Meeting the Net Zero challenge: a key role for the land sector

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Abstract
Achieving the goal of the Paris Agreement, to limit global warming to "well below 2 °C", will require net zero greenhouse gas (GHG) emissions to be reached in the second half of this century. Carbon dioxide removal (CDR) from the atmosphere will be needed, in conjunction with deep reductions in GHG emissions. The land sector has a critical role to play in meeting net zero GHG, particularly in providing CDR through soil carbon management and strategic reforestation (environmental plantings, woodlots, shelter belts and energy crops). Other potential CDR strategies include use of biochar, "enhanced weathering" and "blue carbon". Land sector CDR strategies can enhance agricultural production and resilience of agricultural systems, and some offer additional environmental co-benefits. The declaration of net zero targets by governments and industry sectors, and growing demand for carbon offsets in the compliance and voluntary markets, are creating opportunities for landholders through carbon farming. Nevertheless, there are some trade-offs and challenges, including the likely impacts of climate change on plant growth and soil organic matter. Policy-makers at state and national levels are devising incentives to encourage adoption of carbon farming practices that enhance sustainability and productivity.

Keywords
Carbon dioxide removal; soil carbon sequestration; reforestation; biochar; bioenergy; enhanced weathering.

Introduction
The Paris Agreement, under the United Nations Framework Convention on Climate Change (UNFCCC), aims to limit global warming to "well below 2 °C" and to reach net zero GHG emissions, a condition in which emissions are balanced by carbon sequestration, in the second half of this century. Achieving net zero GHG will require a substantial amount of carbon dioxide removal (CDR) from the atmosphere, in conjunction with deep reductions in GHG emissions. Australia has recently adopted a target of net zero GHG emissions by 2050. While the agriculture sector makes a significant contribution to Australia's GHG emissions, largely from livestock production, there are substantial opportunities for the sector to reduce emissions, and to provide CDR, particularly through carbon sequestration in vegetation and soil, and use of biochar. Carbon farming is an increasingly attractive option for landholders, particularly as the recent upward trend in carbon prices is expected to continue, the co-benefits and relatively low cost of "natural climate solutions" (Griscom et al. 2017) are being recognised and rewarded, and demand for low-carbon products is growing.

Emissions reduction
Livestock emissions, comprising enteric methane and manure management emissions, are the largest source of agricultural GHG emissions. The feed additives *Asparagopsis* and 3-NOP are highly effective in reducing enteric methane (Almeida et al. 2021), but are not yet commercially available, and must be fed daily, so are best-suited to feedlot and dairy cattle. Currently available strategies applicable to grazing animals include use of pasture legumes with anti-methanogenic properties such as Lotus, Desmanthus, biserrula, Leucaena and Gliricidia, and management of pastures to enhance productivity and quality (Banik et al. 2019; Almeida and Hegarty 2021). A slow-release formulation of 3-NOP, that could be administered to pasture-fed sheep and cattle, is in development.

The major source of GHG emissions in cropping is N_2O associated with use of organic or inorganic nitrogen fertiliser, although N_2O emissions from Australian dryland cropping systems are generally much lower than global averages. N_2O, a GHG nearly 300 times more powerful than CO_2, is released from soil through nitrification and denitrification, particularly in waterlogged conditions. N fixed by legumes is also a source of N_2O, released as crop residues decompose. Mineralisation of soil organic matter (SOM) also adds to soil N_2O emissions, where SOM levels are declining. GHG emissions from manufacture of N fertiliser are a significant pre-farm source, that is included in calculations of the carbon footprint of products. Soil N_2O emissions can be reduced through use of enhanced efficiency fertilisers, including formulations with slow-release coatings or nitrification inhibitors, and through modified fertiliser management (rate, placement and timing, including split applications) as well as strategic irrigation scheduling (Schwenke et al., 2016; Snyder, 2017). These practices can also enhance profitability through increased N use efficiency. Biochar application has been found to reduce soil N_2O emissions by over 35 % on average, though effectiveness varies widely (Borchard et al., 2019).

