Environmental Impacts of Raised Bed Cropping in South West Victoria

Summary

Raised bed systems have revitalised the broadacre cropping industry in the high rainfall areas of south-west Victoria (Vic). By 2003, there were an estimated 50,000ha of raised beds installed, and potential for 1 million ha with high to moderate suitability for raised beds. This project has gathered valuable knowledge on water movement and nutrient losses from raised bed and conventional cropping systems. Results from this project underpin the best practice guidelines to minimise environmental impacts of raised bed systems. The guidelines have been produced and distributed to growers through the Southern Farming Systems (SFS) grower network.

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Conclusions
This project has gathered valuable data on water movement and nutrient losses from raised bed and conventional cropping systems in southern Australia.

Results from the field measurements and modelling indicate that raised beds change the hydrology of the landscape. The impact of raised beds on the volume of run-off is dependent on many factors, including soil type, slope, amount of ground cover, antecedent soil moisture and rainfall intensity. Field measurements on a typical soil type and slope in the region indicate that raised beds generally increase the volume of run-off by up to 100% compared with conventional cropping systems, depending on seasonal rainfall. Run-off modelling also indicated that raised beds on heavy textured soils (e.g. heavy clays) generated a greater proportion of run-off per unit of rainfall than lighter textured soils.

Field measurements indicated that raised beds shed run-off more rapidly than conventional systems on a typical soil type in the region. Consequently, proper paddock planning, including a contour survey, is essential before installing more than 10ha of raised beds. This will minimise the potential for erosion and off-farm nutrient losses. An introduction to paddock planning is given in the best management practice guidelines fact sheet developed by the project.

The concentrations of nitrogen (N) and phosphorus (P) in run-off waters from all treatments using district fertiliser practices exceeded the upper limits for the south-west river region in Vic, but were similar to those observed in grazing systems. Raised beds generally released higher annual loads of N and lower annual loads of P in run-off compared to conventional systems. In addition, most P in run-off was mobilised in a dissolved form. In terms of control measures, there are limited opportunities to remove dissolved nutrients from run-off flows, so the aim of remedial studies must be to prevent nutrients getting into the waterways. Guidance to minimising nutrient losses in run-off is given in the project’s best management practice guidelines fact sheet.

The project found that the Agricultural Production Systems sIMulator (APSIM) could not be used to simulate the water balance under raised beds because of the lack of parameter descriptors to describe the beds and furrows in a raised bed system. Under a conventional cropping system, APSIM simulated deep drainage ranging from 4.3mm to 154mm per year over the duration of the project. While it has been observed that raised beds generally shed more run-off than conventional treatments, it can be assumed that deep drainage under raised beds will be slightly lower than under conventional systems.

Most soil types in south-west Vic have a moderate to high suitability for raised beds, but soils with a light soil texture, or exposed sodic subsoils, should be managed with caution. Growers should adhere to best management practice guidelines.

The experimental site at the SFS Concept Farm was a successful awareness and communication tool in the wider community. Environmental issues associated with nutrient losses and farm design have had wide exposure at field days, field site visits and in media articles generated by the project.

Recommendations
**Support for of HRZ grower groups**

Increasing expansion of cropping and raised beds in the high rainfall zone (HRZ) will require increased grower input to deal with issues of nutrient losses into waterways, increased risks of acidification and practical options for management of nutrients. Support of SFS by GRDC to underpin cropping research in southern Australia is recommended as a vital ingredient of research in the environmental aspects of crop production.

**Increasing frequency of severe weather events**

Design of raised bed systems should include the potential for climate change and the possibility of extreme weather events. There is a need for the development of new techniques to slow down surface water flows around and off-farm through grassed waterways, buffer strips and holding dams.

**Modelling in the HRZ**

The pathway of water movement through the soil is highly variable because of soil type and site conditions that play a large part in determining overall water balance and productivity. It is recommended that a waterlogging module for APSIM be developed as a high priority to enhance variety selection, fertiliser loss assessment and prediction of grain yields from raised beds.

**Implementation of protocols for soil characterisation in GRDC-funded research projects**

Standardised soil survey protocols should be used to characterise research sites and demonstration areas in HRZ research activities to value-add to all investment and data. Appropriate training of scientists and staff by a recognised soil practitioner or institutional trainer could be provided for by GRDC research projects. Soil databases developed in this manner would be useful for input data into cropping models.

**Raised bed farming practice**

An alternative investment option for GRDC would be to contribute to the design and delivery of whole-farm planning programs that encourage grain growers to ensure that drainage infrastructure is planned ahead of the installation of raised beds. Publications and results developed in this project need to be incorporated into education and training programs for the development of whole-farm planning courses specifically for raised bed cropping. This would make them easily accessible (e.g. via GRDC and SFS websites).

