Manaaki Whenua
Landcare Research

Place-based approaches to assessing the impact of Regenerative Agriculture in New Zealand

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‘Think piece’ on Regenerative Agriculture in Aotearoa New Zealand: project overview and statement of purpose

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Find the full project overview, white paper and topic reports at ourlandandwater.nz/regenag and www.landcareresearch.co.nz/publications/regenag

This report is one of a series of topic reports written as part of a ‘think piece’ project on Regenerative Agriculture (RA) in Aotearoa New Zealand (NZ). This think piece aims to provide a framework that can be used to develop a scientific evidence base and research questions specific to RA. It is the result of a large collaborative effort across the New Zealand agri-food system over the course of 6 months in 2020 that included representatives of the research community, farming industry bodies, farmers and RA practitioners, consultants, governmental organisations, and the social/environmental entrepreneurial sector.

The think piece outputs included this series of topic reports and a white paper providing a high-level summary of the context and main outcomes from each topic report. All topic reports have been peer-reviewed by at least one named topic expert and the relevant research portfolio leader within MWLR.

Foreword from the project leads

Regenerative Agriculture (RA) is emerging as a grassroot-led movement that extends far beyond the farmgate. Underpinning the movement is a vision of agriculture that regenerates the natural world while producing ‘nutrient-dense’ food and providing farmers with good livelihoods. There are a growing number of farmers, NGOs, governmental institutions, and big corporations backing RA as a solution to many of the systemic challenges faced by humanity, including climate change, food system disfunction, biodiversity loss, and human health (to name a few). It has now become a movement. Momentum is building at all levels of the food supply and value chain. Now is an exciting time for scientists and practitioners to work together towards a better understanding of RA, and what benefits may or not arise from the adoption of RA in NZ.

RA’s definitions are fluid and numerous – and vary depending on places and cultures. The lack of a crystal-clear definition makes it a challenging study subject. RA is not a ‘thing’ that can be put in a clearly defined experimental box nor be dissected methodically. In a way, RA calls for a more prominent acknowledgement of the diversity and creativity that is characteristic of farming – a call for reclaiming farming not only as a skilled profession but also as an art, constantly evolving and adapting, based on a multitude of theoretical and practical expertise.

RA research can similarly enact itself as a braided river of interlinked disciplines and knowledge types, spanning all aspects of health (planet, people, and economy) – where curiosity and open-mindedness prevail. The intent for this think piece was to explore and demonstrate what this braided river could look like in the context of a short-term (6 month) research project. It is with this intent that Sam Lang and Gwen Grelet have initially approached the many collaborators that contributed to this series of topic reports – for all bring their unique knowledge, expertise, values and worldviews or perspectives on the topic of RA.

How was the work stream of this think piece organised?

The project's structure was jointly designed by a project steering committee comprised of the two project leads (Dr Gwen Grelet[1] and Sam Lang[2]); a representative of the New Zealand Ministry for Primary Industries (Sustainable Food and Fibre Futures lead. Jeremy Pos); OLW's Director (Dr Ken Taylor and then Dr Jenny Webster-Brown), chief scientist (Professor Rich McDowell), and Kaihāpai Māori (Naomi Aporo); NEXT's environmental director (Jan Hania); and MWLR's General Manager Science and knowledge translation (Graham Sevicke-Jones). OLW's science theme leader for the programme 'Incentives for change' (Dr Bill Kaye-Blake) oversaw the project from start to completion.

The work stream was modular and essentially inspired by theories underpinning agent-based modelling (Gilbert 2008) that have been developed to study coupled human and nature systems, by which the actions and interactions of multiple actors within a complex system are implicitly recognised as being autonomous, and characterised by unique traits (e.g. methodological approaches, world views, values, goals, etc.) while interacting with each other through prescribed rules (An 2012).

Multiple working groups were formed, each deliberately including a single type of actor (e.g. researchers and technical experts only or regenerative practitioners only) or as wide a variety of actors as possible (e.g. representatives of multiple professions within an agricultural sector). The groups were tasked with making specific contributions to the think piece. While the tasks performed by each group were prescribed by the project lead researchers, each group had a high level of autonomy in the manner it chose to assemble, operate, and deliver its contribution to the think piece. Typically, the groups deployed methods such as literature and website reviews, online focus groups, online workshops, thematic analyses, and iterative feedback between groups as time permitted (given the short duration of the project).

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[1] Senior scientist at MWLR, with a background in soil ecology and plant ecophysiology – appointed as an un-paid member of Quorum Sense board of governors and part-time seconded to Toha Foundry while the think piece was being completed

[2] Sheep & beef farmer, independent social researcher, and project extension manager for Quorum Sense

Place-based approaches to assessing the impact of Regenerative Agriculture in New Zealand

Contract Report LC3954-6

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Introduction to this report

Interest in regenerative agriculture (RA) practices is currently driven by global environmental, social, and economic challenges. Despite the breadth of challenges and interest in RA, the implementation of RA practices is context-specific, as identified by a working group of RA practitioners (Lang S 2021). One of the four RA principles identified by practitioners was: "Make context-specific decisions: Context varies from place to place, person to person and season to season – adapt your system and practices to suit" (Lang S 2021). The concept of place-based approach is not new. It has been considered in the studies of environmental policies (Norton & Hannon 1997), economic growth and development (Barca et al. 2012), reward / payment for ecosystem services (Reed et al. 2017; Kaiser et al. 2021), politics (Amin 2004), health (Dankwa-Mullan et al. 2016), resilience (Cutter et al. 2008), climate change (Schweizer et al. 2013, Schwalm et al. 2015), among many other topics.

A recent report (Beef+Lamb New Zealand and New Zealand Winegrowers 2021) presented findings from a study of Germany, the UK and the USA markets and also highlighted context/locality as a one of the seven key themes identified. The report states: 'Regenerative Agriculture is Local: one of the key principles of Regenerative Agriculture is the ability to express the essence of place' (Beef+Lamb New Zealand and New Zealand Winegrowers 2021).

In their 2016 white paper 'Levels of regenerative agriculture', Soloviev and Landua, from Terragenesis International (a thought leader organisation in the field of RA), stated: 'Each community of practitioners in each bioregion of the world has the opportunity to re-generate the ecocultural meaning of Regenerative Agriculture. They will do so in a way that is unique to their place, history and whole living ecosystem'.

