Soil, water and weed management—the key to farm productivity in southern Australia

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Introduction

The soils of Australia's farming lands have been exploited for nearly 200 years. The landscape has been extensively cleared, the natural fertility of soils has been depleted and soil structure has been severely degraded. Farmers were not to know that most southern Australian soils were structurally fragile and would react unfavourably to cultivation and, being poorly buffered, would progressively acidify. Government action or inaction contributed to this exploitation.

Until recently, most government involvement in controlling soil degradation had been reaction to particular events rather than as a planned approach to control or ameloration. In addition, government intervention through land-tenure arrangements, soldier settlement schemes and even drought relief programs has accentuated the problem.

This paper reviews the development of a number of the major problems associated with the farming areas of southern Australia and suggests a plan to manage them in order to sustain long-term productivity.

Evolution of farming problems

The history of crop production in Australia (reviewed by Callaghan and Millington 1956; Jenkin 1986; Pratley and Rowell 1986) identifies a series of disasters in terms of soil degradation. Following the clearing of trees, European and then North American farming methods were used on Australian soils until the 1930s when severe soil erosion occurred over large tracts of southern Australian cropping lands. These events, as well as contributing to the formation of soil conservation authorities, led to the development of the ley-farming system of agriculture where crops are grown in rotation with pasture legumes. Ideally, the pasture phase was expected to contribute to chemical fertility and provide time for the regeneration of soil structure which had been disrupted during the cropping phase. A stable system of agriculture was generally considered to be in place from that time in southern Australia.

However, farmers continued to cultivate their soils excessively during the cropping phase, thereby pre-disposing the soil's nitrogen pool to leaching following mineralization of soil organic matter (Russell 1980). In the process, soil structure was substantially degraded. The ability of shallow-rooted annual pasture legumes to restore soil structure fully in the restricted time span of the pasture phase is questioned (Figure 1) (Stoneman 1973; White *et al.* 1978). The unwillingness of farmers, even today, to inoculate pasture legumes with *Rhizobium* bacteria at each pasture establishment phase places in doubt the contribution these pasture legumes have been able to make to soil nitrogen status. For example, Reeves and Hirth (1982) found that only 13% of farmers surveyed in north-east Victoria inoculated subterranean clover seed at sowing.

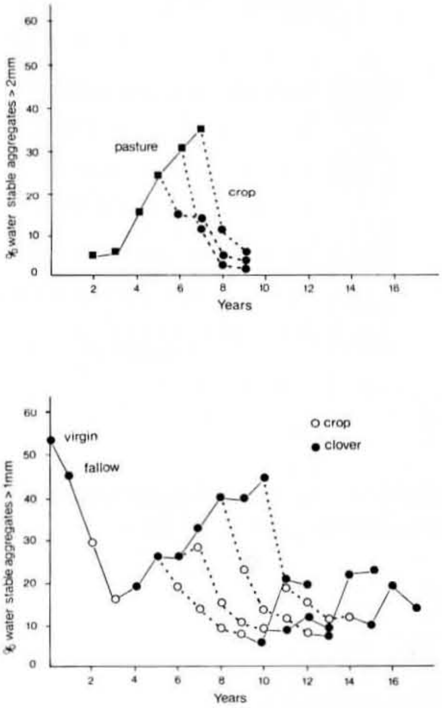

Figure 1 Changes in water-stable aggregation of surface soils under different pasture/crop rotations in Western Australia (Stoneman 1973). (*a*) changes (0–5 cm) on a loam at Merredin; (*b*) changes (0–7.5 cm) on a Wongan loamy sand since clearing.

In the late 1940s the availability of phenoxy herbicides enabled many broadleaf weeds to be controlled but, inadvertently, because of reduced competition, encouraged the proliferation of grass and some resistant broadleaf weeds (Amor and de Jong 1983). The only means of control of these grasses until the late 1960s was by cultivation, often using fallow, and crop sowing was frequently delayed so that late weed germinations could be controlled by cultivation.

Economic pressures encouraged more intensive cropping activity in the late 1970s and early 1980s. This, together with the widespread adoption from the late 1960s of soil-incorporated pre-emergent herbicides, such as trifluralin and tri-allate, for grass weed control, culminated in widespread wind erosion towards the end of the 1982–83 drought. Rather than reduce cultivation, these pre-emergent chemicals actually increased the cultivation required because of the need to have seedbeds in fine tilth for satisfactory herbicide incorporation. With the onset of drought-breaking rains in early 1983, serious water erosion of farming lands also took place.

The advent of Spray-Seed (paraquat plus diquat mix) and then Roundup (glyphosate) in the 1970s provided an opportunity for reducing cultivation. The availability of a number of wild oats (*Avena fatua* L) herbicides, and particularly Hoegrass (diclofop-methyl) for both wild oats and annual ryegrass (*Lolium rigidum* Gaudin) control, facilitated the adoption of reduced cultivation techniques in southern Australia. By 1980, however, misuse of Hoegrass in South Australia had resulted in the appearance of a strain of annual ryegrass resistant to this most important herbicide (Heap and Knight 1982). Resistance to paraquat by barley grass (*Hordeum leporinum* Link) was subsequently reported in the western districts of Victoria (Warner 1984) and resistance to other herbicides has been found in laboratory tests (Medd 1986).

At the same time as the visibly obvious signs of soil erosion and soil surface degradation were taking place, more subtle changes, having a profound effect on productivity, were also occurring – urban encroachment, soil compaction, soil salinity and soil acidification. These problems are now briefly examined.

Evaluation of farming problems

Availability of cropping lands

From the early days, when farmers cropped out areas and then shifted to new locations, there has been a general belief that land is a plentiful resource in Australia. However, whilst there are 768×10^6 ha of land, only 77×10^6 ha have good cropping potential (Nix 1976). Of this farming area, the 1974 estimate indicated that 7×10^6 ha (i.e. 10%) were urbanized (Chittleborough 1986). It is estimated that 400 ha per day of agricultural land are lost, mostly irreversibly, to urbanization, hobby farms, mining and recreation (Chittleborough 1986). Accordingly, over 11% of the cropping area had been urbanized by 1986. Clearly this is a sociological and political problem needing urgent redress.

The prospect exists for farming to extend into the higher rainfall and the more marginal country. Davidson *et al.* (1985) indicate the importance of diversification for the higher rainfall zone and also indicate that species and varieties with superior yields and commercial acceptability that can be successfully and profitably grown in these environments must be available before a significant return to cropping can be expected. Such crops must be tolerant to low soil pH and frost damage, as well as being resistant to sprouting.

