# SOIL CONSERVATION IN AUSTRALIA'S SEMI ARID TROPICS: PATHWAYS TO SUCCESS, AND NEW CHALLENGES

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## Abstract
Management practices in Australia's northern cropping zone were initially imported from Europe and southern Australia. Recognition that structural soil conservation measures were insufficient to control erosion alone was evidenced by excessive rilling, gullies and sedimentation. Realisation that the loss of water associated with high runoff reduced yields, and the understanding that crop residues, if retained, could reduce runoff and erosion led to the widespread adoption of conservation tillage systems in the 1990's. Drivers for change leading to adoption of conservation tillage systems were equal or better profits, and development of new tillage equipment and herbicide technology facilitating rapid adoption.

New challenges to sustainable productions emerging include agri-chemicals appearing in water bodies. Also, better water storage associated with conservation tillage may exacerbate deep drainage and salinity risk, which in itself is an emerging issue. Improved systems that are both profitable and sustainable have been developed through diligent observation and experimentation in the past and continued learning with farmers. The diversity of research approaches used has been effective in supporting widespread change leading to more sustainable production systems. This paper reflects on research, development and extension activities on cropping lands that have lead to adoption of more sustainable production systems in an environment that is challenging from an economic and environmental perspective.

## Introduction
Soil erosion and structural decline have been factors constraining stable long-term production in the semi arid tropical regions of Australia's grain production areas. Soil conservation structures are an important part of most conservation plans, providing a stable drainage network to transport excess rainfall, and are increasingly being supported by conservation tillage practices. Currently, there is much interest in improved farm layouts to increase production efficiency and stability of soil conservation structures (Yule et al., 1996). There is also an increasing emphasis for agricultural land to be managed to control off-site impacts on the quality of surface and groundwater.

Judging by the high degree of implementation of contour banks and associated waterways, there is little question of the effectiveness of soil conservation structures. While these structures have measurable costs, such as construction, maintenance and less efficient tillage, the cost of erosion is much less obvious. This apparent altruism is attributable to Australian farmers innate land care ethic (well before research showed high rates of erosion and well before Landcare) and effective extension programs by soil conservation authorities. In the current climate of economic rationalism, more convincing arguments are needed for implementation of soil conservation measures. The last decade has seen a major change in community and government attitude to soil conservation. There has been a change from a situation of polarised 'production' versus 'conservation' views to a near universal acceptance that production must also include conservation principles while broader landscape issues (biodiversity, water balance and quality) are being considered. It is a happy coincidence that in a semi-arid environment, systems which makes better use of water are likely to have less runoff and therefore less erosion, all other thing being equal.

The road to adoption of better management systems can be attributed to many influences, and we acknowledge that it is impossible to attribute which approaches have been most effective. This paper briefly reviews developments in soil conservation practice from a research scientist perspective, reflects on the role of a range of research approaches.

## Knowledge improvement pathway
Development of new practices and technology arise from many activities, some formal, as in defined research and development projects, and much from the informal activities of farmers and machinery innovators. Many new ideas are built on ideas from other disciplines and environments. While agricultural production systems in the northern cereal belt of Australia originated from European and southern Australia, innovations in terms of machinery were also influenced by developments in Canada and the USA. A description of some key activities that contributed to

improvement in knowledge and adoption of more soil conservative systems follows. Carey and Capelin (this conference) will provide a discussion from an extension viewpoint while this review provides a researcher perspective.

*Tillage experiments*

While soil conservationists had notions that stubble retention and reduced tillage was good for soil erosion control, production oriented agronomists and farmers had yield and profit as their primary concern. Thus there was a need for definitive evidence that alternative tillage methods would be financially rewarding. A key study well ahead of its time began in 1968 (Marley and Littler, 1989). This replicated experiment near Warwick in southern Queensland compared a matrix of tillage (±), stubble retention (±) and nitrogen fertiliser treatments. This experiment is still active with > 30 years of continuous comparisons, and has provided a venue for many other studies. Other studies of note include those conducted by Felton and Martin (1985), Thomas et al., (1990) and Radford et al., (1992). Thomas et al. (1997) reviewed many of the tillage trials in the region.