In this report, a series of regional specific issues and opportunities are considered and proposed as localised case-studies for testing whether RA could deliver sought-after benefits to New Zealand in specific contexts.

Each case-study was compiled by a different author and peer-reviewed separately.

The four place-based case studies are:

- An investigation of surface erosion caused by winter forage-crop grazing in Otago and Southland and if/how novel RA practices could mitigate current environmental issues linked to winter stock management (Mitchell Donovan, AgResearch)
- Predicted increases in the frequency and severity of drought / flood in Hawke's Bay, to investigate the capacity of RA to facilitate climate change adaptation (Charles Merfield, The BHU Future Farming Centre)
- Outdoor vegetable production in South Auckland, to investigate the capacity of RA to produce plant-based food with no or minimal environmental impact (Fiona Curran-Cournane, Ministry for the Environment)
- Kaitiakitanga and RA in the Ruahuwai takiwā, to investigate the capacity of RA to mitigate impacts of land use on water quality through a Te Ao Māori lens (Mike Taitoko, Calm The Farm &Takiwā Ltd)

1 Winter feeding in Otago and Southland

Mitchell Donovan (AgResearch)

1.1 Winter-forage crop grazing: current practices, ongoing impacts and future directions

Aotearoa New Zealand, is home to over 10 million hectares of pastures and land dedicated to sheep, beef, and dairy farming, each of which shape New Zealand's landscapes, people and living environments. These systems not only provide food and fibre, but also play an important role in shaping the environment and perceptions of what consumers are supporting. Public attention and research are increasingly focused on the connections between human activities, animal welfare and environmental issues, with winter-forage crop grazing practices being a recognizable example of how human management has resulted in concerns for both animal welfare and the degradation and loss of soil via surface erosion, among others.

Winter-forage crop grazing has stemmed from the need to support stock nutritional needs throughout winter while pasture growth is typically unable to do so. Forage crops such as kale, swedes, and fodder beet are typical crops used to over-winter stock at high stocking densities (Monaghan et al. 2017), with the drawback that such stocking densities often cause significant soil degradation in the form of pugging, compaction, and accelerated soil loss following rainfall (Donovan & Monaghan 2021; Donovan in press). After grazing, the soils often remain bare until soil conditions are sufficient to be sown with forage crops for the following winter or for re-establishing pasture. This cycle is typically repeated every 2 to 3 years, and in some cases, up to 4 years (Drewry et al. 2020), after which the paddock is converted back to pasture (Monaghan et al. 2010).

Extensive research has demonstrated significant soil degradation from compaction and pugging (Drewry et al. 2003; Drewry & Paton 2005; Styles et al. 2013; Donovan & Monaghan 2021), along with accelerated nutrient and soil losses (McDowell 2006; Burkitt et al. 2017; Fransen et al. 2017; Donovan, in press) following winter forage-crop grazing. The land area used to support winter-forage crops only covers approximately 2–5% of total land area throughout the Southland and Otago regions, but it can account for up to 20-fold higher proportions of the surface erosion within a given catchment (Donovan & Monaghan 2021; Donovan, in press). Research has reported soil losses of up to 3,750 kg/ha/yr and topsoil losses of up to 55 mm/yr (McDowell & Houlbrooke 2009; Laurenson et al. 2018); both are orders of magnitude higher than the rate of soil production (Montgomery 2007; Hancock et al. 2020). Further, the fertilisers and nutrients applied to sustain such high densities of forage-crop growth can be lost via runoff or leaching into adjacent waterways, thereby impairing water quality (Monaghan et al. 2017). Previous and ongoing research has documented numerous strategies to reduce the environmental impacts of winter-forage crop grazing, such as fencing off critical source areas, restricting or deferring grazing while soils are wet or saturated, avoiding grazing along streambanks/floodplains, and applying downslope 'catch crops' or vegetation (McDowell et al. 2005, 2006; Basher et al. 2016; Monaghan et al. 2017; Laurenson et al. 2018).

1.2 Future directions and needs for winter-forage crop grazing

Recently, government bodies have proposed regulations in an attempt to curb the contaminant losses from winter-forage crops. These regulations have been met with resistance and concern, and unfortunately have amplified divisions within farming communities, thereby increasing the strain on this community.

While the regulations and strategies proposed could reduce the contaminants reaching waterways, both reflect attempts to *reactively* mitigate impacts. as opposed to *proactively* shifting towards systems that sustain or improve the health of land and animals (Donovan & Monaghan 2021). Farmers and researchers alike are increasingly recognising the need to shift towards proactive approaches that retain ground cover and soil cohesion following grazing, such as all-grass wintering, baleage wintering, and reduced grazing density.

Specific examples of RA techniques that can address the problems of winter forage grazing include 'bale grazing'. This is where pasture hay or silage in large bales is placed evenly across wintering paddocks in the autumn and then progressively fed to stock over winter using break fences (similar to fodder crops). The paddocks are chosen based on inherent properties that allow them to best withstand stock treading and minimise soil and nutrient loss, rather than on suitability for tillage and cropping. This includes having a base of established pasture with a good amount of pasture foliage and root mass to provide the resistance to soil damage surface erosion. With the use of back fences, stock are only on an area of paddock and associated bales for short periods, thereby minimising the potential for soil damage, dung and urine accumulation and other negative outcomes of in-situ grazing of forage crops. Winter bale grazing over consecutive years has been shown to improve soil fertility and pasture productivity in Alberta Canada (Omokanye 2013; Omokanye et al. 2018).

Another technique is 'deferred grazing', which in the local context of Aotearoa New Zealand, means closing a paddock throughout spring to allow the pasture to mature and set seed, and then using it as a standing crop of hay for direct feeding in autumn into winter (Tozer et al. 2020). Again, paddocks can/should be selected that are less likely to lose soil, nutrients, and dung to overland flow and groundwater environments (e.g. avoiding paddocks next to rivers and streams). RA practices generally promote increased plant diversity in both crops and perennial pastures, which have been shown to be more resilient and recover faster from damage and wet conditions (e.g. Wright et al. 2017; Weisser et al. 2017). The increased adoption of such practices are examples of promising pathways to proactively reduce soil and nutrient losses from farms, thereby improving degraded soils and waterways. Increasing adoption of such practices in New Zealand stems from environmental concerns, and the need to improve both animal welfare and the social well-being of farmers and farming communities.

