Greenhouse gas mitigation: sources and sinks in agriculture and forestry

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Key messages

- Agriculture and forestry can make a valuable contribution to lowering Australia's greenhouse gas emissions by reducing their own direct emissions and by increasing the amount of carbon stored in soils and landscapes.
- Our soils and forests store large quantities of carbon: somewhere between 100 and 200 times Australia's current annual emissions. We can potentially increase these stores in our rural lands and perhaps store or mitigate enough greenhouse gases to offset up to 20% or more of Australia's emissions during the next 40 years.
- Forest plantings are the most straightforward way to sequester carbon in rural landscapes and, along with reduced land clearing, provide the most immediate, significant, and realisable carbon sequestration opportunity.
- Nearly a third of Australia's terrestrial carbon is stored in tropical savannas: the continent's most fire-prone biome in which half or more of the land may burn each year. These fires currently contribute 2–3% of the nation's total accountable emissions and have an important bearing on rates of carbon sequestration.
- Ruminant animals (such as sheep and cattle) emit methane as a by-product of digesting feed. In 2008, this contributed 9.6% of Australia's total greenhouse gas emissions and was the largest component of agricultural emissions.

In Australia, agriculture and forestry can make a major contribution to lowering our greenhouse gas emissions, both by reducing their own direct emissions and by increasing the amount of carbon stored in soils and landscapes. The way we choose to manage our rural lands will have a significant impact on Australia's future net greenhouse gas emissions.

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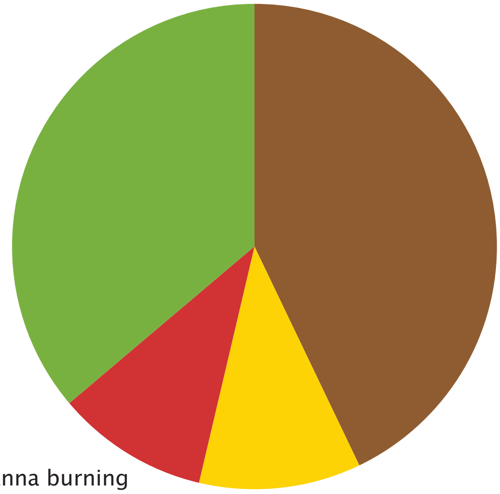
Reducing emissions from Australian land use

In 2008, Australia's agricultural sector and land clearing accounted for about 15% and 9%, respectively, of the nation's gross greenhouse gas emissions. In that year, afforestation and reforestation offset around 17% of the agricultural emissions.[1] The agriculture share of national emissions is high compared with that in many developed nations (at between 5 and 10%, for example, for the USA and the UK) and reflects both the large land base per capita in Australia and our significant agriculture sector. These emissions consist of carbon losses due to land clearing and land-use change (36%), livestock methane emissions and manure management (43%), savanna burning including both naturally caused wildfires and deliberate burning for pasture management (10%), and cropping and agricultural soils emissions (11%) (Figure 8.1).



▸ ***Figure 8.1****: Percentage net contribution of different sources to agriculture, land use, land-use change, and forestry greenhouse gas emissions in 2008.[1] These are gross emissions and do not account for offsets due to afforestation.*

Our soils and forests store large quantities of carbon: somewhere between 100 and 200 times Australia's current annual emissions.[2] We can potentially increase these stores in our rural lands, and perhaps store or mitigate enough greenhouse gases to offset up to 20% or more of Australia's emissions during the next 40 years[3] – but it must be recognised that many factors, such as carbon pricing and other incentives, government policy, technology, and social attitudes will have a major bearing on how much carbon is ultimately sequestered in our landscapes. In attaining this carbon sequestration, other benefits such as restoring biodiversity and ecosystem services, improving soil productivity, controlling salinity and erosion, and improving water quality also may be realised. Unlike many other mitigation options (e.g. rebuilding the power generation sector), forestry and land-management options do not require major investment in infrastructure. Instead, they involve changes in land use and land management and consequently there are trade-offs, as well as benefits, from such large-scale carbon storage: potentially these include lower food, fibre, and timber production and, if unregulated, altered regional water flows. Furthermore, there remain significant uncertainties over estimates of greenhouse gas mitigation or soil carbon storage potential.