In the drier marginal inland, expansion of cropping depends on rainfall and the profitability of cropping relative to pastoral activities. Opportunistic cropping (post flood) and lake-bed cropping are both practised in the Western Division of New South Wales but lack of biologically sound long-term plans result in land degeneration (Campbell and Gammie 1980; Gammie and Campbell 1980). Extending the margins of the farming zone into the drier areas increases the risks of crop failure because of the unreliability of rainfall and shorter rainfall season. Short-season crops are therefore important. Potential degradation of these lands is an ever-present threat, particularly where adequate plant cover is not provided in non-cropping seasons and years (Nix 1981). In much of this land the use of fallows reduces the fluctuation in crop yields by improving water and nitrogen supply to the crop. The techniques of chemical fallowing, stubble retention and direct drilling offer means of reducing the extent of soil degradation and subsequent erosion in these areas (Ridge 1986).

Soil degradation

Soil erosion is only one manifestation of soil degradation. Its extent in Australia is indicated in Figure 2 (Anon 1969) and quantified in Table 1 (Anon. 1978). Part of the soil degradation process has been the development of compaction layers at various depths in the soil profile. While occurring naturally as clay or sodic layers in some soils, compaction has been induced on many cropping soils through excessive cultivation. Compaction at plough depth, usually around 10–20 cm, creates drainage and root-penetration problems and predisposes plants to waterlogging (and perhaps manganese toxicity), poor aeration and drought (exacerbated by shallow rooting). Surface crusting, caused by slaking, dispersion or cultivation, limits water infiltration and seedling emergence.

As the soil structure deteriorates the moisture range and hence the span of time during which soils can be worked easily become restricted (Lynch and Hamilton 1983; Sullivan *et al.* 1983). Working the soils at other times accen-

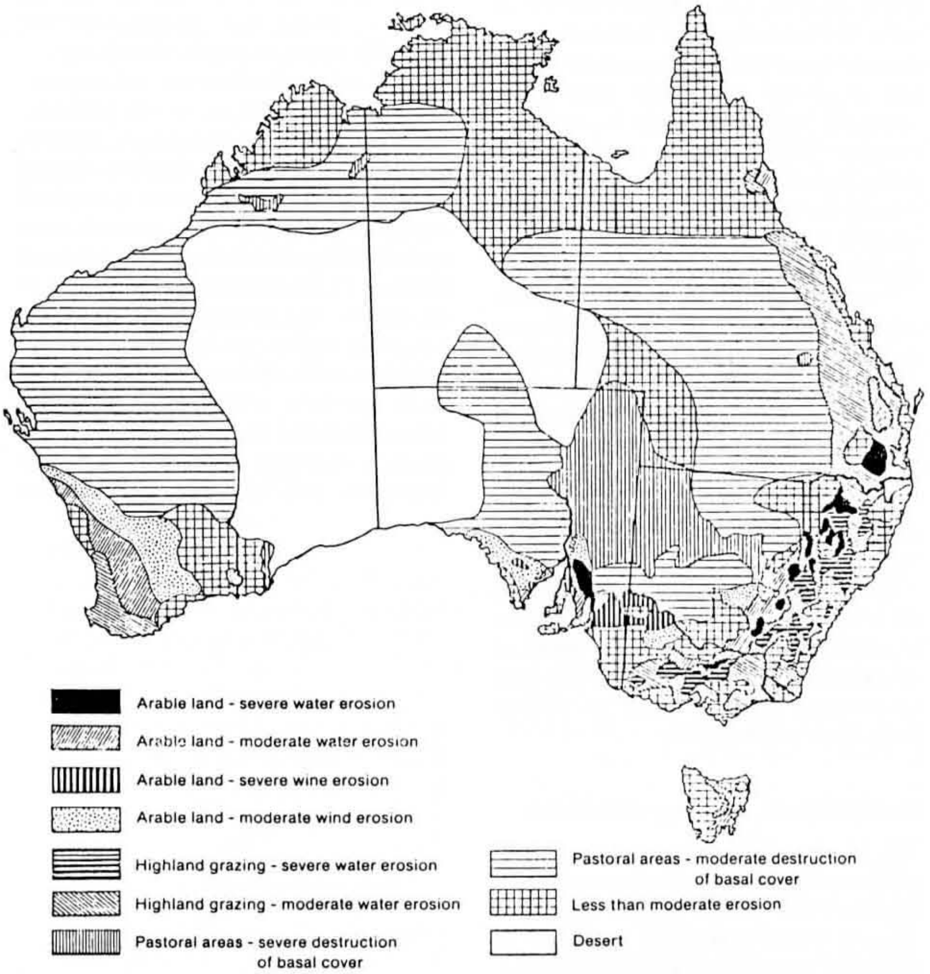

Figure 2 General distribution of soil erosion in Australia (Anon. 1969).

Table 1 Extent and severity of degradation of Australian soils used for crop production (Anon. 1978)

	Extensive cropping	Intensive cropping	Total
Area used (Mha)	0.443	0.024	0.5
Area needing treatment (management practices only) (%)	32	30	32
Area needing treatment (with works) (%)	34	34	34
Total area needing treatment (%)	66	63	66

tuates the degradation process because even more cultivation is required in order to counteract previous tillage operations. With hardening of surface soils, pastures based on annual legumes do not regenerate successfully because of increased stress of radical penetration. Subterranean clover plants find it more difficult to bury seed, thereby reducing seed production (Quinlivan and Francis 1971; Collins *et al.* 1976; Bolland and Collins 1986).

Soil salinity

In establishing Australia's cropping lands, most of the area was cleared of timber. Trees, being generally deep rooted, had been operating as pumps, keeping the watertables at depth in the soil profile. The replacement of the trees by shallow-rooted crops and pasture plants has allowed watertables to rise so that free water now occurs in low-lying areas moving to the surface by capillary action. The process is illustrated in Figure 3.

In Australia soil salinity is facilitated by the widespread occurrence of saline groundwaters. The extent of these is shown in Figure 4. It should not therefore be surprising that dryland salinity has emerged as a significant problem over much of Australia (Figure 5). In excess of 32×10^6 ha of non-irrigated land are salt-affected, of which 4.2×10^6 ha have been induced by land use (Working Party on Dryland Salting in Australia, 1982).