2 Future climate scenarios in Tairāwhiti and Hawke's Bay

Charles Merfield (BHU Future Farming Centre)

This section includes a summary of NIWA's 2020 report on Climate Change Projections and Impacts for Tairāwhiti and Hawke's Bay.

Under global warming, large areas of New Zealand, with the main exception of the South Island's west coast, are projected to have higher temperatures, reduced annual rainfall, more droughts, and more intense rain events (storms) (Ministry for the Environment 2018). In the last few years, areas that have been considered 'drought proof', such as the Waikato and Northland,[3] have experienced droughts for the first time. This was particularly challenging for farmers, as they have no experience of such conditions and do not have systems already in place to deal with such dry weather. Areas on the east coast, particularly Gisborne, Hawke's Bay, Marlborough, and Canterbury, which are in the rain shadows of the mountains to their west, have always had droughts. Farmers in these areas have long developed strategies to cope with this, such as lambing and calving early, keeping a stockpile of feed such as hay, and destocking early. However, the droughts in these areas and the damage they cause are now exceeding anything previously experienced and are increasingly beyond mitigation potential of current management strategies.

In November 2020 the National Institute of Water & Atmospheric Research Ltd (NIWA) was prepared for Envirolink, Gisborne District Council, and Hawke's Bay Regional Council to undertake a detailed review of climate change projections and impacts for the Tairāwhiti and Hawke's Bay regions (Woolley et al. 2020). This section provides an overview of the key findings of that report and others highlighted below, as they relate to agriculture and horticulture, and illustrate the challenges with which farmers and growers will increasingly have to cope, in the face of a warming climate.

2.1 Climate Change projections

The climate of Tairāwhiti and Hawke's Bay is already changing and further warming is predicted in the foreseeable future. The rate of future warming depends on how fast atmospheric greenhouse gas concentrations increase. The NIWA report analysed expected changes for 11 different climate variables, from present day to year 2100. The predictions draw heavily on climate model simulations from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. Two main climate pathways are used: a 'medium concentration pathway' (MCP), and a 'high concentration pathway' (HCP) to give an indication of outcomes under different mitigation scenarios, i.e. what greenhouse gas (GHG) concentrations are achieved.

For the MCP the future annual average warming range is 0.5–1.0°C by 2040 and 1.0–1.5°C by 2090. For the HCP, the 2040 range is the same as the MCP (0.5–1.0°C) but by 2090 it is

[3] www.stuff.co.nz/environment/climate-news/119613334/northland-drought-more-far-north-towns-in-desperate-water-savings-plea

2.0–3.0°C. Annual average minimum temperatures follow a similar path and are expected to increase for most locations in both regions by 0.5–1.0°C by 2040. By 2090, absolute minimum temperatures at most locations are projected to increase for the MCP by 0.5–1.0°C and for the HCP by 1.5–2.5°C. The average number of frost days is expected to decrease, with the largest decreases projected under the MCP for high-elevation locations in the west, where 5–20 fewer frost days are projected by 2040 and 10–30 fewer frost days by 2090, while under the HCP there are 10–50 fewer frost days. Smaller decreases are generally projected for coastal locations because fewer frosts currently occur in these locations.

The average number of heatwave days per year is projected to increase, particularly for eastern and coastal locations. By 2090, under the HCP the majority of both regions is projected to receive 20–60 additional heatwave days per year. Increases are generally not as large for higher-elevation locations further inland.

Projected changes in rainfall show variability across the two regions. By 2040, under both MCP and HCP, annual rainfall is expected to decrease by a small amount for the majority of both regions in the 0–5% range. By 2090, larger and more extensive decreases to annual rainfall are projected: under the MCP a decrease of up to 10%, and up to 15% under the HCP. Spring is generally projected to experience the greatest and most extensive drying, while winter rainfall is generally projected to increase on the western side of the mountain ranges while the eastern side will be drier.

Extreme, rare rainfall events are projected to become more severe in the future. Short-duration rainfall events have the largest relative increases compared with longer-duration rainfall events. Rainfall amounts for 1-in-50-year and 1-in-100-year events are projected to increase for both MCP and HCP. Under the MCP, the annual maximum 1-day rainfall total is projected to be similar to current levels, but under HCP and further into the future, larger and more widespread increases are projected.

For the annual maximum 5-day rainfall in Tairāwhiti, large increases are projected for locations over and west of the Raukūmara Range, while decreasing totals are generally projected for several eastern and inland parts. By 2090, under the HCP, this portion of the region is among the few parts of New Zealand projected to see decreases of more than 5 mm to the annual maximum 5-day rainfall total. Projected changes are also variable across the Hawke’s Bay Region, although most locations are projected to see increasing totals under high greenhouse gas concentrations.

Drought potential is projected to increase across both regions, with annual accumulated potential evapotranspiration deficit totals increasing, and increasing greenhouse gas concentrations. Areas east of the mountain ranges are projected to observe the largest increases to potential evapotranspiration deficit, and eastern Tairāwhiti is projected to experience some of the largest increases in the country by 2090. The probability of potential evapotranspiration deficit exceeding 300 mm in a given year is also projected to increase significantly for most eastern and coastal locations in both regions. Also, large portions of both regions are projected to experience some of the largest increases to the annual number of days of soil moisture deficit compared with other parts of the country.

2.2 River flow projections

The effects of global warming on hydrological characteristics were examined by driving NIWA's national hydrological model with downscaled Global Climate Model outputs from 1971 to 2099 under different greenhouse gas concentration scenarios.

Annual average river flows (discharge) are expected to decrease. Mean annual low river flows are also expected to decrease for most catchments. However, under the MCP, a number of catchments are expected to see an increase in mean annual low river flows, as summer rainfall is expected to slightly increase for those catchments. High river flows are generally expected to see larger decreases by mid-century (2036–2056) under MCP compared to HCP. Increases to high flows are also expected for some catchments by mid-century, with larger increases expected under HCP, particularly in Hawke's Bay. The largest decreases to high flows are expected for the HCP by 2086–2099.