Other on-farm GHG emissions sources include stubble burning and fuel use in farming operations, while methane from flooded soils is a major source of emissions in rice production. Options for reduction of these emissions include stubble retention or removal (such as for bioenergy), and controlled traffic farming to minimize fuel use. Drill sowing and delaying flooding can reduce methane emissions from rice production by over 50 % (Bull and Rose, 2018).

Carbon dioxide removal strategies

Carbon sequestration through management of soil and vegetation present well-known opportunities for the agriculture sector to counterbalance emissions and to generate CDR credits. Lesser-known opportunities include biochar and enhanced weathering.

Soil carbon sequestration

The depletion of SOM in soils with a long cropping history creates theoretical potential for carbon sequestration in these soils (Gray et al., 2021). The benefits of enhancing SOM, to simultaneously improve productivity and resilience of agricultural systems while contributing to climate change mitigation, are well-understood and widely promoted (e.g. Henry et al., 2018; Smith et al. 2020). However, there is ongoing debate about the realistic mitigation potential, and uncertainty about the quantum of carbon that can be sequestered through specific practices (White et al. 2021), and its permanence, particularly under climate change (Wang et al. 2022a). Soil carbon is driven more strongly by climate and soil type than by management (Rabbi et al., 2015). Well-managed pastures often have high soil carbon levels, and there may be little potential for further gain. Cropping practices that increase organic matter inputs and reduce decomposition rate, such as stubble retention with zero tillage, slow the rate of loss or give only small increases in soil C in Australian cropping systems (Luo et al., 2010; Page et al., 2013), and they are already widely adopted. Cover crops have been promoted for their potential to enhance soil C, based on international experience (Poeplau and Don, 2015). However, there is doubt over the effectiveness of cover crops to increase soil carbon in Australian dryland cropping systems. Furthermore, the use of cover crops may limit subsoil moisture storage and reduce yield in subsequent crops. The most effective way to increase soil C in continuously cropped soils is through inclusion of a pasture phase (Rabbi et al., 2015). The variability and vulnerability of soil carbon, and costs of measurement, create challenges for its inclusion in emissions trading (Simmons et al. 2021; White et al. 2021). Australia's "long-term emissions reduction plan" that supports Australia's net zero 2050 target (the Net Zero Plan), states potential abatement through soil carbon management of 35-103 Mt CO_2-e /yr, and assumes a contribution of 17 Mt CO_2-e in 2050 (Australian Government 2021).

Carbon sequestration in vegetation

Strategic reforestation, such as planting windbreaks and shelter belts to protect stock and crops, contour planting to reduce erosion, establishing tree belts to manage dryland salinity, and farm forestry are all options that provide CDR through carbon sequestration in vegetation. These options may also enhance agricultural production either directly, such as through e.g. increase lamb survival rates, or indirectly through the restoration/rehabilitation of degraded, low productivity landscapes. In the case of farm forestry, carbon storage can be extended through production of long-lived building products. Use of native species may also provide biodiversity co-benefits through increased habitat extent and connectivity. While the technical potential for sequestration through reforestation is large, adoption is limited by high costs of establishment and competition for land resources with agriculture, which generally produces higher returns (compared with average ERF auction prices) except in very low rainfall environments such as the rangelands. A further challenge is uncertainty over the potential effects of climate change on forest growth, particularly the extent to which growth may be stimulated through CO2 fertilisation as atmospheric CO2 concentration rises, or limited by water availability in regions where rainfall is projected to decline (Wang et al 2022b). Australia's Net Zero Plan includes 10 Mt CO_2-e sequestration in vegetation in 2050.

