Farming Practices in Australian Grain Growing – the means for both Productive and Environmental Sustainability

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Abstract

Grain productivity, as measured by output and yield has increased markedly in the previous two decades in Australia. This is ascribed to contributions from better cultivars and rapid improvements in crop management and agronomic knowledge, with these advances being rapidly adopted by grain producers. Such improvements have been built into the farming practices and production systems in use around Australia today, and continual improvement is a feature.

These farming practices have also brought dramatic improvements in environmental factors, which it is argued have resulted from these improved practices, while also contributing to the increased grain production seen.

Several aspects of modern Australian grain production systems are examined in the context of their effects on important environmental parameters, notably soil, water, nutrients and carbon.

Recording and reporting the extent to which desirable practices have been adopted can be a suitable and useful measure of an individual or an industry's contribution to environmental management. An approach is suggested that allows these measurements to be made and used, allowing producers to compare their performance with accepted best practices. This system avoids the drawbacks of currently proposed paper-based methods.

Improvements in productivity and benefits from new farming practices.

The rapid growth in Australian grain productivity through the 1990's till today, is seen as due a mix of better cultivars and better farming practices, (agronomy). Growth in productivity has been described as being only approximately 1% per year for the century to 1980, but at almost 4% per year since then. This growth in productivity is attributed to be 1% from better cultivars and the remaining 3% from better agronomy (Turner 2004, Turner & Asseng, 2005). Similarly Knopke *et. al.* (2000) suggest the growth in productivity as 3.2% for the past couple of decades.

Where has this increase in productivity come from? In cropping, yield potential and its realisation is generally a combination of the innate capacity of the crop cultivar to produce and the farming practices (or agronomy) under which that cultivar is grown. Improvements in both of these have been responsible for increases in crop productivity over time. Plant breeders continue to assemble new combinations of genes that provide improved yield in a given environment. Similarly, advances in our understanding of the effects of local environmental conditions coupled with the requirements of crop plants lead to improved agronomy, implemented as changes in farming practices. But what is the relative contribution of improved cultivars compared with improved agronomy? Richards (1991) tested the relative performance of a range of wheat cultivars released over the previous century (to 1980) in a single field experiment (Fig. 1). The yields of the various cultivars were higher than their predecessors, by about 1% per year. Hence, it could be suggested that of the improved crop productivity over this time about 1% has come from better cultivars.

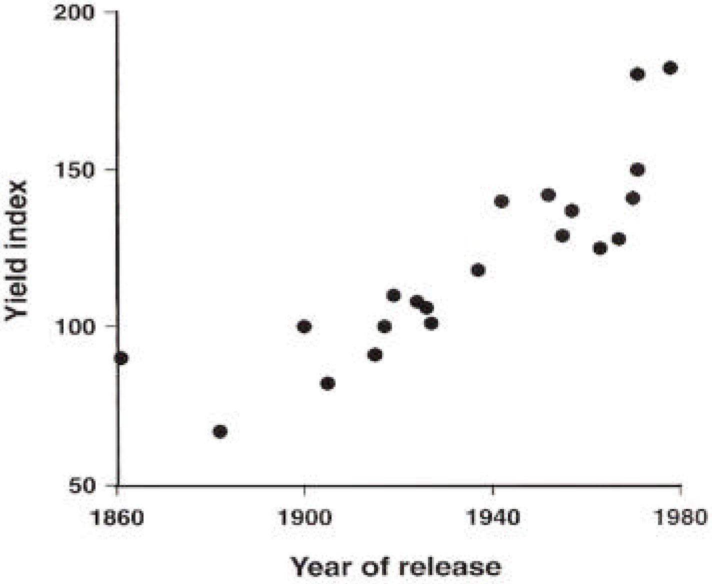

Fig. 1. Yield of successful wheat cultivars grown in NSW, versus year of release, relative to that of the cultivar Federation (=100), released in 1900. Adapted from Richards (1991).

This leaves somewhere between 2% and 3% as being due to better farming practices, flowing from a better understanding of crop needs and a tailoring of these to the various Australian environments where crops are gown. It is likely that some interaction between these occurs.

Recent work in the US (Anderson, 2006, as quoted by Richards, 2006) shows similar trends, where the proportion of yield increase apportioned to agronomy was seen to be between 47% and 83% with an average of 68%, leaving the proportion due to genetic gain at 32%. Richards' own investigations (Richards, 1991, 2006), suggested that crop management improvements was contributing 71% of the yield increases seen between 1860 and 1982.

In a comprehensive review of environmental biology and crop productivity changes over the last century or so, Passioura (2002) describes several factors as being responsible for increases in crop productivity, and details the environmental effects flowing from these.

Accepting that the contribution from better cultivars forms a background of around 1% *per annum* in improved productivity, it is interesting to note that the contribution in improved agronomy has not been steady through time. Average crop yields have shown several periods of accelerated growth, identified by Passioura (2002) as happening in three decades of interest; 1900's, 1950's and 1990's. Fig.2. shows these trends (from Angus 2001, extended from Donald, 1965).

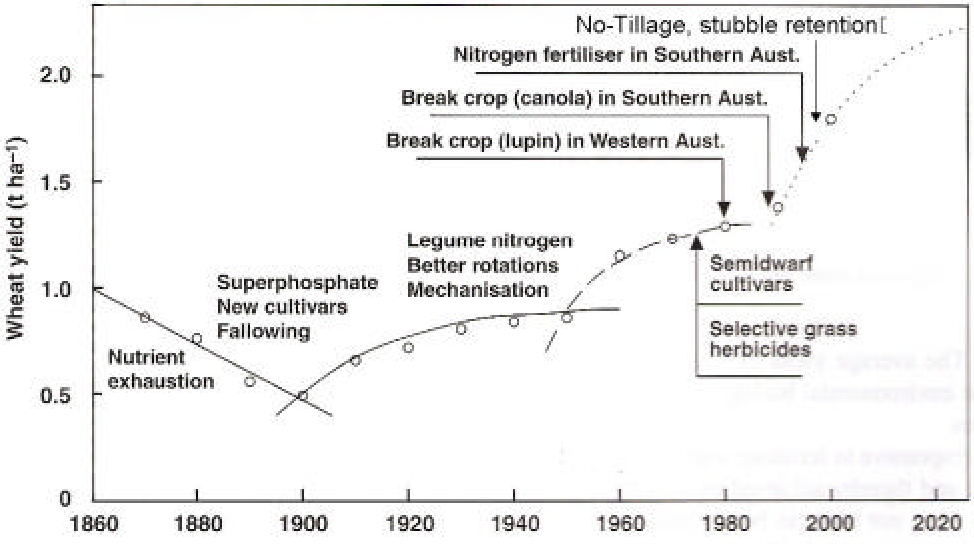

Fig. 2. Average decadal wheat yields in Australia since 1860, an extension of an earlier analysis (Donald 1965) by Angus (2001). Adapted from Passioura (2002). The notes are explanations for the trends. Data from 1860 to 1960 are

from Donald (1965), from 1960 to 2000 from ABARE, the dotted line is Angus' projection for yields through the 1990's and beyond.

During the period till about 1900, crop production occurred without the application of fertiliser, weed control or other management practices, and was produced somewhat akin to 'organic' farming of today.

The understanding of the utility of phosphorus in many of Australian soils led to the introduction of superphosphate early in the last century, coupled with the use of cultivation-based fallowing. This led to the increase in yield seen till the mid of the 20th century.

