Managing resources - the soil resource: erosion, stubble management and catchment

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Summary. Contour banks, the initial mainstay of soil conservation functioned well in curtailing gully formation, yet high erosion rates were still evident. Management practices which improve infiltration and reduce overland flow velocity are now essential elements in erosion control strategies.

Soil erosion and structural decline are still considered major threats constraining stable long-term production. Tillage experiments have shown that management strategies involving retention of crop residues (stubble), reduced tillage and crop rotation can reduce erosion and often improve yield. Results from comparisons of tillage treatments are highly variable, reflecting interactions between soil water, nutrition and disease. Simulation models are being developed to deal with the interactions between variable climate and management options. Such models will 'add value' to existing data as well as providing a tools to examine modifications to existing systems of soil and crop management.

Where has soil management come from?

Australian agriculture has evolved from `imported' European practices. History has shown that many of these imported practices were not suited to Australian environments and resulted in high erosion rates and decline of soil physical fertility. It has been necessary to develop systems of management more in tune with 'older' fragile soils and severe climatic conditions so common in Australia.

Soil erosion is a problem in most agricultural areas of Australia, and particularly in northern Australia where high intensity rainfall associated with tropical and sub-tropical influences is common. Erosion rates are related to rainfall erosivity (43) which generally increases northward in Australia (24,35). Erosion rates measured from several studies reflects erosion potential as well as topographic and management considerations (Fig. 1).

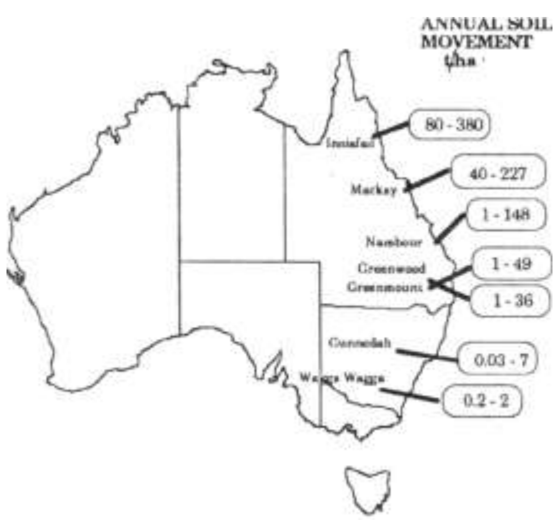

Figure 1. Measured erosion rates from several studies in eastern Australia. The range of values for each location represent the best and worst conservation practices studied.

Conservation structures

Contour or graded banks designed to reduce slope lengths were regarded as the panacea for many erosion problems and were the mainstay of soil conservation until the 1970s. These graded channel and bank structures (typically with a grade of 0.3-0.5%) were designed to reduce slope length, and have functioned well in curtailing gully formation and reducing loss of soil from hillsides (27). The spacing between banks has been determined from experience both in the USA and Australia, but it appears that the criteria for determining spacing in Australia has been more a function of custom rather than to keep soil losses below a critical level, *as* is the case in the USA.

Tillage management

Until the mid 1970s, the most common approach to fallow management was to remove all crop residue either by burning or inversion tillage, disc ploughs being the preferred primary tillage implement. In summer rainfall areas, stubble was often burnt immediately after harvest, while in winter rainfall areas stubble would be burnt in the autumn, after being grazed through the summer. Maintenance of fallow for long periods (6 to 12 months) to store water was also common. These practices resulted in little residue being present when the probability of intense rainfall was high.

The lack of tillage and planting equipment well suited to operation in stubble was a major limitation to the adoption of stubble retention practices, even though some farmers and soil conservationists were aware of the potential for stubble retention to conserve water and soil. A machinery introduction and evaluation program sponsored by QDPI provided an important catalyst for the development of stubble retention systems in northern cereal areas, resulting in innovative farmers experimenting with and developing components of workable systems. Technical problems specific to planting into no-till conditions were largely overcome by field testing and modification of existing equipment (42).

Weed control posed a major challenge in reduced tillage systems. The knowledge base for herbicide strategies grew *as* chemical companies, researchers, extension personnel and farmers experimented with different chemical mixes and weed species. Wetter than average conditions were often useful in 'forcing' farmers to apply herbicides in salvage conditions, thus increasing the number of operators with some experience and proficiency in using herbicides instead of tillage for weed control. Fawcett (10) has presented a comprehensive review of tillage systems for southern and northern cereal areas and readers are directed to his publication for more detail.

