) trialling a combination of raised beds, alley trees, water harvesting and irrigation have been established.

SFS farmers, research workers and commercial sponsors have all worked tirelessly to help develop the system to where it is today. The SFS continues to study all aspects of this new technology so that cropping becomes more profitable and sustainable into the future.

Introduction — the rationale for using permanent raised beds in southern Australia

Permanent raised beds (PRB) and controlled traffic broadacre farming are recent phenomena in southern Australia, developed to overcome waterlogging and improve soil structure on cropping soils in the high rainfall zone [>550 mm] of this area. The high clay content of the B horizon and its low permeability in some of these soils result in a perched watertable during the long, cool growing season, which can cause complete crop failure when grown on flat or gently sloping ground without drainage.

Raised bed farming (RBF) is not a new idea. In Asia and other parts of the world soil beds have been raised and furrows used for irrigation for centuries. In many countries, including Australia, the technique has been used for many years by home gardeners and commercial vegetable and flower growers to assist with drainage. In the early 1980s scientists from Tatura in Victoria developed a system of growing broadacre grain crops on raised beds and using the furrows for irrigation (Tisdall & Adem 1986a, 1986b, 1988). The system has been widely adopted for grain and horticultural crop production in the New South Wales Riverina districts, particularly around Griffith (Beecher et al 2005). The use of raised beds can have several benefits depending on the circumstances. In the context of farming in southern Australia, the main reasons for their use are:

- *Better drainage:* Raised beds are primarily a field drainage tool aimed at decreasing waterlogging and increasing crop yields. When soil becomes saturated with water, as is the case for many 'duplex' soils in Australia[1], anaerobic conditions result in poor plant root growth, which causes plants to become stressed and in some cases (eg under prolonged waterlogging) to die. Where soils become saturated in winter due to high rainfall and/or poor drainage, soil drainage needs to be considered.

- *Better soil structure:* By their very nature, raised beds encourage implements to travel down the furrows, which reduces the amount of soil compaction occurring where the plants are growing. Soils that aren't compacted have a greater ability to hold plant-available water, are less cloddy, allow for greater plant root growth and give higher plant yields. Raised beds offer a form of controlled traffic, the benefits of which have been proven in many areas and over many years (Blackwell et al 2003; Ellis et al 1992; Tullberg 2001; Tullberg et al 2001).
- *Risk management:* The incorporation of raised beds means that the complete failure of crops due to waterlogging is eliminated. Hence, more accurate budgeting of crop yields can occur and there is greater confidence in achieving good results. Many paddocks that were once too risky to crop due to waterlogging problems can now be brought into production with confidence.
- *Higher profits:* Due to more uniform and higher yielding crops under situations where waterlogging would normally be a problem, higher profits can be realised. In many parts of southwestern Victoria crop yields have doubled in recent years where raised bed technology has been used, considerably increasing profit for farmers. It is important to note that many of the costs associated with the installation of raised beds, such as surveying, grader work etc, are one-off costs and should not need to be repeated.

The rapid research and development of raised beds and controlled traffic has been a combined team effort involving farmers, machinery manufacturers, agronomists and researchers, with the Grains Research and Development Corporation (GRDC) and SFS helping to sponsor the project along the way. A range of practices and recommendations have been developed by the SFS group over the years for the establishment of PRB systems in southern Australia. As a consequence of the SFS being a farmer partnership, much of the research underpinning these practices was carried out in an on-farm participatory mode. The aim of this paper is to describe the PRB systems developed for conditions prevailing in southern Australia.

[1] 'duplex' soils are texture contrast soils, where a sandy to loamy A horizon overlies a clayey subsoil with low permeability and, often, sodic properties

Main features of raised beds

An overview of the steps and recommendations being made to farmers when establishing PRB systems is provided in this section.

Design of raised bed paddocks

Inspecting soil and sampling the paddock

The first step is to visually inspect the paddock and decide where the water runs across it. It is recommended to take soil samples at both 0–10 cm and 10–60 cm and send them for analysis to assist in decisions on the need for any soil remediation measures.

Initial survey

A simple survey with a dumpy or laser level will inform the farmer about the general slopes across the paddock. This requires taking a series of readings at 100 m intervals. Slopes are given as a percentage; therefore, a fall of 0.5 m over 100 m is a slope of 0.5%. A double slope is best, so water can run down the furrows and then down the collector drains. It is also important to determine where the water discharges from the paddock and where it goes to.

Making the decision

If the paddock slopes generally fall between 0.2% and 1.5% and a discharge point is available, then raised beds may be a viable option. Once the decision to use beds in the paddock has been made, a full detailed plan must be prepared for the paddock.

Development of a detailed plan

Normally this step requires the assistance of a professional surveyor to carry out a full contour survey at 10 cm intervals using laser and GPS technology. It is practical to have the plans laminated for outdoor use and to enable drawing on the layout with a felt pen (Figure 1).

The contour survey will accurately show all paddock slopes and also define low spots where water may lie in the furrows and waterlog the beds. If low spots are likely to be a problem, the farmer should consider land levelling, for example with a land plane.

The plan should show features in and around the paddock such as roads, creeks, dams, buildings and fences. If there are any moveable features that will prevent an optimum paddock layout, the farmer