During the 1950's the benefits of rotating crops with legume-based pastures (with the example of subterranean clover) for fixing nitrogen, followed by the identification of trace elements as beneficial for these pastures saw a further dramatic increase in yield. Better farm machinery also began to become available, leading to more efficient and timely operations, a trend that has continued to present times.

Other steps in productivity flowed from the introduction of semi-dwarf, and then disease resistant, cultivars, the introduction of herbicides (for example 2,4-D for broadleaf weed control), and medic and lucerne-based pastures.

The last acceleration in crop productivity began in the 1990's and was due a combination of several factors. These include the rapid growth in number and type of herbicides, specially grass selective ones, improved foliar and stem disease resistance in the cultivars, the introduction of canola as a profitable break crop and various pulses also as break crops and for nitrogen fixation. Further advances included the development of non-selective herbicides to aid crop establishment, knowledge of and control measures for root diseases, the identification and addressing of various soil and sub-soil constraints (for example the use of lime for remediating acid soils) and the introduction and acceptance of minimum tillage and stubble retention practices.

Developments continue today with, for example, the use of remote sensing, more comprehensive soil testing and further advances in mechanisation including guidance systems and yield monitoring. Possible future advances may include better seasonal weather forecasting. The consequences of these have seen farmers and their advisors assemble all these developments into the modern farming systems used across Australia today. This integration of technologies has given rise to the rapid increases in productivity of recent times.

At the same time these technologies have brought significant beneficial effects on the natural resources and the farm environment that farmers rely upon for their livelihood. The resource base farmers manage includes the major elements of soil, nutrients, rain and energy, with soil probably representing the most important of these. Modern farming techniques focus on working with these resources to both sustain them and provide optimum production. To this end, modern conservation tillage practices, for example, can be seen to protect soil from erosion, enhance water infiltration and storage, increase soil biomass, and potentially soil carbon. This system also uses substantially less fuel and allows for more flexibility and earliness of sowing while greatly improving soil structure.

It is thus proposed that the adoption of modern agronomic farm practices has been successful due to enhancing the environmental resources farmers have. In return, the environment 'rewards' this improved management by allowing crops greater access to the resources contained therein, with a consequent result of higher crop yields. In this way today's farming practices are more in harmony with the soil and other environmental resources farmers have and are also (and as a consequence of this) responsible for the productivity increases that has kept many grain farmers in business.

Taking one element of a modern farming system, tillage practice, leads to many examples linking increasing productivity with the use of such tillage practices. One example is some earlier work in the Queensland semi-arid tropics (Radford *et.al* 1995), whereby a no-tillage plus stubble retention system resulted in increased wheat yields which they attributed to increased water storage, more efficient use of this water, or a combination of both. Importantly, these effects were accompanied by significant increases in soil macrofauna, notionally a measure of soil health.

This paper attempts to further examine such linkages between farming practices as used in Australia today and the productivity and environmental benefits they bring. Many farmers intrinsically know of these benefits, being their major reasons for adopting such practices. However in the context of using measurements of the levels of adoption of these practices as means of demonstrating the industry's environmental stewardship progress, it is seen as important to revisit the evidence linking these tgether.

Considering the environment from a farmer's view leads to a focus on a notional list of elements including soil, (rain)water, nutrients and energy, since these are the major items a farmer works with and can thus have the greatest impact on. These areas of environmental resources are the subjects of the discussion of this paper.s

Soil Erosion and Farming Practices

Soil erosion involves the detachment and transport of soil particles from the soil surface and their movement elsewhere by wind and water. Erosion results in soil loss, reduction in soil nutrients and organic matter and effects on streams and rivers from sedimentation. The latter have undesirable impacts on water quality including turbidity, nutrient and chemical contamination. Soil erosion also, by definition, means lost soil from the farm, with dramatic effects on farm production.

Erosion depends on soil cover, slope, the structure and condition of the soil, and the energy of the wind and water. Since a farmer cannot do much about the natural elements of slope, wind and water, this leaves only soil cover and to a lesser extent structure and condition of the soil where he or she can have an immediate influence.

The exposure of bare soil by tillage, coupled with the effect of this tillage on removing soil cover and reducing soil strength and structure, increases soil loss through an increase in runoff volume, increased detachment of the soil, and flow velocity (Freebairn 1992)

Farming practices, especially the use of tillage has changed dramatically in the last 40 years. Until the mid 1970s it was common practice to prepare cropping paddocks by aggressive cultivation, even including inversion tillage using disc ploughs as part of fallow management. These practices were considered useful to assist rainfall infiltration and aeration, store soil water, raise nutrient levels, control weeds, diseases and prepare the seedbed prior to sowing. Previous crop stubble would be burnt or cultivated immediately after harvest in summer cropping areas, while in winter rainfall areas this would be burnt or cultivated in the autumn, after being grazed through the summer (Freebairn 1992). In winter rainfall areas ley pastures would typically be terminated in the late winter or spring of the year prior to cropping by use of tillage. This was the commencement of the fallow period, through which it was considered soil water levels and nutrients (mainly legume fixed nitrogen) could be elevated, weed seed set prevented, and alternative hosts of cereal diseases removed.

This tillage-based conventional approach did produce reliable crop yields for some years. However a realisation began to emerge that the system was inherently unstable in that soil structure was degraded, soil erosion was accentuated, organic matter was reduced and energy inputs were high. The effects of this system on soil erosion could be dramatic, with massive erosion events occurring in southern areas of Australia, for example in the mallee soils of Victoria and South Australia.

This realisation was based on the impact such an aggressive system had on soil structure, with structural decline being widely found following repeated tillage operations (Moran 1998; Freebairn 1992). The effects from structural decline include surface crusting (involving the loss of aggregation and porosity in the top few centimetres of soil) where bare soil is exposed to rainfall following cultivation (Valentin and Bresson 1992), and hardsetting (a compact, hard and massive soil condition affecting the A horizon (Chartres 1992)) and compacted layers at the depth of cultivation. These lead to reduced water infiltration and porosity, reducing plants access to soil water (Gupta *et.al* 1989).

Cultivation damages soil structure by preventing organic matter build up and directly destroying any structure that does develop. This in turn reduces water infiltration leading to increased runoff and reduced soil moisture levels (Silburn and Connolly 1995). It also promotes the concentration of nutrients in fine surface materials prone to wind and water erosion (Moran 1998) and limits root growth and yield (Hamblin and Tennant 1979).

The major development in improving soil cover has been by the retention of crop residues. Vegetation cover, or soil protection as offered by retaining crop stubbles, has been demonstrated to reduce soil susceptibility to erosion by avoiding soil exposure to wind and water, for example, McLaughlin *et al* (1998).

Reducing the amount of tillage also has a dramatic effect on soil loss, by leaving structure intact. The use of No-Tillage, where crops are planted with no prior tillage passes is now a relatively common practice in crop areas of Australia. Combining the effects of no-tillage with retention of crop residues can dramatically reduce soil losses from erosion, though the proportion of this effect due to the tillage or the residue retention varies in different environments (Freebairn, 1992).

So it can be seen that the “old” farming system of a reliance on cultivation for paddock preparation has been quite detrimental to the soil, this being the single most important resource farmers have. Fortunately the developments in the farming system that have occurred since the early 1970's and rapidly adopted by grain producers through the period from the early 1990's to today, have greatly reversed this trend in soil decline. The more modern practices of no-tillage and crop residue retention have demonstrably improved soil structure, water holding capacity, infiltration, porosity, organic matter and many other factors. The most obvious effect of these has been a dramatic reduction in soil erosion under these systems.

Evidence for this is substantial, as outlined below.

