PACKHORSE WHITE PAPER

PACKHORSE™

Regenerative grazing practices can increase soil carbon stocks: Science for the conversation.

Introduction

Soils have a crucial role in mitigating climate change by storing carbon that would otherwise end up in the atmosphere [1]–[3]. High profile global initiatives such as "4p1000", an international political effort launched at the United Nations Summit in Paris (2015), provides a goal of increasing soil organic carbon stocks by 0.4% per year[1] to improve food security and tackle climate change [4]. This document establishes the scientific case for promoting regenerative grazing practices to increase soil organic carbon stocks. This scientific case demonstrates alternative ways of practising beef farming that can reduce greenhouse gas emissions through greater carbon storage in the landscape.

Key Points

- Soils play a crucial role in mitigating climate change by storing carbon that would otherwise end up in the atmosphere.
- Soil carbon storage represents a true win-win strategy: It takes carbon out of the atmosphere, where it is causing harm, and locks it in the soil where it is beneficial to soil health, e.g. nutrient and water retention resulting in greater plant productivity.
- Carbon enters the soil through plant decomposition, where it may remain for decades, centuries, or even millennia – particularly if it becomes stabilised within soil aggregates or chemically bonded to mineral surfaces.
- Soil are the largest terrestrial store of carbon, storing approximately three times the amount of carbon in vegetation and twice the amount of carbon in the atmosphere (to a depth of 1m). Therefore, even small changes in soil carbon stocks can significantly impact climate change mitigation.
- The world has lost about 25% of soil carbon stocks in the topsoil from poor land-use management. The good news is that soil carbon stocks can be replenished by implementing regenerative management practices that maximise plant productivity, including time-controlled grazing, and incorporating legumes, mixed species, and deep-rooted perennials into pastures.
- Based on the best available scientific evidence, the range of potential soil carbon storage in Australian grazing lands under improved land use management is likely to be between 0.05 and 0.8t C per hectare per year. The range is dependent on the type of management implemented and site-specific climate and soil properties.
- While the gains in soil carbon may be relatively small on a per hectare basis, rolling these practices out over Australia's approximately 10 million hectares of degraded grassland hugely impact on Australia's greenhouse gas budget.

[1] The UNs target of 0.4% increase in soil organic carbon is well within the range Packhorse predicts for its soil carbon projects.

1. Background on soil organic carbon

What is soil organic carbon, and how is it formed?

Soil organic matter (around 62% of which is carbon) is composed of plant residues in varying states of decay, and the microbes, (both living and dead), that have fed on the residues. Soil organic carbon formation starts when plants suck up carbon (in the form of CO_2) from the atmosphere and use it to store energy and build their stems, leaves and roots. Plants add carbon to the soil both by root exudation while alive and through decomposition upon death. Decomposition adds above-ground plant biomass (e.g., plant leaves, branches, stem) and belowground plant biomass (e.g., dead roots, carbon substances from root exudates, and microbial biomass) directly to the soil organic carbon pool. After carbon enters the soil in the form of organic matter, it may persist in the soil for decades, centuries, or even millennia [5], particularly if it is encapsulated within micro aggregates or chemically bonded to soil mineral surfaces [6] as it is protected from microbial attack.

What are the benefits of increasing soil organic carbon?

Soil organic carbon improves soil structure, fertility, nutrient retention, water infiltration and water-holding capacity and reduces soil erosion and compaction. The more carbon there is in the soil, the healthier the soil becomes. Therefore, increasing soil carbon in agricultural landscapes is a global environmental benefit while delivering healthier soils that support greater grass and animal productivity, ensuring food security for our growing population [7]–[9].

How much carbon do soils store?

Soil organic carbon represents a stock of around 1,500-2,400 Gt C in the top meter of soil globally. This stock is approximately three times the stock of carbon in vegetation and twice the stock of carbon in the atmosphere [2]. Therefore, even small changes in carbon stocks can significant impact the atmosphere and climate change. Sequestering organic carbon in soil may potentially, and in a technically feasible manner, remove between 0.79 and 1.54 G t C per year from the atmosphere [12]. To put this into context, this is around 20-45% of the annual increase in CO_2 emissions – thereby helping to stabilise the climate [13].

What factors influence soil organic carbon stocks?