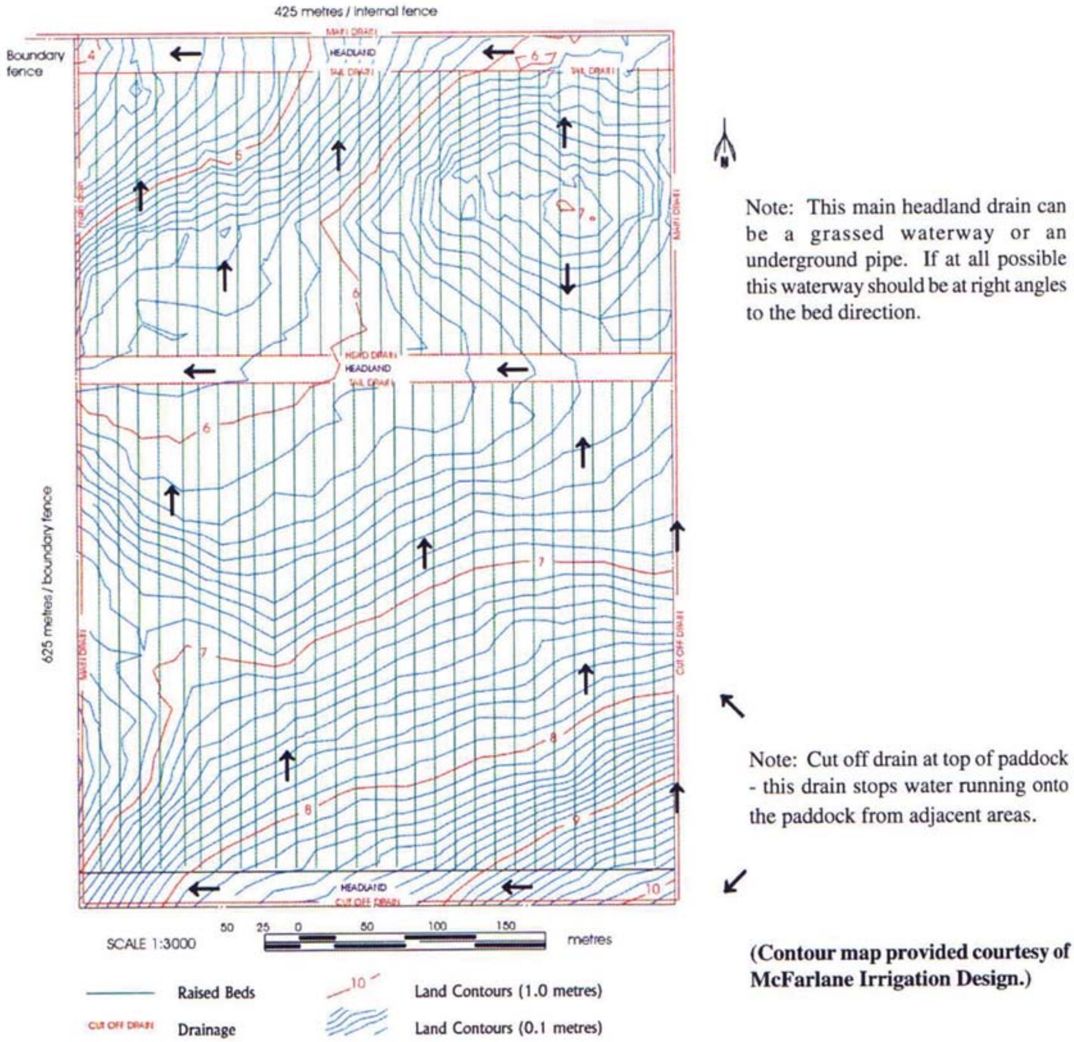

Figure 1. The contour survey will accurately show paddock slopes and facilitate the best plan for beds and drain direction.

should consider moving them or doing without them (Figure 2).

Deciding on the direction of the beds

Success or failure may depend on this critical decision. A professional raised bed survey will usually show recommended bed directions and the placement and layout of all drains. Farmers who have plain contour plans must apply their own layout ideas. The beds must go down the steeper slope; and the collector drains, which carry all the water from the furrows, must go down the lesser slope. This is because the maximum slope and bed run length depend upon the soil's susceptibility to erosion, and serious problems can occur if the guidelines are exceeded. For all slopes and soils, the maximum bed run length between collector drains should be 400 metres.

While it is preferable to run the beds north–south to evenly capture winter sun, that decision must be dictated by the contour plan and the guidelines.

Designing the headlands

After selecting the direction of the beds, the farmer needs to mark the headlands on the plan. Headlands are required for machinery accessibility and turning and should be 20–25 m wide.

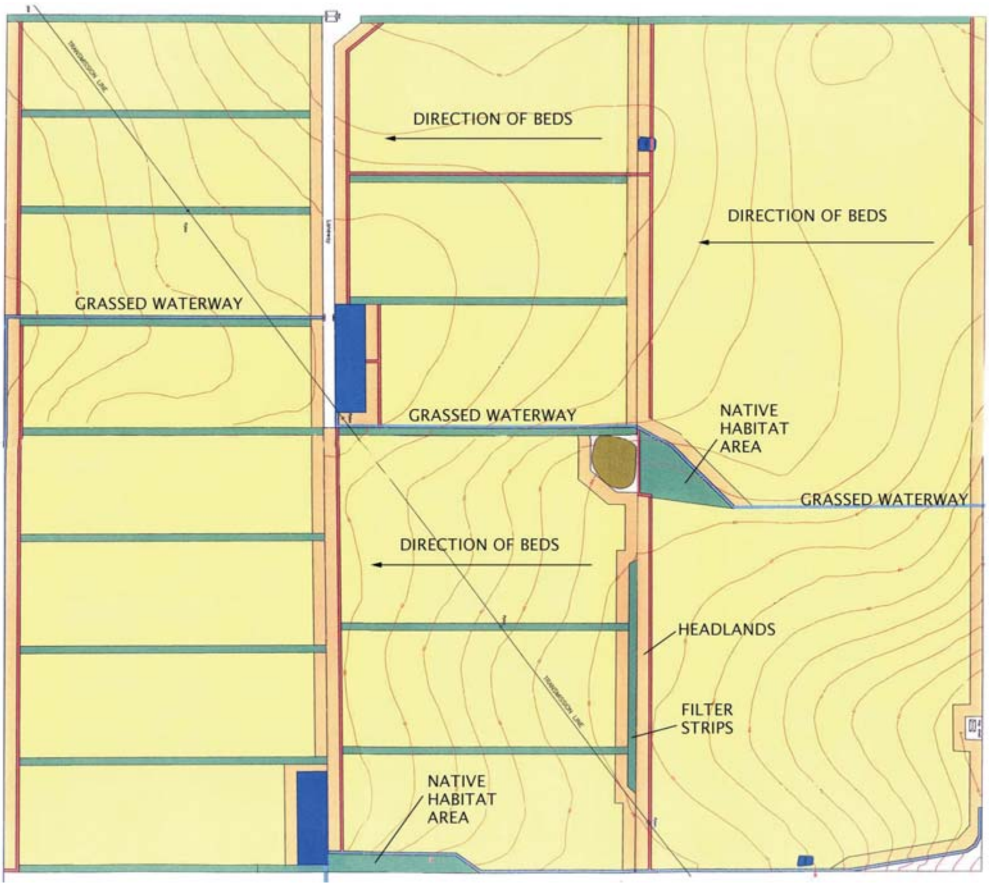

Figure 2. It is recommended that a full farm plan be designed so overall water movement, tree lines and buffer dams can be incorporated with other enterprises.

Planning the collector drains, other surface drains and grassed waterways

The collector drains, which pick up water from the furrows, need to be added to the plan. Because they collect water from many furrows, they often carry large volumes of water and their slope must be well below 1% to minimise scouring and the formation of gullies (Figure 3).

Grassed waterways can also help in managing excess flow and need to be included in the plan. Usually they will run along fencelines, to relieve pressure on the collector drains. This step also requires the farmer to decide on the location of wide, flat herringbone drains that cross the headland at intervals, into which water will be diverted from the collector drains.

Raised bed paddocks should only have to deal with water that falls directly onto them. Hence, it is necessary to add to the plan any other surface drains that

Figure 3. To stop bogging and improve trafficability, collector drains at the ends of the beds can be installed with underground plastic slotted pipes and backfilled with heavy, coarse gravel.

may be required to ensure that no water runs onto the paddock from roads, next-door paddocks or any other areas of land. These drains must be designed so they do not erode, and must be big enough to cope with all likely water flows (see 'Choice of design' below for details on handling excess water).

Planning soil treatments

Finally, on the basis of local experience and the soil test results, any applications of lime, gypsum, poultry manure or other soil treatments that may be needed should be planned before proceeding with the next steps.

Preparation of the paddock

Primary cultivation

Before primary cultivation can be started, consideration should be given to removing any obstacles such as rock piles, surface rock or trees from the paddock. Any rocks brought to the surface during cultivation, bed forming or sowing should also be removed. Any trees that are removed should be replaced elsewhere on the farm, according to the local environmental rules and guidelines.