Biochar

Biochar is a charcoal-like carbon-rich material used as a soil amendment. Biochar is produced through pyrolysis, in which biomass is heated in a low oxygen environment. Its properties vary widely, dependent on biomass properties and pyrolysis conditions. The pyrolysis process releases combustible gases that can be used for bioenergy. Biochar carbon is highly stable, persisting in soil for hundreds to thousands of years. Biochar provides CDR by stabilizing the feedstock carbon, and also through negative priming of native soil organic matter, and enhanced retention of rhizodeposits. Biochar commonly enhances plant growth, particularly in acidic infertile soils, due to the capacity of biochar to catalyze biotic and abiotic reactions, particularly in the rhizosphere, that increase nutrient supply and uptake by plants, reduce phytotoxins, stimulate plant development and increase resilience to disease and environmental stressors (Joseph et al., 2021). Although Australia undertook pioneering research into biochar, and has strong expertise in pyrolysis technologies, there has been limited commercial development to date. The biochar industry is most developed in China, where at least 25 commercial-scale pyrolysis plants are operating, plus gasification plants that operate at higher temperature and produce electricity, with biochar as a co-product. Waters et al. (2020) estimated realistic potential abatement through biochar at 1.6 Mt CO_2-e per year in NSW.

Enhanced weathering
This CDR option involves spreading pulverised silicate-rich rock such as basalt or dunite onto soil where it reacts with atmospheric CO2. When applied to acidic soils it has a liming benefit. It is most effective in high rainfall climates. Estimates of the global technical potential for enhanced weathering vary widely from <1 to around 100 Gt CO_2-e/yr. Fuss et al. (2018) estimated sustainable potential at 2-4 Gt CO_2-e/yr for 2050, but the concept is in early stages of development, and has only been demonstrated at small scale. Enhanced weathering could be synergistic for other CDR options: release of plant nutrients through weathering could enhance plant growth, leading to greater biomass growth in reforestation or biomass crops.

Bioenergy with carbon capture and storage
Bioenergy refers to energy products (heat, electricity, liquid fuels, biogas) produced from biomass, which can be obtained from crop and forestry residues, dedicated energy crops, and organic waste. Bioenergy contributes to climate change mitigation when it displaces fossil fuels, and can be deployed strategically to support the expansion of the intermittent renewables. Bioenergy with carbon capture and storage (BECCS) can deliver negative emissions: when biomass is combusted in an energy plant (generating electricity and/or heat) the CO_2, derived from carbon sequestered as biomass grows, is captured, and pumped into geological storage, where it can remain for tens of thousands of years. Potentially, the CO_2 could alternatively be utilized in products such as carbonated building materials, with decadal storage period. Australia's Net Zero Plan includes 38 Mt CO_2-e CDR through BECCS in 2050.Provision of bioenergy feedstock, from crop residues or dedicated energy crops, is a potential enterprise option for Australian landholders. Lignocellulosic biomass (crop residues, woody biomass crops) is generally utilized for bioenergy through combustion for heat and/or electricity. Conventional biofuel feedstocks include canola, and soy (processed to biodiesel), and sugarcane, maize and other starchy crops (processed to ethanol). Lignocellulosic biomass can be converted to liquid fuels by thermochemical or biochemical processes, known as second-generation technologies. Command and control

Nevertheless, energy crops, when strategically integrated into agricultural landscapes, can provide production and environmental benefits (Davis et al. 2013; Smith et al. 2019).

Blue carbon
Blue carbon refers to carbon sequestration in coastal wetland areas, such as mangroves and tidal marshes. Reintroduction of tidal flow, to restore marshland ecosystems, is a blue carbon CDR option that can be applied on coastal land that has been drained for agriculture. Rewetting the land leads to carbon sequestration in vegetation, accretion of organic matter in soil, and reduces methane emissions. Globally, the mitigation potential of blue carbon is estimated at 0.3–3.1 Gt CO_2-e/yr (Smith et al. 2019).

Growing demand for offsets
Stimulated by growing awareness of the threat of climate change and the need for urgent action, a range of inter-related initiatives has emerged that are providing incentives for landholders to adopt the practices reviewed above that can reduce GHG emissions or sequester carbon.