Where is soil management now?

Soil erosion and structural decline are still considered major issues constraining stable longterm production. Soil conservation structures are still an important part of most conservation plans, providing a stable drainage network to transport excess rainfall, but are increasingly being supported by tillage and stubble management practices.

Conservation structures

While currently not used operationally in soil conservation design, models are now available which can provide a more rational basis for hydraulic design of soil conservation structures. Model such *as* KINCON (2) can be used to determine flow depth and velocity at any point along channels and waterways using kinematic wave theory from open channel hydraulics. Catchment size and channel length can now be designed to meet criteria such as maximum flow velocity and depth using knowledge of catchment hydrology and topography. Variables such *as* channel roughness, slope, cross section and length can be readily modified to examine the effects of various design options (3). This procedure is a departure from some of the 'rule of thumb' approaches adopted in the past which were often limited by experience.

Tillage management

The trend in tillage practice is for greater retention of crop residues and less tillage operations. Tillage experiments have shown that management strategies involving retention of crop residues (stubble), reduced tillage and crop rotation reduce erosion and often improve yield, although responses are variable. Tillage management can be discussed in terms of the physical factors which are manipulated during tillage.

Cover. The amount of crop residue remaining after tillage is determined by crop and tillage type (38). It is now generally accepted that cover is very effective in reducing soil erosion, a conclusion borne out by many catchment and simulated rainfall studies (1,13,25). Cover reduces erosion by: (i) reducing runoff volume through stubble protecting the soil surface, thus reducing aggregate breakdown, compaction of the surface by rain drops, and loss of transmis- sion pores (21); (ii) reducing the rate of detachment of soil readily available for transport, and (iii) reducing overland flow velocity. Measurement of annual soil movement from 1 ha catchments in southern Queensland has clearly shown that surface cover reduces soil erosion. When surface cover was lost by stubble burning (or grazing), soil loss rates of 30-50 t/ha/y, equivalent to an annual loss of 3-5 mm of topsoil were recorded. When stubble was retained, average soil losses were reduced to less than 4 t/ha/y (13).

Cover levels of >30% appear to be critical for erosion control (Fig. 2). While this level is somewhat arbitrary, it appears universal that the steepest part of the cover-soil loss relationship is often around 30%. The reason for this functional form is that soil loss is a product of runoff and sediment concentration, with both quantities related to cover.

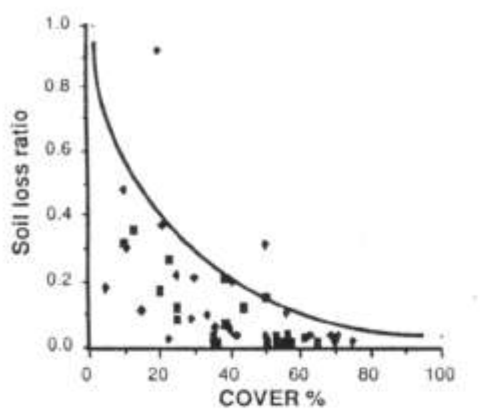

Figure 2. Relationship between surface cover and soil loss ratio (fraction of bare soil loss) for two vertisols on the eastern Darling Downs.

Soil strength. In some cropping systems, for example cane sugar culture, increased soil strength associated with no-till is a major factor in reducing erosion while cover is relatively less important. Reduction in soil strength associated with tillage can exacerbate erosion. For example, soil strength was found to be the most important factor controlling erosion on steep canelands (slope 12-18%) in north Queensland, with soil losses of 150 t/ha/yr from cultivated conditions being reduced to <15 t/ha/yr when the soil was not cultivated between cane rows (30). In wet tropical environments, runoff is frequent and unavoidable, and high soil strength in inter-row furrows allows water to move off hillsides without entraining soil.

Increased soil strength associated with no-tillage (16) may increase the duration when tillage and planting operations are feasible. The potential for improved timeliness of operations, especially planting (45), can result in higher yields and more flexible farming operations.