However, the climate models are not able to correctly reproduce ex-tropical cyclone tracks and other large storms, so these are likely to further increase the number and amount of high-intensity rain events with more warming. In contrast, mean annual flood (MAF) levels (MAF = the mean of the series of each year's highest daily mean flow) are expected to be spatially diverse across time and greenhouse gas concentration pathways. By the end of the century, under HCP, MAF is expected to increase by up to 50% for around half of the Hawke's Bay region's rivers and a smaller proportion of rivers across Tairāwhiti. So, while overall river flows are decreasing, flood events will increase considerably due to the increase in storm / heavy rain events.

2.3 Global warming impacts on agriculture and horticulture

Beyond direct changes to the climate and the impacts of those changes on river flows, global warming will probably affect the primary sector in a range of other ways (Ministry for the Environment 2018; Woolley et al. 2020). There is likely to be an increase in pests and diseases. Cattle will become more stressed during heatwaves (of which there will be more, with greater intensity), which is likely to affect milk production in the dairy sector to a greater degree than at present. Increasing temperatures affects the rate of plant growth, which may affect the quality and quantity of harvested fruit and vegetable crops, as well as the productivity of forestry and pasture. Human health will also be affected by a changing climate due to the increasing prevalence of hot conditions and heatwaves. On the positive side, warmer temperatures in the future may increase the length of the tourism season and provide opportunities for new crops to be grown.

Future reductions in the amount of rainfall and increases in drought severity may cause fire risk to increase in the Tairāwhiti and Hawke's Bay regions, affecting forestry and the natural environment. Future reductions to water availability from decreasing rainfall as well as lower river flows may affect the available water take for irrigation and urban supply, and also affect freshwater ecosystems.

While overall rainfall is projected to decrease, increased high-intensity rainfall events (storms) are associated with more slips, floods, and erosion, and hence damage to infrastructure (e.g. roads, water supply) and land productivity (e.g. soil loss), which can be expected to affect water quality, reduce the quality of grazing areas, and risk the safety of farm buildings, machinery, staff and livestock. Increased rainfall intensity increases the risk of reduced quality of fruit and vegetables, as well as causing soil saturation issues for horticulture and agriculture. However, counteracting that, increased concentrations of carbon dioxide should increase forest, pasture, crop, and horticulture productivity, if not limited by water availability.

In summary, the climate across the farming areas on the eastern side of Tairāwhiti and Hawke's Bay will be hotter, dryer, with less rain overall but an increase in high-intensity rainfall (storm) events. This is the same predicted trend for other agricultural and horticultural areas in New Zealand are predicted to experience (Ministry for the Environment 2018).

2.4 The potential of regenerative agriculture in Tairāwhiti and Hawke's Bay

RA techniques have the potential to facilitate the adaptation of Tairāwhiti and Hawke's Bay's farming landscape to predicted future climate. There is increasing evidence that plant diversity improves carbon sequestration in soil (e.g. Stockdale & Watson 2012; Lange et al. 2015; Bender et al. 2016; Vukicevich et al. 2016; Weisser et al. 2017), and a key principle of RA is to increase plant diversity, particularly through mixtures, in pasture, cover crops, etc. Soil with more organic matter and better biology would also have better structure, and therefore an overall increased ability to store and be permeable to water (higher infiltration capacity) – a key soil property particularly in high-intensity rainfall events (storms). The need to store more rain and absorb it quickly in storms are indeed key climate change adaptations.

RA's 'long residual' grazing practices (Tozer et al. 2020), whereby pastures are grown taller than current best practices, leaving some 10 cm of pasture behind after grazing, have potential to protect the soil surface from raindrop impact and to slow overland flow, both of which should increase infiltration and reduce soil loss under higher rainfall events.

RA seeks to increase pasture functional diversity such that the assemblage of pasture species collectively contain a diversity of plant traits e.g. including different phenology, root systems (e.g. by having both deeper and shallower rooting species). Deeper rooting species can access water deeper in the soil profile, as evidenced by the work, over decades, on lucerne by the Drylands Group at Lincoln University (Sim et al. 2017; Sim & Moot 2019). Species assemblage with a diversity of root systems would access a much larger amount of the soil bulk, and therefore have access to much greater amounts of soil moisture, and in turn maintain productivity in dry conditions that turn the standard New Zealand pasture of perennial ryegrass and white clover brown and lifeless (Tozer et al. 2020). Diverse grasslands have been shown to recover better from flooding events, by promoting better soil structure and complementary plant growth traits, whereby those plant species that are quickest to recover 'stand it' while the slower-recovering species re-establish themselves (Weisser et al. 2017; Wright et al. 2017).

Introducing a range of short and tall species pastures and allowing pastures to grow taller, might also create a moister microclimate just above the soil surface, slowing soil water loss via evaporation, and might also provide shelter to livestock (from wind, sun, rain). Diverse pasture species have already been shown to increase animal welfare and performance (Provenza et al. 2015).

RA might also promote pasture systems that are more resilient to pest and disease pressures – both of which are predicted to increase under future climate scenarios. It is hypothesized that in RA systems (with high plant diversity), when pest and disease pressure increases, if any particular species is badly harmed, there are other species to take up the ecological space left behind – thereby limiting the negative impact on the system as a whole. Evidence for such biodiversity-mediated ecological mechanisms underpinning pest and disease resilience are mounting (Weisser et al. 2017; Barnes et al. 2020).

Increasing plant diversity via agroforestry (Briggs 2012) can also benefit livestock as shade and wind protection are increased, and additional phytochemicals are introduced in the landscape that might be beneficial to livestock (Provenza et al. 2015). There was considerable interest and research into agroforestry in New Zealand in the 1980s and 1990s but with a focus on increased profitability rather than wider benefits (Hawke & Maclaren 1990). Agroforestry, planted, regenerating, and remnant trees, shrubs regulate microclimate in pastures and fields by intercepting winds and sun and are used by farm animals for shade and shelter. This reduces hot temperatures and evapotranspiration, and increases soil moisture (Thomas et al. 2018; Easdale et al. 2021). Agroforestry has hence been proposed as a viable solution for climate change adaptation (Briggs 2012; Hernández-Morcillo, Burgess et al. 2018; Lavorel & Grelet 2021).

3 Outdoor vegetable production in Pukekohe, South Auckland

Fiona Curran-Cournane (Ministry for the Environment)

This local case study in Pukekohe, South Auckland, provides an example of where RA could have high impact, and where scientific approaches to achieve evidence of its impact could be targeted.