At the global level, the IPCC has identified a range of pathways to achieve the temperature goal of the Paris Agreement to limit warming to "well below 2 °C". Many pathways include a period of "overshoot", where warming exceeds 1.5°C followed by a period of net negative emissions to reduce the warming to 1.5°C by 2100. The larger the overshoot, the greater the need for CDR. Even in scenarios where emissions are rapidly reduced and overshoot is avoided, some CDR is required to balance "hard to abate" emissions such as livestock methane and N_2O from soil. The IPCC has highlighted the scale of CDR that may be required, and the feasibility challenges that must be overcome to realise its deployment, including biophysical, technical, economic, socio-cultural and institutional constraints (IPCC 2018).

The parties to the UNFCCC submit, and regularly update, their plans to contribute to the Paris Agreement goals, expressed in their "Nationally Determined Contribution" (NDC). At January 2022, 74 countries had enacted legislation or communicated a net-zero target. To support their NDCs and net zero targets, countries have introduced a range of measures to encourage implementation of abatement strategies. These include command-and-control regulation, carbon taxes, tax breaks and emissions trading. Australia has declared a net zero goal at national level, as have all the states. The Australian government strategy focusses on voluntary action, incentivized through the $2.55 billion Emissions Reduction Fund (ERF), topped up by the $2b Climate Solutions Fund. Options relevant to landholders include several reforestation, vegetation management and soil carbon project types. To date, the scheme has been dominated by ERF method "Human-induced regeneration" projects. Interest in soil carbon projects has recently grown, due to modifications that addressed recognised barriers to participation, including forward payment of credits (Australian carbon credit units, ACCUs) to reduce the upfront cost of baseline sampling and greater flexibility in quantification methods. The need for accurate quantification, necessitating a rigorous approach to monitoring, reporting and verification, and the requirement to maintain sequestered carbon for the duration for the permanence period (25 or 100 years) remain a barrier to some landholders.

Beyond action required by legislation, many companies have adopted net zero or carbon neutrality targets under their Environment, Social, and Governance policies, which is creating demand for carbon offsets on the voluntary market. Microsoft, for example, has pledged to offset all its emissions from its products, including historical emissions. They have purchased offset credits through several schemes and for several CDR types, including soil carbon and biochar credits from Australian projects. Demand for ACCUs is growing amongst Australian organisations participating in the Climate Active program, which issues certification for carbon neutral organisations, products, buildings and precincts.

Conclusion

Several drivers are converging to provide incentives to reduce emissions and enhance carbon sequestration in the land sector. A portfolio of emissions reduction and sequestration options will be required to support global, national and company-level net zero goals. There are substantial opportunities for the land sector to reduce emissions, and to provide CDR, particularly through carbon sequestration in vegetation and soil, and use of biochar. Most options offer synergies with agricultural production, and can provide additional environmental co-benefits. Nevertheless, there are limitations, trade-offs and challenges, including the likely impacts of climate change on plant growth and soil organic matter, that need to be recognised and managed, particularly for landholders participating in emissions trading. The agricultural industry should engage with policy-makers to ensure that the multiple benefits, and large potential, of climate action in the land sector are recognised, and that effective incentive mechanisms are implemented, to facilitate adoption of abatement practices that also enhance sustainability and productivity of agricultural landscapes.

References

Almeida AK and Hegarty RS (2021). Managing livestock to reduce methane emissions: Assessment of strategies for abatement of enteric methane. NSW Department of Primary Industries.

Almeida AK, Hegarty RS and Cowie A (2021). Meta-analysis quantifying the potential of dietary additives and rumen modifiers for methane mitigation in ruminant production systems. Animal Nutrition, 7(4), pp.1219-1230.

Australian Government (2021). Australia's long-term emissions reduction plan: Modelling and Analysis. https://www.industry.gov.au/sites/default/files/October%202021/document/australias-long-term-emissions-reduction-plan.pdf

Banik BK et al. (2019). Anti-methanogenic advantage of biserrula (Biserrula pelecinus) over subterranean clover (Trifolium subterraneum) from in vitro fermentation is maintained across growth stages and cutting treatments. Crop and Pasture Science, 70(3), pp.263-272.