These trials represent an enormous amount of effort, and findings can be broadly summarised as; stubble retention always increases water storage in fallows, often reduces soil nitrate levels and grain protein, and stubble levels are higher where tillage is avoided. Grain yield is improved with increased water storage in the fallow period when soil water is limiting during crop growth, but many experiments provide less than clear evidence that there is extra profit to be made from no tillage and stubble retention (Radford et al., 1991; Freebairn et al., 1993). Studies that provide clear evidence of advantages in production from conservation tillage generally have better rotations and avoidance of disease and nutrition limitations (good agronomy, which may not be the case in statistically constrained designs).

Long-term trials can develop artefacts that are not representative of farmer practice, and thus become less relevant in informing current practice, although they do help us understand long-term changes in soil systems. Farmer experience has since overtaken research studies as conservation cropping techniques (reduced-no tillage, stubble retention) are being widely applied. Farmers, having gained an understanding of principles of efficient water storage and use, have adapted practices to their own situations to make better use of resources. There is a consensus within research community (agronomists and soil conservationists) that conservation tillage systems are clearly best practice, and that there is little conflict in advice to the farming sector, even though some of the claims of yield and profit improvement may be somewhat exaggerated. Good farmers manage all the critical elements of a farming system (weeds, disease, nutrition) thus capitalising on improved water relations resulting from conservation tillage systems.

*Machinery evaluation*

While not well documented, an important element of practice change was the importation from Canada and the US of tillage and planting equipment that better was adapted to operation in high stubble conditions. Groups of farmers, scientists and agricultural engineers toured North America in the early 1970’s to see first hand, equipment and studies where a range of stubble retention practices were being used. This led to a machinery evaluation program where a range of tillage equipment was demonstrated with farmers in their paddocks (Lindsay Ward, personal communication). Subsequent interest led to more detailed studies of tillage components (Ward and Norris, 1982).

One outcome of these activities was that this region now has a viable tillage equipment-manufacturing base that specialises in stubble and no till conditions. While soil and water principles associated with reduce tillage and soil cover may have been appreciated by some farmers and scientists, the implementation of practices using these principles could not proceed without ready access to suitable equipment. This activity was an essential element for promoting and facilitating the adoption of improved tillage systems (Freebairn et al., 1986).

*Catchment studies*

While the principles of erosion control through stubble and tillage management were understood by a few innovators in the early 1970’s, there was little awareness of the magnitude of runoff and erosion from cropping areas, and even less understanding of the impact of alternative tillage practices. This was a period when there were two conflicting messages coming from government extension staff; retain stubble after harvest and reduce erosion and, burn stubble to avoid disease and nitrogen “tie up”. It is worth noting that similar information on hydrology and erosion was available from the US well before this (Smith and Henderson, 1961), but clearly we did not take any notice of it, or more likely needed locally relevant experience!

*Bounded plot catchments*

Much of the database from which the USLE (Wischmeier and Smith, 1978) relationships were derived came from small bounded plots (22*4 m). These plots had the advantage of being easily managed, with a large number of treatments monitored at any one time. While similar studies were carried out on research stations throughout New South Wales for over 25 years (Wiltshire, 1948), there have not been any similar studies in Queensland on croplands. While it is useful in retrospect to have a long record of hydrology and erosion data, the efficiency of such studies would receive critical review today. Having fixed treatments and being research station bound tends to mitigate against relevance and credibility (see earlier comment on experimental artefacts). Even so, data from these plots eventually lead to SOILOSS, a computer based USLE model, (Rosewell, 1993) and made a contribution to the National Land and Water Resources Audit assessment of erosion across eastern Australia.

*Contour bay watersheds*

Graded "contour" banks are used to reduce slope length and control runoff from sloping land. These structures result in the dissection of larger watersheds into a series of small (1-10 ha) watersheds. As such, these watersheds represent the smallest hydrologic management unit within the watershed, and are well suited to studying management effects on erosion at a scale that is experimentally and logistically manageable, and results are directly relevant to land managers. A typical installation consists of a flume at the outlet of each contour bay catchment, allowing runoff and suspended sediment load to be estimated (Figure 1). Soil loss is estimated from suspended sediment and measures of rill and deposit volumes (Freebairn and Wockner, 1986; Sallaway et al., 1988).