In the irrigation areas, salinization of land is also a major problem resulting from rising watertables. While poor land layout, inefficient irrigation

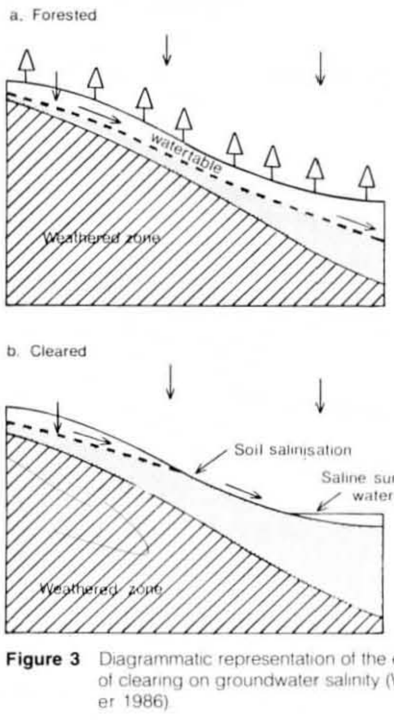

Figure 3 Diagrammatic representation of the effect of clearing on groundwater salinity (Walker 1986).

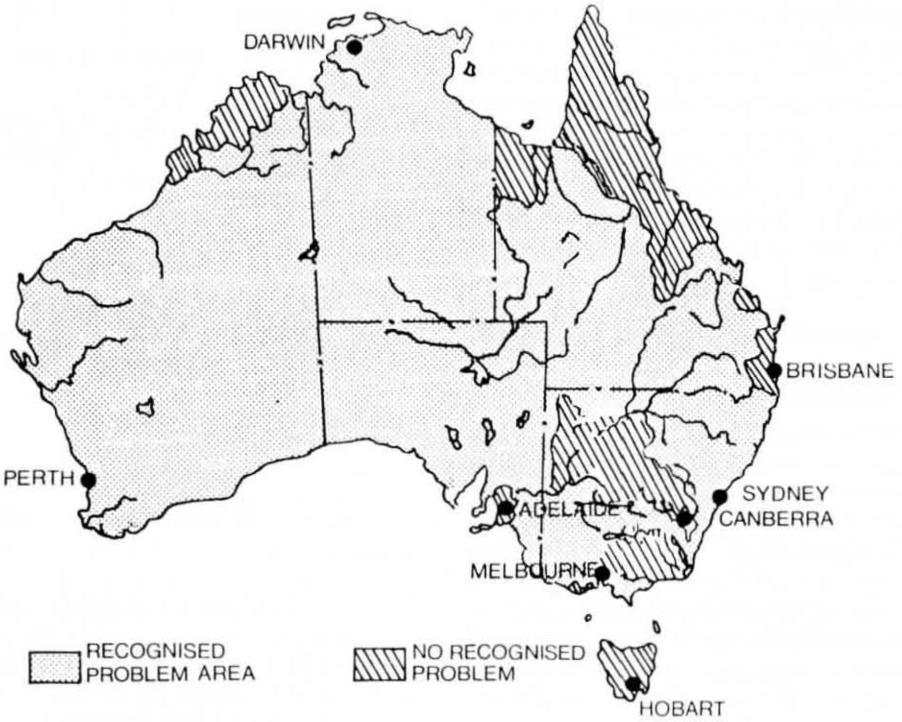

Figure 4 The quality of groundwaters in Australia (McGowan 1984).

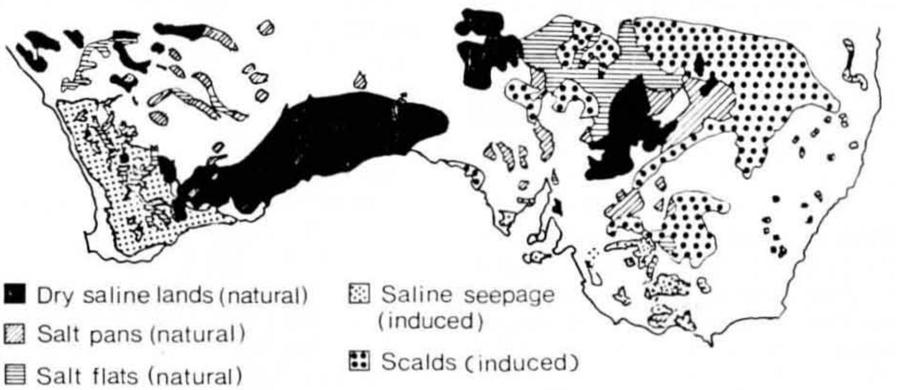

Figure 5 The occurrence of dryland salinity in southern Australia (Working Party on Dryland Salting in Australia 1982).

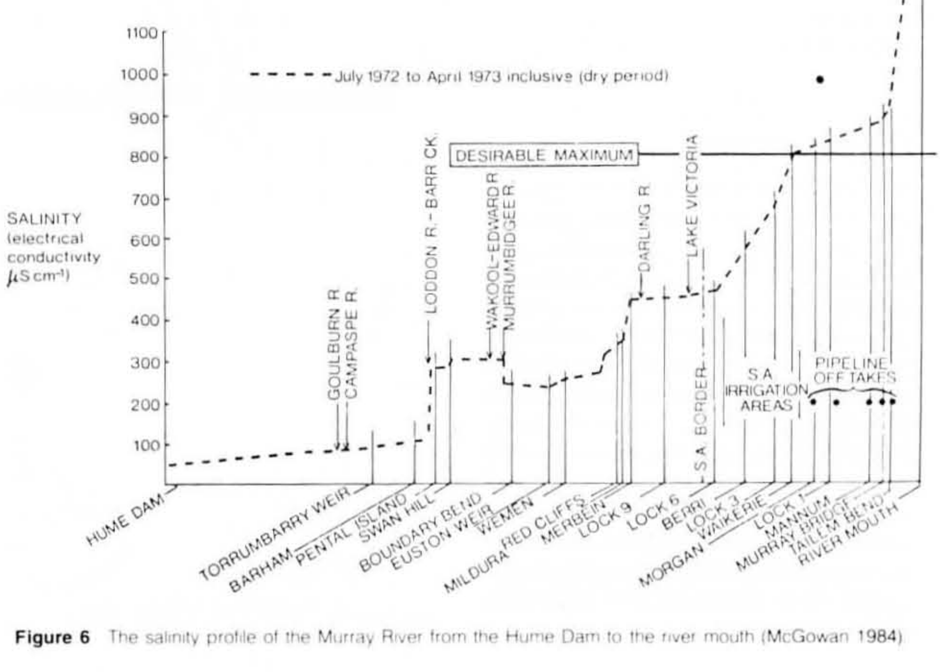

Figure 6 The salinity profile of the Murray River from the Hume Dam to the river mouth (McGowan 1984).

practices and unsuitable soils contribute to the problem, Lyle *et al.* (1986) report that high winter and spring rainfalls are the most important influence in this process in the Shepparton region. The impact on the environment of various practices in relation to salinity is evident in the salinization of the Murray River (Figure 6) thereby resulting in a problem not only for agriculturists but also for the whole community.

