Nutrient and carbon cycling

Environmental indicators reported on in this section as originally listed and defined in Hamblin (1998):

Environmental indicator	
L5.1	Total nutrient export nitrogen, phosphorus and potassium from each AER and drainage basin
L5.1A	Rates and distribution of nitrogen, phosphorus and potassium accessions into each AER and drainage basin
L5.1B	Sources of phosphorus derived from land activities reaching rivers by catchment
L5.2	Terrestrial carbon (organic matter) loss rate by IBRA region
L5.5	Rate of land carbon (organic matter) sequestration by AER and IBRA region
L5.7	Proportion of each forestry and farming system with stable nutrient balance by major catchment, AER
L5.8	Estimated success of programs to reduce land carbon loss and increase sequestration by landcover regions
L5.9	Proportion of farmers using soil and plant tissue testing regularly by industry and AER

Ecologists, agronomists and foresters have studied nutrient cycling in different natural and modified ecosystems for many years, and the relationship to net primary productivity has been established for many systems (Whittaker 1975). Many natural vegetation associations have common attributes that differ from agricultural systems, but all have a set of ‘pools’ that store carbon, nitrogen, phosphorus, and other nutrients, and set of pathways that cycle the nutrients between them via the transporting media of air and water.

So, what is the most sustainable ‘mixed system’ that we can hope to design where landscapes are composed of patchworks of land uses that are modified to greater extent (intensive irrigated agriculture) and to lesser extent (conservation parks, native forests and rangelands that are used for sporadic logging or grazing)? The degree of functionality of each component of a system needs to be considered.

Typical patchwork of land uses across mid-rainfall regions of eastern Australia.

Source: Ann Hamblin.

Some guidelines for good nutrient cycling in mixed systems are:

- nutrient pools should be adequate for maintenance, reproduction and growth of each component,
- nutrients should not accumulate to excessive degree (potentially toxic) in some areas and be totally depleted from others,
- nutrient leakage from land systems into water systems (surface, aquifers and estuaries) should be similar to geological accretion rates, and
- the scale at which cycling is assessed should be the same as the scale of the constituent elements in the landscape. There is no point in monitoring nutrients in a single irrigation block if a whole irrigation scheme is potentially out of balance, unless the single block is representative of the whole in every respect.

The relationships between the different parts of a mosaic, or patchwork system have recently been studied in both natural and disturbed arid ecosystems (Arnalds and Archer 2000, Ludwig and Tongway 2000).

The increased public attention paid to carbon cycling demonstrates how much knowledge gain of a topic depends upon its status in the public eye. Much more information is now being gathered on various aspects of carbon cycling in Australia, as a result of the Kyoto Agreement, and large gaps in knowledge are also being identified.

The recent Commonwealth Government initiatives to improve our knowledge of continental-scale carbon, water and nutrient systems, through the Australian Greenhouse Office and the National Land and Water Resources Audit, has provided new insights into how these essential processes operate on the island continent.

Until these recent estimates of carbon (C), nitrogen (N) and phosphorus (P) were undertaken, there had been no attempt at a continental budget for N or P since 1990, when McLaughlin et al. estimated fluxes of these elements and sulfur (S) using broad assumptions and available statistics. This earlier work concluded that overall, continental exports of P, S and N have increased dramatically since European occupation, but that even so, inputs generally match or exceed exports of agricultural commodities by 5 to 6 fold (McLaughlin et al. 1990).

The present estimates are still continuing, but preliminary results suggest that application of fertilisers of all forms (including nitrogen fixation from introduced legumes, fertiliser additions, animal manuring, and plant residues) has increased continental nutrient stores by about 15% since European settlement (Raupach et al. 2001).

Nutrients

Much of the research and published literature on nutrient cycling in Australia relates to agricultural systems. There has been a tendency to describe the essential nutrient requirements of agricultural plants applying to all plant systems, so that soils are frequently described as ‘infertile’ or ‘impoverished’, when this really refers only to the assessment of their suitability for agricultural production. Many Australian native plants have highly specialised mechanisms for efficient scavenging of sparse nutrients, while others use alternative pathways, symbiotic or parasitic habits, or associations with various micro-organisms, to overcome these deficiencies. Australian perennial species often have extraordinarily deep roots, or two or three separate root systems, which provide the plant with a variety of mechanisms for extracting and cycling water and nutrients through different parts of the regolith and soil horizons (Atwell et al. 1999).

PRESSURE

Are nutrient loads causing environmental pressures on water bodies?

[L Indicator 5.1B]

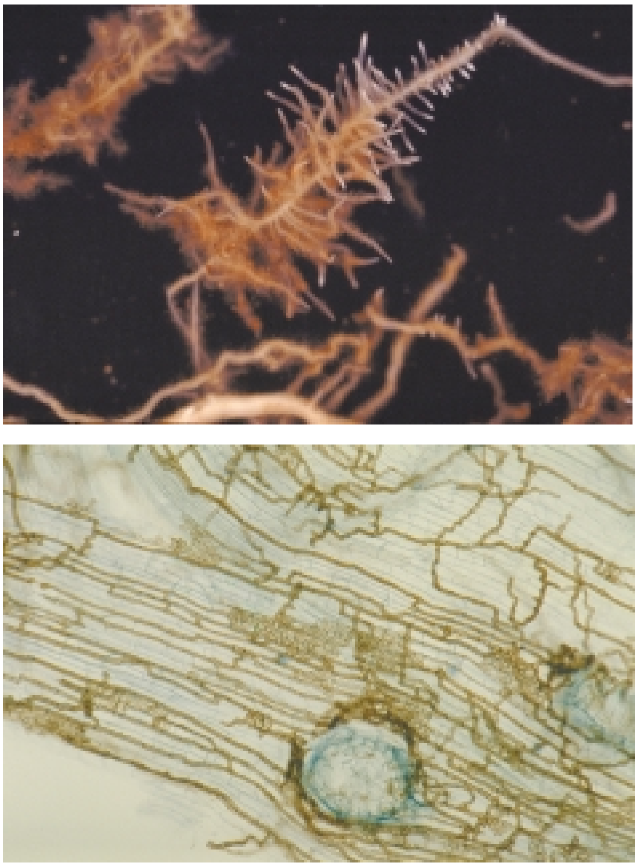
Algal blooms are often a very visible symptom of nutrient imbalance in catchments. An unusually extensive bloom of over 1000 km of the Darling River in 1991 has stimulated a large amount of research in the past decade, together with more attention to reporting on bloom incidence. Although cyanobacteria (especially *Anabaena* spp.) are toxic, not all blooms are; and blooms can occur in unoccupied as well as heavily used catchments. Figure 60 shows the incidence of major blue-green algal blooms from 1991–1998.

Where does this water pollution come from, and how much of it is anthropogenic? Scientists have over the past decade established different lines of evidence to address these questions.