3.1 Soil quality and receiving environment

Maintaining soil quality is crucial to sustaining food security and maintaining resilience (FAO 2018). Auckland, and in particular in-and-around Pukekohe, contributes over 20% of the nation's vegetable production (Aitken & Hewett 2014), a result of unique climate and land and soil characteristics allowing production all year round. Pukekohe is a renowned market gardening area (Hunt 1959), with some families commercially producing vegetables on their land for the past 150 years (Curran-Cournane et al. 2016). However, intensive continuous cultivation can be to the detriment of the soil, resulting in very low carbon levels (Figure 1) and reduced biological activity, and coinciding with excessively high synthetic fertiliser application rates can pose increased risk to the receiving environment (Basher et al. 1997; Haynes & Tregurtha 1999; Meijer et al. 2016; Curran-Cournane 2020; Wallace et al. 2020). Issues with declining soil carbon levels associated with intensive outdoor vegetable production in Pukekohe have been reported since at least the early-1970s (Gradwell & Arlidge, 1971).

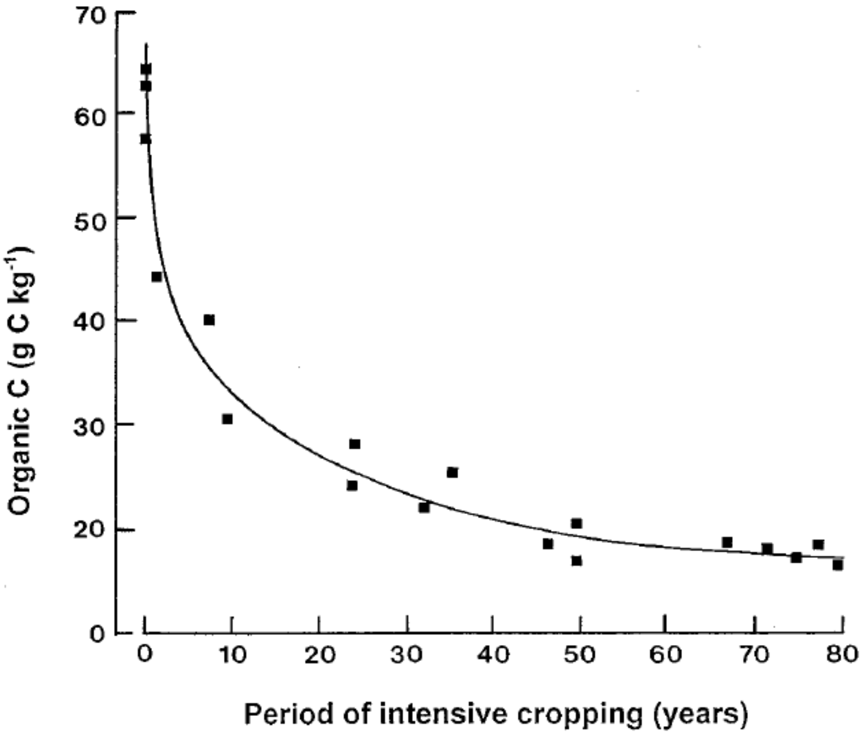

Figure 1. The effect of time under intensive vegetable production on soil organic content for Patumahoe clay loam soils in Pukekohe (Haynes & Tregurtha 1999).

Since the commencement of state of environment soil monitoring in Auckland, dating back 20-plus years, there have been persistent issues concerning very low soil carbon levels and excessive fertiliser application rates at monitored outdoor vegetable production sites (Curran-Cournane 2020). Constant soil disturbance associated with outdoor vegetable production activity in the Pukekohe area involves the soil being continuously rearranged by cultivation (e.g. ploughing, hoeing, harrowing, deep ripping), resulting in losses of soil carbon (Haynes & Tregurtha 1999). Subsequently, mean total carbon levels for monitored soil sites in previous sampling events in the Pukekohe area would be regarded as falling within the 'depleted' range for sustaining farm production and ensuring environmental protection (Sparling et al. 2008), measuring at 2.7% (n = 7; range 1.81–4.28%). Similarly, mean anaerobic mineralisable nitrogen concentrations measuring at 21mg/kg (range 7–48 mg/kg) fell within in the 'low' range, collectively indicating that the soil is less resilient, with poorer functioning (Curran-Cournane 2020). Coinciding mean Olsen P concentrations were measured at 206 mg/kg (range 48–361 mg/kg), indicating excessive phosphorus fertiliser application rates (the suggested target range for these volcanically derived soils are 20–50 mg/kg (Mackay et al. 2013)).

Soils with poorer structure are more subject to erosion and nutrient leaching (Basher et al. 1997), particularly when large quantities of fertiliser are being applied to the land. Declines in soil carbon in the Pukekohe area indicate an increased risk of contaminant leaching losses, particularly nitrogen (Cathcart 1996; Crush et al. 1997; Ledgard et al. 1997; Williams et al. 2000; Francis et al. 2003). Issues with elevated nitrate concentrations in Franklin surface water and groundwater are apparent (Meijer et al. 2016). For example, in the Franklin Whangamarie stream, nitrate concentrations have remained high above the national bottom line of 6.7 mg NO_3-N/L since monitoring began in 2009, with concentrations periodically peaking around 15 mg NO_3-N/L (Meijer et al. 2016) – which also exceeds Ministry of Health drinking water guidelines (11.3 mg NO_3-N/L). Also, dissolved oxygen and ammonium concentrations have been significantly decreasing ($P < 0.05$) since 2009. For outdoor vegetable growers within these catchments, resources should be targeted at improving soil carbon levels as well as a reduction of N and P fertiliser application rates via, for example, regular soil testing by the landowner to ensure more targeted use and the avoidance of excessive application rates.

3.2 A finite resource

At the same time as intensive land management pressures are being experienced, rural land (particularly highly productive land) is being lost to irreversible development, affecting the availability of the resource for continued primary production as well as the flexibility of options and choices to ensure intergenerational equity (Andrew & Dymond 2013; Curran-Cournane et al. 2016, 2018).