Soil acidification

Since the advent of pasture legumes and superphosphate in Australian farming systems, particularly in the higher rainfall zones, soil acidification has increased. The problem now extends over an estimated 17×10^6 ha where productivity has been impaired due to acidity (P. D. Cregan, personal communication). The situation in southern Australia is shown in Figure 7.

Causes of soil acidity have been reviewed by Porter (1981), Coventry (1985, 1986) and in Robson *et al.* (1987). Significantly implicated are product removal (Table 2) and leaching, particularly of nitrates formed under legume-based plant communities (Figure 8).

Table 2 Lime required (kg $CaCO_3$ t^{-1} product) to balance the acidity resulting from product removal from the ecosystem (Helyar and Cregan 1986)

Product	Lime requirement
Lucerne and clover hay	55–65
Grass hay	35
Cereal hay	22
Cereal grain	3

Soil management

All these issues reinforce the notion that for farming to be sustainable in the long term in Australia, soil management is the key. Although appropriate sowing times, sowing rates, nutrient requirements and rotations for fertility and disease control are known, agronomists and farmers have tended to treat the soil simply as a medium to support plant growth rather than as the means to control plant growth. The soil therefore has often been used, and abused, for short-term gains (albeit usually unwittingly) rather than managed for long-term high productivity.

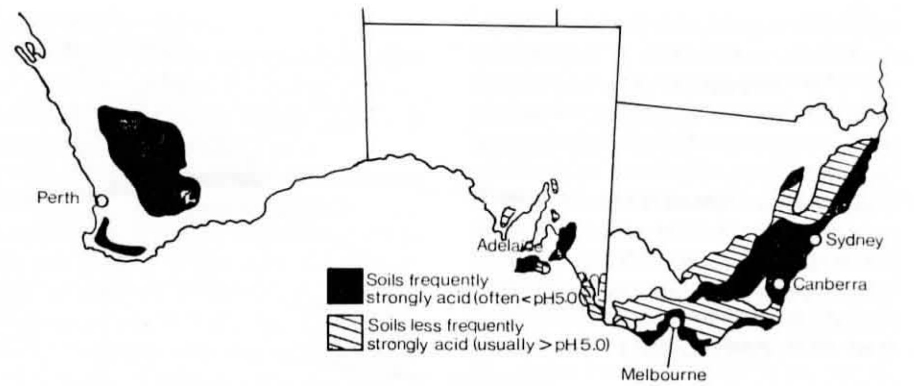

Figure 7 The estimated areas of soil acidity in southern Australia (Porter 1984; P. D. Cregan and A. Richards, personal communication).

According to Cockroft (1984, 1985), higher soil productivity leads to sustainable agriculture, while low productivity is often exploitive. Farmers who aim for high productivity per hectare are more likely to be concerned about the productive capacities of their soils and thus manage them to ensure that high productivity is achieved.

Such an approach with peaches at Tatura has been described by Olsson and Cockroft (1980). Here, the principal soil physical parameters for root elongation were defined (Table 3*a*) and soil management practices used to achieve the appropriate values. Annual yields of 75 t ha^{-1} from mature trees under this system compared very favourably with the district average of 18 t ha^{-1} and 37 t ha^{-1} by the best local growers. The first cropping year occurred earlier as did profitability, although costs were initially higher (Table 3*b*).

Because structural degradation, salinity and acidification contribute to

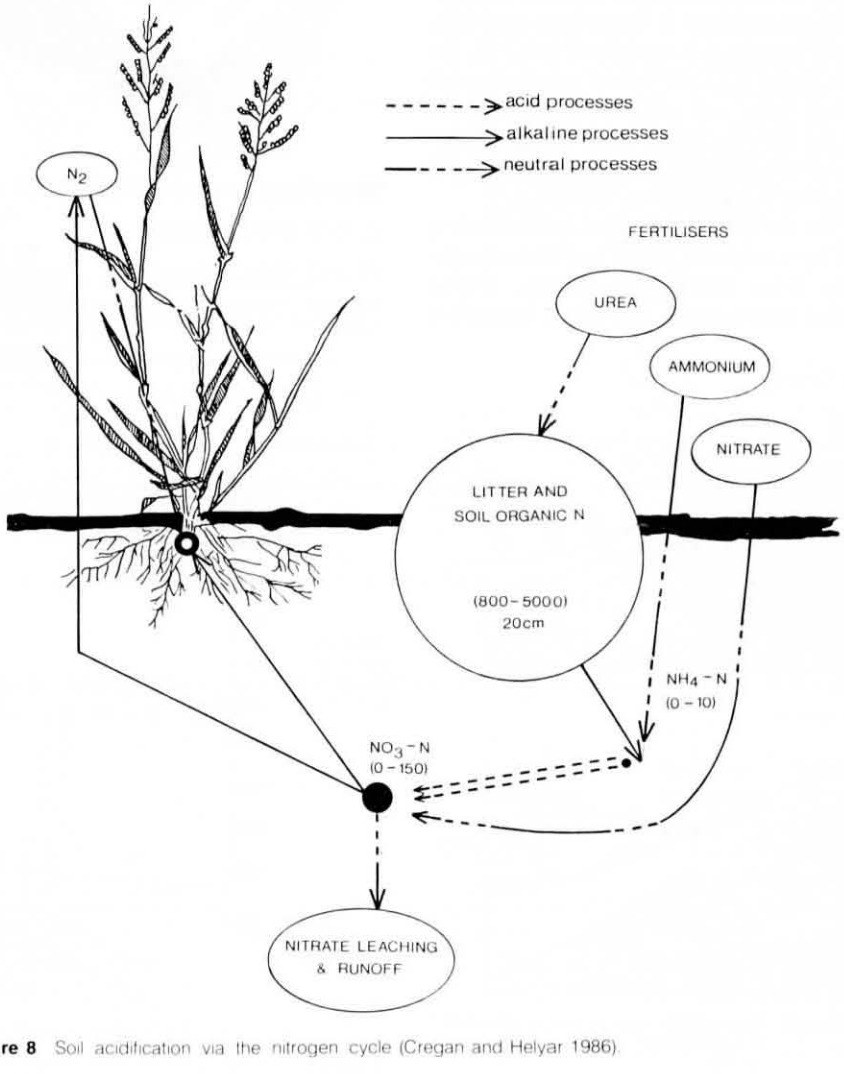

Figure 8 Soil acidification via the nitrogen cycle (Cregan and Helyar 1986).