Lines of evidence

Phosphorus studies

At the time of the Darling episode, much of what was known in Australia about blue-green algae came from overseas (principally US) sources. Phosphorus was considered the limiting nutrient to rapid algal growth, and it was presumed that fertilisers were the principal source of phosphorus. Studies of blooms in the Peel–Harvey and other estuaries in Western Australia during the 1980s tended to confirm this. In the very sandy, rapidly percolating soils of coastal Western Australia, phosphate retention in catchments is low, except where reactive iron, in laterites, adsorbs phosphorus. However, evidence from other parts of Australia has shown that in other environments these assumptions are not always correct (Davis and Hamblin 1998).



Special root adaptations to low nutrient environments include fine 'proteoid' roots and symbiotic phosphorus-absorbing fungi in tree roots.

Source: Ann Hamblin.

More recent work has identified light as the limiting factor in many eastern water bodies, which are often highly turbid with dispersed clay (NLWRA 2001b) that has its origins in the sodic soils that cover so much of Australia (Naidu et al. 1995). When low flow river conditions lead to stratification in the water column, algae access nutrients at the interface between warmer but turbid upper water and colder nutrient-rich lower water, and their numbers increase rapidly. Water management can minimise this risk by maintaining mixing conditions through flow regulation (Banens and Davis 1998). Detailed studies in the Murray–Darling Basin have shown that the origin of stream bed and dam sediments can be traced to calculate the contribution of surface soils since the 1950s. In northern New South Wales rivers, the amount of fertiliser and recent soil contribution to the total in-stream phosphorus load is very small (Martin and McCulloch 1999). In the Darling and its tributaries most of the phosphorus rich sediments have come from earlier accelerated erosion of parent rocks within deep gullies, and not from contemporary erosion of farmland (Olley and Caitcheon 2000).

Nitrogen studies

Although phosphorus has been the principal focus of work seeking to control algal blooms, nitrogen has been the cause for concern in 'leaky' catchments, where water and dissolved nitrogen are rapidly transmitted into rising groundwater and discharge areas, mobilising salt in the process. The environmental consequences of nitrate accumulations in groundwater, water bodies and estuaries are still largely unexplored, but there is no doubt that more nitrate is entering sensitive ecosystems than can be absorbed and utilised by the aquatic biota (NLWRA 2001b). It is not clear what contribution these nitrates make to overall waterway loads of nitrogen, or whether they have in-stream geological consequences.

From the large international literature, and some Australian studies, hydrologists have concluded that land use is the best predictor of phosphorus and nitrogen generation rates. This is used in modelling the expected nutrient loads in streams and the effect of land use change (Young et al. 1996). 'Land use' is here a surrogate for a range

Figure 60: Locations of algal blooms in Australia, 1991–1998.

Source: Richard Davis, CSIRO (unpublished data).

of changes that European settlement has introduced, including clearing vegetation, adding fertilisers, and tilling soils. Thus the estimates of nutrient generation can be defined more precisely where detailed information on land management is available.

National Pollutant Inventory

This finding has been the basis of the Catchment Management Support System model (Davis and Farley 1997), which has been used to estimate the emissions of total phosphorus (TP) and total nitrogen (TN) from priority catchments in the National Pollutant Inventory. As no measurements of actual export loads have yet been related to these estimates, they should be treated with caution. They serve solely to provide some relative ranking of probable loads entering major rivers and estuaries in the catchments that support most of the population. Additional impacts from point sources of nitrogen and phosphorus cannot be assessed from these data as yet, because not all types of emission facility have started to report, including intensive animal industry installations such as feedlots, poultry farms, dairies and piggeries. Outfall locations of water treatment and sewage works, which have reported, according to scheduled protocols, for one year, are not reported on a geo-locational basis, and cannot be related to the catchment stream values.

Table 29: **Catchments monitored for pollutants: CMSS estimated values for nitrogen (N) and phosphorus (P).**

Catchment	Area (km^2)	Total N (t/year) into water	Total P (t/year) into water
Adelaide River	177 468	550	64
Botany Bay	110 157	275	48
Derwent River	971 070	1 306	342
Hawkesbury–Nepean River	2 154 881	5 300	432
Hunter River	2 124 138	5 000	463
Lake Illawarra	52 395	180	246
Perth: Swan River–Kwinana	208 064	260	65
Port Jackson	59 512	179	34
Port Philip Bay	995 080	2 247	186
SE Queensland	3 399 815	10 000	1 511
Total	10 252 580	15 297	3 391

Source: National Pollutant Inventory (2000).

Table 30: **The Hawkesbury–Nepean catchment: total N and P estimated entering into water bodies, using CMSS model.**

Land use	Total N (kg/year)	Total P (kg/year)
Bushland	2 220 000	150 000
Unfertilised grazing	620 000	95 000
Fertilised grazing	420 000	65 000
Intensive vegetables, orchards, turf	50 000	37 000
Urban	110 000	21 000
Unsewered urban	6 500	6 900
Unsewered peri-urban	290 000	43 000
Industrial and commercial	51 000	20 000
Disturbed land	19 000	3 800
Small subcatchments (aggregated)	92 700	18 400
Total	3 879 200	460 100

Source: National Pollutant Inventory (2000).

Catchment Monitoring Studies

An earlier report to the Murray–Darling Basin Commission in 1992 following the major algal bloom outbreak in the Darling River, provided estimates of all point sources of nitrogen and phosphorus entering these river systems (Gutteridge, Haskins and Davey 1992). Table 31 lists the numbers of different types of establishments contributing effluents to the rivers.

Table 31: Point Sources of N and P entering the Murray–Darling river systems.

Type of establishment	Number and/or capacity	P effluent load produced (t/year)	N effluent load produced (t/year)	Main locations
Animal feedlots	264 feedlots 180 000 cattle[B]	7 200	1 620	80% Qld and northern NSW
Fish farms	43 fish farms	120	17	Victoria and southern NSW
Piggeries	1 110 000 pigs	8 800	2 530	Darling Downs NSW and Victorian river valleys
Sewage treatment works[A] (four centres over 60 000)	38 treatment works	3 860 (dry year) 5 260 (wet year)	670 (dry year) 880 (wet year)	Throughout, close to main rivers
Urban stormwater	24 outfalls	446 (wet year) 1 012 (dry year)	55 (dry year) 124 (wet year)	Throughout, close to main rivers
Irrigation drainage from major irrigation districts	7 major districts	630 (dry year) 1 480 (wet year)	110 (dry year) 260 (wet year)	MIA negligible Surface drains: Murray districts, Shepparton and Kerang, SA Lower Murray Subsurface drains: Sunraysia, Riverland

[A] Estimates based on type of treatment plant, size of populations, means of effluent disposal, types of disposal and phosphorus retention in reservoirs.
[B] For comparison, in 1999, Australian feedlots held 550 000 head of cattle, which represented only 63% of their capacity. Over 150 000 cattle are held on just 14 feedlots and over 700 hold <1 000 head each.

Source: Gutteridge Haskins and Davey (1992).