In the following sections we explore different options for reducing emissions or increasing carbon storage from different land-use and management activities.

Afforestation

Forest plantings are the most straightforward way to sequester carbon in rural landscapes and, along with reduced land clearing, provide the most immediate, significant, and realisable carbon sequestration opportunity. They are eligible for carbon credits under existing agreements, they are effective (they store significant quantities of CO_2 per hectare), and carbon sequestration is easily verifiable. At the present time, to qualify as a 'carbon forest', both reforestation and afforestation need to meet the requirements of Article 3.3 of the Kyoto Protocol – for example, forests would need to be planted after 1990 on agricultural land cleared before 1990.

Australia's landscapes offer many opportunities to integrate trees as part of mixed farming, landscape rehabilitation, or catchment management. Research indicates that it is possible over the next 40 years to store on average 9 tonnes of carbon dioxide equivalent (CO_2-e – that is, the amount of all greenhouse gases that would give the same warming as the equivalent concentration of CO_2 alone) per hectare per year. However, this depends on many local and external factors, which lead to a variation in storage amount in the range 3–20 tonnes of CO_2-e per hectare per year.

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Doing this over a sufficiently large area to reduce significantly national net greenhouse gas emissions by 2020 presents challenges: sufficient suitable land must be found, a great deal of seed is needed, and the trees must survive and grow well. A doubling in the national plantation estate of 2 million hectares could sequester around 20 million tonnes (Mt) of CO_2-e per hectare per year over a 40-year cycle – but it would have to be as carbon forest and remain unharvested (at least on a net area basis if carbon stocks were pooled across harvested and newly planted areas). Maximum rates of afforestation in Australia in recent times have been around 100 000 hectares per year, suggesting it will take around 20 years to achieve 20 Mt of CO_2-e per year of abatement potential.

To achieve the full benefits of carbon storage, carbon forests need to be managed (and their carbon counted) according to natural cycles of death and decay, including the periodic impact of fire. The long-term aim might be to manage forests of a range of ages: the amount of carbon registered being an average of old and young forest, rather than the maximum possible for any given hectare.

Analysis has shown that, at even a modest carbon price (AU$10–20 per tonne of CO_2-e), forestry could be a competitive land use across large areas, with many tens of millions of tonnes of abatement generated. However, many factors, including community and landowner attitudes, will govern where carbon forests can be planted. Water availability is also an important consideration, but carbon forests are only likely to have an impact on water supplies where a large plantation is established in a continuous block and, in most cases, existing policy and analysis tools are in place to prevent negative impacts. Because carbon forests do not need to be near processing facilities, they can be scattered across the landscape, lowering the risk of carbon release by fire, pests, and storms, and spreading their impact on water supplies. Many farmers now integrate trees into farmland as part of a mixed agricultural enterprise. Areas of land where on-farm productivity is limited by unmanageable constraints (e.g. shallow soil depth) offer prime locations for afforestation, although the rates of carbon capture may be low. Trees occupying about 10% of the farm can be used as shelter for livestock, wind breaks, for controlling salinity, enhancing native biodiversity, and adding to capital value. Sensible afforestation, optimising the sequestration of carbon with the production of food across the nation, could achieve significant national carbon sequestration, have minimal impact on food production, and accrue many environmental benefits.

Native ecosystems

Native ecosystems are vital to Australia's greenhouse gas dynamics because they both store and emit large volumes of greenhouse gases, which fluctuate depending on disturbance and climate variability. Australia is the world's most fire-prone continent, and fire is a particularly influential factor on the carbon cycle in many native ecosystems. This is also influenced by the climate, through the effects of temperature and rainfall on plant growth and its impact on fire regimes.