Soil preparation should ideally begin prior to sowing in the spring, which is the ideal time to spray out potentially troublesome weeds and perennial plants such as phalaris. Adding an insecticide to the tank mixture at this stage will break the life cycle of pests such as red-legged earth mites. If the soil is susceptible to wind erosion, cultivation should not start before autumn.

Cultivation is best done when soil moisture is high enough to allow the cultivation gear to achieve the desired depth. Raised beds can be successfully installed in dry conditions but achieving the initial deep cultivation in dry soil can be difficult. Machines such as rippers, chisel ploughs and scarifiers are all suitable for primary cultivation.

The depth of cultivation required depends on the planned bed height. Deeper cultivation will produce a greater volume of loosened soil for mounding; the higher the beds, the deeper the tilth required. Loose cultivated soil must extend below the anticipated furrow depth to enable accurate, straight furrows and uniform bed height. The minimum cultivation depth of 17.5 cm will achieve about 20 cm of loose soil, which is possible in most paddocks in southwestern Victoria.

It is not recommended to try to obtain full depth in one pass but, rather, to gain depth slowly and stop if too much clay in very large clods is being brought to the surface. A fine tilth is not required at any stage, and cloddy soils with enough fines to achieve good soil seed contact at sowing are ideal. In fact, scattered clods the size of a fist can offer protection from run-off on newly bedded paddocks, and from wind damage to newly emerging crop plants.

The final cultivation should be run at right angles to the proposed direction of the beds to help the bed-former travel in straight lines and not hook into grooves formed by cultivator points or ripping tines.

Paddock levelling

The contour survey and general paddock knowledge gained from primary cultivation will help determine if land levelling is required. Laser levelling, as practised in irrigation areas, does not usually offer many benefits to the generally undulating paddocks typical of southern Australia. However, land planes can be extremely useful in helping to even up the surface, removing small depressions and bumps and greatly aiding water movement down the furrows.

Application of soil treatments

After land planing any soil treatments in the plan, such as lime and gypsum, can be applied.

Final cultivation

A final cultivation may be required to achieve an even 20 cm depth over the whole paddock.

Construction of the beds

Choice of bed design

The first step is to make sure that the bed width and bed height decided on at the planning stage are appropriate. The chosen width and height of raised beds quite often depends on paddock/farm conditions, availability of machinery/contractors and farm finances, and a case-by-case approach is necessary. Ground that has little slope and waterlogs easily may need high beds, while paddocks with good slope and better internal drainage may be best served by little or no bed height and concentration on controlled traffic alone. Raised beds alone and controlled traffic alone are quite compatible in the one paddock (Figure 4).

In most situations a new bed height of approximately 20–25 cm is very effective, and gives room to practise water harvesting on top of the bed and still have enough relative height between the water harvesting groove left by the sowing press wheel and the drainage furrows between the beds.

Bed width quite often depends on the machinery availability. For example, our first attempt at commercial bed farming in 1997 contained beds ranging from 1.5 m to 2.16 m (centre of furrow to centre of furrow) due to the availability of existing farm

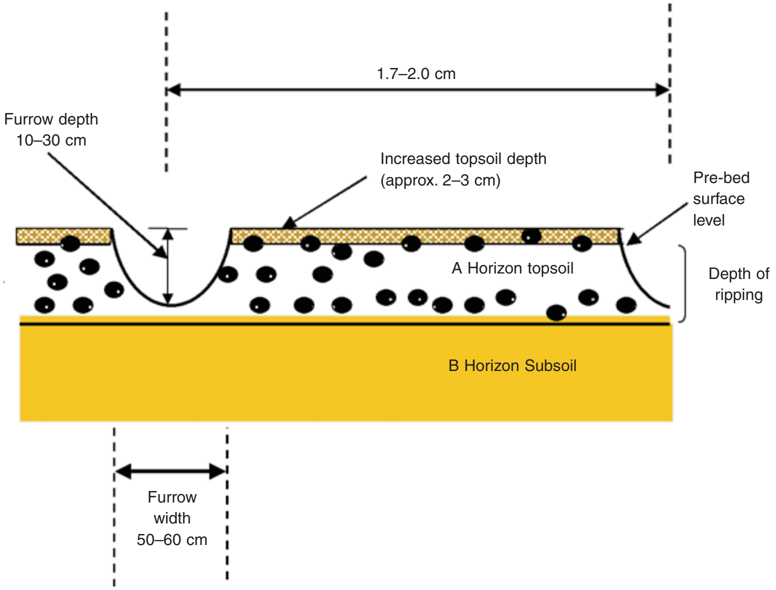

Figure 4. Schematic diagram of raised bed.

machinery. All these sizes worked well but farmer experience in Victoria and Western Australia (Greg Hamilton, pers comm) indicates that beds in most of these soils should not exceed 2 m in width. Bed widths of 2 m are becoming more and more popular and air seeders are easily manufactured to suit these widths. Also, with 2 m beds standard 450-mm-wide tractor tyres are quite suitable. The only problem with 2 m beds is that full controlled traffic is very hard to achieve because the header needs to be 4 m wide. Because soils in southwestern Victoria are naturally dry and strong at harvest, running the header on top of the beds has so far not created serious soil compaction problems.

Selection of a bed-forming machine

Bedding machines suitable for southwestern Victoria have been evolving since 1997. Most types have been successful but the more up-to-date models may be faster, stronger and lighter.

Options for farmers include purchasing their own machine, sharing one with neighbours or using a contractor to construct the beds. Contractors may have the largest and most modern machines, and may also have plenty of experience. Some are now using GPS guidance systems to install beds, ensuring that the beds formed in two halves at the ends of the machine are the same width as those formed in the middle of the machine.

The very first machine used in southwestern Victoria was based on a rotary hoe with shaping baffles fitted, but these have not been used recently. They evolved into types based on rotary harrows, which are still favoured by some farmers. However, they are slow and have great difficulty coping with rocks, and the bigger ones, especially, have a high power requirement. They may come back into favour as a means of incorporating heavy cereal stubbles into beds to avoid the need to burn.

Most bed-formers are based on tool frames carrying furrow formers, with a range of levelling devices (including grader boards, heavy chains and crumble rollers) fitted behind, either singly or in combination. As the furrowers dig out the furrows, they throw a mound of soil onto the edges of the beds. The levelling devices then move this soil across towards the centre, flattening out the bed top. Grader boards and furrower 'wings' are often made of plastic to reduce weight. Using chains to level the soil on the beds between the furrows does have a weight advantage, but they are less effective than grader boards and crumble rollers.

Many of these machines make two (one complete and two halves) or four (three complete and two halves) beds at a pass. The former is a good option for farmers who wish to install one or two paddocks per year using their own relatively small tractor.

Machines that make half beds each side have a grader board at each end of the tool frame. There are also some machines that make three whole beds and have a furrower at each end of the tool frame. Machines that make a half bed at each end are preferred because when whole beds are formed the furrower at the extreme end of the tool frame passes for a second time down what was the outside furrow formed on the previous run, digging out a furrow deeper than the others. This uneven furrow depth can hamper subsequent passes over the paddock with other equipment (Figure 5).

Bed-forming machines are made in both trailed and three-point linkage configuration. Large linkage machines may require very large tractors to lift and operate them.