This study was particularly concerned to assess the relative contribution of point sources and diffuse sources of nitrogen and phosphorus that could be responsible for major algal bloom outbreaks. Diffuse sources were calculated from descriptions in other studies, from land use areas, climate statistics and modelling for the Murray–Murrumbidgee and Darling basins. The study is particularly instructive in showing the great differences that occur between the various components for wet and dry years. In dry years point sources are the principal contributor, whereas in wet years the very much greater extent and duration of loads derived from runoff ensure that diffuse sources dominate (Figure 61).

Actual studies of nutrient export data

The amount of sediment that is being exported from northern catchments in Australia was reported earlier (see ‘Surface soil loss’ on page 16). Apart from the concern over loss of topsoil, which is the critical source of most microbial ‘decomposers’, clay and organic carbon, the sediments transported in run-off contain much nitrogen and phosphorus. Table 32 summarises data from three climatic regions of Australia.

There are marked regional differences, in the few studies that have been undertaken, relating to the total nitrogen and phosphorus loads for crops grown in some districts, with high export loads from some tropical crops such as sugarcane and bananas. In general, market gardening (annual horticultural crops) has the highest export rates, followed by other types of cropping and urban land uses. Improved pastures (which have received fertiliser applications and contain more legume) export ten times more phosphorus than unimproved pastures, but nitrogen export is similar from both and similar to losses under forests.

A very comprehensive study of the Johnstone River catchment in north Queensland, was undertaken between 1991–1996 to measure nitrogen and phosphorus from the major types of land use, and the impact that nutrients and sediments might be having on the Great Barrier Reef (Hunter et al. 1996, Prove et al. 1997). The rivers rise on the Atherton Tableland and flow through large expanses of

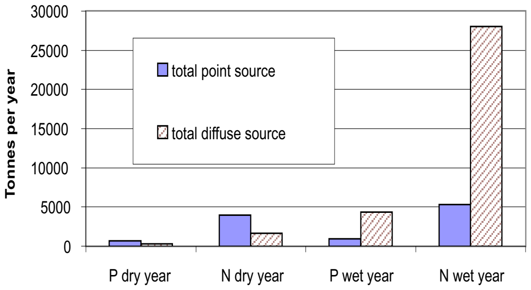


Figure 61: Effect of wet and dry seasons on the balance of point sources and diffuse sources of land-derived total phosphorus and nitrogen into the river system of the Murray–Darling Basin.

Source: Gutteridge Haskins and Davey (1992).

Table 32: **Typical annual total phosphorus and total nitrogen loads exported from catchments under different land uses in three regions of Australia.**

Region	Urban	Improved pasture	Unimproved pasture	Cropping	Market gardens	Forests
			Annual total phosphorus (kg/ha/year)			
SE Aust	1	0.3	0.07	nd	7.1	0.06
SW WA	0.4	1.1	0.1	nd	nd	0.05
NE Aust	nd	0.5	0.06	1.9	nd	0.14
			Annual total nitrogen (kg/ha/year)			
SE Aust	6.6	3.3	2.2	nd	26	1.1
SW WA	2.5	3.0	nd	nd	nd	nd
NE Aust	nd	7.5	3.5	12.3	nd	0.9

nd = no data

Source: Hunter et al. (1997).

native forest in their midsections, before reaching undulating lowlands and flood plains that are used for grazing pastures, horticulture (bananas), sugarcane and dairying. The CMSS model was used with a 40-year run of rainfall statistics to compute the contribution each land use would have towards sediment, nitrogen and phosphorus in the long term. The relative amounts of phosphorus were closely aligned with the relative amounts of sediment that came from each land use as runoff, as less than 20% of phosphorus was in a soluble form. The amount of bio-available nitrogen, however, showed that nearly 50% of the nitrate (NO_3–) form of nitrogen came from sugarcane, and only 11% from forests, despite the fact that the area of forest is 4 times that of sugarcane. Figure 62 shows the annual export of total nitrogen and phosphorus that came from each type of land use, and the nitrate-nitrogen. The nitrate form of nitrogen is very soluble, entering groundwater, rivers and estuaries.

Routine water quality monitoring

A recent national study on water quality was commissioned by the NLWRA (NLWRA (2001b). In summary, it demonstrates that nutrient and turbidity are the most widespread of all contaminants, followed by salinity, and acidity/alkalinity, and that pesticides and biological contaminants are of much lower occurrence.

Key findings of the study were as follows:

- Australia spends A$142–168 million on water monitoring per year, but much of the information is not publicly available.
- Nutrients are the second-most serious water quality issue in 43 of the 70 assessed river basins that cover the most populated regions of mainland Australia (Figure 63).
- There are more cases of turbidity exceeding water quality guidelines than for either phosphorus or nitrogen, but only 50 basins could be assessed for nitrogen because of difficulties in obtaining data, which was limited by ownership issues.
- Lack of good data and the limited availability of data were major issues throughout this study, and probably seriously underestimate the extent of water quality contamination.

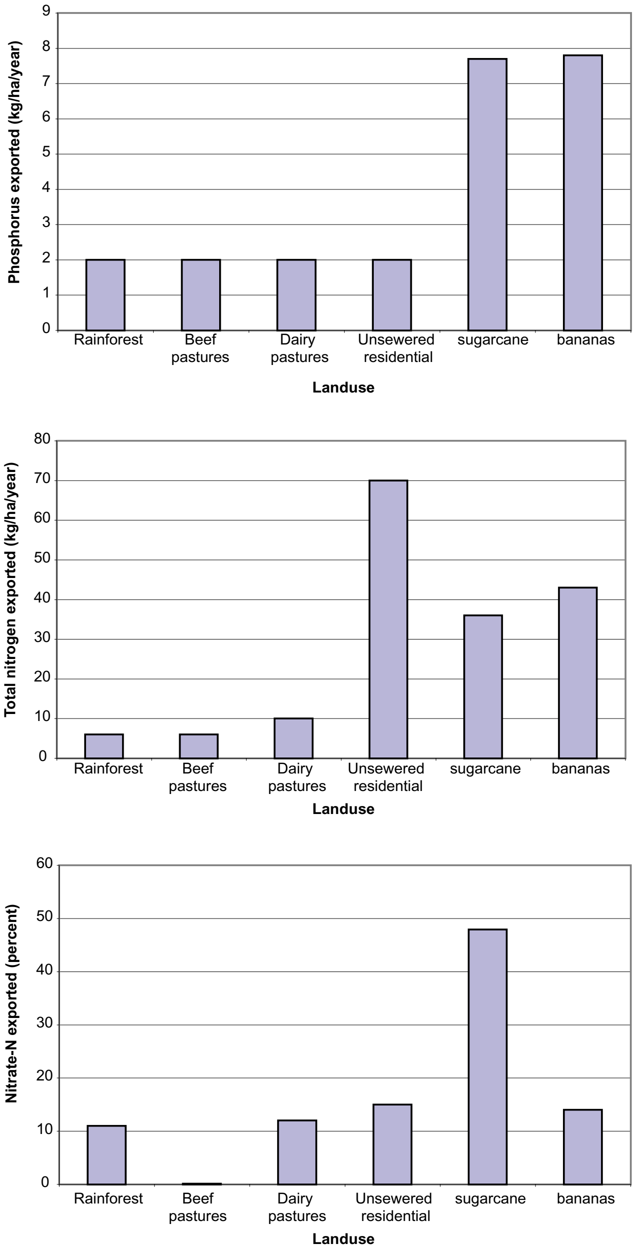


Figure 62: **Export of total N and P, and Nitrate-N from different land uses in the South Johnstone catchment, Queensland.**

Source: DNR Qld (1997).