Even if growers opted to de-intensify in Pukekohe and spread across a wider area of land in Auckland, there is a growing question of land availability. Already, at least 34% (according to the FARMLUC classification (Hicks & Vujcich 2017)), 38%, and 19% of LUC land classes 1, 2, and 3, respectively, has been occupied by legacy zones and the Auckland Unitary Plan (including the rural urban boundary, future urban zones, countryside living zones, etc.) (Curran-Cournane 2019). However, these figures do not take into account pre-existing, ad hoc rural residences beyond these zonal boundaries that also coincide with highly productive land, so the figures will be greater than that previously described.

In contrast, only 10% of LUC land classes 4–8 land have been occupied in the same way in Auckland (Curran-Cournane 2019). The figures are since the mid- to late-1970s, and if the trajectory continues without effective intervention it could eventuate in the complete loss of the resource before 2100 in Auckland (Curran-Cournane 2019). This is an uncommon resource, to which certain land-use activities, such as outdoor vegetable, grain and certain fruit production that are essential to our nutritional health, are limited (Clark et al. 2019; Afshin et al. 2019; Drew et al. 2020; Curran-Cournane & Rush 2021). This is a resource that will become increasingly important as the population continues to grow.

At the same time, a growing volume of international and national literature indicates the need to shift towards more sustainable diets that include large amounts of whole-plant-based foods such as vegetables, to ensure health outcomes as well co-benefiting the climate (Swinburn et al. 2019; Willett et al. 2019; Drew et al. 2020). Such literature recognises that various food categories not only require uncommon land and soil characteristics that need to be better realised, but their production also has varying climatic and environmental implications. Establishing sustainable diets needs to consider a variety of environmental outcomes, for example, but not limited to carbon footprint, nutrient pollution, freshwater use and land use, to avoid the risk of potentially shifting the environmental burden from one land-use activity to another (Clark et al. 2019; Eme et al. 2019; Chandrakumar et al. 2020; Springmann et al. 2020).

3.3 Policy tensions

Another question regarding the de-intensification of outdoor vegetable production in regions experiencing these built development pressures is the feasibility of other locations picking up some of the shortfall if there is a question of volume to ensure the maintenance of affordable prices (Ford 2018). If such circumstances eventuated, questions of climate, access to city and labour markets, water availability, etc., would be factors requiring consideration. Yet shifting some production to other areas may require a fertiliser cap to ensure expansion is not at odds with maintaining or improving freshwater quality objectives (Ministry for Environment & Ministry for Primary Industries 2020).

For example, arable and horticultural activities are currently exempt from fertiliser cap restrictions and would therefore be contrary to adhering to such freshwater objectives if expanding into catchments where the adoption of caps by other land uses was being applied. Applying an evidenced-based systems approach can help refine policy solutions, reducing potential unintended consequences. In any case, it is not a matter of replacing outdoor vegetable production in Pukekohe, given its optimal growing conditions, but rather a question of sustainable land and soil use and management across the board that needs to be considered in any location.

3.4 Towards sustainable land and soil use and management

Improving soil profile carbon storage content for intensive outdoor vegetable production can be accomplished with the adoption of conventional best management and RA practices, ultimately offering multiple environmental, agronomic and climate mitigating benefits (Basher et al. 1997). Recommended strategies in general, such as the use of cover crops to restore the carbon content of the soil, minimal tillage practices (Bloomer & Powrie 2013), application of green manures, including at least 4 years pasture in the crop rotation, minimising the time between harvest and re-establishment of the new crop etc, can result in achieving such benefits (Basher et al. 1997; Komatsuzaki & Wagger 2015; Myers & Watts 2015). The total quantity of fertilisers applied on-farm can also have a relatively large effect on total greenhouse emissions, hence the dual benefit of a reduced carbon footprint with the avoidance of unnecessary, excessive application rates, reiterating the need for optimal fertiliser use (Ledgard et al. 2011).

Regenerative agriculture can play a role for every aspect of described strategies that could be explored and adapted. RA has a strong focus on increasing plant diversity both in space (e.g. through crop mixtures, highly diverse cover crops, living mulches) and time (e.g. more diversified rotations). Increasing plant diversity, if plant species mixes are well designed, may yield a plethora of benefits for all aspects of soil health, crop production, and farm profitability (Tamburini et al. 2020).

A well-functioning, resilient soil ecosystem, achieved through, for example, the adoption of a range of RA techniques, could position growers favourably, given that they are, and will continue to be, on the front line tackling and responding to climate change. The compounding effects of climate change increasing the risk of water shortages and drought are already being experienced[4,5,6], and will add another layer of stress on our resources, making it harder to recover from other impacts such as pollution.

Farmers and growers require ongoing rural land management advice that empowers sustainable land use decision-making – something that will become increasingly important in a changing climate. A functioning soil ecosystem can provide landowners with resilience and multiple benefits to ensure: 1) valuable topsoil remains on the land; 2) water storage capacity and structural integrity of soil are at their maximum; 3) biological activity and diversity are supported; and 4) the over-application of high or excessive quantities of synthetic fertiliser is not wasted (that not only negatively impacts the environment but offers no additional agronomic benefit to the food producer).

Evidence gathering of more sustainable land and soil use and management practices such as RA is gaining scientific momentum. Synergies already exist between RA, te ao Māori perspectives on soil sovereignty (Hutchings & Smith 2018, 2020) and conventional best

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[4] The climate record that keeps getting broken. 03 July 2020 https://niwa.co.nz/news/the-climate-record-that-keeps-getting-broken

[5] Auckland's drought most extreme in modern times. 22 May 2020 https://niwa.co.nz/news/aucklands-drought-most-extreme-in-modern times

[6] Auckland's dam levels. 28 July 2020 https://www.watercare.co.nz/Water-and-wastewater/Where-your-water-comes-from/Auckland-s-dam-levels

management practices (Basher et al. 1997; Meijer et al. 2016), but the uptake and/or the effectiveness of the latter are questionable given the long-term persistence of certain issues. This highlights the need for more sustainable land and soil use and management resourcing to ensure future resilience, intergenerational equity and kaitiakitanga, particularly in light of a changing climate. Scientific evidence on the benefits of RA may encourage the uptake of its practice.

4 Kaitiakitanga and regenerative agriculture in Ruahuwai takiwā

Mike Taitoko (Calm The Farm; Toha Foundry Ltd)

4.1 Kaitiakitanga and regenerative agriculture

Land use within the Upper Waikato River Catchment is predominantly a mix of dairy, sheep & beef, and forestry operations. Over the past 20 years at least 14,000 hectares of land adjacent to the Upper Waikato River has been converted from pine forests to dairy farms, with many under irrigation, placing additional pressure on freshwater quality of the Waikato River.