**Outcomes**

**Economic**

Results suggest that significant amounts of nutrients, particularly N, are being lost in run-off. Topdressed N fertiliser application rates could be reduced (up to 30%) by placing fertiliser only at the top of raised beds and not in the furrows, providing a win-win situation economically and environmentally.

**Environmental**

Knowledge of off-farm nutrient loss run-off from cropping systems in Australia is scarce. This project has promoted the importance of the development of cropping systems in the HRZ that maintain water and nutrients on-farm and mitigate off-farm nutrient losses. The strong support by the SFS group ensured that the project had excellent exposure to growers, advisers and researchers. Results have highlighted the need for further understanding of the relationships between the rates, timing and application technology used for fertilising crops, the quality of water leaving paddocks and the yield and profitability of crops.

Knowledge of soil-water characteristics and soil hydraulic properties in southern Vic is also very limited. The data collected are not only necessary for the water balance and run-off computer modelling associated with this project, but they are highly sought-after by other modellers within the Department of Primary Industries (Vic DPI), and externally, because of the scarcity of soils information in the region.

**Social**
Through the demonstration site at the SFS Concept Farm, this project has increased community awareness about the environmental impacts of raised beds. The site received approx. 3,500 visitors during the life of the project, allaying community concerns and providing confidence for outside investment in raised beds. Growers have become more aware of the importance of good farm design to minimise potential environmental impacts. They have also questioned some of their methods for applying fertiliser and realised the adverse impacts of nutrient losses off-farm.

Achievements/Benefits

In the HRZ (more than 550mm) of southern Australia, the declining profitability of livestock enterprises in the mid-1990s resulted in a shift into broadacre grain cropping. In south-west Vic, raised beds have been developed by the SFS group for the alleviation of waterlogging and soil compaction.

Raised beds were introduced in 1996 and, following the rapid adoption of the technology by growers, an estimated 50,000ha had been installed by 2004. The advent of raised bed cropping has the potential to substantially increase grain production in southern Vic and make a significant contribution to Australia’s overall production. More than 300,000ha in south-west Vic potentially is suited to raised bed cropping, with an additional 700,000ha of moderate suitability. However, the change in land use raises concerns about the impact of raised beds on surface water flows and deep drainage because of the intensified agricultural production.

This project has five major achievements associated with its milestones:

1) Surface hydrology

In 1999, a main experimental site was established on a commercial grain and wool-producing property near Winchelsea, in south-west Vic. The aim of the site was to assess the environmental impact of raised beds on the quantity and quality of surface run-off compared to conventional pasture and cropping systems using district practices. The site is typical of much of the potential cropping country on the basalt plains of the region. It has an average annual rainfall of 520mm, soil type is a yellow duplex (light, sandy loam topsoil over a heavy clay subsoil) and an average slope of 1% (1-in-100). During the life of the project, annual rainfall for the site was significantly less than the long-term average for six out of the seven years.

Waterlogging on conventional flat treatments was rarely observed. Consequently, the frequency and quantity of run-off from all treatments was lower than anticipated in years of average rainfall. However, some valuable data were gathered. Results indicate that the intensity, duration and timing of rainfall during the season are significant contributors to differences in run-off volumes between raised bed and flat-cropped treatments. Some of these differences can be described by the two main processes of run-off generation:

1. Infiltration excess flow.
2. Saturation excess flow.

When rainfall intensity exceeds infiltration capacity at the soil surface, raised beds tend to release greater volumes of run-off than conventional flat cropping and pasture treatments. These infiltration excess rainfall events dominated run-off during the period of the study. They typically occurred before or following a dry start to a season, and during seasons of below average rainfall.

However, when waterlogging on flat-cropped treatments remained prevalent mid to late in the cropping season, saturation excess run-off events occurred. During these events, data indicated that the volumes of run-off from conventional flat-cropping treatments were greater than from raised beds. The lower volumes of run-off from raised beds can be attributed to the improved soil environment within the beds, leading to improved water use efficiency of the crop and ultimately higher grain yields compared to the flat-cropped treatments.