Carter and Steed (1998) found that in northeast Victoria direct drilling (DD) plus retention of stubble had the effects of increasing sorptivity (akin to absorbing ability of soil for water), wetting depth and time to runoff, and decreased runoff rate and sediment loss compared to direct drilling with stubble burnt and conventional cultivations plus burning. The DD with stubble retained system also improved the potential for saturated infiltration, maximised rainfall storage in the surface horizon and increased the stability of macroporous infiltration. These results point to DD plus stubble retained system as important in reducing soil erosion while at the same time increasing water infiltration and storage of a soil, giving increased crop productivity and better soil characteristics.

While working in a very different environment and with very different soils, Dilshad *et al* (1996) also reported a strong effect of no-tillage and stubble retention systems in reducing soil erosion. Up to 100 tonnes per hectare of soil could be lost under conventional tillage systems without catchment banks, though typically with banks this was around 8 tonnes per ha. Under conventional systems with banks 1.5 to 2 times more runoff and 1.5 to 6 times more soil loss was observed. While the environment of northwest Australia is very different from that experienced in the main grain producing areas, such trends and positive differences in favour of no-tillage and stubble retention are consistent, thought e magnitudes may be somewhat less.

Many other reports from years of experiments have indicated significant reductions in soil erosion from the adoption of No-Tillage methods, especially when retaining stubble.

Malinda (1995) showed that soil erosion and sediment loss could be dramatically reduced in a 10 year experiment in South Australia. The results show a dramatic reduction in both runoff and soil loss where a no-tillage and stubble retention system is used, with up to 94% reduction in soil loss as measured under the conditions of the experiment. The retention of stubble was very important, though modified by crop type, whereby cereals were seen to be most effective.

This work reflects similar findings earlier by Packer *et. al* (1992), where in central NSW the combination of stubble retention and minimum tillage greatly reduced soil loss and also increased soil carbon and water stable aggregates. Similar results were found from no-tillage and stubble retention in Queensland by Freebairn *et.al* (1993), where these practices were seen to reduce soil erosion and increase crop yield.

Figure 3, from Wockner and Freebairn (1991) below, represents a further example of the differences in soil loss that can be observed with different farming practices.

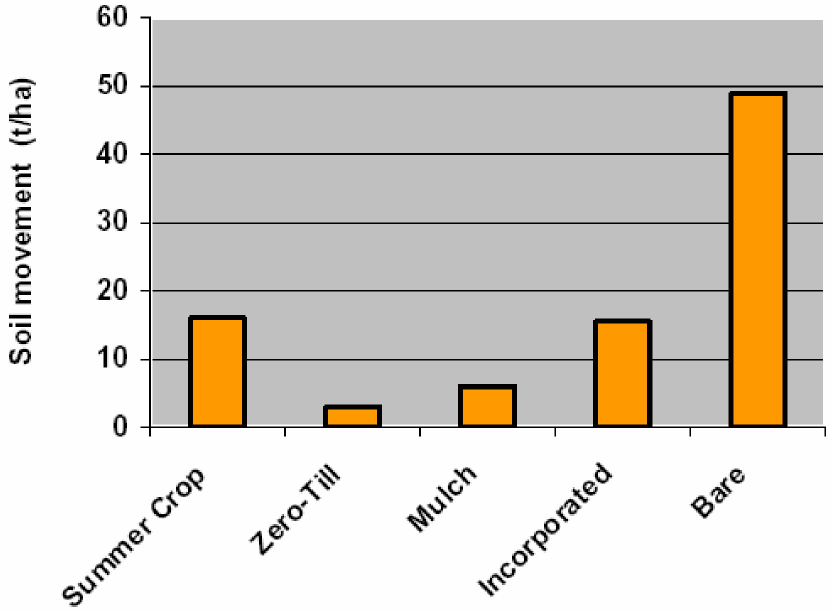

Figure 3. Impact of soil cover on soil movement (after Wockner and Freebairn 1991)

Other workers also report evidence for reduced erosion where conservation tillage is practiced, including Bell *et.al* (2005), with some improvement in water infiltration, though this did not necessarily resulted in better crop performance in their observations.

Australian effects of conservation farming methods on soil erosion is a reflection of similar findings in the US (see Uri *et.al* 1999), where these techniques are reviewed and found to have beneficial effects on many environmental factors, while conserving and improving crop yields. Positive effects are seen on soil water and wind erosion, with lesser effects on soil carbon.

The evidence is now relatively clear that the use of reduced and no-tillage methods of crop establishment, especially where the previous crop residue is retained, can lead to dramatically reduced soil losses from erosion. Farmers are practicing these cropping systems for reasons of increased production and reduced risk, resulting in sustained returns in the face of declining terms of trade. However, they also welcome the benefits in soil health and preservation of this asset that flows from this system, satisfying their general desire to remain profitable and sustainable.

Soil Water and Salinity

Crops transpire water for their growth and development. This water in Australian cropping systems comes mainly from rainfall, since only limited areas of grain crops are grown under irrigation. Most of Australia's grain areas exist in what are commonly Mediterranean climates, with generally winter dominant rain and summer dryness. The exceptions to this are in the grain areas of northern NSW and Qld, where summer dominant rain is more the norm.

In general, however, the common perception is that grain production in Australia is limited in most years by rainfall, with droughts a constant worry. Certainly lack of rain will severely limit yield of grain crops and farmers have developed strategies to maximise the amount of (rain) water available for their crops. Such strategies aim to do this either by storing more in their soils (traditionally by fallowing yet recently by stubble retention and no-till), by trying to grow crops such that they assist with reducing evaporative losses from the soil surface, and by assisting crops to access more rainwater from deeper in the soil. The general aim is to increase what is now known as water use efficiency (WUE), a measurement that can now be quantified and used to compare the management of different crops.

Commonly WUE is expressed as kg of grain yield per mm of growing season rainfall (GSR). GSR consists of not only the rainfall that falls during the crops life but also on that stored within the soil from rain that fell prior to planting the crop. The amount possible to store in this way varies due to many factors, including the soil type (for example, texture and depth, components of the water holding capacity of the soil), the avoidance of plant (weed) growth that would otherwise use this water, and the avoidance of evaporative losses. The practice of fallowing (a period of no plant growth in a field, once done by cultivating to remove plants) was a method adopted by many farmers in Australia in an attempt to store some water from what fell at one time till needed by the crop they intend to plant later.

Cultivation-based fallowing, as mentioned in the previous section, came to be seen as having drawbacks. These included the need for continuous cultivation for weed removal, since whenever rain fell through the fallow period, weeds tended to emerge requiring removal. The more frequently rain fell during the fallow period the more common and repetitive cultivations could be. These cultivations exposed soil to the effects of erosion, and some serious soil losses have been seen due to this practice, from both water and wind erosion. Secondly, fallowing does not eliminate evaporation from the soil. While some conjecture remains, evaporation of water from the soil can still occur in a bare fallow, such that rarely can all of the rain received through the fallow period be stored. Thirdly, during the fallow period water will tend to migrate to deeper layers in the soil, especially if rain continues to fall. Such water deeper in the soil was often unable to be accessed by crop plants due to other constraints preventing their roots from penetrating to these depths. Commonly water may be found at depths exceeding 1 metre, but rooting depths of crops of perhaps 50cm would be common in these soils.

Reasons for shallow rooting depths include root diseases, subsoils that are either too massive (i.e. compacted) or chemically hostile (e.g. containing toxic levels of boron), low vigour in the plants and possibly other reasons.

How much of the GSR a crop is able to use is also modified by how much is lost through evaporation from the soil surface, while the crop is present. Commonly this amount is set by agronomists at around 110mm, though this can vary considerably in the field (Passioura 2004, Hanks *et al*. 1969).