The ability to sequester soil carbon is dependent on the soil type, climate, and management practices [9], [14]–[17]. Clay soils typically store more carbon. Sandy soils generally store less carbon as the soil microorganisms can access the organic carbon more easily for energy, and the decomposition rate is accelerated [14]. Rainfall also influences soil organic carbon; it dictates plant productivity and, therefore the amount of plant material that enters the soil. In warm climates with high rainfall, the rate of soil organic carbon decomposition is accelerated, whereas in cooler climates there is typically a greater soil organic carbon. Finally, management can increase soil organic carbon by increasing plant productivity and photosynthetic input to the soil. As land management is the only factor affecting soil organic carbon that humans can control, this is the focus of the next section.

2. Regenerative management practices to increase soil organic carbon

At Packhorse, we apply regenerative principles to increase plant and animal productivity and increase soil organic carbon stocks. Our soil and plant regeneration principles are as follows:

- Plan, monitor, and manage soil health
- Maximise living plant production
- Focus on enhancing soil biology to heal and repair soil health
- Enhance biodiversity at all scales within landscape (above and below ground)
- Maximise thickness and availability of ground cover
- Utilise livestock as a natural way of recycling nutrients

Through careful observation and measurement, each pasture is managed to incorporate some or all of the following practices in a holistic approach to management.

2.1 Time-controlled grazing

Time-controlled grazing involves using smaller paddocks that are heavily stocked for short periods, followed by periods of rest that allow the pasture to recover and regenerate before grazing is applied again. The rest period is adjusted to suit the plant's growth rate and the stocking rate is matched to the carrying capacity of the land. Time-controlled grazing of pastures results in an even pasture utilisation and an even distribution of nutrients from cattle excrement. At the same time, the increased trampling of animals breaks up the soil surface and enhances the transfer of above-ground plant material into the soil organic carbon pool [18]–[20]. In summary, animal density can be used as a tool for soil and pasture revitalisation.

2.2 Incorporating mixed species & biodiversity

Biodiversity has been demonstrated to increase plant productivity and improve the stability and resilience of grassland ecosystems [21]–[24]. For example, a review highlighted that mixtures of species produce an average of 1.7 times more biomass than monocultures [22]. The resultant positive relationship between biodiversity and productivity is often explained by resource partitioning; as individual plant species differ in resource use and acquisition, the more species grown together in a community, the more resources the plant community can obtain (e.g. [25]). Greater plant productivity elevates carbon inputs to the soil, particularly from belowground inputs from roots [26]. There are also indirect mechanisms for increased carbon storage through greater plant production. For example, an increase in plant cover improves soil water retention, increasing plant inputs' conversion to microbial biomass [27], [28]. Greater microbial growth and turnover increase microbial necromass which constitutes as much as half of the soil organic matter pool [29].

2.3 Incorporating legumes and perennial pasture species

After water, nitrogen is usually the primary nutrient limiting plant growth. By fixing N from the atmosphere, Legumes pstures can remove this limitation, thereby increasing pasture productivity and biomass input to the soil [30]–[32]. An average well-grown legume pasture will fix around 25 kg of nitrogen per tonne of dry matter per year, with extra nitrogen leading to more grass production [33], which contributes to increased soil organic carbon storage. Research in buffel pastures recorded a 40-100% increase in annual pasture production (dry matter per hectare) by incorporating legumes compared to grass-only pastures approximately 15 years after establishment on low phosphorus soils

[34]. Furthermore, leguminous plants typically have longer tap root systems that allow them to access deep moisture and nutrients out of reach of more shallow root grass pasture species, resulting in greater productivity and ground cover during extended dry periods. A deep root system is more likely to sequester carbon at delpth in the soil profile, which is less likely to be decomposed by soil microbes [35].

3. How much soil carbon can Australia's grazing land store?

The best estimate of what can be realistically and technically achieved in Australian soils is likely to range between 0.1 and 0.8 tC per hectare per year [9]. The largest gains are typically found in the first 5 to 10 years after improved management is implemented, with the rate diminishing to zero after 40 years [9], [36]. A summary of the most relevant literature for soil carbon gains under improved management are provided in Table 1 below.