Spring release gear on furrower tines was used for some time but has been superseded by hydraulic breakaway tines. The added tension available means the furrow depth can be made more even and smooth because the machine has added ploughing ability. However, if the paddocks are fully and evenly cultivated to the correct depth there is less advantage in using hydraulic breakaway gear.

Another development is machines fitted with double listers. The second lister simply sits in the furrow and cleans out clods, and is usually fitted with small grader boards on its wings to spread its spoil over the bed.

Trailing multipurpose machines have been developed that make raised beds, renovate beds and sow seeds into both bedded soil and flat soil. The bedding component comprises excellent high-winged listers and is sometimes fitted with heavy duty chains to help spread the soil. In well-cultivated and prepared soil the machine makes excellent beds. Rolling the bed tops may be beneficial if the soil is light and/or fluffy after bed forming.

Machines should be set up and operated in a way and at a speed that ensures they make the smoothest, most even beds possible, with furrow depths as even as can be achieved. This care will pay large dividends when it comes to sowing and establishing the crop on the beds, and spraying and fertilising the crop.

Alternatively, raised beds can be formed in uncultivated soil. This is easiest to achieve into a burnt stubble situation but has also been done successfully on old pasture ground. In both cases multiple passes of the bedding machine are usually required, gradually increasing the furrow depth with each pass.

Figure 5. A bed-former used in Southern Australia.

Establishment of turning headlands, surface drains, collector drains and buffer dams

Choice of design

Correct construction of the headlands, collector drains, grassed waterways and other components of the water management system is very important if environmental problems such as serious erosion are to be prevented.

When a paddock of raised beds is being sown, sprayed or harvested, or some other operation is being conducted, the tractor or vehicle travels along the furrows. It must then cross the collector drain before climbing up onto the headland, turning, crossing the drain again and proceeding up the next run of furrows.

Collector drains must be carefully engineered to avoid erosion, and this requirement usually means they must be wide and flat, which conflicts with the need to travel across them at right angles.

Turning headlands must not only be wide enough (see ‘Designing the headlands’ above), but must be constructed well enough and high enough to drain effectively and remain trafficable. They are built up like highly cambered roadways (see Figure 4).

Choice of machinery and construction method

A variety of suitable vehicles is available for constructing headlands and collector drains, including scrapers, road graders and linkage graders behind farm tractors. The use of dumpy or laser levels will ensure that drain falls and headland heights are optimised during construction.

Vegetation on collector drains and headlands

Collector drains and headlands should be kept vegetated or covered with crop residue at all possible times. Fully grassing collector drains with a perennial species such as tall fescue, perennial ryegrass and clovers is preferable, but it will always be hard to maintain these species because the sprayer has to cross them when applying crop herbicides. An alternative is to ensure that collector drains and headlands are completely sown down to the crop being grown on the beds.

Grassed waterways and herringbones

It is often a good idea to construct a grassed waterway in behind the headland, and to make herringbone drains across the headland from the collector drain at appropriate intervals. These drains and permanently vegetated waterways become an important part of overall water management. Appropriate machines such as scrapers, graders or drainers should be used to construct them, and dumpy or laser levels used to ensure the falls are correct. These waterways need to be kept well grassed and, if desired, trees can be planted alongside them.

Buffer dams

The final part of water management engineering at the raised bed paddock scale is to use a buffer dam, which receives all the water from the fenceline grassed waterway as well as the collector and surface drains, and is used to regulate the flow of that water out of the paddock. Buffer dams ensure that the rate of water run-off from raised bed paddocks is as close as possible to the rate before the beds were installed (Figure 6).

Figure 6. To reduce peak water flow run-off events, off-site buffer dams can be installed. Dam levels are kept low between rainfall events.

They require careful location, design, engineering and construction if they are to fulfil that role. They must be built with sufficient capacity to fill up and hold flows from most water run-off events, and must be equipped with pumps or siphons so that between each run-off event they can be slowly emptied into the natural water drainage lines outside the paddock.

Environmental risks

Water and nutrient losses from conventional flat and raised bed cropping systems

Since 1999 an experimental site near Geelong has been used to investigate changes in the hydrology of raised beds compared to conventional non-bedded flat-crop and pasture systems. Annual rainfall in this region is 520 mm and the Sodosol soils (Isbell 1996) are typical of the majority of soils on the basalt plains. Current results indicate that the intensity, duration and timing of rainfall during the season are significant contributors to measured differences in run-off volumes between raised bed and flat-cropped treatments (Table 1) (Johnston et al 2003).

When rainfall intensity exceeds soil infiltration capacity, raised beds tend to release greater volumes of run-off than conventional flat-cropping and pasture treatments. These 'infiltration excess' run-off events have been dominant over the period of the experiment, typically occurring prior to or following a dry start to a season and during seasons of below average rainfall. To reduce run-off from the top of the beds in these situations, it is recommended that press wheels are used on sowing equipment to install drill row grooves on the tops of the beds (T. Johnston, pers comm).

Table 1. Mean annual surface run-off volumes (mm) for 1999–2004.

Year	Annual rainfall (mm)	No. of overland flow events in year	Dominant run-off process	Surface run-off volume (mm)		
				Conventional non-bedded flat crop[a] (n=3)	Permanent raised bed crop[a] (n=3)	Conventional non-bedded flat pasture[b] (n=1)
1999	451.6	0	-	0	0	0
2000	430.9	2	IE	1.9	2.5	9.8
2001	599.4	7	IE	104	140	96
2002	376.2	4	IE	9.3	16.8	0
2003	440.0	4	IE	0.2	1.4	0.2
2004	479.2	2	SE	13.7	9.1	5.8

IE = infiltration excess, SE = saturation excess
[a] Mean annual surface run-off from 3 × 0.2 ha plots
[b] Annual run-off from 1 × 1.5 ha plot

However, when waterlogging is prevalent mid to late in a cropping season on flat-cropped land, ‘saturation excess’ run-off events can occur. During these events, trends indicate that the volumes of run-off from conventional flat-cropping treatments are greater than from raised beds (T. Johnston, pers comm). The benefits of using raised beds can be attributed to alleviation of waterlogging during the period, leading to increased dry matter production and greater canopy cover during the season, and higher grain yields. The resulting enhanced soil environment within the beds and higher water-use efficiency of the crop leads to the increase in grain yields (T. Johnston, pers comm) (Table 1).

There has been very little research on nutrient losses in run-off from cropping systems in southern Australia. However, data from this project indicates that growers are losing a significant amount of phosphorus and nitrogen from both crop and pasture systems. Total phosphorus and nitrogen concentrations from all treatments measured were well in excess of the ‘safe’ levels considered for Victoria’s inland rivers and streams.

Phosphorus is generally only applied at sowing, typically as mono-ammonium phosphate (MAP), at rates of 20–30 kg P/ha/year. Phosphorus loads in run-off from all cropping treatments have ranged from 0.01 to 1.4 kg P/ha/year, with trends indicating higher loads from the conventional flat-cropped compared to raised bed treatments (Table 2) (T. Johnston, pers comm). Phosphorus in run-off water is predominantly in a dissolved form, suggesting that previous nutrient management strategies based on physically trapping phosphorus attached to sediment (ie grassed waterways and buffer strips) are unlikely to be successful.