Roughness and storage. Smooth soil surfaces associated with no-till systems can result in higher runoff compared to tilled soil (4,15). For example, during a summer fallow (1988-89) runoff from a hard setting soil near Wallumbilla with chisel (rough) and no-tillage (smooth) was 16 and 34 mm respectively. Tillage operations on the chisel tilled catchments created surface roughness and broke crusts formed by rainfall.

Depression storages can be constructed with specialised equipment and are variously referred to as furrow dykes, tied ridges or pits. Their function is to store excess rainfall , allowing more time for infiltration. Tied ridges studied in Africa (19,5) offered advantages for water conservation and yield of row crops in dry conditions, but caused yield losses through waterlogging in wet periods. Using simulated rainfall on a vertisol in Queensland, both surface pitting and cover improved infiltration (S. Glanville, pers. comm.). Similar pitting applied to catchments in central Queensland, (C. Carroll, pers. comm.) and the Maranoa showed no effect on runoff.

Deep tillage. Deep tillage (20-40 cm depth) has been practiced to improve water storage and root growth but results have been variable. Radford *et al.* (32) found no benefit to wheat and sorghum from `paraplowing' in southern Queensland while Mead and Chan (26) found that any beneficial effect of deep tillage was short-lived on a hard-setting soil.

Crack management. A feature of vertisols when dry is the presence of cracks, commonly to the depth of water extraction. Water movement to depth via cracks, sometimes referred to as `wetting from the bottom up' can occur during high intensity rainfall, and provides a means for improving the efficiency of water storage. Tilling cracked soils can reduce the effectiveness of soil cracks in carrying excess rainfall to lower soil layers (22).

Soil structure. Tillage is implicated in the decline of soil structure (6,8,17,18,39). Retention of residues and reduction in tillage has been expected to reverse or at least retard observed declines in soil structure. Surface porosity is commonly lower with no-till although the amount and connectivity of macropores may be greater than in cultivated soils, with resultant improved drainage characteristics (9). Also, these changes may be associated with more active macro-fauna (37) due to lack of disruption of structural voids associated with tillage. Higher macropore numbers may lead to better aeration, quicker drainage of water during wet periods and improved root growth. Alternatively, faster movement of water may lead to rapid movement of salts and agricultural chemicals into ground water.

Packer *et al.* (28) measured soil and infiltration characteristics on two soils in southern New South Wales. Observed benefits of changes in tillage practice were both small and slow to develop. For example (29), changes in soil structure using infiltration and aggregate stability indices were only measurable after five years use of stubble retention and direct drilling (no-tillage). Loch and Coughlan (22) and Harte (18) found only subtle changes in soil properties of a vertisol after eight years of reduced tillage. In these cases, the soils were well structured. Prove *et al.* (31) found no-tillage and stubble retention had significant positive effects on several indices of structural stability for a krasnozem soil, but infiltration of simulated rainfall was not different between tillage treatments.

The above results have prompted greater interest in the use of ley pastures to achieve significant improvements in aggregate stability. Differences in water accumulation between tillage treatments are often due not to changes in aggregate stability, but to factors such as surface protection and pore (crack) continuity (11). Dexter (7) has suggested that 'natural' processes may be as important as tillage management in ameliorating soil structure, and that with a better understanding of the processes controlling soil structure, soil management strategies might be designed to optimise physical processes influencing crop production.

Yield and profit

Results from tillage experiments are highly variable both in magnitude and direction of responses, making extension of apparently more sustainable practices difficult (Table 1). This superficial unpredictability is often a result of climate variation and interactions between climate and the soil/plant system.

Table 1. Mean winter crop yields (t/ha) for four tillage experiments in Queensland (results for nil fertiliser treatments at first three sites).