Being able to calculate GSR, (allowing for some stored water where fallows, either cultivated or using herbicides are still practiced) and then being able to calculate WUE allows farmers and agronomists to assess the health of the crop. This arises since the higher the grain yield per mm of GSR, the more healthy the crop can be assessed as having been. Crops able to achieve a high WUE, are suggested as being able to access more soil water (though deeper and more vigorous roots), are able to grow more vigorously early (and hence reduce evaporative losses from the soil surface by rapidly producing leaves). They are also seen as able to more efficiently exchange water for CO2 and hence into biomass, or have a higher harvest index (ratio of grain produced per unit of crop biomass). Of these the first two are most under the control of farmers management, and are able to be modified by such management for increased WUE and hence profit. The additional benefit of such efficient water using crops is that more total water is transpired from the soil by the crop, leading to a reduction in deep drainage of water beyond the root zone. Where water otherwise drains deeper into the soil it can often interact with saline groundwater and re-emerge elsewhere in the landscape, thus contributing to salinisation.

In the context of this paper, improved WUE, from better farming practices is seen as one of the means to improved crop yields and hence a contributor to economic sustainability, but also leads to less deep drainage, thereby lowering the risk of salinisation, and so also contributes to environmental sustainability (Passioura, 2004).

Figure 4, adapted from Angus and van Herwaarden (2001), compares computer modelled yields of wheat with mean annual reported yields in the Wagga Wagga shire, as related to growing-season rainfall. The solid line corresponds to a WUE of 20 kg ha-1mm-1, a figure considered high and not often exceeded by farmers (e.g. French and Schultz 1984, Cornish and Murray 1989). The intercept of the line with the x-axis estimates the amount of water lost by evaporation from the soil (Hanks et al. 1969), a figure of 110mm, though this can vary substantially.

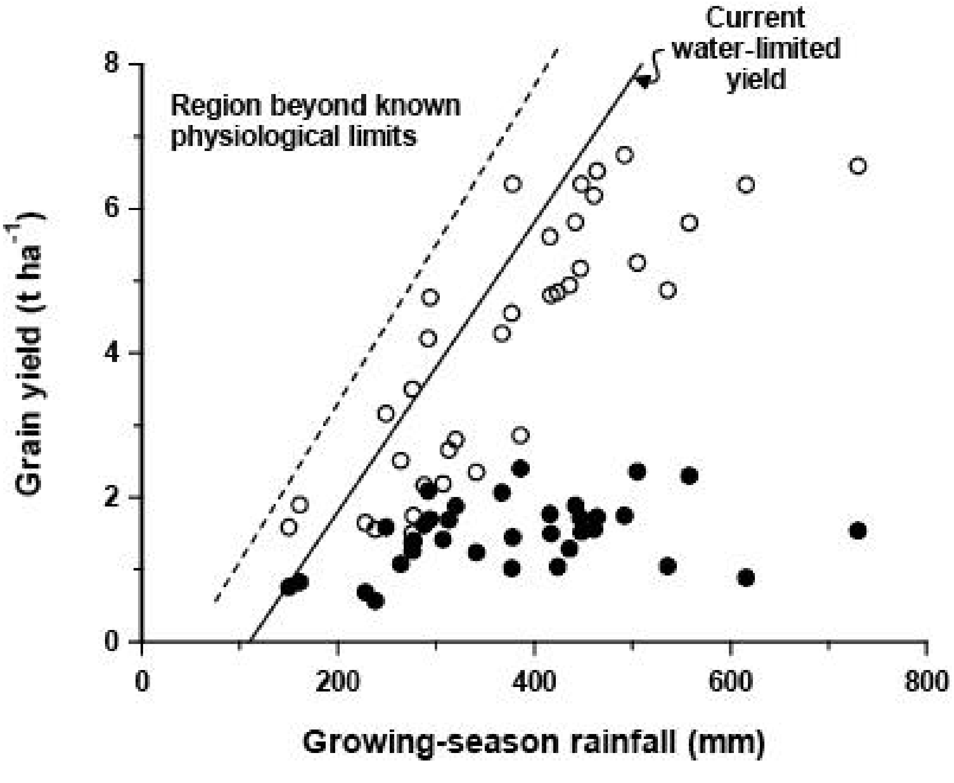

Figure 4. Reported (?) and modeled (?) mean wheat yield in Wagga Wagga shire for 1949 to 1983, related to growing-season rainfall. The solid line depicts the upper bound of reported yields across a range of studies in southern Australia. It has a slope of 20 kg ha-1mm-1. The intercept of this line on the x-axis indicates the loss of water by evaporation. The region above the dashed line is outside known ecophysiological limits. Adapted from Angus and van Herwaarden (2001).

The crop model data in the figure (Stapper and Harris 1989) were for well-managed crops without disease. While they tend to agree with the upper levels of yield as determined in a range of field measurements, they show many crops to yield below the line.

Reasons for this can lie in the distribution of rain during the growing season, for example, where many light falls lead to higher evaporative losses (Sadras, 2003), dry conditions at flowering in an otherwise good year leading to infertility and reduced yield, or water losses from runoff where intense rain events occur within the total GSR (Hammer et al. 1993).

However, from Figure 4, most of the field data of crop yields can be seen to be very much below both the solid line depicting 'good' yield, but also the crop modeled data. Many factors can reduce yield, apart from water shortage, including weeds, disease, poor nutrition, frost and heat. Given the flat distribution of most of the points it can be seen that water is not the limiter of crop yield in most years, but that other factors can contrive to reduce a crops ability either to access soil water, or to convert this water in exchange with CO2 for crop biomass.

What can be suggested now is that where farmers have learned to manage factors like root diseases, sub-soil constraints and weeds, the crops have been able to access more of the soil water, and in turn respond more fully to, for example, better nutritional regimes. Other management factors can also contribute to higher WUE, including timeliness of planting, evenness of establishment, earliness of weed control, better matching nutrient supply with crop demand and crop rotation. In short, where farmers have learned to manage the non-water constraints, the crops have been able to explore more soil and extract more water, resulting in strong yield increases. By so doing, these higher yielding crops have extracted more of the rain water from the soil, leading to less of this water being available for drainage to the sub-soil, with consequent reductions in risk of salt emerging elsewhere in the landscape. Passioura (2004) lists and describes these in more detail.

The amount of water lost by evaporation from the soil is usually greater than that lost to deeper drainage. However, the failure of a crop to access deeper soil water can be important for both productivity (Angus and van Herwaarden 2001), and environmental reasons. Losses to deep drainage can range up to 100 mm per year depending on soil, management, and season (Dunin et al. 2001).

Accessing water otherwise susceptible to drainage can significantly increase yield. Where plants do access this water, this usually occurs late in the season, after anthesis, when plants are actively filling grain. Angus and van Herwaarden (2001) estimate this deeper water can provide up to 33 kg ha-1mm-1, considerably higher than the 20 kg ha-1mm-1 generally attributed to WUE. Managing crop to capture some of this water could give relatively high rates of return in grain yield terms. This water often contains mineral nitrogen, leached from the topsoil earlier in the crops life (Angus, 2001) which can further be advantageous.

The key to accessing such deeper soil water is to have active deep roots that can penetrate and draw on this water and thus reduce drainage losses. Many soils in semi-arid cropping areas unfortunately have inhospitable subsoils for root growth. These subsoils may be saline, sodic, hard, alkaline, acid, high in boron or low in zinc and other nutrients that roots need. Because of these constraints many crops do not root below about 50 cm in such soils, though water may be present down to 1 metre.