Implications

These studies have two major implications:

1. Erosion is still the largest contributor to nutrient pollution in water bodies, as well as to turbidity. Indeed suspended clay carries with it adsorbed pesticides and organic matter, so protection from erosion is by far the most important strategy for improving water quality. This is as important in forests as it is on agricultural land. Unsealed roads or earthworks may be as significant a source as degraded pastures.
2. A small area of poorly managed land can have a significant environmental consequence out of proportion to the total area occupied. Keeping surface cover (green manures, trash retention, cover crops) is the only feasible way to reduce the threat in most agricultural lands. In the ‘Accelerated erosion and loss of surface soil’ section it was shown that over half of the sugar industry practises continuous surface cover, as do all orchards, but vegetable growing, tropical plantations and rain-fed cotton crops are grown with a bare soil surface. Irrigated cotton crops are very carefully managed, and grown in controlled bays, but very heavy storms may cause occasional flooding even in the best-managed systems.

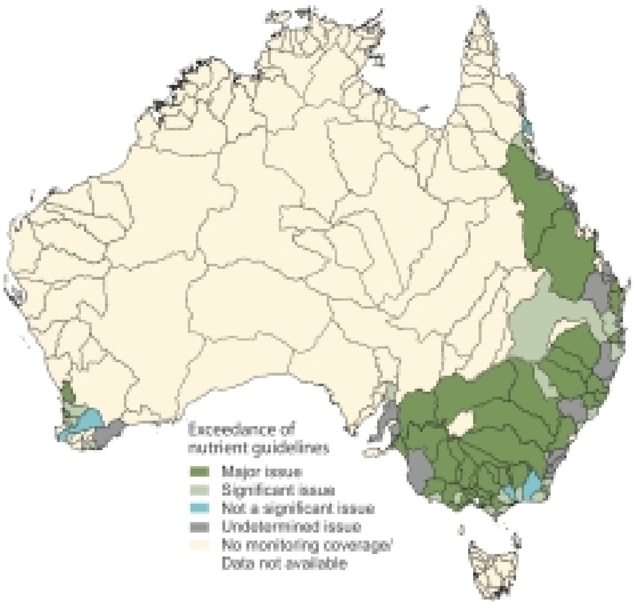


Figure 63: Surface water quality in 2000; significant nutrient exceedances.

Source: NLWRA (2001b).

CONDITION

Net nutrient balances in the Intensive Land-use Zone [L Indicators 5.1 and 5.1A]

A mid-1990s assessment of the nutrient status of agricultural lands in Australia indicated that inputs (via fertilisers and nitrogen-fixing legumes) are not always balancing exports (via meat, grain and hay removed) (SCARM 1998). This gives cause for concern; not only where excess nutrients leach into waterways and groundwater, but also where nutrient deficiencies lead to poor plant growth and low water utilisation. There is probably as much water leaking into groundwater from lack of efficient fertiliser use as there is from replacement of one form of vegetation by another in some medium and low rainfall environments, such as the inner margins of the cropping belt (Hamblin and Kyneur 1993, Latta 1997).

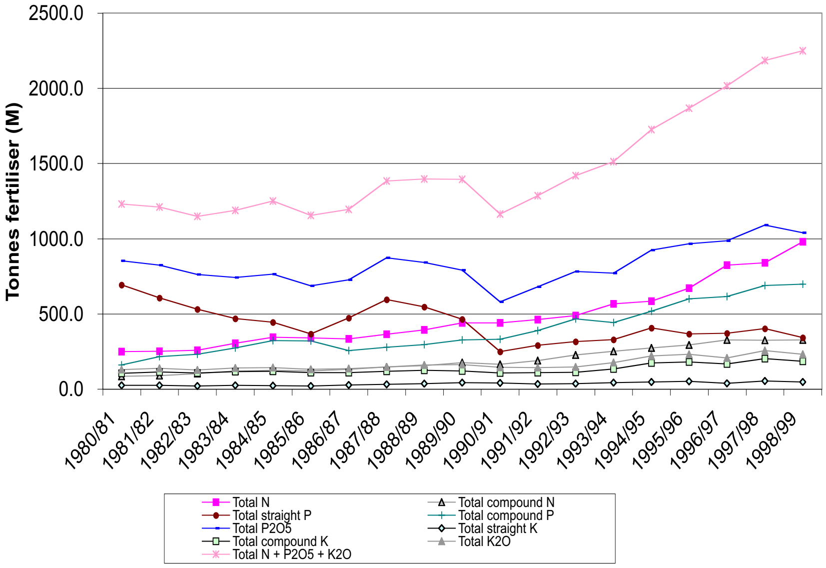


Figure 64: Increases in the consumption of nitrogen (N), phosphorus (P) and potassium (K) fertilisers between 1980 and 1999.

Source: International Fertiliser Association (2000).

The cost–price squeeze, intensification, and market signals for higher quality products have all stimulated a significant rise in fertiliser use over the past decade (Figure 64).

Recent studies, undertaken for the National Land and Water Resources Audit have extended the SCARM 1998 study, and placed nutrient balance estimates on a continental footing. The continental flux estimates of carbon, water, nitrogen and phosphorus have been developed through a modelling framework using daily climate records for the past twenty years on a 25 km^2 grid across the continent (Raupach et al. 2001). The work of Reuter (2001) has provided detailed nutrient balances at the scale of Statistical Local Area (SLA), that has been used to provide measures of agricultural input and off-take across those parts of the continent where these impacts are greatest. The study does not provide an estimate of what the off-take may be in the rangelands, where fertilisers and legume fixation are not normal inputs.

Which farming and forestry systems have nutrient balances that are sustainable? [L Indicator 5.7]

Farming systems

The nutrient balance project undertaken for the National Land and Water Resources Audit provides an assessment of nutrient balances covering the period 1992–1996 for agricultural land uses in the ILZ. Additional information extends back to 1989 in WA for the major nutrients N, P and K, and supplemental information for sulfur (S), calcium (Ca), and magnesium (Mg) is available (Reuter et al. 2001).

The National Collaborative Project on Indicators for Sustainable Agriculture (NCPISA) provides additional information for the whole country for the period 1987–1995 (SCARM 1998). Most of the data used in these studies come from the farm soil samples referred to in ‘Carbon and its relationship to other nutrients’ (page 102), and are therefore limited to the condition of the surface 100 mm of soil. However, general points drawn from this continent-wide study assist the interpretation of the later, more detailed study undertaken for the National Audit.