Deforestation contributes significantly to Australia's greenhouse emissions (9% in 2008, much reduced from levels in the 1980s and 1990s). This contribution has been reduced with recent land-clearing restrictions. Around half of these emissions result from the clearing of regrowth on grazing properties. As with integrating trees into farming landscapes through afforestation, strategically retaining strips of regrowth in pastoral landscapes has been suggested as a low-cost abatement opportunity, with little impact on productivity and with the potential to improve the condition of surrounding pasture by reducing wind and erosion, as well as providing shelter for stock.

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Nearly a third of Australia's terrestrial carbon is stored in tropical savannas, the continent's most fire-prone biome in which half or more of the land may burn each year. These fires currently contribute 2–3% of the nation's total accountable emissions and have an important bearing on rates of carbon sequestration. Consequently, there is growing interest in curbing the extent and severity of these fires using Aboriginal early season mosaic burning techniques, which produce cooler, less-destructive fires. This could generate livelihoods in remote Aboriginal communities, reduce the risk of wildfires, encourage native species and – through reduced greenhouse gas emissions and increased carbon storage – help to lower Australia's emissions. An existing project using this approach has been estimated to reduce emissions from a 28 000 km^2 area by 100 000 tonnes CO_2-e/year.[4]

It may also be possible to increase carbon stocks in stands of managed native forests. Based on the findings of the *Green carbon* report,[5] CSIRO has examined the idea that harvesting of native forests reduces carbon stocks and cessation of harvesting activities in native forests would allow carbon stocks to build. A high level of uncertainty surrounds this option, and future research needs to refine the estimates of carbon stocks, the longer term impacts of harvesting and fire, and the fate of carbon stored in forests and timber products.

Finally, it is important to realise that native forests dominate the carbon and water cycles in Australia and that climate change poses a significant threat to native forests and to their carbon stocks. Droughts, fires, pests, and disease in these native ecosystems could potentially overwhelm any gains made in carbon storage.

Soil organic carbon and biochar

Carbon exists in soils in organic and inorganic forms. Only the organic component is currently considered in greenhouse gas emissions accounting. Soil organic carbon can consist of materials ranging from recently decomposed plant residues through to well-decomposed materials and particles of charcoal. Typically, soil organic carbon accounts for less than 5% of the mass of upper soil layers and diminishes with depth. The total store in the top 30 cm (the depth over which most organic soil carbon is held) for Australian soils usually ranges between 5 and 250 t C/ha.

Although methods exist to quantify the amount of organic carbon contained in a soil at any one location, spatial and temporal variations can contribute significant uncertainty to estimates of soil carbon stocks. Spatial variations of up to 20 t C/ha within paddocks are common, with much greater variations existing between soil and landscape types. Soil organic carbon can also vary within and between years according to climate and farming methods used. Collectively, these factors present a major challenge to measuring changes in soil organic carbon stocks over time at individual paddock and landscape scales with any significant degree of confidence.

The amount of organic carbon present in a soil is determined by the rate at which organic matter is added and the rate at which it decomposes. Organic carbon in soils turns over constantly. New carbon is regularly added to soil though the growth of plants and the addition of organic matter in and on the soil. The carbon fixed over short time periods by photosynthesis in growing plants is an input to the soil carbon system, but does not in itself represent long-term carbon storage. Decomposition converts part of the existing soil organic carbon and plant residue carbon back into CO_2. Temperature, rainfall, land management, soil nutrition, and soil type all influence the size of the soil carbon pool by determining the rates of plant and vegetation inputs and decomposition. The term sequestration means achieving and maintaining a net increase in the amount of organic carbon present in a soil.

There are two main ways to build soil carbon: by increasing the amount of organic matter entering the soil or by reducing CO_2 losses – and Australia's approach to soil carbon management will depend on both. For example, reduced tillage of some cropping land may reduce the rate at which soil organic carbon decomposes. Retaining plant residues (e.g. stubble) increases plant growth through reduced fallow periods and the addition of organic residues or biochar can also help lift soil carbon by increasing carbon addition rates or by adding materials that do not readily decompose.