Recently developed cultivars with Boron tolerance have been useful in allowing plants to gain access to such water, however this is perhaps an isolated example of where plant breeding has made an impact (Paull *et al*. 1991). However, this remains a relatively isolated, though important, example of where a plant breeding approach has assisted with overcoming such a subsoil constraint.

Passioura (2004) describes how roots typically penetrate inhospitable subsoils through biopores, large extended pores made and repeatedly recolonised by successive generations of roots. These pores act as conduits from which lateral roots can explore the adjacent soil matrix. Leaving these pores intact may be a significant strategy in allowing successive crops to explore deeper into the soil with the use of no-tillage potentially being a means of achieving such an outcome.

Supporting the effect of conservation tillage systems to assist with soil water access is work by Bissett and O'leary (1996) in a grey cracking clay, where they found significantly more water able to be stored under such systems than with conventional, cultivation based systems. Up to an 8 fold increase in saturated hydraulic conductivity was seen compared with he conventional practice including stubble burning.[1]

It can be suggested that an increase in hydraulic conductivity and an associated increase in water holding capacity for such soils under conservational tillage and stubble retention systems would lead to a lowering of water runoff from such soils, with this in turn leading to a proportional reduction in soil erosion.

Young, vigorous crops tend to extract more water from the subsoil, since their roots grow deeper (Angus et al. 2001). There are substantial effects of crop management on early vigour, for example cropping history on the abilities of crops to extract water from the subsoil (Angus et al. 2001).

In summary, there is substantial variation in the ability of crop roots to capture water that may otherwise be lost to deep drainage. Agronomy is seen to have the largest effects in this. Having crops managed to allow them to capture this water can have environmental benefits as well as improving yield. In semi-arid

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[1] Bissett, MJ and GJ Oleary (1996)

environments especially, where saline subsoils are common, water lost to deep drainage may mobilise salt and bring it to the surface elsewhere causing dryland salinity.

In wetter environments, such water may carry nutrients or other agricultural chemicals to discharge areas contributing to algal blooms and other problems

It can thus be argued that better-managed crops use water more efficiently and use more total water, and in so doing contribute to reduced dryland salinity and possibly other problems. In this way, modern, productive farming practices that advantage crops, and allow them to extract more soil water can have significant environmental benefits.

Soil Carbon

Soil organic matter comprises living and decayed plant and animal material and charcoal that become mixed with the mineral components of the soil. It is important in maintaining soil structure, as a source of nutrients for plants and micro organisms and as a source or sink for atmospheric carbon.

Significant losses of organic matter in soils have been recorded in Australia as a result of cropping (Barson and Leslie, 2004, Chan *et al* 1992) through both increased *in situ* losses and soil erosion. Reduced soil organic matter is due to lower returns of organic matter to the soil, and is a function of rates of biomass production, harvesting and residue management.

Tillage promotes the rate of mineralisation of organic matter, increasing microbial activity by soil mixing and disturbance and exposing organic matter protected by the soil matrix to the biosphere (Grace *et al* 1994, 1997), resulting in a loss, through this mineralisation, of soil organic matter.

Systems of crop production that enhance soil carbon, and slow the rate of decline, while also enhancing production, are desirable. No-till systems can play a role in this especially when used in combination with other elements in the system, like using cover crops, minimizing summer fallows and growing high-residue crops (Rainbow, 2006).

Experimental results examining the impact of tillage practices on soil carbon stores have not always shown that conservation tillage on its own will lead to increases in soil carbon. Fettell and Gill (1995), in a relatively low rainfall environment, found under 15 years of continuous wheat, direct drilling and stubble retention had little long-term effect on soil organic carbon. Other work with continuous cropping over 10 years involving a wheat/lupin rotation showed organic carbon declined by 31 percent under stubble burnt/conventional tillage when compared to stubble retained/direct drilled (Chan *et al* 1992). These observations indicate that conservation tillage practices alone may not be the total answer to soil carbon, but that they can play an important role, along with other management practices.

Burning of crop residues would be expected to deplete inputs of organic matter into soil. Stubble burning is now far less common, and tends to be only used where heavy stubble loads are present at planting. In today's circumstances farmers who need to remove stubble in order to get planting machinery through stubble, attempt to minimize loss of soil organic carbon by delaying burning until late summer/early autumn and by practicing a light burn whereby only a proportion of the stubble is burnt (Chan *et al* 1992).

Experimental results demonstrating the impact of management practices on soil carbon have been variable. Reasons include unknown histories of rotation, tillage method, residue management, crop species and fertiliser use, soil type, climate, incidence of weeds and disease.

However simulation modeling can assist, and has been extensively calibrated for Australian conditions (Skjemstad and Spouncer 2003). Such models have shown that reducing tillage can slow the rate of soil carbon depletion, and that incorporation of pasture phases can increase the low carbon in soils resulting from long periods of cultivation (Skjemstad and Janik 1996).

More recent research by Skjemstad *et. al* (2001) has shown that simply measuring total soil organic carbon may not be telling the whole story regarding soil carbon. This is because there are several major fractions (inert organic carbon, active organic carbon and humus). Of these the active carbon fraction is made up of recent additions from stubble and roots, while the humic fraction is derived from microbial activity in decomposing organic matter and produce compounds that hold soil particles together and so improve soil structure. It is also the main provider of nutrients for plants.

Both these fractions are benefited by a system of less tillage and stubble retention, with the indications that the active organic matter can improves the most rapidly, while the humic matter more slowly increasing.

How much additional carbon can be added to soil by no-tillage and stubble retention remains contentious, though some earlier work (Haines and Uren, 1990) does suggest that a regime of direct drilling and stubble retention in Victoria does lead to slow increases in soil organic carbon. Increases may be in the order of 0.01% per year, though totalled 12% over 9 years for soil organic carbon and 43% for microbial carbon., These can be useful in assisting with other soil properties, and these authors found significantly increases earthworm numbers and soil microbial biomass, both potential indicators of soil health in a more general sense.

A review of the possible effects of conservation farming practices on soil carbon by Chan *et.al* (2003) indicates that for much or most of the Australian grain growing areas the effects of no-tillage and stubble retention on soil organic carbon may be small at best (though greater in higher rainfall areas). Some evidence is presented to suggest that under conservation tillage regimes the decline in soil carbon may be held or minimised and that where crop yields are high the potential for some sequestration does exist.

Loss of soil carbon is known under conventional tillage systems, with either less loss or some increase in soil carbon under no-tillage systems. Dalal and Chan (2001) note these effects, and suggest the losses of soil carbon are mainly due to the cultivation regime. They also point to the earlier work of Grace *et.al* (1994), where positive effects on soil microbial carbon were seen under conservation tillage practices. This suggests that even if total organic carbon does not show a great increase from conservation farming practices, other (microbial) forms of carbon may.

More recently, work in Queensland vertisols under a long term experiment of different farming practices indicated that the use of No-Till with stubble retention, especially when practiced together could give increases in total soil carbon of between 1.1 and 3.4 t/ha of carbon (Wang *et. al.* 2004), especially in the surface 10cm of soil. These effects changed through a fallow period, but the implications are that the use of a no-tillage and stubble retention system can give increases in soil carbon.

There exist data from overseas work that similarly suggests that no-tillage and stubble retention can sequester carbon and reduce emissions of greenhouse gasses (GHG) from farmland. For example Samarawickrema and Belcher (2005) in a Canadian black soil suggest that reduced tillage gives rise to reduced GHG emissions. Similar suggestions have been made in US studies, for example, Unger *et.al* (1997), who argue that the use of conservation tillage and residue retention forms the basis of sustainable crop production while also enhancing soil organic matter, reducing or eliminating erosion and enhancing soil and water quality.