Location	Mean rate C sequestration (t C/ha/yr) 0-30 cm[2]	Management factors[3]	Ref.
Global meta-analysis	0.66 0.28 0.57	Legume pasture Grazing management fertilisation	**[37]**
NSW	0.5	Annual and perennial pasture	**[30]**
ACT	0.6 (to 60 cm)	Fertilisation and increased stocking rate	**[38]**
Australian meta-analysis	0.1 to 0.3	Fertilisation, legumes and irrigation	**[9]**
QLD	1.37[4]	Time-controlled grazing	**[18]**
NSW	0.78	Cropping to permanent pasture	**[39]**
NSW	0.5	Pasture phase in cropping and P addition	**[30]**
NSW	0.26-0.72	Pasture improvement using P application	**[40]**
NSW	1.04 to 1.46	Grazing management (strategic and rotational)	**[41]**
NSW	1.09 to 2.47	Organic amendments	**[42]**
QLD	0.28	Pasture plus legume	**[43]**
QLD	0.76	Pasture plus legume	**[44]**
QLD	1.5	Pasture plus legume	**[31]**
ACT	0.6	P fertilisation	**[38]**
NSW	0.46 to 0.55	Liming	**[30]**
NSW and QLD	0.6 to 1.8	Cell grazing	Carbon Link data (personal comm).

[2] *Amount of soil carbon measured to a depth of 30 cm unless stated otherwise.*

[3] *Some values may be conservative given that they monitored the implementation of one management measure. If multiple measures are implemented, this may achieve higher gains.*

[4] *Change in soil carbon stocks not statistically significant over time.*

Notes on the baseline for measuring changes in soil carbon.

Rates of change are dependent on the baseline and previous management. For example, converting from a heavily tilled cropping soil will likely result in greater carbon accumulation initially, as you start from a relatively low carbon baseline. The period over which carbon sequestration is measured is also important – if it is measured over the year, the C gains are likely to be much greater than if changes are measured over 10 years as the rate of C accumulation declines over time.

Conclusion

Best management practices, such as time-controlled grazing, improved pasture with mixed species and legumes, and perennial grasses, can improve Australia's grazing lands' soil organic carbon stocks. While the gains in soil carbon may be relatively small on a per hectare basis, rolling these practices out over Australia's approximately 10 million hectares of degraded grassland will hugely impact Australia's GHG budget. Packhorse will continue to collaborate with research organisations, such as QUT (Figure 4), to understand emerging practices and to provide robust data to support the large-scale implementation of regenerative grazing. Overall, Packhorse aims to demonstrate that regenerative agriculture has the potential to achieve multiple objectives: ensuring food security, restoring degraded land, and achieving net-zero emissions through the storage of carbon in the landscape.

Figure 4: *Packhorse is investing in research to detect small changes in soil organic carbon over time at a lower cost using Eddy Covariance flux towers. Associate Professor David Rowlings (QUT) is pictured with a flux tower at Longreach.*

References

[1] K. Paustian, J. Lehmann, S. Ogle, D. Reay, G. P. Robertson, and P. Smith, "Climate-smart soils," Nature, vol. 532, no. 7597, pp. 49–57, 2016, doi: 10.1038/nature17174.

[2] P. Smith, "Soils and climate change," Curr. Opin. Environ. Sustain., vol. 4, no. 5, pp. 539–544, 2012, doi: 10.1016/j.cosust.2012.06.005.

[3] P. Smith, "Soil carbon sequestration and biochar as negative emission technologies," Glob. Chang. Biol., vol. 22, no. 3, pp. 1315–1324, 2016, doi: 10.1111/gcb.13178.

[4] A. Chabbi et al., "Aligning agriculture and climate policy," Nat. Clim. Chang., vol. 7, no. 5, pp. 307–309, 2017, doi: 10.1038/nclimate3286.

[5] M. Wiesmeier et al., "Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales," Geoderma. 2019, doi: 10.1016/j.geoderma.2018.07.026.

[6] M. W. I. Schmidt et al., "Persistence of soil organic matter as an ecosystem property," Nature. 2011, doi: 10.1038/nature10386.

[7] B. W. Murphy, "Impact of soil organic matter on soil properties - A review with emphasis on Australian soils," Soil Res., vol. 53, no. 6, pp. 605–635, 2015, doi: 10.1071/SR14246.

[8] A. Richardson, E. Coonan, C. Kirkby, and S. Orgill, "Soil Organic Matter and Carbon Sequestration Origins of SOM and pools of soil C," pp. 255–271, 2017, [Online]. Available: http://agronomyaustraliaproceedings.org/images/sampledata/specialpublications/Australian Agriculture in 2020 web PDFs larger/Australian Agriculture in 2020 Pt4Ch16.pdf.

[9] J. Sanderman, R. Farquharson, and J. Baldock, "Soil Carbon Sequestration Potential : A review for Australian agriculture," 2010.