Nitrogen fertiliser is commonly applied at sowing (typically as MAP) and as a further in-crop application of urea, commonly known as topdressing. Annual fertiliser application rates are generally around 60 kg N/ha/year, while N loads in run-off from cropping systems range from 0.50 to 30 kg N/ha/year. Trends are indicating higher N loads from the raised bed compared to conventional flat treatments (Table 3).

Topdressing with urea is commonly undertaken with a spinner, resulting in considerable amounts (30–40%) of fertiliser accumulating in the raised bed furrows. Current best management practices recommend that growers use equipment that directs the urea only onto the tops of the beds, thus reducing potential nitrogen loss in subsequent run-off events,

Table 2. Annual P loads (kg P/ha/year) in surface run-off from Mt Pollock (2000–04).

Year	Annual P loads (kg P/ha/year)		
	Conventional non-bedded flat crop[a] (n=3)	Permanent raised bed crop[a] (n=3)	Conventional non-bedded flat pasture[b] (n=1)
1999	0	0	0
2000	<0.01	<0.01	0.1
2001	1.4	1.0	1.2
2002	0.09	0.09	No flow
2003	No significant flow	<0.01	<0.01
2004	0.2	0.1	0.1

[a] Average annual P loads from 3 × 0.2 ha plots
[b] Annual P loads from 1 × 1.5 ha plot

Table 3. Annual N loads (kg N/ha/year) in surface runoff from Mt Pollock (2000–04).

Year	Annual N loads (kg N/ha/year)		
	Conventional non-bedded flat crop[a] (n=3)	Permanent raised bed crop[a] (n=3)	Conventional non-bedded flat pasture[b] (n=1)
1999	0	0	0
2000	0.44	0.58	1.3
2001	26	43	14
2002	3.8	5.4	No flow
2003	No significant flow	0.10	<0.01
2004	1.2	0.60	0.50

[a] Average annual N loads from 3 × 0.2 ha plots
[b] Annual N loads from 1 × 1.5 ha plot

fertiliser usage and ultimately off-farm nutrient loss. Incorporation of slow release fertiliser prior to sowing could also be considered to minimise volatilisation and run-off losses.

Pest problems

A range of potential problems can occur when crops are grown on raised beds, and the potential damage caused by some pests and diseases may be different or more of a risk compared with crops grown 'on the flat'. Such problems need to be monitored and carefully managed. A few examples include:

Rodents

It has become clear that mice seem to thrive in the dry friable soil of raised beds. In the cold wet winters of southwestern Victoria mouse problems in broadacre paddocks have been rare, but this is a problem to watch out for on raised beds.

Disease

The friable, well-aerated soils in raised beds have many advantages but they may stimulate some soil fungi, such as Rhizoctonia, to be more of a problem (see 'Sowing points' below).

Insects

Many insects such as false wireworms thrive in well-drained and well-structured soils, as in raised beds.

Slugs

Due to the use of mulch and consequent moister conditions in the furrows, slugs may become an increased problem in raised bed crops.

Managing soils, crops and pastures on raised beds

Farming systems and crop rotations

Grazing by livestock

An important decision included in the choice of which farming system to adopt on a raised bed paddock is whether livestock should be grazed on the paddock; and if so, how and when it should be done.

Grazing the stubbles on raised beds is usually safe for soils because the dry conditions minimise compaction damage from the animals' hoofs, but it may be advisable to remove the sheep after summer rain until the soil dries out. There are simple but very important guidelines to follow for the safety and management of animals grazing on raised bed paddocks (GRDC 2004).

Some farmers may wish to establish pastures and graze their stock on raised beds, and this can be quite successful if care is taken. Tactical grazing is recommended and sheep should be moved out of raised bed paddocks during the rainy season. Again, livestock safety considerations are vital.

Livestock safety

The problem of sheep getting cast in the furrows when grazing raised beds has never been as bad as was feared and many farmers now successfully graze raised beds, but it is a potential problem that must be properly managed. Sheep can get stuck upside down or on their sides in the furrows, as happened in the early years of raised bed trials, and can die in that position. Factors influencing the problem include the bed height and furrow depth, and the nature, condition and state of the fleece of the sheep.

When farmers are attempting to graze beds for the first time with a new mob of sheep, it is very important that frequent inspections are carried out during the initial period to assist any sheep that may be cast in the furrows. Experience on farms and from the trial program suggests that, with time, the sheep adjust to the furrows, the furrows themselves may become shallower and the problem almost disappears. For stock welfare reasons, regular inspections must still take place.

Crop rotation

The standard rotations that have been used for years in the high rainfall zone (>550 mm) are generally applicable on both flat-cropped paddocks and raised beds. The principles underlying those rotations, such as soil fertility, crop disease control and economics, are also the same. However, soil improvements and waterlogging prevention resulting from raised beds may increase the choice of crops available. Presently, the most economic and practical rotation used by farmers is canola–wheat–barley–canola, which may be continuous or broken up with a phase of mixed pasture or lucerne. With the alleviation of waterlogging, pulse crops such as field pea and faba beans have shown to be suitable rotation crops producing economic returns.

Growing and using pastures on raised beds

Pasture productivity and benefits

Experimental evidence indicates pasture productivity and survival on raised beds during a series of dry seasons can be relatively poor (Peries et al 2004a) but this does not mean that pasture rotations on raised beds are unproductive or uneconomical. A pasture phase can help to improve soil structure and enhance soil water storage, especially in soils that have been cropped for long periods or become degraded.

Trial results have shown that a pasture phase on raised beds contributed to improved aggregate stability of the soil, which in turn improves soil aeration, water retention and soil structure (Jaikirat Singh, pers comm) (Figure 7). However, the below average seasonal rainfall experienced on the trial site in three out of five growing seasons between 1999 and 2003 resulted in poor performance from the recommended pasture varieties. Persistence was also poor, with few of the recommended annual pasture varieties surviving beyond 1 year.

It must also be noted that soils on raised beds are generally more friable and porous than on the flat. In the absence of significant autumn rain (delayed autumn break), pastures struggled to regenerate until late in the season in the absence of a good seed soil contact. The result was a lower than expected carrying capacity from pastures on raised beds between 1999 and 2003. Peries et al (2004a) shows the rainfall distribution over the 6 years from 1998 to 2003. Compared to the previous 6 years there was a reduction of over 30% in the January to March rainfall, which apparently had a huge impact on pasture regeneration and growth.

Re-establishing crops after the pasture phase

Trials over a 5-year period showed that it is possible to direct seed a crop on beds following grazed pasture without the need for any re-forming of beds (GRDC 2004). This may not be the case on sandy and sandy loam soils, or when there has been excessive movement of soil from bed shoulders into the furrow. Reshaping the beds before crop sowing is advisable if this has occurred.

Grazing guidelines for raised beds

Grazing of raised beds mainly occurs on stubbles over summer and autumn when soils are dry and structurally strong. If raised beds are grazed when the soil is wet, compaction damage can occur. Whenever sheep are on beds, it is advisable to remove them when the soil is wet and likely to be damaged by compaction.