Phosphorus (P) and potassium (K) nutrient trends, 1987–1995

Application:

- 91% of P and 76% of K fertilisers are applied in southern Australia.
- There has been a sharp increase in total fertiliser applied from 1990 onward.
- 46% of P is applied to crops, 37% on pastures, and 17% to horticultural crops.
- 60% of K was applied to temperate pastures in this period.
- There was a similar, but fluctuating increase in use of N fertilisers.

Removal and balance:

- Nearly 70% of the P removed was exported in food and fibre, but nearly twice as much P was applied as was removed.
- Twice as much K was removed as was put back in fertiliser, and 76% of that was exported in products.
- Most of the nutrients exported go in cereals, meat and hay.

Regional differences

Much of northern Australia is considered deficient in phosphorus for the purposes of pasture production. However, very little fertiliser is applied except in the sugarcane and other cropping areas of the east coast.

The phosphorus balance is positive and becoming more so in most of the southern cropping and pasture zone, but the potassium balance is negative and becoming more so, except in Western Australia, where deficiencies at the start of the period have mostly been rectified.

The NLWRA study (Reuter et al. 2001) has focused on the Intensive Land-use Zone, but has had the benefit of ten years of soil testing data from all the major analytical laboratories and the fertiliser records of private fertiliser companies. Nearly half-a-million soil samples were contributed by these companies and government laboratories to the database.

Soil carbon and associated phosphorus values decrease inland from the coast as rainfall decreases. Nearly half the soils had organic carbon values of less than 1%, which indicates low

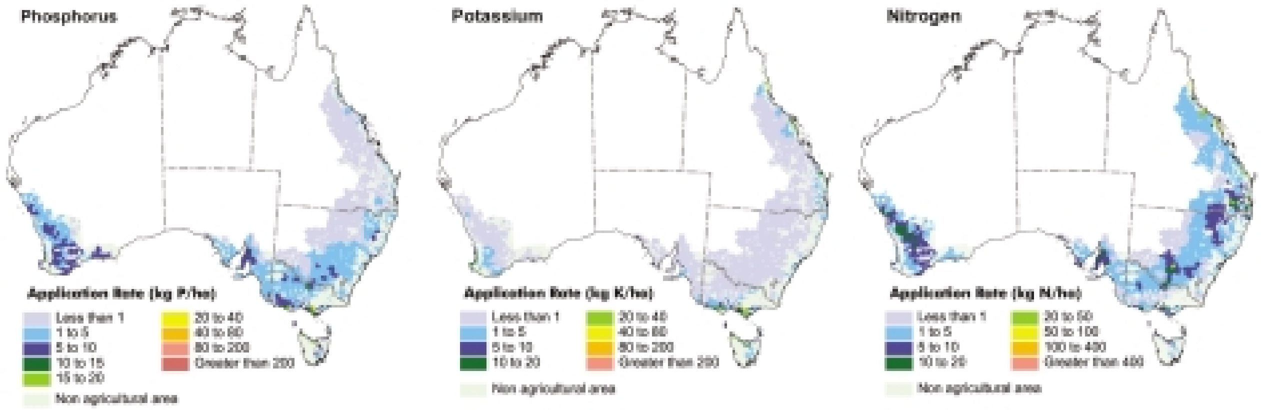


Figure 65: **Nitrogen, phosphorus and potassium fertiliser application rates for crops and pastures, 1992–1996.**

Source: Reuter et al. (2001).

biological fertility. Less than 2% of the total area is considered absolutely deficient in available phosphorus and potassium, but 12% of farmlands sampled are considered deficient in sulfur (less than 5 mg/kg), and over a quarter of Western Australian agricultural soils were low in plant-available potassium.

Records of fertiliser application showed that the nearly all fertiliser is applied to crops (including broadacre grains, horticultural crops, sugarcane and cotton). The exception is for irrigated pastures principally used for dairy cows (and for sheep grazed in rotation with rice). Figure 65 shows this difference very clearly.

As with soil acidity and the lack of liming of pastures, the lack of phosphorus, and increasingly potassium, appear to be contributing both to low productivity and to undesirable off-site impacts from water leakage.

This finding demonstrates that nutrient management of agricultural lands is not in balance. While rotation of cropland with improved pastures in some districts means that most of these lands receive fertiliser at some stage, upland regions and marginal soils that are too poor (e.g. too acid or too shallow) for cropping are not being maintained at productive capacity. The situation may be exacerbated where legumes are providing more than adequate nitrogen, but deficiencies in other elements reduce its utilisation and lead to nitrate leaching.

At a continental scale, a comparison of carbon, nitrogen and phosphorus fluxes that would occur in the presence and absence of artificial inputs (fertilisers and introduced legumes), using the BIOS model demonstrate the major stimulatory effect that these inputs have had on biomass production in the Intensive Land-use Zone. Figure 66 shows comparisons between 'with and without fertiliser' (plus legumes) on soil carbon and nitrogen.

The increase in soil carbon has been from one to five times that of unaltered soils. Soil nitrogen has been increased from one to eight times (particularly marked in the infertile sandy soils of Western Australia) and soil phosphorus has been increased from one to ten times. Use of fertilisers is estimated to be increasing the overall continental nutrient store by about 15%.

Forestry systems [L Indicator 5.7]

In normal, undisturbed situations, forests are relatively self-contained nutrient systems, and losses into streams and groundwater are small. Likewise, export of nutrients in timber is low, apart from carbon itself. Nevertheless, disturbance does cause significant sediment loss from unsealed roads, tracks and snig-lines in forests that are harvested, and nutrient loss where soil is exposed to heavy rain for prolonged periods (Croke et al. 1999). Some

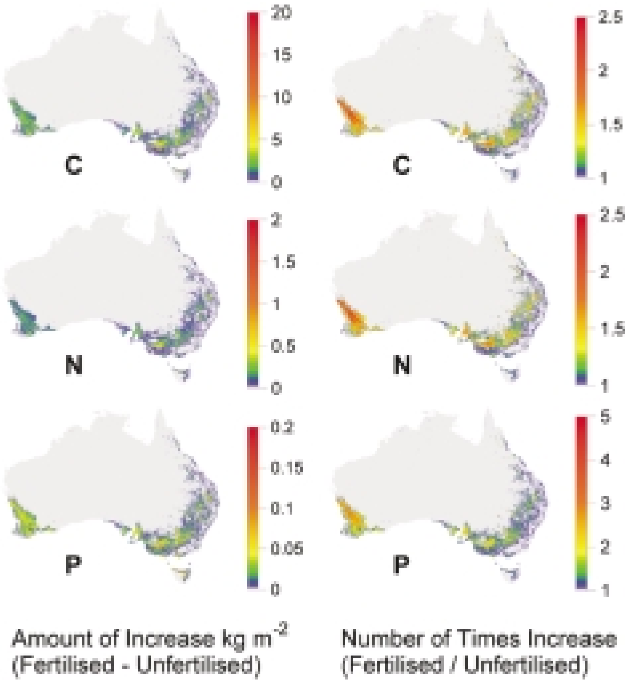


Figure 66: **Continental soil carbon, nitrogen and phosphorus simulations using the BIOS model, with and without the effect of current levels of fertiliser and legume inputs.**

Source: Raupach et al. (2001).

undisturbed forested areas within large catchments have been monitored in comparative nutrient and sediment erosion studies as described earlier in this section.