Table 3*a* Working limits of principal soil physical parameters influencing root elongation (Olsson and Cockroft 1980)

Parameter	For maximum root elongation rates	Root elongation ceases
Soil-water (matric) suction (bar)	<0.5	>15
Air-filled porosity (% of soil volume air-filled at 0.1 bar suction)	>15	<2
Mechanical (penetrometer) resistance (bar)	<6	>30–40
Soil temperature (°)	18	30–35

Table 3*b* Cumulative net outlay/return ($\$\text{ha}^{-1}$) of Tatura system compared with conventional soil management over years 1–6 from planting[A] (Olsson and Cockroft 1980)

Year	Conventional system	Tatura system	Difference
1	− 2001	− 2729	− 728
2	− 2606	− 3806	− 1200
3	− 3238	− 4960	− 1722
4	− 3935	− 1119[B]	2816
5	− 2196[B]	2356	4552
6	− 615	5508	6123

[A] Based on operating costs only, other components of cost being assumed the same for both systems. The calculations allow 10% for cost of capital.

[B] First cropping year.

lowered productivity, management practices which ameliorate these conditions (Tables 4*a*,*b*) and prevent their deterioration or recurrence provide the basis for attaining high productivity. Whether a farmer can afford to undertake the amelioration has to be considered.

Water management

In Australia, moisture is the principal limiting factor for plant production. The potential yield of a crop is determined by the water used by that crop. This has been amply demonstrated by Cornish (1984) (Figure 9*a*) in southern New South Wales and by French and Schultz (1984) (Figure 9*b*) in South Australia.

Because water is the ultimate yield determinant for dryland farming in Australia, and because the major source of water to plants is available soil moisture, it is clear that efforts should be directed towards maximizing soil moisture in the root zone, while at the same time minimizing percolation beyond the root zone. Percolation contributes to leaching, which is important in soil acidification, and to rising watertables which often result in soil salinization. Root zone moisture may be maximized by maximizing infiltration, maximizing soil water storage (but not at the expense of aeration) and minimizing non-productive losses from the root zone. Added to these is the importance of maximizing crop utilization of root zone moisture to further reduce percolation.

Maximizing infiltration. Soil surface structure needs to be conducive to allowing rapid infiltration of moisture. Clearly, soils which crust through excessive cultivation interfere with this process, as do soils subject to raindrop impact. Undisturbed soils having transmission pores extending from the surface into the root zone facilitate the process. Vegetation reduces raindrop impact and slows the rate of movement across the surface, thereby increasing the time available for infiltration. For example, an extra 55 mm of water stored over summer/autumn using weed-free stubbles at Wagga Wagga, N.S.W., produce an extra 0.7 t ha^{-1} in the subsequent wheat crop (P. S. Cornish and J. R. Lymbery, personal communication). Soils which crust or which have been compacted, e.g. by livestock, would benefit from one tillage operation with a tined implement to improve infiltration.

Maximizing soil water storage. Two aspects are important: (i) the depth of the root zone for storage and (ii) the capability of the soil to store moisture.

(i) In many soils the depth of the root zone can be increased by removing impediments to root growth and water percolation. Thus, where compaction layers exist, deep tillage will substantially increase the depth of the root zone and the amount of water that can be held in the root zone. Aeration will also be improved. The use of deeper rooting species such as rapeseed (*Brassica napus* L., *B. cam-*

Table 4*a* Soil impediments to plant production and commonly accepted treatments

Problem	Cause	Treatment
Soil salinity	Tree removal, poor irrigation management resulting in rising watertables	Re-establishment of trees, use of deep-rooted species, subsoil drainage, improved irrigation layout
Soil acidity	Leaching, product removal, ammonia fertilizers	Liming, reduce leaching, use of deep-rooted species, use of acid-tolerant species in the short term
Soil compaction	Dispersable surface and sub-soils high in sodium, clay layers, excessive cultivation (particularly under wet conditions to the same depth using discs)	Gypsum addition to dispersable layers (technology currently limiting), deep ripping to break up compaction layer, reduce cultivation and traffic, particularly when soils are wet
Soil erosion	Excessive cultivation and soil structure breakdown, wind and raindrop impaction on bare soil surfaces	Reduced cultivation, retention of crop residues, improvement of soil structure

pestris L.), lucerne (*Medicago sativa* L.), safflower (*Carthamus tinctorius* L.) and perennial pasture grasses (Cornish 1985) in the rotation increases the depth of the root zone, and has the positive effect of tapping basic cations, nitrates and moisture which are unavailable to shallower species such as annual legumes and grasses. This might bring these back into the production cycle (Cregan and Helyar 1986) and may reduce the rate at which surface soil acidity increases, besides decreasing the risks of rising watertables with the resultant salinity problems (e.g. Cooke and Willatt 1983). The use of safflower for drying subsoils in the cotton (*Gossypium hirsutum* L.) areas of northern New South Wales is now practised prior to deep tillage (McGarry and Chan 1984).

Where watertables occur in proximity to the soil surface the proposal to increase the depth of the root zone increaes the risk of salinization unless the level of the watertable is lowered at the same time. If one of the major reasons for rising watertables has been the clearing of deep-rooted trees from the landscape, then substantial and strategic replanting of trees may lower the watertable and allow an increase in the depth of the root zone.

(ii) As the soil structure of the root zone deteriorates, usually because of excessive cultivation and/or compaction, the ability of the soil to store plant-available moisture also usually declines. As a result of structural degradation, bulk density of the soil tends to increase at the expense of porosity. Particularly important is the loss of medium-sized pores where much of the plant-available water is held. Therefore, not only is less water held by the soil (unless waterlogging takes place) but that which is held is less available since it is confined to soil micropores where it is held more strongly. This is clearly demonstrated by McGarry and Chan (1984) in cotton fields (Figure 10).