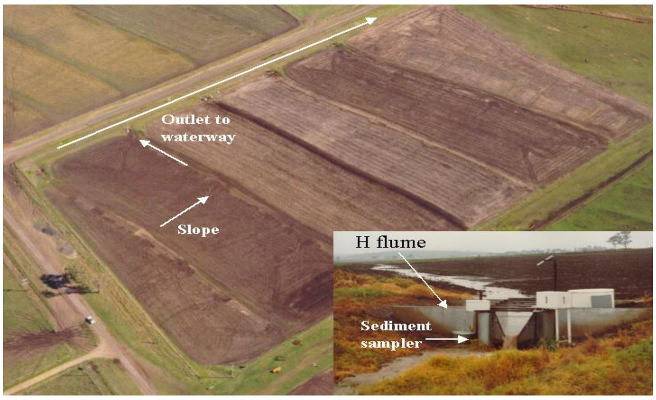


**Figure 1. Aerial view of a set of 5 instrumented contour bay catchments near Greenmount, southern Queensland, and flume (inset) at outlet to measure runoff and sediment.**

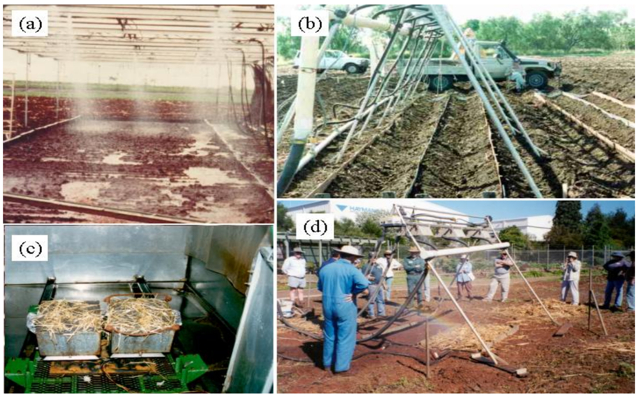


**Figure 2. Rainfall simulators used for erosion research and extension (a) rainulator 22 *4 m, (b) reciprocating nozzle simulator 10 * 2 m, (c) small trays in a laboratory simulator and (d) rainfall simulator 2*2 m.**

These small-scale catchment studies were valuable in creating awareness of the extent of water and soil loss from agricultural practices. For example in one extreme event, 100 t $ha^{-1}$ of soil was lost from the cultivated area where the soil was bare (stubble burnt) compared to 1 t $ha^{-1}$ from a no till area with 75% soil cover. When events such as this were observed, maximum value was obtained from impromptu field inspections with extension staff and farmer - seeing was believing. Initially our focus was on demonstrating how dramatic an impact soil management could have on runoff and erosion. This was well received, but it was not until we changed the angle of our story to one that emphasised that when we reduced runoff, this led to better water storage, and subsequent crop yields, that management changes accelerated. While these small-scale catchment studies were clearly effective as a research arena and extension tool, the production of results is uncertain in climates characterised by high variability. It is uncertain whether such long-term (> 5 years) studies could be initiated in our current research-funding environment where most research is planned on a 3-year basis.

*Small agricultural watershed*

Small agricultural catchments are generally instrumented to gain an understanding of the hydrology of a region and the impact of land use and topography on runoff and erosion processes at a larger scale (Titmarsh et al., 1985, 1991). Such data are also used in design of hydraulic structures. A typical catchment includes a number of land uses, soil conservation structures and natural drainage lines. A landmark catchment study in central Queensland, initiated in 1965, had three 12-17 ha catchments with natural vegetation (*Acacia harpophylla*) instrumented for a 18 year calibration period. In 1982, two catchments were cleared; one planted to pasture and the other cropped

(Lawrence, 1990). Average runoff doubled from 41 mm/yr under forest to 86 mm/yr under cropping and increased to 67 mm/yr with pasture, over an 8 year period. Studies such as these long-term experiments provide valuable baseline data to gauge impacts of agricultural development on hydrology and other ecosystem properties. For example, soil data from this study have recently been invaluable in assessing changes in deep drainage and salinity risk using chloride (Tolmie and Silburn, 2002) and in carbon cycling (B. Cowie, personal communication, Skjemstad et al., 2004).