In both situations, peak discharge from the raised beds occurred sooner than from the conventional treatments, highlighting the importance of good on-farm waterway design to slow water flows and reduced potential erosion. The flow-weighted mean concentrations of P and N in run-off from all treatments exceeded the upper limits of 0.04mgP/L and 0.90mgN/L respectively for Vic’s south-west river region. But the concentrations were comparable to previous published studies of run-off from sheep and dairy pastures. P loads in run-off from all cropping treatments ranged from 0.01-1.4kg P/ha/year, with trends indicating higher loads from the conventional flat compared to raised bed treatments. These loads are lower than what would have been anticipated in years of average to above average rainfall because of the low volumes of run-off measured during the study period. N loads in run-off indicate that raised beds discharge higher N loads compared to conventional cropping treatments.
Dissolution from fertilisers and organic compounds represented the dominant mechanism of nutrient mobilisation in the cropping systems. Total dissolved P measured in 2004-05 ranged from 33-76% of total P in the crop plots. In terms of control measures, there are limited opportunities to remove dissolved nutrients from run-off flows, so the aim of remedial studies must be to prevent nutrients getting into waterways. The application of fertiliser only to the top of the beds and not in the furrows, and incorporation of nutrients below the surface to reduce exposure to surface flows, is recommended in raised bed systems.

In summary, raised beds generally increased the annual volume of run-off by up to 100%, depending on rainfall characteristics, and increased the peak discharge compared to conventional systems. Nutrient concentrations and loads in run-off from all cropping systems were high but comparable with previous studies.

2) Run-off modelling

Run-off modelling was undertaken to assist in the interpretation of the Mount Pollock field measurements with respect to other soil types in the region. The modelling was carried out using the Water Erosion Prediction Project (WEPP) hydrological model and assisted in filling the gap in knowledge because of the dry years. The simulations were based on an approximation using wide-spaced ridge tillage as a surrogate for raised beds. The model was run for a generic winter wheat grown during a 20-year simulation period on six different soil types and slopes, ranging from 0.5-8%.

Most simulations were undertaken on a slope of 1%, which is typical of many cropping paddocks in the region. The simulations have shown that the soil type had a significant impact on differences in the mean annual run-off volumes from raised bed and conventional flat treatments. On the lighter surface soil types (e.g. a brown chromosol at Hamilton), the predicted mean annual run-off volume was slightly greater from the raised beds compared to flat treatments. Raised beds shed 8mm of run-off compared to 5mm from flat treatments. On the Mount Pollock grey sodosol soil type, the predicted mean annual run-off from raised beds was only slightly higher than the flat treatment, at 13.5mm to 13.1mm, respectively, representing about 2.4% of annual rainfall. However, on the heavier soil types at Winchelsea and Streatham, the raised beds were predicted to shed approx. 10mm less run-off than the conventional flat treatments on a mean annual basis. Raised beds were predicted to shed 32mm compared with 42mm from conventional flat tillage. Heavier soils increased the proportion of run-off to approx. 7% of annual rainfall, compared with lighter soils that shed 1-2% of annual rainfall for raised beds and conventional cropping systems. The annual amount of rainfall and its seasonal pattern were also important in determining whether run-off was greater from one or the other type of tillage management.

On all soil types, modelled daily peak flows from raised beds consistently exceeded those from the conventional flat cropping, consistent with the field measurements taken at Mount Pollock. Where annual run-off values were similar between the two types of management, run-off under the conventional flat treatment was produced from longer run-off events. An increase in slope tended to increase the differences in mean annual run-off between treatments. As the slope increased from 1-8% at the Mount Pollock site, raised beds were predicted to shed significantly more run-off than the flat treatments. In summary, the WEPP model was able to satisfactorily simulate run-off from raised beds over a range of soil types and rainfall regions.

3) Water balance modelling

APSIM was used to simulate the water balance under a conventional cropping system and results compared with actual measured values. The object of this work was to estimate deep drainage under cropping in the high rainfall zone. The model was chosen because APSIM and its derivative products (eg. Yield Prophet® and Whopper Cropper) are used extensively by growers in Australia for the simulation of crop growth and provision of N application recommendations. Unfortunately, this project found that APSIM could not be used to simulate the water balance under raised beds because of the lack of parameter descriptors to describe the beds and furrows in a raised bed system. The project also found that under a conventional cropping system, the soil profile water content predicted by APSIM was higher than values observed in the field during 2003 and 2004. This may have resulted from highly variable soil water retention curve parameters.

Simulated soil water content at the surface was found to be unresponsive to drying conditions compared with the observed values, and remained greater than 30% during the seasons. The conclusion was that improved soil water retention curve parameters, and knowledge of the behaviour of SWCON and MWCON parameters under waterlogged conditions, is required for APSIM to accurately reproduce the observed water content data.