Results from a long-term (21 year) tillage, rotation and fertiliser systems experiment at Wagga Wagga in NSW on a red earth soil showed that direct drilling and retaining of stubble could increase soil organic carbon by up to 3.8t/ha over that period (Heenan *et. al.* 2004). Including a subterranean pasture in rotation with wheat, or rotating with lupins and retaining stubble in a direct drilled system were seen to be most beneficial for soil carbon.

No-till and crop residue retention have been seen to reduce the loss of organic matter in soil. For example, Dalal (1989) measured higher organic C contents in a Vertosol under no-till plus crop residue retention than under conventional till with a positive interaction of tillage practice x crop residue x N fertiliser application being observed after 13 years. These effects occurred in the top 0–0.025 m or 0–0.05 m layers in Vertosols, after 18 years of no-tillage (Dalal *et al.* 1991, 1995). Thus, no-tillage practices can be seen to enhance soil organic carbon stratification in a Vertosol, although total amounts of soil organic matter may be similar to that in the conventional cultural practice.

Similarly, in Ferrosols, no-tillage was seen to enhance or reduce the decline in organic carbon concentrations in the top soil layers. In addition to providing carbon inputs, surface residue cover also reduces raindrop impact and enhances water infiltration, which may increase plant biomass production, and reduce soil erosion from the surface with higher organic C content. On the other hand, Fettell and Gill (1995) reported no effect of different tillage practices including NT practice and/or stubble management practice on a red chromosol after 14 years of cereal cropping, although fertiliser N application significantly increased soil organic carbon. Similar effects on other soils have been reported by Haines and Uren (1990) and Carter and Mele (1992). These results were attributed to the fact that cereal grain yields and hence plant C input, especially below ground, were essentially similar under No-till and stubble retention compared with conventional tillage practice. However one may argue that the reduction in cultivation may lead to more of this carbon remaining in the soil rather than being lost through oxidation.

Table 1 (below), from Dalal and Chan (2001), attempts to show the potential for carbon incorporation in soils under different management practices.

Table 1. Potential greenhouse C sink due to management practice in the rainfed cultivated

Australian cereal belt, excluding methane and nitrous oxide emissions/absorption. (From Dalal and Chan 2001)

Management practice	Area (Mha)	Plant input (t C/ha.year)	CO2 sequestration Mt CO2/year	Mt CO2 per 20 year period
No till, stubble retained [a]	2.5	1.6	0.2	4.0
Improved ley pasture[B]	21	4.2	10.8	216
Sugarcane trash retention[B]	0.4	4.2	0.2	4
Cotton[B]	0.4	1.7	0.1	2.0
Others (manure application) [C]	0.1	0.5	0.1	2.0
Total	24.4		11.4	228.0

[A] In regions with annual rainfall >500 mm in temperate areas (Chan *et al*. 1998) and >700 mm in subtropical and tropical areas (Dalal 1989; Dalal and Carter 2000).
[B]Adapted from AGO (2000), NGGI (1999), and Dalal and Carter (2000).
[C]Calculated from AGWISE (1999) assuming annual 4 t/ha manure application.

From these observations and experiments into the effects of tillage and residue management on soil carbon, it is becoming more clear that under many circumstances operating in Australian grain production, significant reasons exist to suggest that these techniques at worst will reduce carbon loss, and at best will add carbon to the soil. While the quantities of carbon involved may be unclear, it would appear that under regimes of higher biomass production, for example in higher rainfall environments, carbon will more likely be added to soil where no-tillage is practiced and stubbles retained. For this reason, grain producers in these environments using such systems, may be well placed to sequester carbon in their soils, with resulting increased soil properties, production and environmental outcomes.

Soil nutrients and farming systems

The major nutrients used in Australian cropping include phosphorus and nitrogen. Phosphorus is mainly applied in fertiliser form, and many Australian soils are naturally deficient in available P for crop use. Nitrogen is also required by plants for healthy growth, and once P is satisfied, N can drive both crop yield and grain protein content, both of which are important determinants of grower profit, especially in cereal production.

There are several farming practices that can have impacts on soil nutrients and their availability. These include crop rotations (including pulse and oilseed crops), use of legume-based pastures, and more careful use and budgeting of fertiliser applications.

The use of crop rotations and the retention of crop residues in the system can have positive effects on some nutrients. For example, soil potassium levels in NSW red earth soils can be preserved or improved where crop residues are retained compared to where burnt (Whitbread *et.al.* 2000). The authors believed that better recycling of crop residues and improved ley systems would enhance soil nutrient levels and organic carbon. This indicates that crop rotation and residue retention in a conservation farming system would be beneficial to soil nutrient levels, and may reduce the depletion of such nutrients as compared to more conventional systems.

Fertilisers are frequently used to provide nutrients for cropping (and pasture) production. However, fertilisers are relatively expensive inputs for grain producers, and as such, agronomic practices that can increase the efficiency of plant use of these are valuable, and can enhance the profitability of fertiliser use. Research in the last decade and more has increased the efficiency of use of both these nutrients, driven by a better understanding their dynamics (Angus, 2001).

In the case of nitrogen, producers are now more sophisticated in their management of this nutrient. They now more frequently use deeper soil tests to better gauge the total amount of N available in the soil profile, take account of legume fixed N present in the soil and calculate mineralisation of N from soil organic matter in their N budgets. This has led to them tailoring the application of fertiliser (both in amount and timing through the crops life) to cater for the total N availability. This has led to higher yields, better protein levels and savings from not buying more N fertiliser than the crop needs.

However, nitrogen use as fertiliser also brings potential environmental risks, including soil acidification, groundwater accessions of nitrate, runoff in soil and potential pollution and eutrophication of water bodies. For these reasons better nitrogen use efficiency and closer tailoring of N use to crop need, considering N available from 'natural' sources, is desirable both for crop production and profitability, but also from an environmental viewpoint.

The use of fertiliser has grown as cropping area has increased, as well as a result of research and findings that use of fertiliser gives higher yielding crops. Figure 1 shows this increased trend in fertiliser use, in the case shown for nitrogen.