*Rainfall simulator studies*

The biggest disadvantage of catchment studies is the uncertainty in data collection, even if all the equipment designed to measure water and sediment functions on the odd day of the year when water does run! In southern Queensland, runoff occurs at the paddock scale on average 5 days a year, and significant soil movement about once every 2-4 years, and it is completely unpredictable when this will occur. Field sites may need to be maintained for years before a reasonable number of "events" are sampled, this can be expensive, and is not well suited to demonstration or extension. While the results presented above may be impressive, it is easier to document them after the event, with many years compressed onto a page. Being able to determine rainfall, soil and surface conditions using simulated rain allows for many comparisons to be made under relatively controlled conditions, with the capacity to make any number of measurements. Figure 2 shows a number of rainfall simulators used both as research and demonstration tools

A rainulator (McKay and Loch, 1978) applies simulated rain to a 22.5 * 4 m plot, or subsets of this area. This plot size is well suited to the study of rill erosion processes that operate at a scale larger than 1 $m^2$. Rainulators have been valuable in gaining an understanding of detailed erosion processes (e.g. Loch and Donnollan, 1983) and quantification of erosion parameters for computer models. Rainulator style equipment (travelling gantry) have been replaced by mechanically simpler reciprocating nozzle machines (Figure 2b, 2c). Plot size is generally determined by the processes being studies and resources available. Small plots or trays (<1 $m^2$) may be appropriate for studying surface processes and infiltration both in the field or laboratory, while 1 - > 20 $m^2$ may be more appropriate for erosion studies.

Simulated rainfall studies have been valuable for two reasons; enabling us to do detailed process studies and also being able to demonstrate many of the principles of soil management for better water and soil conservation. Features of using rainfall simulators for extension are that they allows participants to discover and learn in their own environment, the process is readily reproduced and can reach a large audience, and results can be owned by each group through participative processes. The spectacle of being able to see what happens to your soil during a rain storm, in the comfort of a sunny sky, provides a stimulating environment for discussion and exploration of ideas –a case of seeing, doing, talking, sharing, learning.

*Integration through simulation models*

Development and application of a range of models has been an important research area, both to support field experimentation, and as a method for summarizing research findings (Freebairn et al., 1996, 2003; Littleboy et al., 1992; McCown, 1996). The relevance of results from soil and water conservation studies described above are constrained by their specific conditions and treatments, and highly influenced by a relatively short sample of weather. Conceptual and mathematical models describe the main processes of hydrology, erosion, sediment transport and deposition, and aim to unify findings from many studies. Systems models have been used to capture the main management influences such as tillage, crop type and sequence, and grazing management so that estimates of any specified land use system can be generated, reducing the need for long term experiments to assess outcomes from any scenario, both current and proposed. An important capability required of erosion system modeling is to be able to predict long-term consequences and relative efficacies of alternative management practices. Typical applications of models include; decision support systems to assist land use planning, interpretation of experimental data in terms of physically meaningful parameters so that generalised conclusions can be made across locations, and time scales, exploration of effects of land use on off-site sediment load, and estimation of interactions between erosion, management and productivity.

While models have not become stock in trade with land use planners or managers in Australia, they are part of many research scientists' tool kit. There is no equivalent application of the USLE in Australia as has been the case in the US, where estimates of erosion risk have had a important role in allocating farm support. With the emergence of target setting as part of the National Action Plan for Salinity and Water Quality, it is likely that models will be required to support natural resource groups in priority setting and in reporting progress. Given increased demands for "science" to provide support to industry and government, models are likely to play an increasing role in policy setting and natural resource management.