Location (duration)	Tillage treatment			
	Cultivated No stubble	No-till Stubble	No stubble	Stubble
Hermitage (23) (11 years)	2.69	2.53	2.79	2.48
Billa billa (32) (4 years)	2.65	2.68	2.31	2.70
Mt. Murchison (40) (7 years)	2.83	3.16	2.35	3.05
Greenmount (44) (8 years)	2.78	2.95	-	2.77

To demonstrate some common issues with tillage experiments, I will use the long term fallow management trial at Hermitage near Warwick as an example (23,41). This experiment is one of the most comprehensive data sets available, dealing with nutrition, water storage and disease associated with fallow management. A simple economic analysis of crop yield and protein in an 18 years period (1968-87) was carried out. Since the trial commenced, the original treatments have been split several times to investigate new issues as they arose. I will consider only the original main treatment effects; ? tillage, ? stubble and three rates of nitrogen (0, 24 and 46 kg,/ha N, the latter increased to 69 kg/ha about half way through the trial). Sub-treatments were selected to minimise any long-term artefacts present due to the extended length of the trial (e.g., nematodes, nutrition carry over effects). Difference in yield and gross profit (less fertiliser) between the cultivated, stubble-burnt, nil-fertiliser treatment and other treatments are presented in Table 2.

Table 2. Comparison of yield and profit relative to stubble burnt, tilled and nil nitrogen for four tillage methods and three nitrogen rates on the Hermitage Research Station fallow management trial -1968-87. Gross profit was determined from the product of yield and price (with bonus for protein) less fertiliser cost. All prices based on August 1991, with wheat prices; $125/t @ 9% protein, $180/t@ 15% protein. Yield and protein data extracted from Marley and Littler (23) and Thompson (41).

	Yield change (kg/ha)			Gross profit change $/ha		
Nitrogen (kg N/ha)	0	23	57	0	46	57
Tillage treatment						
Tilled / stubble burn	0	82	134	0	33	51
Tilled / stubble retained	-199	81	140	-32	36	46
No till/ stubble burn	92	219	223	15	50	60
No till / stubble retained	-207	98	226	-46	19	51

When analysed using averages of 18 crop years, the most striking result was that the largest and most consistent yield response was due to fertiliser nitrogen. The second feature was that fertiliser responses were greater if stubble was retained. The third feature was that difference in 'profit' between tillage treatments were relatively small at higher rates of nitrogen application, with yield gains on stubble retained plots somewhat offset by lower grain protein.

From this analysis it is clear that tillage practices can not be considered on the basis of water and soil conservation alone. Rather, other factors, such as nutrition, must also be taken into consideration. Disease can also have a major bearing on the success or failure of alternative tillage systems (33,37).

A deficiency in this simple analysis is the ability to factor in a cost for erosion. For example we have shown a bonus of $51/ha for the implementation of no-till, stubble retention and moderate nitrogen fertiliser application (relative to stubble burnt, tilled and nil nitrogen); what is the value of reducing erosion from 30 t/ha/y to < 4 t/ha/y?

Application of erosion models

Physically based models have been developed to predict erosion (34,12). To date, these models have not been used extensively in planning or extension of soil conservation in Australia. A development in application of erosion models has begun in the NSW Soil Conservation Service where a decision support package, SOILOSS (36) is being used for preparing soil conservation plans (Rosewell, pers. comm.). SOILOSS is a computerised version of the Universal Soil Loss Equation (USLE) with some local knowledge incorporated. A more complex cropping system model, called PERFECT (20), has also been developed. PERFECT considers many of the interactions between crop production, rotations, tillage management and soil erosion.

Planning ahead

Soil conservation has evolved from predominantly structural treatment of the problem using contour banks to a combination of structures and tillage management. Future developments will build on these foundations but incremental improvements will need to be solidly justified in economic terms. Maximum exploitation of renewable resources (rainfall, irrigation) will also need to be in balance with the natural resource - to use a well worn term, sustainable production. Given today's economic situation, sustainability to a farmer means economic survival. It is many technologists' belief that profit and resource preservation can be achieved in symphony.

Simulation as a tool

Physical and biological responses to management strategies often appear erratic, but this `apparent' unpredictability is the result of interactions between weather and the physicobiological system. Simulation models provide an analytic framework to examine these interactions. PERFECT has been developed to simulate the dynamics of plant-soil-watermanagement in agricultural systems of the northern cereal growing area on eastern Australia. Major effects of management (e.g., tillage and fallow management, crop rotation, planting decisions) and environment are simulated to predict soil water, runoff, erosion, drainage, crop growth and yield using daily climate data.

The following examples of model application are presented to demonstrate the role of simulation methodology in studying complex systems.