[10] N. H. Batjes, I. S. Reference, I. C. Isric, P. O. Box, and A. J. Wageningen, "Total carbon," no. June, 1996.

[11] J. Sanderman, T. Hengl, and G. J. Fiske, "Soil carbon debt of 12,000 years of human land use," Proc. Natl. Acad. Sci. U. S. A., 2017, doi: 10.1073/pnas.1706103114.

[12] S. Fuss et al., "Negative emissions - Part 2: Costs, potentials and side effects," Environ. Res. Lett., vol. 13, no. 6, 2018, doi: 10.1088/1748-9326/aabf9f.

[13] R. Lal, "Soil carbon sequestration to mitigate climate change," Geoderma, vol. 123, no. 1–2, pp. 1–22, 2004, doi: 10.1016/j.geoderma.2004.01.032.

[14] E. Mitchell, C. Scheer, D. Rowlings, F. Cotrufo, R. T. Conant, and P. Grace, "Important constraints on soil organic carbon formation efficiency in subtropical and tropical grasslands," Glob. Chang. Biol., vol. 27, no. 20, pp. 5383–5391, 2021, doi: 10.1111/gcb.15807.

[15] M. J. Pringle et al., "Soil carbon stock in the tropical rangelands of Australia: Effects of soil type and grazing pressure, and determination of sampling requirement," Geoderma, 2011, doi: 10.1016/j.geoderma.2011.09.001.

[16] D. E. Allen et al., "What determines soil organic carbon stocks in the grazing lands of north-eastern Australia?," Soil Res., 2013, doi: 10.1071/SR13041.

[17] S. Weidermann and J. Dunn, "Carbon Accounting Technical Manual," vol. 364, 2021.

[18] G. Sanjari, H. Ghadiri, C. A. A. Ciesiolka, and B. Yu, "Comparing the effects of continuous and time-controlled grazing systems on soil characteristics in Southeast Queensland," Aust. J. Soil

Res., 2008, doi: 10.1071/SR07220.

[19] G. E. Schuman, J. D. Reeder, J. T. Manley, R. H. Hart, and W. A. Manley, "Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland," Ecol. Appl., 1999, doi: 10.1890/1051-0761(1999)009[0065:IOGMOT]2.0.CO;2.

[20] Y. Wei et al., "Transformation of litter carbon to stable soil organic matter is facilitated by ungulate trampling," Geoderma, vol. 385, no. March, p. 114828, 2021, doi: 10.1016/j.geoderma.2020.114828.

[21] D. A. Fornara and D. Tilman, "Plant functional composition influences rates of soil carbon and nitrogen accumulation," J. Ecol., vol. 96, no. 2, pp. 314–322, 2008, doi: 10.1111/j.1365-2745.2007.01345.x.

[22] B. J. Cardinale et al., "Impacts of plant diversity on biomass production increase through time because of species complementarity," Proc. Natl. Acad. Sci. U. S. A., vol. 104, no. 46, pp. 18123–18128, 2007, doi: 10.1073/pnas.0709069104.

[23] F. Nobilly, R. H. Bryant, B. A. Mckenzie, and G. R. Edwards, "Productivity of rotationally grazed simple and diverse pasture mixtures under irrigation in Canterbury," Proc. New Zeal. Grassl. Assoc., pp. 165–172, 2013, doi: 10.33584/jnzg.2013.75.2920.

[24] T. H. Oliver et al., "Biodiversity and Resilience of Ecosystem Functions," Trends in Ecology and Evolution. 2015, doi: 10.1016/j.tree.2015.08.009.

[25] N. Oram, K. Barry, A. Weigelt, and C. Hongmei, "Belowground complementarity effects in a grassland biodiversity experiment are related to deep-rooting species," J. Ecol., 2017.

[26] S. Chen et al., "Plant diversity enhances productivity and soil carbon storage," Proc. Natl. Acad. Sci. U. S. A., vol. 115, no. 16, pp. 4027–4032, 2018, doi: 10.1073/pnas.1700298114.

[27] B. Richards, C. E. Martínez, and I. Kögel-knabner, "Soil organic carbon accrual due to more efficient microbial utilisation of plant inputs at greater long-term soil moisture," Geochim. Cosmochim. Acta, 2022, doi: 10.1016/j.gca.2022.04.028.

[28] L. Mommer et al., "Lost in diversity: the interactions between soil-borne fungi, biodiversity and plant productivity," New Phytol., vol. 218, no. 2, pp. 542–553, 2018, doi: 10.1111/nph.15036.