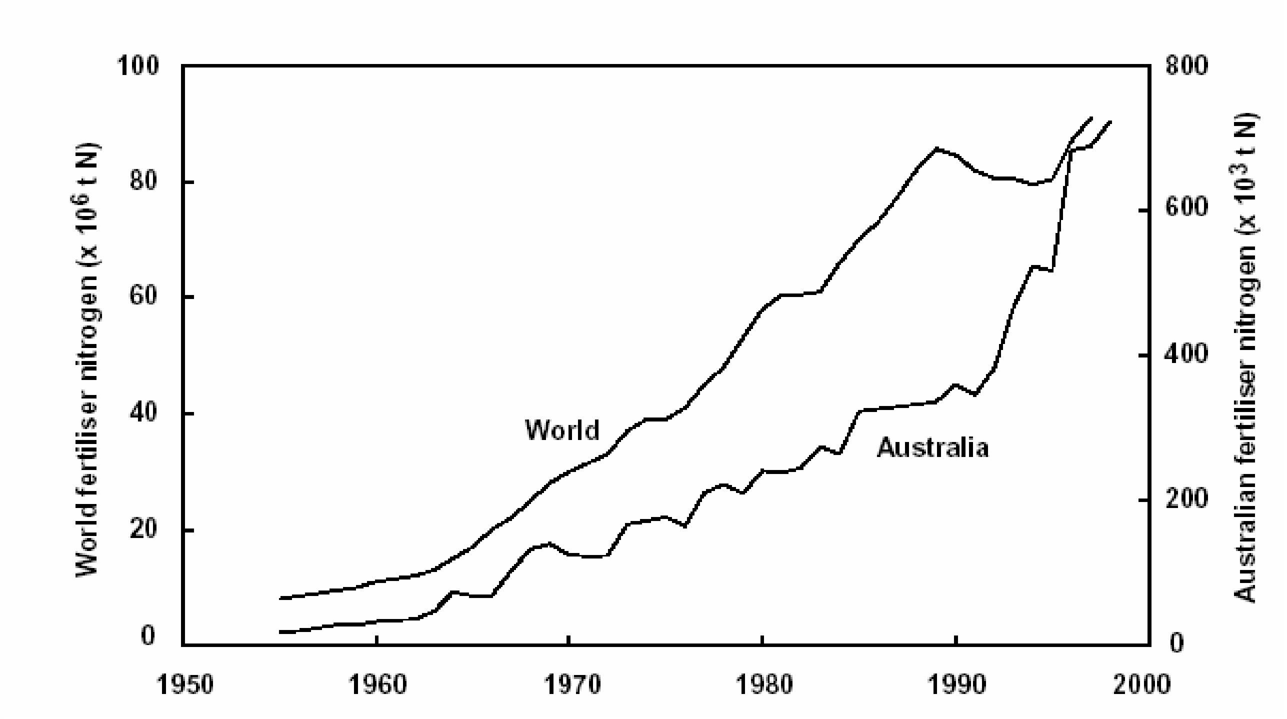

Figure 5. Fertiliser nitrogen use in Australia in comparison with the world. (Adapted from Angus, 2001)

What is apparent in Figure 1 is the rapid increase in nitrogen use in recent times, since the early 1990's in particular where increases in use have been up to 14% per annum (Angus 2001). One of the contributory factors in this increase in nitrogen use has been a real decline in nitrogen cost, at least in the years till 2000. Figure 6 shows this price decrease. Other factors include the findings of how judicious use of fertiliser N in crops can boost yield and profitability during this time. Use of fertiliser N in conjunction with other agronomic improvements has been seen to work in synergy to allow crops to access and use more soil water and so produce healthy economic returns from N use.

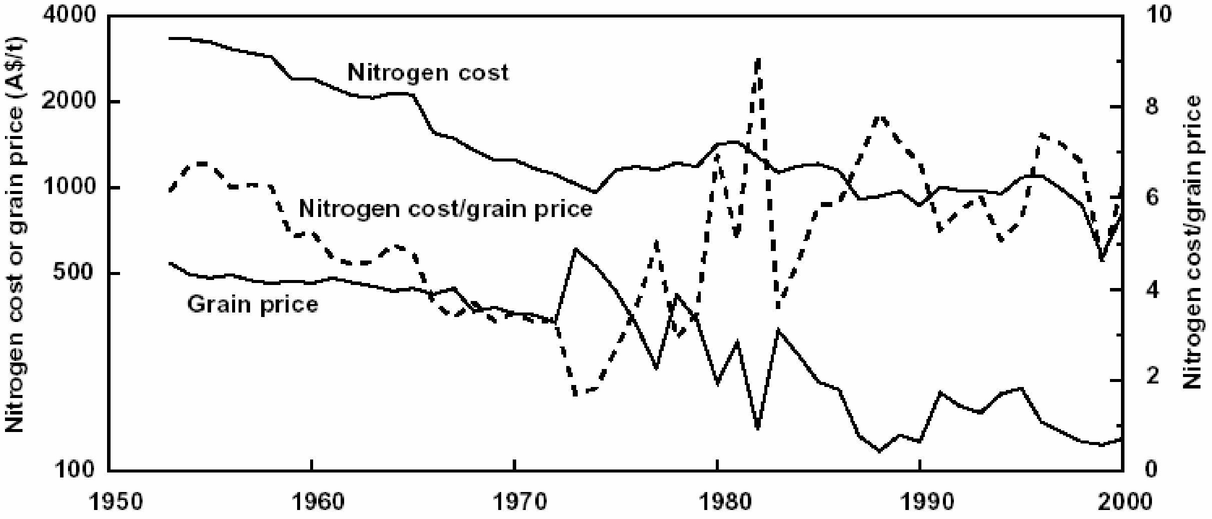

Figure 6. Fertiliser nitrogen cost and grain prices expressed in A$ for 2000, and the cost:price ratio for nitrogen and wheat. (From Angus, 2001)

What is also apparent from the data presented in Fig 6 is that while the cost of nitrogen has fallen in real terms, the price of wheat has also fallen, but a faster rate, as evidenced in the ratio of nitrogen cost / wheat price. What this means for producers is that while N has become more affordable, the decline in grain price has meant that they have needed to become even more efficient with the use of this N to show a return on this investment. Fortunately this has occurred, and it is this increased efficiency of N usage that has led to both economic returns and a lowering of the risks of environmental side effects from N use.

Another factor stimulating increased N fertiliser use was the decline in returns from the livestock industries in Australia in the 1980's and 1990's, which led to a reduction in legume-based pastures, with an increase in cropped areas. Both of these lead to an increased need for nitrogen from other (fertiliser) sources. Other factors include the development of more responsive crop varieties (for example semi-dwarf wheats, where less nitrogen is used in producing stem), the use of herbicides for better weed control and the control of leaf and root diseases, allowing crops to better explore soil for nitrogen and other nutrients).

One way of looking at the use of nitrogen fertiliser and trends in this use is to examine at a national level trends in this use. Angus (2001) has done this with some of his data presented in table 2. It can be seen that over the period of the estimated budget, whilst N use in agriculture increased, so did N outputs in food and fibre (dominated by crop products), only to a greater extent, such that the final balance of 'surplus' N has reduced over this time. It is also likely that since 1998-9 improved fertiliser practices, especially in the cropping industries may have further extended the trends apparent in this table.

Table 2. Estimated budget of nitrogen (,000 t) for Australian agriculture in 1987-8 and 1998-9. Adapted from Angus (2001). (nk= not known)

	1987-1988	1998-1999
	Nitrogen Inputs	
Fixation by sown pastures	1500	1320
Fixation by crops	200	235
Non-symbiotic fixation	nk	nk
Atmospheric deposition	160	160
Fertilisers	380	750
Total	2240	2465
	Nitrogen Outputs	
Food and fibre crops	415	800
Ammonia volatilisation from urine	320	224
Ammonia volatilisation from fertilisers	14	28
Leaching of fertiliser N	3	6
Leaching of soil and urine-derived N	220	220
Denitrification of fertiliser N	41	82
Denitrification of soil and urine-derived N	nk	Nk
Soil erosion	18-98	18-98
Fire	170	170
Total	1200-1281	1548-1628
N Balance	**960-1040**	**837-917**

What can be suggested is that with improved fertiliser use patterns, notably through such practices as soil testing to depth, banding of fertiliser slightly away from seed at planting, budgeting of fertiliser needs and the application of additional fertilisers through a crop's life rather than all at planting, farmers have saved money on unnecessary fertiliser as well as optimising fertiliser responses, thus benefiting their profitability. However, in so doing they have also minimised the amount of N (and P) available for detrimental effects in the environment, for example via leaching or movement to waterways.