The measured soil water deficit developed under all treatments did not reach field capacity from 2003 to 2004. This
indicated a low capacity for deep drainage. Deep drainage simulated by APSIM was variable under different sets of climatic data from 2000 to 2005 and ranged from 4.3mm to 154mm per year. For many years, when simulated deep drainage was two to five-fold greater than run-off, it was considered that APSIM simulations were unrealistic. Run-off simulated by APSIM was also variable, but equated to observed data in 2001 (a high rainfall year) and 2002 (a low rainfall year) of the five-year measurement period. The run-off component was important in reducing waterlogged soil at peak times of risk, even in dry years. Dry seasonal conditions during grain-filling or other management issues were more likely to have influenced yields than run-off losses because modelled grain yields for wheat were similar to observed values.

In summary, this project found that while APSIM is a commonly used model in the HRZ, it could not be used to simulate the water balance under raised beds. This was because of the lack of parameter descriptors to describe the beds and furrows in a raised bed system. However, field measurements indicate that raised beds shed more run-off than conventional treatments, so it can be assumed that deep drainage will be lower under raised bed systems.

4) Soil suitability

In order to provide guidance on soil suitability for raised beds, MacEwan et al (2003) devised a set of rules to re-classify the Maher and Martin (1987) soil-landform units with respect to the qualities required for raised bed cropping. The criteria took into account slope, waterlogging potential and surface soil texture, and described soils as having a low, moderate or high suitability for raised beds.

The soils which fit into the moderate suitability category are typically yellow duplex or brown sodosols. The soil erosion hazard of sodosols is generally high because of the light texture of the surface soil, sloping nature of the landscape and the sodic nature of the subsoils. The lighter textured surface soils (e.g. with less than 15% clay content) are particularly prone to water erosion and not suitable for raised beds. Surface soils with a clay content between 15% and 30% are generally stable when placed into raised beds on slopes of less than 1%. However, they can be highly erodible if the soil is dispersive.

The soils that are highly suitable for raised beds are black, self-mulching vertisols. These soils have a high clay content (e.g. more than 30%) throughout the soil profile and typically occur in the lower (and flatter) parts of the landscape. This makes them less susceptible to water erosion, and particularly suitable for raised beds.

The estimate of a total potential area in south-west Vic highly suited to raised bed cropping is in excess of 300,000ha in the basalt plains, with the bulk of it under pasture or occasional crop. There is about 700,000ha that has moderate suitability for raised bed cropping. Another 88,000ha with high suitability is being used for dairy or blue gum plantations. The total potential area in south-west Vic, including areas of moderate and high suitability, is nearly 1 million ha.

In summary, there is enormous potential for raised bed cropping in the region. In order to minimise the negative environmental impacts of this expansion, it is imperative that the best practice guidelines developed by this project are followed. This is particularly important on those soils classified as being moderately suitable for raised beds.

5) Best management practice guidelines

The project has developed a set of best management practice guidelines which outline the key environmental issues a grower must consider when installing raised beds. They focus on good on-farm water management and include conservative estimates for maximum slopes and length of runs to ensure that the potential for water erosion and nutrient loss is reduced.

The guidelines have been produced as GRDC High Grains fact sheets and included in the Raised Bed-Controlled Traffic Farming CD manual produced for GRDC by SFS and Vic DPI in September, 2005.

Other research

This project has identified that significant nutrient losses in run-off from raised beds will occur if growers continue using current district fertiliser practices. The results have highlighted the need for further understanding of the relationships between the rates, timing and application technology used for fertilising crops, the quality of water leaving paddocks and the yield and profitability of the crops.

More research needs to target:

* Techniques for the placement of fertiliser under the surface of raised beds - not on the furrows.
* The forms of fertilisers available, including the role of slow-release and liquid fertilisers.
* Other forms of tillage, including subsoil amelioration under beds, required to reduce potential nutrient losses.
Knowledge of soil-water characteristics and soil hydraulic properties is very limited in the southern Vic region. Confidence in the use of the APSIM and other models for south-western Vic would be improved by increasing knowledge of the physical nature of soils in the region.

The project found large differences in run-off based on different soil types and tillage practices. This indicates that a more comprehensive modelling framework is required for raised beds, combining infiltration of the bed surface and traditional furrow drainage theory. Development of a user-friendly model to characterise drainage, run-off and associated nutrient losses under raised beds is recommended. This model could be considered as part of a specialised raised bed module for APSIM. Such development would help lower the amount (and cost) of the field verification required.

**Intellectual property summary**

All results from this project are freely available within the constraints of the communication requirements of GRDC for acknowledgment of support and there are no commercial intellectual property rights. Scientific papers and other reports based on this work will be the responsibility of the principal investigator.

**Additional information**