[29] C. Liang, W. Amelung, J. Lehmann, and M. Kästner, "Quantitative assessment of microbial necromass contribution to soil organic matter," Glob. Chang. Biol., vol. 25, no. 11, pp. 3578–3590, 2019, doi: 10.1111/gcb.14781.

[30] K. Y. Chan et al., "Soil carbon dynamics under different cropping and pasture management in temperate Australia: Results of three long-term experiments," Soil Res., vol. 49, no. 4, pp. 320–328, 2011, doi: 10.1071/SR10185.

[31] Terry McCosker, "Increase in Carbon Stocks with the incorporation of Progardes."

[32] Q. Li, P. Yu, G. Li, and D. Zhou, "Grass-legume ratio can change soil carbon and nitrogen storage in a temperate steppe grassland," Soil Tillage Res., vol. 157, pp. 23–31, 2016, doi: 10.1016/j.still.2015.08.021.

[33] Unknown, "Sown pasture rundown: Strategies to increase nitrogen inputs," Future Beef, 2014. https://futurebeef.com.au/knowledge-centre/rundown-management-strategy-2/ (accessed Oct. 11, 2021).

[34] G. Peck, F. Chudleigh, C. Guppy, B. Johnson, and D. Lawrence, "Use of phosphorous fertiliser for increased productivity of legume-based pastures in the Brigalow Belt region - a review," 2015.

[35] D. P. Rasse, C. Rumpel, and M. F. Dignac, "Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation," 2005, doi: 10.1007/s11104-004-0907-y.

[36] C. E. Stewart, K. Paustian, R. T. Conant, A. F. Plante, and J. Six, "Soil carbon saturation: Concept, evidence and evaluation," Biogeochemistry, 2007, doi: 10.1007/s10533-007-9140-0.

[37] R. T. Conant, C. E. P. Cerri, B. B. Osborne, and K. Paustian, "Grassland management impacts on soil carbon stocks: A new synthesis: A," Ecol. Appl., vol. 27, no. 2, pp. 662–668, 2017, doi: 10.1002/eap.1473.

[38] E. C. Coonan et al., "Soil carbon sequestration to depth in response to long-term phosphorus fertilisation of grazed pasture," Geoderma, vol. 338, no. December 2018, pp. 226–235, 2019, doi: 10.1016/j.geoderma.2018.11.052.

[39] W. B. Badgery, A. T. Simmons, B. W. Murphy, A. Rawson, K. O. Andersson, and V. E. Lonergan, "The influence of land use and management on soil carbon levels for crop-pasture systems in Central New South Wales, Australia," Agric. Ecosyst. Environ., vol. 196, pp. 147–157, 2014, doi: 10.1016/j.agee.2014.06.026.

[40] A. Oates, G. Li, and W. Wagga, "Soil carbon stocks under different pastures and pasture management in the higher rainfall areas of south-eastern Australia Soil carbon stocks under different pastures and pasture management in the higher rainfall areas of south-eastern," no. January, 2010, doi: 10.1071/SR09092.

[41] S. E. Orgill et al., "Removing Grazing Pressure from a Native Pasture Decreases Soil Organic Carbon in Southern New South Wales, Australia," L. Degrad. Dev., vol. 29, no. 2, pp. 274–283, 2018, doi: 10.1002/ldr.2560.

[42] W. Badgery et al., "Soil carbon market-based instrument pilot – the sequestration of soil organic carbon for the purpose of obtaining carbon credits," Soil Res., vol. 59, no. 1, pp. 12–23, 2020.

[43] K. A. Conrad, R. C. Dalal, S. A. Dalzell, D. E. Allen, and N. W. Menzies, "The sequestration and turnover of soil organic carbon in subtropical leucaena-grass pastures," Agric. Ecosyst. Environ., vol. 248, no. May, pp. 38–47, 2017, doi: 10.1016/j.agee.2017.07.020.

[44] A. Radrizzani, H. M. Shelton, S. A. Dalzell, and G. Kirchhof, "Soil organic carbon and total nitrogen under Leucaena leucocephala pastures in Queensland," Crop Pasture Sci., vol. 62, no. 4, pp. 337–345, 2011, doi: 10.1071/CP10115.

PACKHORSE™

PO Box 255, Paddington QLD 4064
t. 07 3858 0502 | **packhorse.net.au**