<u>Example 1. Keeping up with changing practices.</u> An emerging fallow practice in the western Darling Downs, the near south west (Waggamba shire of Queensland) and north west slopes and plains of NSW is the maintenance of a no-till fallow using herbicides and/or sheep to control weeds until early autumn - stubble is then burnt to reduce disease incidence and facilitate easier tillage and planting operations.

The question arises; what is the impact of this strategy on water storage and soil erosion, and are strategies available that reduce any negative aspects of this emerging practice? Solutions to these questions would require years of field experimentation, especially in a variable environment where no two years are the same.

We examined the effect of several fallow tillage methods; zero tillage, zero tillage for part of the fallow with a range of stubble burning dates and disc/chisel tillage, on runoff and erosion at Goondiwindi and Roma using PERFECT (20). A soil with 150 mm of plant available water capacity on a 2.5% slope and 100 m slope length was simulated using 77 years of climate records (1899-1975).

Monthly distribution of predicted runoff at Roma through the year is shown in Figure 3. A surprising result is that March has the highest runoff at both Roma and Goondiwindi (not shown). The reason for the March peak is not only high rainfall, but soil profiles are filling, evaporation is decreasing and cover levels are declining. If stubble is removed in early March, soil erosion will increase from 4 t/ha/yr (zero till) to 12 t/ha/yr.

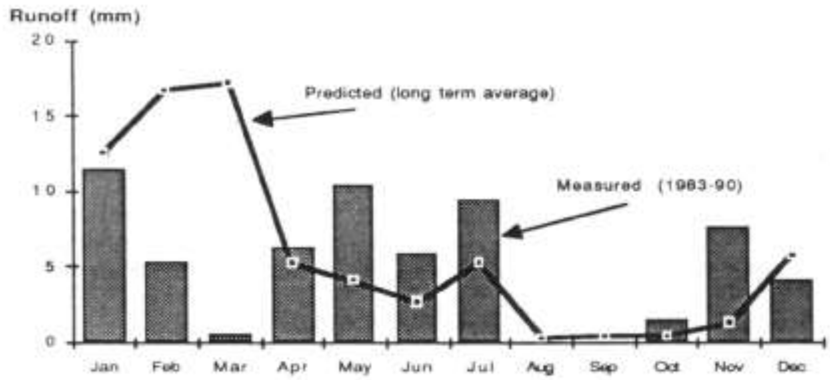

Figure 3. Monthly distribution of runoff measured from the Wallumbilla catchment study (1983-90) and runoff predicted using the PERFECT model with 76 years of daily climate data.

Measured monthly runoff from catchments on a brigalow-belah clay near Wallumbilla (1983- 90) is also presented in Figure 3. Runoff recorded during March was much lower than predicted while May-July runoff values were higher than predicted, reflecting the wet autumns of recent years and generally below-average summer rainfall at Wallumbilla. An important aspect of this analysis is that even 7 years of experimental data must be viewed with care, but with the aid of computer simulation and long term climate records, more informed decisions can be made.

Example 2. Interaction between soil, climate and tillage practice. The response of yield to tillage management and soil depth was investigated for two environments (eastern Darling Downs and Maranoa) and a range of soil depths (described by plant available water capacity [PAWC]). Median yields on the eastern Darling Downs are more responsive to management and soil depth whereas yields in the drier and warmer Maranoa region do not increase for PAWCs greater than 200 mm, and differences due to fallow management are also smaller in the drier environment (Fig. 4). Results shown in Figure 4 suggest that research examining the influence of tillage management in the Maranoa might not be as profitable in terms of achieving yield gains as studies in a less severe environment. Such a result is by no means intuitive, but could be considered in setting research priorities.

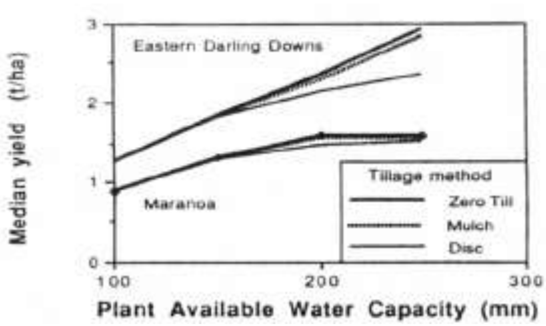

Figure 4. Interaction between climate (location), soil (plant available water capacity) and tillage management (zero till, stubble mulch and disc incorporation of stubble) based on PERFECT.