**Adoption and impact**

The apparent slow adoption by the whole farming community of conservation tillage practices is often used to indicate that we still have along way to go before we can say that erosion is under control. It needs to be recognised that barriers to change include; cost of machinery changes, age structure of the farm community, lack of need to change (perceived and real), and inability to change through insufficient skills. In some cases we may have the general solutions, but the specific solution is either not available or uneconomic. On the other hand, we should acknowledge that change in tillage practices has been relatively rapid and widespread (Figure 3).

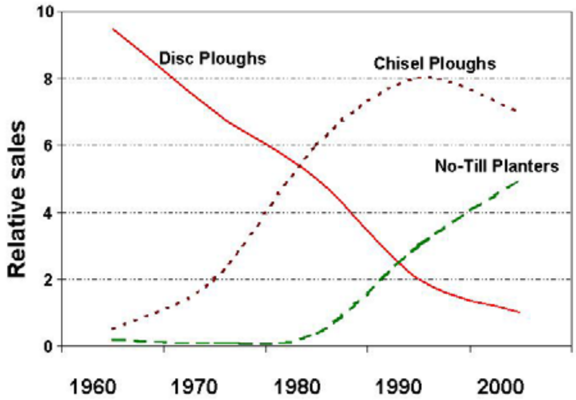


**Figure 3. Qualitative trends in machinery sales in southern Queensland, 1960-2000. Data from a survey of machinery manufactures, farmers and scientists (Freebairn and King, 2003).**

The impact of this change in practice on erosion risk is presented in Figure 4. Given the difficulty in measuring erosion or water quality trends, it is more practical to monitor simple land condition indicators (such as cover) and infer improvements through data and relationships such as in Figures 3 and 4.

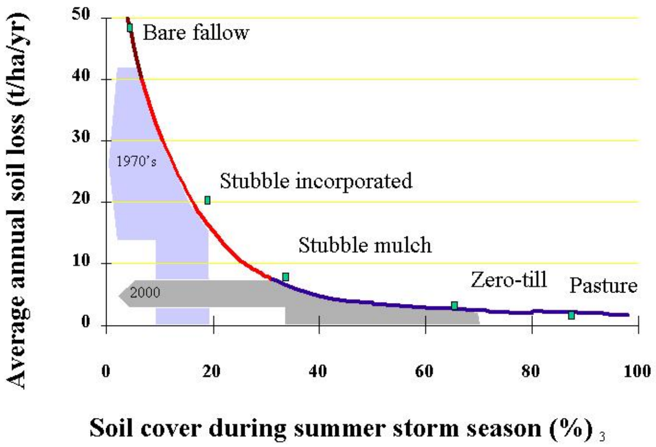


**Figure 4. Changes in tillage practices have increased soil cover over the last 30 years. Reduced tillage has reduced erosion risk significantly (see shaded lines).**

**Unplanned outcomes and new developments**

While we may be pleased with progress made in improving the stability of our landscape through adoption of soil conservation structures and conservation tillage, there are some unexpected outcomes that need consideration. Increased infiltration and water storage as a result of conservation tillage can result in increased deep drainage and consequent risk to dryland salinity (Tolmie and Silburn, 2002). This might easily be addressed through increased cropping frequency, but at least needs to be considered in a landscape setting. A key element of conservation tillage systems is the increased use of herbicides. Some of these chemicals have found their way into water bodies, putting at risk the registration of what are very effective agronomic tools. A range of options is available for reducing risks of contamination (Rattray et al., this conference). Another consequence of the greater reliance on herbicides for weed control is the emergence of herbicide resistance. If more weeds become resistant, and alternative chemicals are not found, then there may be an increase in tillage and reduced soil cover.

Technology and innovation has allowed Australian agriculture to meet the challenges of the cost:price squeeze. With the advent of accurate GPS guidance systems linked to tillage, planting and spray equipment, previously impossible tasks become feasible. Biotechnology, however controversial, may offer new options in pest control and disease avoidance. For example, fertilizer and seed can be accurately placed to make better use of resources and weed control may become more targeted and less reliance on residual chemicals.

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