Past clearing of farmland and tillage has generally led to declines in the organic carbon content of most soil types. Some land-management practices may reduce the rate of soil organic carbon decline or potentially increase soil organic carbon compared with more traditional management practices. Minimum tillage and no-till are already practised on much of Australia's 27 million hectares of cropping land and, if such practices were extended across the other 9 million hectares, croplands may offer 2 to 5 Mt CO_2-e abatement per year. Other practices such as changes to cropping systems (stubble retention, changing crop rotations, increasing frequency of pasture leys, and increasing fertilisation), increasing production by incorporating a higher proportion of legumes (nitrogen fixers), and reversal of existing degradation (saline, acidic, and eroded land) by planting perennial species may all contribute. The biggest gains are likely to come from converting cropping land to secondary forest or pasture. The area converted will depend on the economics of land-use change, the opportunity costs of forgone food production, and social factors.

The 400 million hectares of Australia's rangelands represent the biggest theoretical opportunity for locking up carbon in landscapes outside forestry options. Estimates of sequestration potential in these landscapes are based heavily on evaluations of the extent of their degradation, and assumptions about the extent to which carbon stocks can be increased by reducing grazing or changes in pasture management. Recent estimates of what might be attainable nationally are in the order of 4–50 Mt CO_2-e per year.[3, 6, 7] At present too little is known to be confident of these estimates.

Biochar is a form of charcoal created by burning organic matter in a closed system under conditions of low oxygen availability. In closed systems, the gases released during the formation of biochar can be captured and used for energy generation. The chemical nature of biochar stabilises this form of organic carbon against biological decomposition. It can act as a long-term carbon storage material relative to the typically more decomposable material from which it was created. The chemical and physical properties of different biochars depend on the original material used and conditions under which the biochar was produced. The most beneficial sources of organic material for biochar production are carbon-rich waste streams, including human wastes, forest thinning (or custom-grown carbon forests), and agricultural by-products. The removal of crop residues explicitly for the creation of biochar is not recommended because it may lead to reductions in soil organic carbon levels, soil biological activity, and nutrient cycling. This may result in detrimental effects on soil productivity (and ultimately soil organic carbon content), reducing carbon sequestration gains made through the creation and application of biochar.

The process of generating biomass, producing biochar, and applying biochar to soil has the potential of sequestering carbon from the atmosphere and storing it in a stable form in soil. However, a full life-cycle analysis of all processes involved in the creation and land application of biochar is needed to define the net impact on reducing greenhouse gas emissions. The production of biochar also has the potential to yield bioenergy in the form of synthesis gas (or 'syngas') or biofuels that can substitute for carbon-polluting fossil fuels. Additionally, some biochars have been shown to enhance soil fertility. This can reduce fertiliser requirements and thereby emissions associated with fertiliser production, delivery, and application.

In order for biochar to be a useful sequestration and soil amendment tool, it is important that pyrolysis facilities are close to biomass production sites and locations for biochar use: otherwise greenhouse gas emissions and costs associated with transport would reduce the magnitude of any offsets and affect the economics of the operation. In the immediate future, and with existing production technologies, biochar is only likely to operate on a limited scale in situations where existing processing plants collect organic material for biochar production. One example is the potential to use biomass waste from the sugar cane industry (bagasse).[3] Estimates of sequestration potential from this process in Queensland are around 4 Mt CO_2-e per year.

Livestock methane

Ruminant animals (such as sheep and cattle) emit methane as a by-product of digesting feed. In 2008, this contributed 55 Mt of CO_2-e to Australia's national Kyoto accounts, corresponding to 9.6% of Australia's total greenhouse gas emissions and the largest component of agricultural emissions. The contribution is defined by the total number of animals and the emission rate per animal, which, in turn, is controlled by the animal's diet and management. Methane production by these animals represents lost energy that would otherwise be directed towards animal growth; hence, reducing methane emissions offers a win–win situation by increasing livestock productivity and reducing livestock greenhouse gas emissions per animal.