It can therefore be argued, given the above sections, that modern farming and cropping practices as used in Australian systems have given boosts to production and profitability, and have also brought with them environmental benefits. These benefits can be categorised in terms of soil erosion, soil water relations, soil carbon characteristics, soil structure and nutrient balances and efficiencies. All of these are important environmental considerations, both for the farmers themselves and for a community interested in such environmental sustainability. The following sections describe more directly the environmental flow-on effects of the farming systems described above.

Effects of farming systems on environmental parameters and catchments.

Crop farms in Australia normally operate within catchments of one or other river system. How farmers operate and manage their farms can have off-site effects of Importance to the catchment, and may influence the catchment in terms of various environmental targets. It is contended that the adoption of modern farming practices as outlined above, with the consequent effects these practices can have on, for example, soil, water, nutrients and carbon, can be the means towards enhancing the environmental status of the catchments such farms operate within.

Moss *et. al.* (1996) suggests that many river systems in Australian have greater turbidity, sediment and nutrient loads, higher flood peaks and shorter flows (leading to damage to river banks, silting and scouring) due to agricultural development in their catchments. Soil erosion is often implicated as a causal factor In these. Yet, agricultural land use is only one factor that influences sediment and water movement in catchments (Wasson 1998). Agricultural practices may have a minor effect compared to other factors within a catchment. For example, if gully erosion has already developed much eroded material in downstream sediments can be derived from the subsoils so exposed (Olley *et al* 1993).

The effects of farming practices on larger catchments has been difficult to describe because of their size and many of them being discontinuous in terms of catchment transport systems, and the effects of the storage structures often in them. Further, it is often inaccurate to extrapolate from plot studies and experiments in small catchments to larger catchments. Some evidence exists that gully and riverbank erosion are the dominant erosion processes and sources of sediment delivered to streams in most areas (Olley and Deere 2003). Hence it is, so far, difficult to directly attribute the effects seen in streams and rivers to the presence of farming in those catchments.

Nonetheless, it often seems reasonable to suggest that soil erosion may be a contributory factor in sediment loads, and the potential associated nutrient and pesticide content of these (Finlayson and Silburn 1996). However, these effects appear not to be uniform, and can vary across Australia (Moran *et. al.*2003). As such it has been suggested (Barson and Leslie, 2004) that further work is required to more accurately quantify the contribution of agricultural practices on catchment targets. They argue that, for southern Australia at least, in relation to sediment and nutrient targets, that reducing gully and/or riverbank erosion rather than focussing on farming practices associated with hillslope erosion minimisation, may have the biggest impact on these targets. Suggestions to address these include controlling stock access to waterways, protecting existing riparian vegetation and replanting previously cleared streamlines, as well as maintaining good cover in areas prone to gullying.

As such, it can be seen that the use of farming practices that minimise soil erosion, and as such the risk of soil, nutrients and other components contained with such soil from entering river systems would be desirable. Similarly, the use of cropping practices that maximise soil water use, and minimise the risks of increased salinisation would also be desirable in a catchment sense. In terms of nutrients, like nitrogen, cropping practices that maximise the use of applied fertiliser nitrogen would be expected to minimise the likelihood of excess nitrogen from entering the catchment, and would also be desirable.

Farming Practices as the means to Environmental Management for the Australian Grains Industry

It is highly likely that the adoption of the types of farming practices outlined in this paper has contributed, even if in variable ways in different catchments, to improved soil health, reduced erosion and the associated benefits for the catchments. The practices have strong on-farm benefits that mainly drive their adoption, however can also contribute to general environmental benefits through their effects on soil health, water, nutrients and soil carbon.

Grain producers across Australia have shown a strong move toward the adoption of many of the practices now seen as having environmental benefits. These include

- The use of no-tillage and direct drill crop establishment systems,
- Soil testing and budgeting for fertiliser and nutrient efficiency,
- Retention of crop stubbles for soil and water benefits
- Increase water (rain) use efficiency from higher water holding soils, deeper rooting depths (from better crop agronomy and improved soil structure)

Since these practices for the basis for many of the environmental benefits outlined above, the level of adoption of these practices by farmers can confidently be used as a measure of farmers' environmental management. An increasing knowledge base of the environmental benefits from such practices will increase this confidence, and empirical measurements will hopefully confirm these effects and linkages.

It is for these reasons that the grains industry has embarked on an approach to Environmental Management Systems (EMS) for the industry that differs from the traditional approach. Under the traditional approach to EMS individual producers would embark on a process of self assessment of their property and the things they do on their farm. This has been traditionally paper-based, but is more commonly offered in electronic form in recent times. The self assessment is then ideally followed by a process of 2nd or 3rd party auditing to determine what actions are needed and how these are implemented.

Several difficulties arise from this approach:

- Currently there are few or no signals (price or access) for grain produced under a formal EMS or other environmental assurance system. This means the producer who chooses to follow the EMS pathway is not rewarded at all for the financial and time expense of this.
- The process requires the recording of much information about what is done on the farm and in the production system. Many farmers now have electronic means of recording their actions and do not see any value of the tedium of re-recording this for little reward.
- The greatest impact most farmers can have on the environment is via the farming practices they employ. Given that the soil and related parameters are the largest natural resource asset they have, systems and practices that enhance the health and productive capacity of the soil are the major means for them to provide improvements in the environment.
- They are unable to accurately, if at all, measure many of the environmental factors their catchment may have as targets, for example water quantity and quality leaving their farm, nutrient flows or greenhouse gas emissions.

If the major concern of governments and the community is the health of the broader environment, then the environmental assets most closely managed by farmers would be the ones they would ask farmers to better manage. Within rural Australia, the major environmental resource farmers can have the greatest impact on is the soil. As described above, soil erosion, structure, nutrient content, water holding capacity and carbon content are examples of the major effects farming systems and techniques can have on this resource. Consequent effects of these management practices on air and water quality, nutrient flows, greenhouse gas emissions, sediment loads in streams and rivers, all important environmental factors, are able to be directly addressed by the farming practices employed on farms.

Farmers today record what they do on their farms more than ever before. They are also surveyed on a regular basis by agencies like the Australian Bureau of Statistics (ABS) and the Australian Bureau of Agricultural and Resource Economics (ABARE). Most of these surveys, and the 5 yearly ABS Agricultural census, include questions that are directly relevant to and can describe the farming systems used on farms. These data have formed the basis of the approach to EMS reporting for the grains industry.

The industry is able to use data gathered by these agencies to show levels of soil management, fertiliser use in relation to production, rainwater use efficiency and others. It can do this with scientific knowledge as outlined above, and using the data available from these sources. Through processes of data management and calculations the industry is able to show progress in environmental management for a region, catchment or other area on terms of soil, nutrient, energy, and water factors. These results and reports can be produced on behalf of producers to satisfy various audiences and users of environmental information, including catchment authorities and the general community.

It is for these reasons that the grains industry will be using data already available, plus gather data as possible from producers, groups and other sources to continue to show the performance and changes over time in the key farming practices that have direct effects on environmental factors of interest. This will negate the need for a formal EMS approach. The adoption of the best farming practices will also be encouraged in this way, with further improvement in environmental outcomes flowing from farmers seeing how their farming practices compare to others in their region.

Individual farmers, or groups of farmers can easily access these data to have their own farming practices evaluated against those of the broader farming community in their relevant area. This can form the basis of showing how they are performing in adopting those practices seen as desirable from an environmental perspective. To do this, a comprehensive database is being constructed.

This database will form the basis for grain producers to have their farming practices evaluated and compared with accepted benchmark levels. These comparisons will enable them, either as individuals, as groups, or as an industry to report their progress in continuing to provide environmental benefits as well as sustainable crop production.

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