Table 32 (page 97) and Figure 67 show that, where forests occupy the largest proportion of a catchment, they inevitably contribute significantly to nitrogen and phosphorus exports, with rates of loss little different to those of grazed native grasslands or shrublands. These rates (0.05 and 0.1 kg/ha/year) are tens or hundreds of times less than exports from cropping lands, but local sources of disturbance (tracks and earthworks) in many of the more fragmented regions adjacent to populated regions (as in the Hawkesbury–Nepean catchment) have higher rates than this.

Implications

The increases in carbon, nitrogen and phosphorus, demonstrated in the synoptic continental modelling study of Raupach et al. (2001), have substantial implications for the off-site impacts from agriculture. Catchment studies show how the effect of land use influences water quality. Cropping regions have much higher levels of nitrogen, phosphorus and even potassium and sulfur than they would in a natural state. Native pastures and rough grazed areas are not fertilised, or only rarely. Forested and wooded areas tend to have higher natural levels of carbon, nitrogen, phosphorus and potassium by virtue of their geographical position. There are thus large disparities in nutrient concentration across the landscape.

In summary, nutrients are not in balance across most of the eastern third of the continent, where agricultural activities and land clearing are contributing both to sediment movement and to imbalance between nitrogen, phosphorus, potassium and other plant nutrient requirements. This is having an effect on the status of water quality in the major catchments of the Intensive Land-use Zone, clearly demonstrating the major impact arising from transported sediments (leading to turbidity) that are rich in nutrients (leading to algal blooms).

RESPONSE

What proportion of agricultural lands is being tested for nutrient needs? [L Indicator 5.9]

Adoption of regular soil and plant testing is an excellent indicator of good farming practice, but depends on having sufficient servicing infrastructure to conduct necessary analyses. Some testing was offered by State agricultural agencies in the past, but since the 1980s, fertiliser companies have taken over this function. The Western Australian fertiliser company CSBP was the first to initiate a large-scale testing service for a suite of plant nutrients and soil properties. Their data, recorded in a GIS database, has proved to be an invaluable resource for monitoring trends in soil fertility (Hamblin and Kyneur 1993).

The growth of soil testing has been slower in other agricultural regions. Figure 67, based on work by Peverill (1993) and Reuter (2001), demonstrates that there has been a big increase in the 1990s, with the advent of a quality assurance scheme for testing laboratories. This increase is still dominated by the Western Australian component, which represents over 60% of the total. Density of sampling is also high in all horticultural and broadacre cropping regions, and most intensive grazing regions of South Australia, but numbers are lower throughout eastern Australia. The actual number of landholders testing soil has been recorded from time to time through surveys. The proportion of landholders who use testing ranges from 30–70% across different industries, years and regions (SCARM 1998).

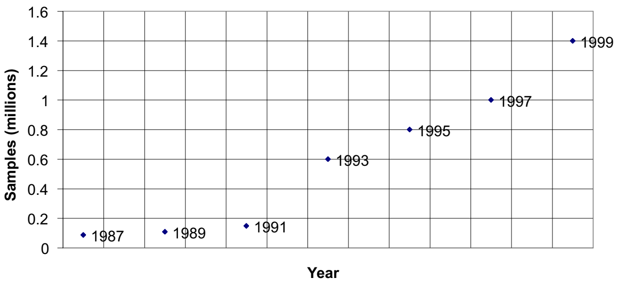


Figure 67: Number of soil test samples from farms analysed, 1987–1999.

Sources: Peverill (1993), Reuter (pers. comm.).

Interpretation

As with various land uses, nutrients are not in balance in most cropping soils. Potassium is not being replaced when it becomes deficient in many lower-input farming regions, whereas phosphorus and nitrogen are in excess in highly intensive farming regions. This is a particular concern in higher rainfall regions, such as coastal regions growing sugarcane, horticultural crops and dairy pastures, where nutrient discharges are contributing to reduction in water quality. This observation is true for most of the eastern half of the Murray–Darling Basin, and east coast catchments in New South Wales and Queensland.

While the number of soil tests has doubled in the past decade, a substantial proportion of farmers in the Intensive Land-use Zone still do not test their soils. The explanation for this is complex but it includes a spectrum from unprofitable farms that cannot afford good environmental management, to poor management practice, including excessive nutrient application contributing to off-site impacts with adverse environmental effects.

PRESSURE

Carbon – and its relationship to other nutrients [L Indicator 5.2]

On land, most carbon is stored in soil, and in living and dead vegetation. This forms the primary energy store and structural basis of all biological productivity. Without carbon in the form of organic matter, soil cannot develop the full range of biota, so necessary for the decomposition and transformation of debris, residues and detritus. Where decaying and dead vegetation is removed from the land surface (as it is in many agricultural systems, by harvesting, cultivation and burning) soil organic matter declines, even without the added problems of surface erosion. Where plant cover is thick and growing rapidly, more carbon is fixed through photosynthesis than where vegetation is thin, growing slowly, or not at all.

In semi-arid Australia plant growth rates and carbon accumulation is inevitably slow and lost carbon takes longer to replenish than in sub-humid and humid environments. In addition carbon retention is important for ecosystem renewal and survival.

Because the composition of most woody vegetation is chemically similar, the relationship between carbon, nitrogen and phosphorus is remarkably stable between different environments: most natural plant–soil systems have carbon to nitrogen ratios of about 20:1. Agricultural systems have ratios often approaching 10:1 (i.e. they have a larger proportion of protein and non-cellulose based components in the plant material). Domesticated plants have been selected and bred to enhance their harvestable (protein or oil-rich) components, whereas natural plants invest more energy in structural and protective components that will withstand climatic fluctuation and predation by herbivores. The ratio of carbon to phosphorus in such plants may be as high as 100:1.

How much carbon is being lost from our ecosystems? [L Indicator 5.2]

The pattern and rate of release of soil carbon is not known for the full range of Australian soil and vegetation types. In addition the net uptake or emission of carbon from certain management practices is not known (AGO 2001a; for updated information see http://www.greenhouse.gov.au). There are good data for only a few of the parameters that have to be regularly reported to the United Nations Framework Convention on Climate Change. As a result, the National Carbon Accounting System (NCAS) was established in 1998 to overcome these uncertainties and provide improved data towards meeting Australia's obligations to the Kyoto Protocol.