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Reducing stock numbers would, at first glance, appear the most practical way to reduce Australia's livestock emissions. However, because most grazing land is unsuitable for other productive uses, this would have an adverse impact on food production and employment. Ecological interactions also make the abatement gains from this action difficult to calculate. For example, in some parts of Australia's rangelands, grazing reduces grass biomass, fire frequency, and competition with tree and shrub seedlings, potentially allowing regeneration of shrubs and trees, which might increase carbon stock in the long run. It has also been suggested that, in the absence of a parallel reduction in demand for meat, reduced livestock numbers in Australia would likely be offset to some extent by increased production overseas.

There is no single, high-impact strategy currently available to reduce emissions per animal. A range of approaches, tailored to specific industry sector constraints, could be expected to reduce per animal emissions by 10–20% in the next decade, and perhaps up to 40% in the longer term.[3] Options include dietary manipulation, modification of rumen fermentation, feedstock quality, and selective breeding for reduced emissions. Dietary manipulation is an option available today, while others, such as the modification of rumen fermentation and animal breeding, will take longer to have an impact. In general, options that increase animal growth rates and reproductive performance can reduce emissions intensity and increase producer profitability. Often, best-management practices that reduce emissions per unit of saleable product (emissions intensity) also offer advantages in restoring land condition by removing livestock from marginal or sensitive areas and increasing biodiversity.

In addition to direct emissions from sheep and cattle, methane can also be produced from manure. Such emissions are generally low in grazing situations, but more-intensive production systems where manure is concentrated in lagoons or ponds can cause more significant levels of methane production. Emissions from manure contribute over 1.5 Mt of CO_2-e per year to our national emissions, principally from dairy and piggery sources.[1] In intensive and large operations, this methane can be captured and used to displace fossil fuel use. Realistically, two-thirds of these emissions could be abated with appropriate incentives, with additional abatement from avoided fossil fuel use in energy production.[8]

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Cropping emissions

In 2008, agricultural soils contributed 15 Mt CO_2-e, principally from nitrous oxide (N_2O) emissions associated with the use of fertilisers.[1] Emissions of N_2O from soils under cropping systems occur principally when excess inorganic nitrogen is present in the form of nitrate. High soil nitrogen levels, particularly under wet soil conditions, are a significant driver of greenhouse gas emissions associated with fertiliser use. Both cost savings and greenhouse gas emissions abatement are possible by controlling inputs of nitrogen fertiliser, with the aim of improving the match between crop nitrogen demand and nitrogen supply. Benefits can be obtained by matching the timing, rate, and method of application (for example, surface placement versus incorporated or banded, and liquid versus solid forms). The main goal is to minimise the potential occurrences of denitrification and nitrification. In many cases, the actions required to reduce emissions through fertiliser use in agriculture are identical to best-practice strategies to maximise the efficiency of fertiliser use and minimise undesirable environmental impacts such as the contamination of waterways.

Conclusion

Although there is significant potential to build vegetation and soil carbon stocks, offset emissions, and enhance the productivity of Australia's soils, this is limited by our climate, by the soil's own capacity, by the necessity for Australia to continue to balance land use for the range of production, environmental, and livelihood needs of its people, and by biodiversity considerations. For these reasons, carbon prices or incentives to store carbon will have to be sufficient to encourage the widespread adoption of carbon sequestration practices by landholders. With clear evaluation of the wider benefits to productivity and environmental services, and appropriate incentives and complementary measures, carbon storage can be part of 'win–win–win' outcomes for greenhouse gas abatement, food production, and the environment. Using our land and modifying our land management wisely can give us time to reduce sources of emissions from other sectors of the economy and may offer some ongoing carbon pollution abatement potential (while affording landscape and production benefits) that reduces the overall cost to the economy of climate-change action. Additionally, the generation of carbon credits or offsets from agricultural land has the potential to be a major source of income in rural Australia, allowing landowners to further diversify income streams. As we identify opportunities to use our rural lands for carbon sequestration, we need to be mindful of the liabilities and constraints we might impose on future landowners: engaging in carbon forestry or changing land management to increase soil carbon pools restricts future land management decisions and, in some cases, places an onus on land managers to maintain particular land-management regimes. Finally, as we act, we need to consider the implications of our decisions on existing – and developing – international agreements on greenhouse gas abatement, and on global food security.

Further reading

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