Principles of sowing on beds

Compared with cropping on the flat, successfully sowing and establishing crops on raised beds introduces a new set of variables, requiring alignment of thought processes and machinery for successful management. The basic aims when sowing crops on raised beds are to:

- establish crop over the entire surface of the paddock including bed tops, shoulders and furrows (but not the permanent grassed waterways) (Figure 8).
- retain as much rainfall within the paddock as possible, while at the same time improving trafficability and preventing waterlogging.

Cultivation

To conserve bed shape and benefit from improvements to soil structure, it is desirable to use direct drilling whenever possible on raised beds (ie adhere to a permanent raised bed system). Direct drilling is a proven method of achieving good seed germination, plant establishment and growth in most stubble situations. Cultivation should only be considered when renovating the beds, or adding and incorporating products such as gypsum, poultry manure or lime.

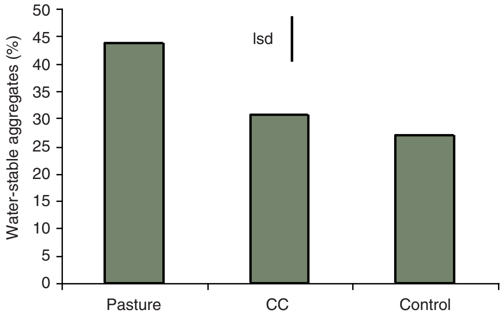

Figure 7. Water-stable aggregates >0.5 mm diameter (% of total soil) (0–0.2 mm depth) from permanent raised beds at Gnarwarre after more than four years of pasture (Pasture), continued crops (CC), or fallow (Control).

Figure 8. To slow water movement, reduce nutrient runoff and compete with weeds, crop is sown (without fertilizer) into the furrows between the beds.

Bed shape

Difficulties such as uneven cultivation depth, inaccurate bed forming and presence of underground rocks can make the beds and furrows uneven in height. Sowing, operating machines such as harvesters with tyres wider than the furrow, and grazing all cause the beds to become very rounded as soil falls off the shoulders and into the furrows. Under such conditions using seeders with normal rigid undercarriages and tine assemblies results in uneven sowing depth, especially on the bed shoulders.

Soil structure

Raised bed controlled traffic systems greatly improve soil structure. Soil properties such as slaking, dispersion and bulk density are all decreased while water infiltration is increased (SFS 2000). The loose and friable nature of the soils can make good soil–seed contact hard to achieve. Firming the seed bed after sowing will enhance the soil–seed contact and improve seed germination and plant establishment.

Run-off from bed tops

The rounding of beds also accelerates water run-off, particularly from the bed shoulders. Grooving the beds in the direction of the bed using water harvesting furrows, usually formed with press wheels, can greatly help retain this valuable moisture (Figure 9).

Nutrient loss from paddocks

One option to minimise nutrient loss with run-off leaving the field is to sow the furrows between the beds with crop. Especially in drier seasons these furrow-planted crops will contribute to overall yield, and crop plants growing in sown furrows will also compete with weeds.

Figure 9. To improve water harvesting on bed tops and reduce surface run-off, beds are left with grooves after sowing, made by the press wheels.

Sowing machinery

Combine and drill modifications

A normal sowing combine or drill is quite adequate to sow good quality, even and level beds; however, some modifications will be needed. Generally, a 24-row machine can be adjusted to sow three beds of 1.7 m width, while a 28-row machine can sow three beds of 2 m width. A machine with easily adjustable tine positions is the best choice.

Stubble clearance and tine positions

For best stubble handling characteristics 'combine seeders' need to be modified to a 'drill' configuration by removing all tines without sowing boots. The undercarriages on most combines and drills are not wide enough to sow the shoulders of the outside beds, and outriggers must be added, either to the front or back of the undercarriage or to both for increased versatility, so that tines can be fitted closer to the wheels.

Elevated seed and fertiliser boxes

On gravity-fed combines and drills the delivery tubes to the outrigger tines may be too horizontal for good seed and fertiliser flow, but elevating the boxes will solve this problem.

Sowing height

At sowing the wheels of the machine travel in the furrows so the sowing points need to be 15–20 cm above this height. Most machines will be at or near their normal 'travelling position' when operating at this height, but If adjustment or modification of the travelling position cannot be achieved, larger wheels may need to be fitted to lift the overall height. Alternatively, some tines can be adjusted for height or shorter tines can be fitted.

Wheel and tyre width

To minimise furrow width and compaction of the bed shoulders, the maximum tyre width on tractors and seeders should be 350 mm for 1.7 m beds and 450 mm for 2.0 m beds.

Sowing points

Long narrow knife points, angled as vertically as practical, work well on raised beds. Their narrowness and vertical aspect help to minimise soil throw and disturbance, resulting in more even seed cover and reduced soil shedding into the furrows (Figure 10).

Importantly, these long points also cultivate the soil below sowing depth, helping to break up and destroy Rhizoctonia fungi and allow the primary roots of cereals and tap roots of canola to quickly and easily access the deeper topsoil in the bed and the subsoil below it.

Long narrow points can help to compensate for uneven bed heights and bumps and hollows, as they may still cut a sowing groove when the bed height falls away below the drill undercarriage.

Tine length

Adjustable tine lengths can be very useful for sowing the bed shoulders, which are almost always lower than the bed tops. A longer, or a lowered, tine will ensure seed is drilled into those lower shoulders. However, the relative heights should not be too great, or adjustment will be needed every time the machine needs to sow flat ground such as the headlands.

Sowing the furrows

A delivery tube positioned in front of the machine at 150–400 mm height will evenly distribute seed into the furrow. The seed will be covered by soil thrown by the other tines or will be pressed in by the machine's wheels. Seeds sown into furrows may germinate first because the furrows stay moist.

Rollers and press wheels

The soil in raised beds is often quite fluffy, and therefore improvements in crop establishment can be obtained by rolling after sowing (see Figure 8). On flat-topped beds a ridged steel or rubber tyred roller can be used, while for rounded beds a flexible roller that fits the bed shape is best. However, raised beds can be very uneven and the best results are usually obtained by using press wheels, which can be readily fitted to most combine seeders, drills or air seeders. These wheels have independent travel and adjustable springs so the pressure they place on the soil can be adjusted to suit the conditions.

The use of press wheels in flat-cropped paddocks in the high rainfall zone is considered to be very risky as rainfall after sowing can fill the grooves with water, waterlogging the drill row and reducing germination. On raised beds, however, the improved soil structure prevents waterlogging in press wheel grooves, and the improved seed–soil contact results in less free water close to the seed. Another very important benefit from using press wheels (Figure 11) on raised beds is that the furrows they leave harvest rainfall and reduce run-off from the bed tops.

Press wheel depth control

Press wheels are often used as the ideal means of controlling sowing depth. Sowing assemblies have been designed that incorporate good trash clearance, breakaway tines fitted with long knife points, and a press wheel that controls the depth of the sowing boot. These are working very well in beds of all shapes. With each assembly being independent, the whole surface profile of a raised bed paddock, including the bed tops, shoulders and furrows, can be sown with seed at the correct depth.

The multi-purpose sowing machine

Multi-purpose machine development

Machines are now available, including a model from a consortium of Geelong machinery manufacturers, that meet the full requirements of raised bed farming in southern Victoria.