A continental base line

An important starting point has been provided by the work of Barrett (2001), in establishing what the long-term carbon sequestration and residence time for continental Australia would be if the whole continent were still under a minimally disturbed vegetation cover. This work provides the values against which contemporary and projected future variations, both natural and anthropogenic, can then be assessed. Figure 68 shows the amount of carbon present in all parts of the system that are likely to have accumulated carbon, across the continent, with individual examples from three contrasting environments.

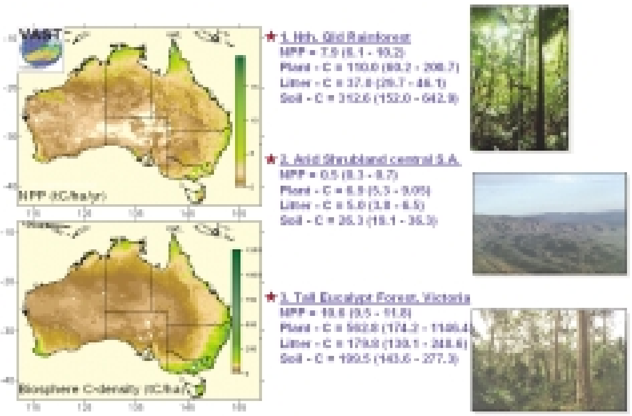


Figure 68: Continental estimate of net primary productivity extrapolated from 183 undisturbed natural habitats.

Source: Barrett (2001).

The important findings from this significant study are:

- Mean residence time of carbon in the terrestrial ecosystem (either in living or dead plant material, or in soil) ranges from 15–300 years, with the highest residence times in the interior southern desert environments, and the smallest residence times in the north-east wet tropics.

- The amount of carbon sequestered over the two-thirds of the continent that are arid and semi-arid regions is much less than international calculated amounts based on northern hemisphere modelling have assumed. The total annual net primary productivity (NPP) for the continent is just under 1 Gt (1000 Mt), much less than previous estimates. Kirschbaum (1993) estimated the total at 1.6 Gt C/year using a different model, while an estimate by Gifford et al. (1992) put the pre-industrial annual NPP at 2.4 Gt and recent annual NPP at 2.7 Gt, assuming a fertilisation effect from carbon dioxide had more than compensated for any loss of vegetation through clearing.
- The most recent estimate is likely to be the closest to actual amounts, both because it is based on a very much larger and more rigorously screened set of measured values, and because the model used has the capacity to account for a larger number of carbon pools and interactions.
- On the time-scale of climate change (centuries to millennia) most annual effects on vegetation and soil carbon cycling, such as grazing or burning have only minor effect when considered against the seasonal variability of climate at any one site. Permanent clearing of one type of vegetation structure and replacement with another is the only change in which the signal is larger than the ‘noise’ of statistical variation.

This last point is of particular interest. The Atmosphere Theme Report describes in detail the intra-annual and inter-annual variations and growth in carbon dioxide recorded at Cape Grim since 1976. There is large inter-annual variability in the rate of atmospheric carbon dioxide increase and very recent work suggests that most of this is due to variations in the exchange of carbon dioxide between the atmosphere and the terrestrial biosphere (Schimel et al. 2001).

Fossil fuel-derived carbon dioxide concentration is increasing at an overall linear rate of some 15 ppm per ten years, short-term concentration fluctuates substantially between 0.8 and 3.2 ppm per year. These oscillations, similar to the large variations in pressure cell strength and location, and resulting rainfall events, are now ascribed to fluctuations in the land–air flux, as the ocean–air flux appears remarkably constant (CSIRO Biosphere Working Group unpublished).

In the light of these large seasonal fluctuations, it may be difficult to determine the extent to which anthropogenically induced carbon changes are influencing the total atmospheric carbon dioxide concentration.

CONDITION

How much carbon (plant biomass) are we storing in different environments? [L Indicator 5.5]

Net primary productivity (NPP) is the term for the amount of plant growth that accumulates in a time period minus the amount that has been lost through decomposition. However, because it is a fluctuating variable it is less easy to appreciate than the term ‘biomass’, or store of carbon. Consequently, in this report the term biomass is used in reporting carbon stores. Biomass tells us how much food and energy there is to support all the other biota (decomposers, herbivores and carnivores) in the food chain.

Recent variations from the pre-European vegetation baseline

Baseline data for net primary productivity and standing biomass store has recently been calculated at continental scale (Raupach et al. 2001). A combination of land and climate information sources have been used, together with a modelling approach, to calculate the seasonal accumulation and decomposition of carbon over the past decade, and compare that with the continental baseline study. This baseline study has attempted to combine the above-ground store of plant material, including standing dead wood and litter, with estimates of below-ground soil pools. These include roots, below ground lignotubers and other woody plant structures, and the soil organic matter that is finely dispersed and adsorbed onto soil clays, and stored in micro-organisms.

The results show that regional differences are largely driven by effective rainfall (rainfall minus evaporation), with the major stores of carbon associated with high rainfall regions.

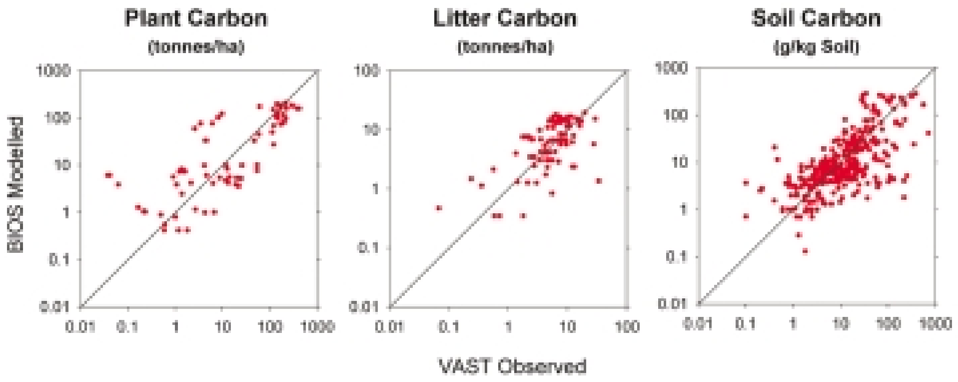


Figure 69: **Logarithmic plot of carbon pools computed from BIOS model compared with measured values from Barrett (1999).**

Source: Raupach et al. (2001).

Most of the continent, being semi-arid and low-lying accumulates carbon very slowly, and can lose it fast when land is disturbed. While stored carbon amounts vary by three orders of magnitude across the full range, over 90% of the land area has less than 500 kg carbon per hectare. Forested regions store the most carbon, and desert environments the least.

The results show that:

- rainfall is the primary driver of seasonal and spatial variation across the continent,
- less plant biomass is produced than was anticipated in the northern half of the continent because of the strong evaporative demand, which reduces the plant-available water more than in southern regions, and
- variations in computed carbon, nitrogen and phosphorus stored in soil agree with logarithmic distributions of measured values of soil carbon, nitrogen and phosphorus drawn from literature collated by Barrett (1999) (Figure 69).