The capacity of soil to hold water is related to the organic matter level of the soil. Its water-holding ability increases with increasing organic matter, although water availability does not necessarily increase by the same extent because wilting point occurs at higher soil water levels (Russell and Shearer (1964) (Figure 11)). There are important considerations, however, in restricting water percolation – leaching is reduced (less acidification) and there is less likelihood of additions to the watertable (less salinization). A further advantage from the increase in organic matter is

Table 4*b* Management options possible in the acidifying annual legume pasture/cereal cropping rotation (Adapted from Cregan *et al.* 1987)

(i) CROPPING PHASE

Seasonal events	Processes influencing acidification	Reaction[A] (+ = acid added) (− = alkali added)	Possible management modifications
		Summer	
Fallowing	Nitrification of OM →accumulation of NO_3-N	+	Reduce or eliminate cultivated fallows
		Autumn	
Sowing	Nitrification of NH_4 fertiliser	+ +	Earlier sowing to give more opportunity to use NO_3-N.
	Nitrification of OM	+	
	Leaching NO_3-N	CEC↓	Use NO_3-N fertilizers preferably after root systems established
		Winter	
Crop growth	NO_3-N uptake	−	
	Further leaching NO_3-N	CEC↓	Improve crop growth to provide a larger NO_3-N sink
	Grain legumes		
	•N fixation	+	Use cereals instead of grain legumes
	•excess cation uptake	+	
		Spring	
Harvest	Product removal		Use cereals
	•legume grain	+ +	
	•cereals	+	

(ii) ANNUAL LEGUME PASTURE PHASE

Seasonal events	Processes influencing acidification	Reaction[A] (+ = acid added) (− = alkali added)	Possible management modifications
		Summer	
Dead and decaying pasture	OM accumulation	+	Use perennial pastures with summer growth potential to use accumulating NO_3-N.
	Decomposition of OM →nitrification	+	
	Feeding conserved forage	−	Eliminate large stock camps and night paddock to reduce intra farm transfers
	Nutrient cycling through animals*	*o*	
		Autumn	
Seasonal break	Further nitrification	+	Use permanent autumn-growing pasture
	Leaching of accumulated NO_3-N	CEC↓	
	Limited NO_3-N uptake by pasture		−
		Winter	
Pasture growth	Feeding conserved fodder	−	Avoid heavy stock concentrations.
	Urine N→NO_3-N*	+	Use vigorous deep-rooted grass species in pasture mix
	Symbiotic N fixation	+	
	NO_3-N leaching to subsoil	CEC↓	
	NO_3-N uptake	−	
	Excess cation uptake by legume →H^+ excretion		Use grass/legume pastures
		Spring	
	Fodder conservation		Use mixed pastures
	•grass hay,	+	
	•legume hay	+ +	
Senescence	Animal product removal[A]	+	

[A] +, acid added; −, alkali added.

[B] Can occur in any season.

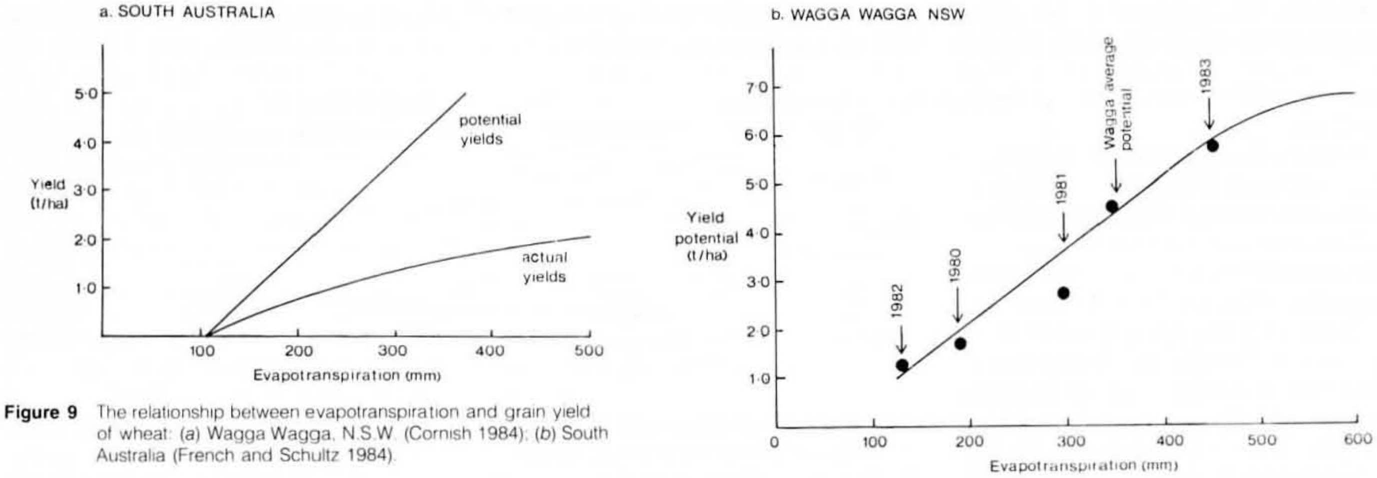

Figure 9 The relationship between evapotranspiration and grain yield of wheat: (*a*) Wagga Wagga, N.S.W. (Cornish 1984); (*b*) South Australia (French and Schultz 1984).