Borchard N et al. (2019). Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: a meta-analysis. Science of the total environment 651: 2354-2364.

Bull N and Rose T (2018). Rice stubble, fertiliser and water management options to reduce nitrous oxide emissions and build soil carbon. AgriFutures Publication No. 17/060 (https://www.agrifutures.com.au/wp-content/uploads/publications/17-060.pdf)

Davis SC et al. (2013). Management swing potential for bioenergy crops. GCB Bioenergy, 5(6), pp.623-638.

Fuss S et al. (2018). Negative emissions - Part 2: Costs, potentials and side effects. Environ. Res. Lett., 13(6), 063002, doi:10.1088/1748-9326/aabf9f.

Gray JM et al. (2021). Digital mapping of soil carbon sequestration potential with enhanced vegetation cover over New South Wales, Australia. Soil Use and Management. DOI: 10.1111/sum.12766

Griscom BW et al. (2017). Natural climate solutions. Proceedings of the National Academy of Sciences, 114(44), pp.11645-11650.

Henry B, Murphy B and Cowie A, 2018. Sustainable land management for environmental benefits and food security. A Synthesis Report for the GEF (Global Environmental Facility); GEF: Washington, DC, USA. https://stapgef.org/sites/default/files/publications/SLM-Henry_Murphy_Cowie.pdf

IPCC (2018). Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte VP et al. (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

Joseph S et al. (2021). How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. GCB Bioenergy, 13(11), pp.1731-1764.

Luo Z, Wang E and Sun OJ (2010). Soil carbon change and its responses to agricultural practices in Australian agro-ecosystems: a review and synthesis. Geoderma, 155(3-4), pp.211-223.

Page KL et al. (2013). Organic carbon stocks in cropping soils of Queensland, Australia, as affected by tillage management, climate, and soil characteristics. Soil Research, 51(8), pp.596-607.

Poeplau C and Don A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. Agriculture, Ecosystems & Environment 200, 33-41.

Rabbi SMF et al. (2015). Climate and soil properties limit the positive effects of land use reversion on carbon storage in Eastern Australia. Scientific Reports, 5(1), pp.1-10.

Schwenke GD et al. (2016). Greenhouse gas (N2O and CH4) fluxes under nitrogen-fertilised dryland wheat and barley on subtropical Vertosols: risk, rainfall and alternatives. Soil Research, 54(5), pp.634-650.

Simmons A et al. (2021). US scheme used by Australian farmers reveals the dangers of trading soil carbon to tackle climate change. The Conversation. https://theconversation.com/us-scheme-used-by-australian-farmers-reveals-the-dangers-of-trading-soil-carbon-to-tackle-climate-change-161358

Smith P et al. (2020). Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification? Global Change Biology, 26(3), pp.1532-1575.

Snyder CS (2017). Enhanced nitrogen fertiliser technologies support the '4R'concept to optimise crop production and minimise environmental losses. Soil Research, 55(6), pp.463-472.

Wang B et al. (2022a). Modelling and mapping soil organic carbon stocks under future climate change in south-eastern Australia. Geoderma, 405, p.115442.

Wang B et al. (2022b). Future climate impacts on forest growth and implications for carbon sequestration through reforestation in southeast Australia. Journal of Environmental Management, 302, p.113964.

Waters C et al. (2020). Abatement opportunities from the agricultural sector in New South Wales: Modelling to support the development of the Primary Industries Productivity and Abatement Program. NSW Department of Primary Industries: Sydney, Australia, 170. (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/1315562/FINAL_May2021Abatement-opprtunities-in-NSW.pdf)

White RE, Davidson B and Eckard R (2021). An everyman's guide for a landholder to participate in soil carbon farming in Australia. Australian Farm Institute Occasional Paper No 21.01.