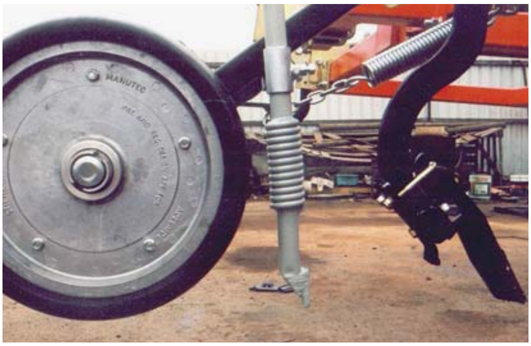

Figure 10. Knife points and press wheels are standard, good agronomy on raised beds.

Figure 11. Press wheels ensure improved seed-soil contact and also help in the formation of grooves for water harvesting.

Such machines are designed to have the following necessary capabilities:

- bed making ability
- bed renovating ability
- excellent clearance and sowing height to accommodate the tallest of beds
- ability to sow raised beds as well as controlled-traffic flat country and beds with few adjustments
- ability to cultivate soil below the sowing seed
- press wheel sowing depth control
- excellent trash clearance
- foldability for easy transport
- light enough to sow through wet conditions
- ability to sow more hectares than a normal combine/drill between fills
- ability to handle soil conditions ranging from sand through to rocky heavy clays
- press wheels that can handle sticky and cloddy soils.

These Geelong built machines have so far lived up to all expectations, offering farmers in southwestern Victoria a locally adapted piece of equipment.

Crop management on raised beds

Spraying

Successful spraying has been one of the easy operations to achieve on raised beds. Of course, once the tractor wheels are set up to the correct centre-to-centre measurement for the beds, a three-point linkage sprayer becomes the cheapest option. Otherwise, trailing rigs can easily be set up to the right wheel track width, and some commercial machines even come with adjustable width axles.

Gantry-type self-propelled sprayers have recently been released which have variable axle widths, narrow wheels and excellent ground clearance. These machines are generally owned and operated by contractors.

Because all guidance comes from the tractor travelling in the furrows, the need for foam markers is eliminated. Spraying at night, when wind speed is often much lower than during the day, becomes perfectly possible and very easy. If the boom width is a good fit to a number of bed widths, overlapping and missed strips are also eliminated, provided the operator accurately counts or marks the correct number of beds to straddle on each pass. This improves safety, saves money on chemicals and reduces adverse impacts of pesticide drift.

Fertiliser application

For economic plant growth and environmental reasons it is most important that fertilisers are only applied to the tops of beds (Figure 12).

When a twin spinner is used to apply urea, up to 40% of the product ends up in the furrow. Although the furrows only occupy 25–30% of the total surface area the urea granules that fall into the furrow don't bounce out and those that fall on the top of the bed quite often bounce into the furrows.

A pneumatic fertiliser spreader has been developed which blows granular fertiliser along a boom with outlets positioned only above the bed tops. The current model covers five beds but such a machine could cover seven or even nine beds.

Such a machine would be fast and accurate and would considerably cut the fertiliser budget for a cropping enterprise because the 40% of the fertiliser that falls in the furrows is essentially wasted. It would improve crop yield by allowing the application of multiple low doses of essential nutrients to be applied, as required by the crop, at all critical stages of the growing season. This would benefit both the crop and the environment by reducing nutrient losses from the bed furrows.

Although such spreaders have been available since 1999, they had not been widely adopted by 2004, perhaps surprisingly given the benefits and savings possible.

Windrowing

Both power-take-off (PTO) and self-propelled windrowers can be adapted to fit raised beds, with the wheels running in the furrows. Narrow wheels can also be fitted to avoid bed shoulder damage. It is also considered acceptable to leave windrowers unchanged and allow them to travel on the tops of the beds. Provided the soil is dry and in a strong condition, compaction damage can be minimised.

Machinery modifications

Achieving controlled traffic with harvesting equipment is the most difficult and expensive of all

Figure 12. Recent developed machinery ensures the application of fertiliser confined to only the top of beds.

machinery modifications for raised beds. Harvesters can be built or modified so that their wheels straddle two beds, which means a 4 m track for most raised bed systems, but the modifications are not easy and must be safely and correctly engineered. Suitable strength wheels and tyres must be used especially if narrow tyres are chosen. When harvesters have to run on the bed tops, soil damage is generally minimised because the soil is usually dry. However, if the soil is wet and compacted by headers, a full bed and furrow maintenance operation should be carried out the following autumn to restore structure and smooth/deepen furrows.

The length of the bed runs needs to be considered. If the header has a 9 m front and the bed length is 400 m, the harvest area is 0.36 ha. For a 10 t/ha crop, the header box needs to have a 3.6 t capacity if storage is available at each end of the paddock, and a 7.2 t capacity if storage is only at one end. Chaser bins that fit the bed furrows can solve this storage problem.

Stubble management

Dealing with crop residues is important in high rainfall zone crop production. While raised beds do not greatly alter the issues, they may alter the options available.

Harrowing, slashing, mulching and burning are the main stubble management methods used. The best method depends on the crop type, the amount of stubble, how well it has been chopped and spread behind the harvester, and other factors including farmer choice.

Burning

This is still a legitimate method of stubble disposal but it causes nutrient losses and environmental problems from smoke, and is becoming a method of last resort rather than a preferred option.

Canola and pulse stubbles

These are the easiest crop residues to manage, and burning is rarely required if the straw has been chopped and spread.

Cereal stubbles

Crop residues from cereals, especially from higher yielding raised bed crops, can be a difficult problem. Large amounts of cereal straw left on the surface can have major impacts on sowing and on the establishment of the following crop. For cereal crops with a low grain yield, less than 2.5 t/ha, most direct drilling machines can handle the remaining standing stubble. Once again, a chopper and spreader fitted to the header is beneficial. However, if the yield is over 2.5 t/ha, there can be a range of potential problems when sowing the following crop.

Achieving good trash clearance through heavy stubbles can be very difficult. Cereal stubble provides a suitable habitat for slugs, which can severely damage canola and pulse seedlings in the following crop.

Because heavy cereal stubble acts as mulch, the soil can remain very wet and cold following heavy autumn and winter rains, and this can adversely affect crop sowing operations and crop growth. Also, toxins released from cereal stubble can poison new seedlings and reduce establishment.

For these reasons many farmers choose to burn heavy cereal stubble. However, a range of alternative methods involving using the straw on or off the site is being developed.

Harvesting low with the header and baling the straw is one emerging possibility. Potential markets include pig producers, dairy farmers and mushroom growers. Sowing into the remaining short stubble can be very successful.

Some farmers have successfully baled and carted straw from raised bed paddocks using full controlled traffic, with all machinery wheels in the furrows. It is challenging but possible.

Incorporating the stubble to retain nutrients and improve the soil is an increasingly attractive option. Farmers and researchers are working to develop satisfactory methods, including cultivation with disc ploughs or disc harrows. However, with raised beds it may take two or three passes, and the final pass will have to involve bed renovation and reshaping.

Yield monitoring and mapping

Yield mapping is very effective on raised beds. Because the crop is grown in rows, it is easy to apply various treatments, study the results, observe the effects on yield maps in future years, and plan ongoing management.