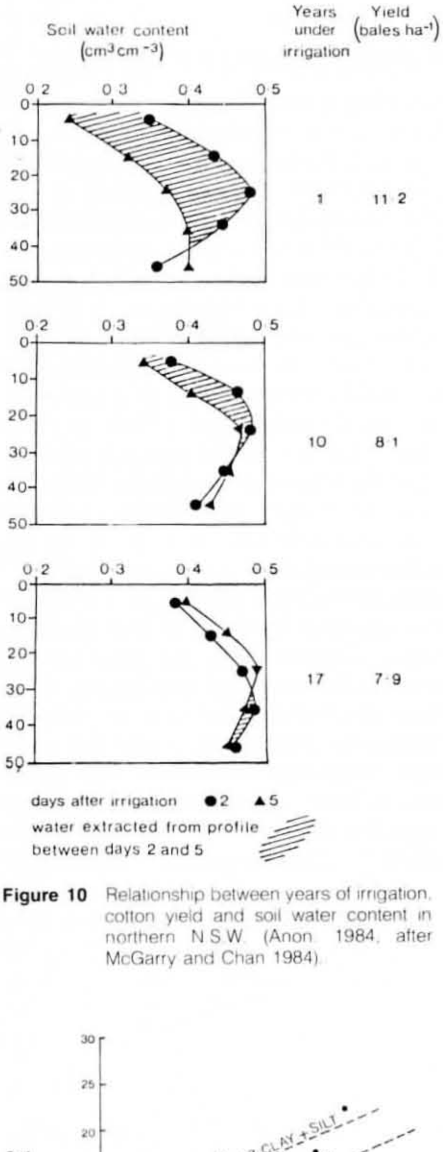

Figure 10 Relationship between years of irrigation, cotton yield and soil water content in northern N.S.W. (Anon. 1984, after McGarry and Chan 1984).

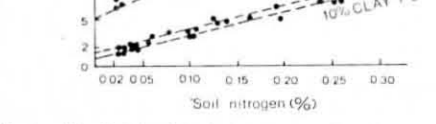

Figure 11 Relationship between organic nitrogen (%) and soil water (%) at −0.3 bars and −15 bars for two soil types (Russell and Shearer 1964).

the build-up in soil microbial populations and, particularly, earthworms which make a positive contribution by increasing soil porosity and mixing organic matter through the root zone.

Minimizing non-productive losses from the root zone. As yield is related to crop water use, losses of water from the root zone through drainage will generally be non-productive and may contribute to acidification and salinization. Where high productivity is achieved, crop plants will be maximizing water use and removing high quantities of water from the root zone, thereby reducing percolation. Evaporation from the soil surface is also non-productive as it is not used by plants and therefore does not contribute to yield. Crop residues can reduce the rate of evaporation from soils. Non-crop plants, i.e. weeds, are non-productive as they utilize water, nutrients, CO_2 and light which would otherwise be available to the crop. Clearly, then, part of this process of yield maximization involves weed management. This is considered later.

Efficiency of water use by the crop plants themselves needs to be maximized. Water is used as a substrate in plant metabolism, as a nutrient carrier and in plant structure. It also is a significant part of the heat-regulating mechanism of the plant in maintaining stomatal openings for as long as possible to allow CO_2 entry into the leaves. If the conditions for transpiration were made less demanding, water would be used more efficiently. Trees and shelter belts perform this useful function by reducing wind speeds, and hence evaporation and transpiration rates. Lynch *et al.* (1980) showed that 12.3 mm less water was lost from the soil of sheltered, compared to unsheltered, paddocks over a 29-day period at Armidale, N.S.W. The cumulative loss of stored soil moisture is shown in Figure 12.

These savings in non-productive moisture loss during the growing season therefore contribute to increase moisture availability at the end of the season where effects on yield can be pronounced.

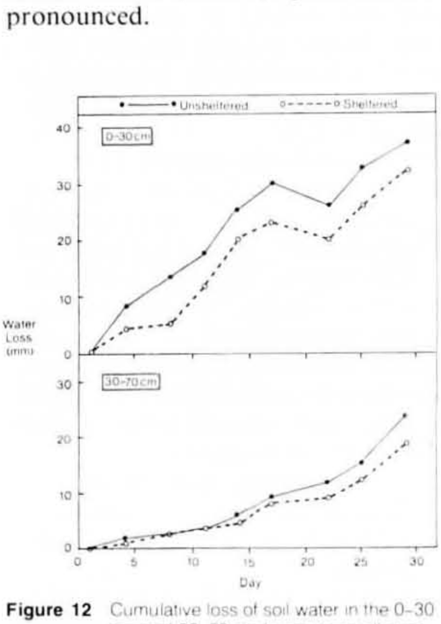

Figure 12 Cumulative loss of soil water in the 0–30 cm and 30–70 cm layers (over all stocking rates) in sheltered and unsheltered paddocks (Lynch *et al.* 1980).

Weed management

To achieve high yields of crops it is necessary to minimize competition from weed species. In practice, farmers react to weed problems as they arise by choosing a herbicide to reduce their impact. Choice of herbicide is restricted by crop species and, more recently, by variety (Lemerle *et al.* 1985). Cost is particularly relevant. Where cheap chemicals are suitable the tendency is to use at least the maximum recommended rate and to continue using these chemicals annually, or even more often. For the more expensive chemicals, the tendency is to apply marginally low rates. Fortunately, the herbicides are mostly paid for by crop responses and the customer is usually satisfied.

There is concern that this approach may increase herbicide resistance. Extension material from government and chemical companies has promoted efficiency of herbicide usage, but rarely has the issue of management of herbicides to reduce resistance been considered. Chemical management must include consideration of the long-term availability of important compounds. Pesticide resistance in the cotton-growing areas put at risk the cotton industry in Australia. The integrated pest-management approach now adopted for cotton, where particular pesticides are restricted at particular times, may provide a lead for other agricultural industries. Herbicide resistance puts at risk the entire conservation farming effort in Australia.

The reactionary approach to weed problems outlined above should be only one strategy in weed management. High crop yields are more likely to be achieved where weed control strategies are planned. Such plans should include:

- full use, in the pasture phase, of techniques such as spray-grazing (Pearce 1972), spray-topping (Pearce 1973; Jones *et al.* 1984) and hay-freezing, all of which minimize chemical usage. This has environmental advantages and reduces disease carryover. Costs are reduced, workloads and cash flow are spread and livestock production improved (Pratley and Cornish 1985).
- Close attention must be paid to farm hygiene and seed quality in relation to weed introduction and spread.
- Spraying or roguing of low weed populations in crops and pastures is necessary to prevent seed set. This must be considered in terms of its long-term benefit rather than its economic contribution solely in the year of spraying.
- Early spraying enables lower rates to be used more effectively on weeds which are generally more susceptible when young. Maximum crop benefits are achieved by early spraying (Pearce 1984) (Table 5).
- Early sowing (Reeves 1976) and higher sowing rates of crops (Radford *et al.* 1980) provide greater competition with weed species.
- Crop rotations that enable chemical control of particular weeds can be incorporated. Using allelopathic effects may be a worthwhile management strategy in the future (Figure 13) (Purvis *et al.* 1985).
- Flexible tillage practices can be used depending on the weed species to be controlled. These practices include one working (a 'tickle') to encourage germination of, e.g. annual ryegrass (Pearce 1973; Pearce and Holmes 1976), complete soil disturbance at sowing where, e.g. silvergrass (*Vulpia* spp.) is present (Forcella 1984; Pratley 1985) and minimal soil disturbance where, e.g. fumitory (*Fumaria* spp.) occurs (Pratley and McNeill 1982).
- Fire on occasions may kill populations of seed present on the soil surface (Pearce and Holmes 1976). The effect is reduced where stock have trampled the seed into the soil and when cool conditions occur during burning. Consideration should be given to whether weed control is more important than the benefits accruing from the presence of stubble.
- Rotation of herbicides and other strategies can minimize the build-up in resistance of weed species to herbicides.