Increased regulations and social licence to operate are placing increasing pressure on landowners and operators, councils and industries to minimise their impact on freshwater quality of the Waikato River and its environs.

Te Arawa River Iwi Trust (TARIT) represents three iwi in the restoration of the Waikato River from a co-governance and co-management perspective. TARIT's three strategic goals are:

- mana tangata – enabling our people to participate in the restoration and protection of the river
- mana taiao – implementing restoration and protection measures
- mana mātauranga – upholding tikanga (customs), preserving wāhi tapu (sacred sites) and enhancing mātauranga (knowledge).

Te Arawa River iwi's tribal lands make up the Ruahuwai takiwā, which covers much of the Upper Waikato River Catchment (Fig. 2). Over the past few years TARIT has been working to re-engage their people, wherever they live in the world, with their land and rivers through a digital and data strategy. The strategy includes collecting real-time freshwater data from multiple sensor sites via telemetry, as well as other datasets such as cultural data, mahinga kai, land-use, soil type and depth, resource consent and on-farm data. TARIT's multi-dimensional view via their website provides a rich source of data and information that brings visibility and provides education to their members regarding the mauri and health of the Waikato River and its environs.

Figure 2. Map of the Ruahuwai Catchment and Upper Waikato River Catchment.

4.2 Influencing change though data, tech, culture, and regenerative agriculture

TARIT's digital and real-time data strategy means they are well-placed to help their members identify options for land-use and land practice change. Some of TARIT's members, along with other Māori landowners within the wider region, are currently exploring the role of RA as a solution to reduce the negative effects nitrogen and other nutrients and chemicals have on the mauri of the Waikato River, its tributaries, and their environs.

TARIT's tools and technologies also help them articulate their aspirations, strategies, and actions relating to land-use and freshwater impacts to their Treaty partners, including regional councils and government agencies, and various industry stakeholders within the catchment.

With learning from TARIT's Ruahuwai takiwā project coupled with Te Puni Kōkiri's Whenua Māori Fund, Māori landowners within and around the Ruahuwai takiwā are embarking on a planning process to give effect to their responsibilities as kaitiaki and meet their own cultural and business standards for environmental stewardship.

A mauri model of well-being, developed by Māori-owned milk processing company Miraka, is at the heart of the programme, which takes into account cultural health indicators regarding the health and well-being of the water and wider environment, the people, and the farming businesses that supply Miraka's Central North Island processing plant.

Based on feedback from workshops and on-farm engagement with Māori landowners and farmers, participants have shown a high level of interest in RA. For example, many make connections between RA and their own views on the mauri and well-being of the whenua within a te ao Māori paradigm, in which increased plant diversity and biological activity, and less reliance on chemicals, are necessary to improve soil health and preserve the mauri of the whenua. Further, some Māori landowners have said that moving to regenerative practices to improve the mauri of waterways and restoring te mana o te wai are 'non-negotiable bottom-lines' to ensure future generations benefit from their own healthy and productive whenua and freshwater.

For iwi and Māori landowners within and around the Ruahuwai takiwā, RA resonates strongly. Based on current RA initiatives and planning processes, these groups will increasingly celebrate and strengthen their culture and connection to their land and rivers, develop and embrace leading-edge tools and technologies, evolve farming practices, and design their own models of mauri and well-being to drive changes in land-use and regenerative on-farm practices.

5 Conclusions

Winter feeding in Otago and Southland, climate change impacting Tairāwhiti and Hawke's Bay, intensive conventional vegetable production in Pukekohe, and the value of RA concepts helping improve Kaitiakitanga in the Ruahuwai takiwā, all provide specific and place-based examples of where RA has the potential to address many of the problems faced by farming communities and restore the mauri of the whenua.

While some of the previously described conventional best management practices (whether adopted or not) are not specific to RA, RA itself is more than an integrated set of practical on-farm tools and approaches. Fundamentally, RA is a different attitude and mindset (Lang 2021), considering landscape and communities from a more holistic, integrated, circular, biological and ecological perspective. The RA mindset also has strong parallels with te ao Māori as discussed in the section 'Kaitiakitanga and regenerative agriculture in Ruahuwai takiwā' and by Seymour (2021), helping all farmers and growers move in the direction signposted by the Primary Sector Council's 'Fit for a Better World – Taiao Ora, Tangata Ora[7] vision and strategy.

6 References

Afshin A, Sur PJ, Fay KA, Cornaby L, Ferrara G, Salama JS, Mullany EC, Abate KH, Abbafati C, Abebe Z, Afarideh M, Aggarwal A, Agrawal S, Akinyemiju T, Alahdab F, et al. 2019. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 393: 1958–1972. doi:10.1016/S0140-6736(19)30041-8

Aitken AG, Hewett EW 2014. Fresh facts 2014. New Zealand Horticulture. http://www.freshfacts.co.nz/file/fresh-facts-2014.pdf

Amin A 2004. Regions unbound: towards a new politics of place. Geografiska Annaler: Series B, Human Geography 86: 33–44. doi:10.1111/j.0435-3684.2004.00152.x

An L 2012. Modeling human decisions in coupled human and natural systems: review of agent-based models. Ecological Modelling 229: 25–36. doi:10.1016/j.ecolmodel.2011.07.010

Andrew R, Dymond JR 2013. Expansion of lifestyle blocks and urban areas onto high-class land: an update for planning and policy. Journal of the Royal Society of New Zealand 43: 128–140.

Barca F, McCann P, Rodríguez-Pose A 2012. The case for regional development intervention: place-based versus place-neutral approaches. Journal of Regional Science 52: 134–152. doi:10.1111/j.1467-9787.2011.00756.x

[7] mpi.govt.nz/about-mpi/structure/government-advisory-groups/primary-sector-council
fitforabetterworld.org.nz

Barnes AD, Scherber C, Brose U, Borer ET, Ebeling A, Gauzens B, Giling DP, Hines J, Isbell F, Ristok C, et al. 2020. Biodiversity enhances the multitrophic control of arthropod herbivory. Science Advances 6: eabb6603 doi:eabb6603. 10.1126/sciadv.abb6603

Basher LR, Cathcart SN, Crush JR, Hart B, Clark S, Ross CW, Williams PH 1997. Soil and water management for sustainable vegetable production in a peri-urban area, Pukekohe, New Zealand. 24th Hydrology and Water Resources Symposium: proceedings: water/land: wai-whenua. Auckland, New Zealand. Pp. 321–326.