Ongoing bed management

Trials and on-farm experience show that renovation of raised beds used for cropping is beneficial from time to time. Many farmers are now carrying out renovation every 2 or 3 years to:

- return some of the collapsed soil from the furrows (or gutters) back to the top of the bed and regain the original bed shape, height and crop rooting depth
- reduce some of the compaction that may have occurred on the beds
- address, on a regular basis, any hostile subsoil issues

- facilitate improved water infiltration into beds, especially in soils known for low macro-porosity and therefore poor water movement
- smooth and even out the furrows to allow free water movement.

Timing of renovation of raised beds

A decision about when to renovate beds is very site specific. The farmer needs to decide on when and how to renovate based on knowledge of the local soils and the shape and physical condition of the beds. If any one or a combination of the factors listed above may be beginning to have an impact on machinery operations or crop performance, it could be time to consider renovating the beds.

Renovations are best carried out during relatively dry periods, and experience suggests that late summer to early autumn is about the best time. Avoid periods when the soil is too moist because use of bed renovation equipment under such conditions may do more harm than good.

Measured benefits of farming systems on raised beds in southern Australia

Yield performance

Since the mid 1990s there have been many trials, demonstrations and surveys comparing grain yields from raised beds and flat land over a very diverse range of environments and soil types.

Commercial results reflect this research work, which has shown that grain yield responses depend on the degree of waterlogging experienced during various stages of crop growth.

A recent analysis of 56 comparisons of raised beds and flat land throughout southern Australia, including trials, demonstrations and surveys, showed that 40 indicated a positive yield response for beds, 13 a negative response, and 3 were similar for beds and flat land. Overall, the yield response was +35% in favour of raised beds.

Soil structure improvement

Research conducted by SFS to date suggests that improved yield on raised beds may be the result of better drainage during wetter years (SFS 1997), as well as increased root proliferation (SFS 2000) under conditions of minimum tillage (MT) and controlled traffic (CT) associated with raised beds (Peries et al 2004a, 2004b).

In a farming systems trial conducted near Geelong, southwest of Melbourne in Victoria, from 1998 to 2004, the hypothesis was tested that crops on raised beds will experience a different root environment over time. A black Vertosol (Isbell 1996) and a brown sodic Vertosol behaved differently in response to minimum tillage and controlled traffic and the alleviation of waterlogging. Three years after the installation of raised beds, crops experienced a lower soil bulk density and a consequent higher total porosity in the root zone compared to crops on the flat.

These differences in soil structure were also detected below the initial depth of tillage (20 cm), suggesting that processes other than the simple mixing of soil during the installation of beds and/or the wetting and drying cycles on beds were having an impact on soil structure under the beds in the long term. These differences may be explained in part through processes that are triggered by the removal of compaction compared to conventional farming practice. The improvements in soil structure resulted in enhanced plant available water (PAW) capacity in the subsoil, which could aid crops under suboptimal rainfall conditions (Peries et al 2004b) and lead to yield stability in the long term (Figure 13).

Economic benefits

The use of raised beds is expanding rapidly into the higher rainfall zones and commercial yield responses are quite often between 50% and 100% where waterlogging is severe. It is estimated that there are between 70,000 and 80,000 ha of raised beds in the high rainfall zones of southern Australia.

The grains industry in Victoria now produces over $200 m in grain exports annually. Raised bed development has led to the direct creation of more than 150 skilled jobs in the last 4 years, and it is expected

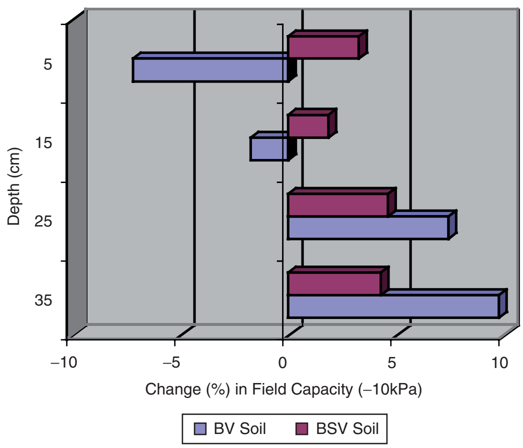

Figure 13. Measured differences in the upper level of plant available water (field capacity) in a black Vertosol (BV) and a brown sodic Vertosol (BSV) to a profile depth of 40 cm in 3-year-old permanent raised beds.

that there will be continued exponential growth in grain production and raised bed farming for the foreseeable future.

Farmer experience and adoption

This research and development of raised beds and controlled traffic began with the SFS partnership, including government agronomists, farmers and agribusiness. This partnership was formed with the primary aim of solving waterlogging and improving soil structure. After just 2 years of research and development and commercial trialling, the concept received very positive responses from farmers, media and machinery manufacturers. Positive peer group influences were and still are present throughout most of the high rainfall cropping areas.

The keys to development of this positive attitude were the initial success in reducing waterlogging and the low-cost methods demonstrated to farmers to enable them to begin bed farming very cheaply. Many contractors saw the potential of raised beds and entered the business. Their presence, together with the cheap modifications developed from existing farm machinery, has resulted in easy access to the technology. However, there are still a few issues that act as constraints to adoption which need to be addressed in the future, including:

- dry seasons — which reduce the impact of waterlogging damage
- machinery cost — initial costs could be a significant deterrent to some farmers
- paddock suitability — not all paddocks may be suitable for PRBs, eg red gum country with scattered trees
- non-arable country — eg rocks (due to the cost of clearing) or flat country
- disposal of excess water
- conservative farmers.

A number of research gaps have also been identified that need to be addressed if PRBs are to be significantly adopted as recommended best practice in the high rainfall zone. These include:

a. More plant available water (PAW) in spring — the low harvest index (HI) of cereals grown on raised beds has been attributed to the non-availability of adequate PAW in the subsoil during grain filling. Future research needs to address ways of overcoming this situation.
b. Managing stubble on raised beds — low HI of crops further exacerbates the problem of stubble loads on beds, leading to issues such as physical handling, slugs and toxicity. Inter-row sowing, inter-row weed control and herbicide resistance would also need to be addressed.
c. Trafficability of furrows in wet conditions — there is a need for guidelines for minimum damage to soil.
d. Compaction by windrowers and headers — at this stage it is assumed that the damage is minimal because these operations occur during early summer when soil is generally dry.
e. Fertiliser type, placement and timing are important to minimise nutrient run-off and improve the development of drainage plans for whole catchments.
f. Good comparisons of PRBs vs controlled traffic (CT) – many of the benefits of PRBs may be realised simply through CT, an area not yet investigated sufficiently.
g. Bed sizes, eg the use of 3-m-wide and deeper (400 mm) beds – the aim is to concentrate on improving a larger volume of soil above the hostile (sodic, dense and waterlogging) zone in the subsoil.

Acknowledgments

The rapid research in, and development of, raised beds and controlled traffic has been a combined team effort involving farmers, machinery manufacturers, agronomists and researchers. Authors acknowledge the financial support of the Grains Research and Development Corporation (GRDC) Australia; Department of Primary Industries, Victoria; and Southern Farming Systems in conducting the research and development work reported in this paper.

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