Example 3. Whole farm catchment management. Physical evaluation of complex farming systems is often impractical but comparisons of systems is well suited to simulation using a computer model which mimics with the major physical and biological processes of a system. As an example of what might be considered a 'model' of sustainable farming, a comparison of a farm system involving contour banks, stubble mulching and storage of runoff water for later use as supplementary irrigation was compared to a system of bare fallow and no soil conservation structures (Table 3) (15). Mean yield was increased by 12.5 %, (due to better water storage in the fallow resulting from stubble retention and supplementary irrigation) and sediment loss from the catchment was reduced to 0.5t/ha/y.

Table 3. Influence of stubble management, contour banks and use of runoff water, collected in a farm dam for supplementary irrigation, on mean annual runoff, soil loss and yield for an eastern Darling Downs catchment (15). Data are based on experimental results and simulation using long term climate records.

	Wheat, bare fallow	Wheat, stubble mulch contour banks Dam + suppl. irrigation
Runoff (mm)	54	21
Sediment loss (t/ha)	37	0.5
Wheat yield (t/ha)	2.8	3.15

Example 4. Design of soil conservation structures. Connolly *et al.* (2) developed a model called KINCON for determining flow depth and velocity at any point along graded channel. Catchment size and channel length can now be designed to meet certain criteria such as maximum flow velocity and depth using knowledge of catchment hydrology. This procedure is a departure from some of the 'rule of thumb' approaches adopted in the past and allows the designer to experiment with and optimise layouts for more efficient farming (3).

Adoption of conservative land management practices

Judging by the high degree of implementation of contour banks and associated waterways, there appears to be little question of the effectiveness of soil conservation structures in reducing erosion. Structures have measurable costs, such *as* construction, maintenance and less efficient tillage (i.e., increased time to cultivate, more overlaps on 'finish out'), yet the cost of erosion is much less obvious. I believe this apparent altruism is indeed attributable to farmers innate land care ethic (well before Landcare) and effective extension programs by soil conservation authorities. In the current climate of economic rationalism, more convincing arguments might be needed for implementation of soil conservation measures.

The last decade has seen a major change in community and government attitude to soil conservation. The change has been from a situation of polarised 'production' and 'conservation' camps to a near universal acceptance that production principles must also include conservation principles. It might be a happy coincidence that, in a semi-arid environment, any system which makes the best use of water is likely to have the least runoff and therefore erosion, all other thing being equal. So why has the push for adoption of conservation tillage in the last 15 years had such variable success, or has it? I have mentioned the change in attitude (my perception!) but there are also many positive outward signs of progress. How many stubble fires do we see on the sloping lands of the northern cereal belt? Less than we used to - this is progress. Tillage and planting machinery capable of handling stubble are readily available while stubble handling is a positive attribute used to sell new equipment which is manufactured locally, surely this is progress. On a random 'survey' driving from Toowoomba to Moree (summer 1990-91)

I estimated that at least 50% of paddocks had made an attempt to retain stubble on the surface. There is a paucity of solid evidence regarding the adoption of 'conservation tillage' while even the definition of conservation tillage varies between protagonists.

There is hardly a tillage experiment whose results would not leave a farmer in some doubt as to what was the most appropriate method of managing his soil (e.g., Table 1), yet we have seen widespread adoption of conservation tillage principles. I believe that farmers are open to change when change is demonstrated clearly to have benefits. Research findings, even when published, are not always easy to find, and then may not be in a useful form. It is up to the research and extension community to deliver the goods. Regarding incentives, I believe the best incentive for adoption of a new practice is knowledge. Researchers and farmers have responded well in the past and have more incentive to do the same in the future.

In summary, many of the principles for farming conservatively and profitably are known in general but it is the specific problems which hinder adoption. Such problems might only be apparent one year in five or ten, but so is frost! There is a real danger in assuming we know all the answers if such a perception lessen efforts leading to a better understanding of constraints and opportunities in our farming systems; what would we be driving if Henry Ford settled on the model T? Admittedly future gains may be smaller and harder to gain, but the realities of a free market dictate that efficiency must continue to improve.

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