This good relationship gives the modellers some confidence that their results are reasonably accurate and can be used where no actual data exist.

Regional differences in carbon stores with and without the presence of agriculture were also computed. Details of how this is calculated are given in Barrett (1999). Figure 70 shows where total biomass is highest and lowest per unit area by major drainage basins.

Agriculture has made little difference to the carbon stores in the arid regions of the rangelands, but has made a significant difference in those areas of higher rainfall where tall perennial vegetation has been replaced by short annuals and scattered perennials (Drainage Divisions 1, 2 and 3, and parts of 4, 5 and 6; see Figure 70). The below ground store of carbon, already larger than above ground prior to vegetation change, has become even more pronounced.

RESPONSE

What are we doing to increase environmental carbon storage and reduce losses? [L Indicator 5.8]

Carbon stores in soil, litter, standing trees and fallen dead timber are crucial in providing habitats, as well as nutrients, for the majority of land biota, that is, the invertebrates, as well as to the better known but less abundant vascular plants and vertebrates. As described in earlier sections, the loss of surface soil, litter and associated woody materials has been very significant historically. In the past two to three decades, improvements have been made in a number of pastoral, agricultural and forestry practices that eventually restore the depleted A (organic rich) horizons found in many agricultural and pastoral soils.

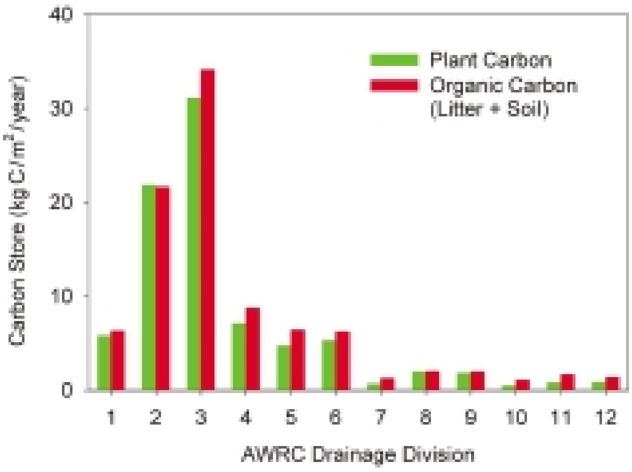


Figure 70: **Biomass stores of above and below ground carbon (kg C/m^2/year) for Australia's 12 drainage basins, with and without agriculture.**

Source: Barrett (1999).

Green harvesting of sugarcane

Sugarcane is grown in wet tropical regions. In Australia most cane is grown in Queensland, but extends south into northern NSW within 50 km of the coast, from latitude 17° to 30°S. South of 27°S, cane grows too slowly to be harvested in the first year after planting. Traditionally cane was burnt before harvesting to allow access for cutters, but in the late 1970s mechanisation rapidly developed in Australia to offset rising labour costs. This provided the technical opportunity to the development of green cane harvesting, which was advocated as a way of overcoming the high erosion hazard that occurs in this region of intense rainfall. Green cane harvesting was rapidly adopted in the 1980s.

In hot wet climates mulches (from the trash left after green harvesting) have an added advantage in keeping the soil surface cool and moist, stimulating rapid growth. This in turn has a yield advantage. However, further south, the mulches serve to slow the warming up of the cold wet soil in spring. This slows the rate of growth even more than would otherwise occur. Thus, despite the clear advantage of green cane harvesting for erosion control and soil organic matter retention, farmers in the southern regions have struggled to develop a system that does not retard growth and yield. Some varietal improvement in early maturation has been achieved, but in 1995 when the industry undertook an environmental audit of its practices, less than 50% of farmers in the southern and central cane-growing regions had adopted this practice. The percentage of farmers surveyed who had adopted green cane harvesting in 1995 were:

Far North	82 (90)
Northern	90 (45)
Central	37 (45)
Southern	35 (40)

(Figures in parentheses are industry estimates for the same year.)

Ironically it is in the southern and central regions where community pressure is greatest on growers, because urban encroachment onto farming land has resulted in protests at smoke pollution. Twenty-five percent of farmers surveyed said they had adopted green cane harvesting because of community pressure. Overall nearly 50% of farmers also left trash on the ground at harvest (whatever method of harvesting used), and only 23% burnt trash, while 32% incorporated the trash. Incorporation is often resorted to where pests such as slugs and snails build up. (Gutteridge, Haskins and Davey 1996).

Thus it can be seen that while most farmers recognise the need to cut cane green and retain trash, they must juggle the environmental benefits with the need to get a fast-growing, healthy and pest-free crop if they are to have profitable yields.

Green harvesting of sugarcane.

Source: AFFA.

Practices that are most important for this process are maintaining vegetation cover on pastures; stubble retention and conservation tillage (minimum or zero tillage); green cane harvesting of sugarcane; laying brushwood in the rangelands in patch mosaics; and retaining all non-harvestable timber as surface cover in forestry coups. These practices have been discussed in the section ‘Accelerated erosion and loss of surface soil’ in relation to controlling erosion. This is why control of accelerated erosion is so vital as the starting point in the control of ecosystem function. It is instructive to consider one agricultural industry as an example of how environmentally sound practice may be adopted, and the limitations to universal adoption (see Box: ‘Green harvesting of sugarcane’).

In response to the Kyoto Protocol, the Greenhouse Gas Abatement Program of the Australian Government offers investment incentives for projects that deliver cost effective, additional abatement by reducing fossil fuel consumption or through direct carbon sequestration. Carbon sequestration projects may include action to increase perennial vegetation, to control secondary salinity, or to control accelerated erosion.

Bush for Greenhouse, launched in 2000, aims to increase Australia’s greenhouse gas sink capacity by increasing corporate investment in native vegetation. Revegetation removes carbon dioxide from the atmosphere.

The program builds on programs such as Bushcare and Greenhouse Challenge. Bush for Greenhouse seeks to build new partnerships between industry and landholders to achieve greenhouse and other environmental outcomes including prevention of land degradation.

The Australian Greenhouse Office has appointed a carbon broker to secure corporate investment and manage a pool of revegetation projects.

The National Carbon Accounting System (NCAS), established in the Australian Greenhouse Office, is gathering estimates of carbon stores in the environment as a part of Australia's responsibilities under the Kyoto Protocol on greenhouse gas emissions. Much of NCAS's work is currently in progress, with data relating to the situation in 2000 not yet available. Details of the approach, and progress to date can be viewed on the AGO's website (http://www.greenhouse.gov.au/ncas.html). The program is carried out in four components: wood change, vegetation cover, soil change and tree change. Investment in farm forestry and commercial plantations has risen in recent years, stimulated in part by the potential of carbon credits from the increased sink that fast-growing tree crops represent. Without such information, it will be difficult to substantiate the extent to which different anthropogenic activities are contributing measurably to carbon sinks.