Table 5 Effect of time of spraying of different weed species on wheat yield at five sites in Western Australia (Adapted from Pearce 1984)

Crop growth stage at spraying	Grain yield (t^{-1}ha)				
	Doublegee	**Radish**	**Capeweed**	**Ryegrass**	**Ryegrass**
1-2 leaf				1.66	1.24
2 leaf	2.50	3.21	1.02		
3-5 leaf				1.39	1.06
5-6 leaf				1.38	0.41
tillering	2.18	2.52	0.78	0.63	0.24
control	1.88	1.60	0.48	0.56	0.25
SITE:	Wongan Hills	Moora	Merredin	Newdegate	Katanning

Farming systems for the future

Farming systems for the future should have high productivity achieved through proper soil, water and weed management. Further evaluation of the data of French and Schultz (1984) Figure 9*b*) and P. S. Cornish and G. Murray (1986, personal communication) (Figure 14) indicates that actual yields approach potential yields only in poor years. As the potential for yield increases, the gap between actual and potential yields widens. This suggests that farmers are preoccupied by drought strategies and risk minimization in the poor years. Inputs are too low to enable high crop yields to be achieved when conditions are favourable. Budgeting exercises must identify the requisite levels of nutrient inputs (e.g. nitrogen and phosphorus) to achieve particular output levels. This may involve greater use of growth regulators (to prevent lodging losses) and fungicides (for disease control) and involves counteracting the acidifying effect of product removal, particularly in hay production, by lime

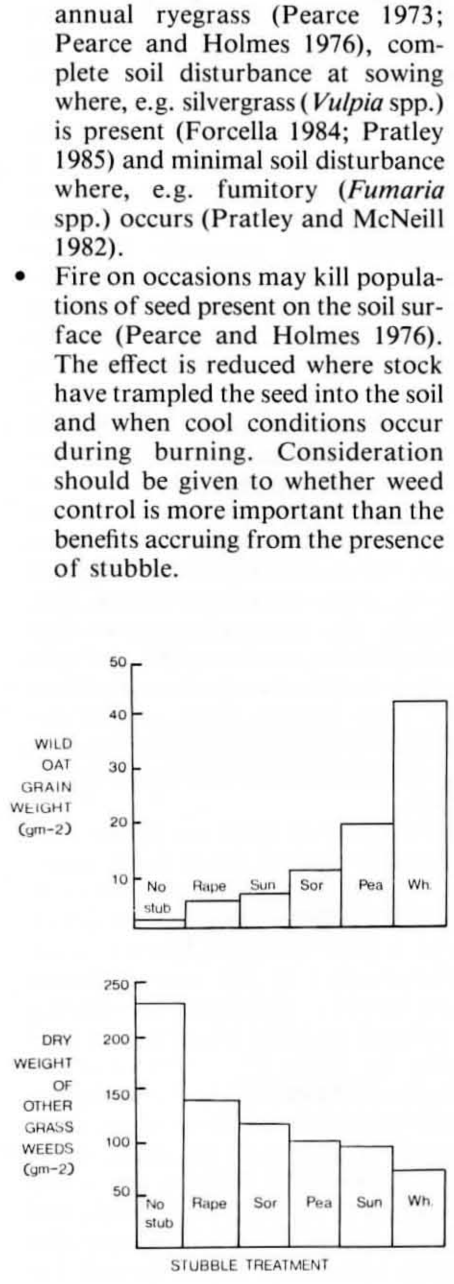

Figure 13 Effect of different stubbles on the grain yield of wild oats at Armidale, N.S.W. (Purvis *et al.* 1985).

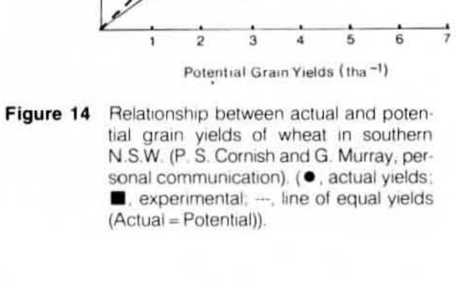

Figure 14 Relationship between actual and potential grain yields of wheat in southern N.S.W. (P. S. Cornish and G. Murray, personal communication). (●, actual yields; ■, experimental; ---, line of equal yields (Actual = Potential)).

applications. In the pasture phase, the use of deeper rooting perennial grasses in the pasture mixture to reduce rates of acidification and salinization may be a worthwhile strategy.

Farming systems of the future will embrace the conservation farming ethic (Pratley and Cornish 1985). Direct drilling will enable optimum sowing and spraying times to be achieved. Tree planting on a strategic basis becomes a more integral part of the conservation-farming system. Rotation planning also becomes a much more important exercise involving deep-rooting species for weed management.

In order to make these systems work, more information is needed on stubble retention methodology including machinery to handle the stubble. Also required is more information on the ecology of important weeds, particularly in relation to crops species. Development of herbicides and herbicide technology is needed to facilitate their use in stubble retention systems (e.g. Electrodyn, granulated formulations) as soil-incorporated herbicides are incompatible with the concepts expressed in this paper.

In order to put the proposals into practice, farmers may have to accept lower returns in the early stages for benefits in the longer term (Olsson and Cockroft 1980) (Table 3*b*). Farmers may be better off producing more per hectare from less area. An increase in yield per hectare of 50%, probably achievable in most situations, needs an area only two-thirds as large. The surplus land then becomes available for alternative uses, perhaps forestry. Concentrating efforts on the better land initially would engender confidence in the landholder who would probably proceed to incorporate the less productive land into the program.

The role of research and extension is critical. Research programs must be integrated better, whilst extension efforts must be focused more sharply on a systems approach.

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