Basher LR, Moores J, McLean G 2016. Scientific basis for erosion and sediment control practices in New Zealand. New Zealand: Manaaki Whenua – Landcare Research.

Beef+Lamb New Zealand, New Zealand Winegrowers 2021. Regenerative agriculture market scan: Understanding the current state and future potential of regenerative agriculture in the United States, United Kingdom, and Germany. Accessed October 5th 2021 at https://beeflambnz.com/sites/default/files/data/files/Regenerative%20Agriculture%20-%20MARKET%20SCAN%20-%20FINAL%20v4.pdf.

Bender SF, Wagg C, van der Heijden MGA 2016. An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability. Trends in Ecology & Evolution 31: 440–452. doi:10.1016/j.tree.2016.02.016

Bloomer DJ, Powrie J 2013. Permanent beds for vegetables farmer guidelines. Havelock North, New Zealand: LandWISE. 24 p. http://www.landwise.org.nz/wp-content/uploads/Permanent-Beds-2013.pdf

Briggs S 2012. Agroforestry a new approach to increasing farm production: a Nuffield Farming Scholarships Trust Report 85.

Burkitt LL, Winters JL, Horne DJ 2017. Sediment and nutrient losses under winter cropping on two Manawatu hill country soils. Journal of New Zealand Grasslands 79(4): 27–33.

Cathcart SN 1996. An investigation of the nitrate contamination of an unconfined, shallow, fractured, basaltic aquifer at Pukekohe, South Auckland, New Zealand. Recent developments in understanding chemical movement in soils: significance in relation to water quality and efficiency of fertiliser use: Proceedings of the workshop held by the Fertilizer and Lime Research Centre at Massey University, Palmerston North, New Zealand, 14–15 February 1996.

Chandrakumar C, McLaren SJ, Müller K, Vetharaniam I, Lister CE, Johnstone PR 2020. Assessing climate change and nutritional tradeoffs in substituting animal-based foods with plant-based alternatives – a New Zealand study. 12th International Conference on Life Cycle Assessment of Food 2020 (LCA Food 2020) 'Towards Sustainable Agri-Food Systems' 13−16 October 2020, Berlin, Germany [virtual format].

Clark MA, Springmann M, Hill J, Tilman D 2019. Multiple health and environmental impacts of foods. Proceedings of the National Academy of Sciences Nov. 116(46): 23357–23362 doi:10.1073/pnas.1906908116

Crush JR, Cathcart SN, Singleton P, Longhurst RD 1997. Potential for nitrate leaching from different land uses in the Pukekohe area. Proceedings of the New Zealand Grassland Association 59: 55–58.

Curran-Cournane F, Cain T, Greenhalgh S, Samarasinghe O 2016. Attitudes of a farming community towards urban growth and rural fragmentation: an Auckland case study. Land Use Policy 58: 241–250.

Curran-Cournane F, Golubiewski N, Buckthought L 2018. The odds appear stacked against versatile land: can we change them? New Zealand Journal of Agricultural Research 64(4): 483–507. doi:10.1080/00288233.2018.1430590.

Curran-Cournane F 2019. Evidence in Chief of Dr Fiona Curran-Cournane on behalf of Auckland Council before the Environment Court at Auckland ENV–2016–AKL-304–000199. 20 December 2019.

Curran-Cournane F 2020. Differences in soil quality and trace elements across land uses in Auckland and changes in soil parameters from 1995 to 2017. Auckland Council Technical Report TR2020/001.

Curran-Cournane F, Rush E 2021. Feeding the New Zealand family of five million, 5+ a day of vegetables? Earth 2: 797–808.

Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J 2008. A place-based model for understanding community resilience to natural disasters. Global Environmental Change 18: 598–606. doi:10.1016/j.gloenvcha.2008.07.013

Dankwa-Mullan I, Pérez-Stable EJ 2016. Addressing health disparities is a place-based issue. American Journal of Public Health 106: 637–639. doi:10.2105/ajph.2016.303077

Donovan M, Monaghan RM 2019. Modelling spatial and temporal variability in erosion risk for winter grazing management. Proceedings of the workshop held by the Fertilizer and Lime Research Centre at Massey University, Palmerston North, New Zealand.

Donovan M, Monaghan RM (in review). Impacts of grazing and treading on ground cover, soil physical properties and soil loss via surface erosion: a novel geospatial modelling approach. Journal of Environmental Management 287: 112206. doi:10.1016/j.jenvman.2021.112206.

Donovan M (in press). Modelling soil loss from surface erosion at high-resolution to better understand sources and drivers across land uses and catchments; a national-scale assessment of Aotearoa, New Zealand. Environmental Modelling & Software.

Drew J, Cleghorn C, Macmillan A, Mizdrak A 2020. Healthy and climate-friendly eating patterns in the New Zealand context. Environmental Health Perspectives 128: 1 017007. doi:017007-017001-017007–017013.

Drewry JJ, North H, Belliss SE, Amies A 2020. Winter-forage crop grazing in the Gore-Mataura area of Southland: using time-series mapping to estimate location and frequency of cropping. Journal of New Zealand Grasslands 82: 129–137. doi:10.33584/jnzg.2020.82.425.

Drewry JJ, Paton RJ 2005. Soil physical quality under cattle grazing of a winter-fed brassica crop. Soil Research 43: 525–531. doi:10.1071/SR04122.

Drewry JJ, Singleton PL, Boyes M, Judge A, Wheeler D 2003. Short term recovery of soil physical properties after winter grazing in Waikato: implications for environmental monitoring. In: Currie LD, Hanly JA eds Tools for nutrient and pollutant management: applications to agriculture and environmental quality. Massey University, Palmerston

North, New Zealand. 17th workshop held by the Fertiliser & Lime Research Centre. 2–3 December 2003. Occasional Report 17. Pp. 194–204.

Eme P.E, Douwes J, Sunia F, Foliaki S, Burlingame B 2019. Review of methodologies for assessing sustainable diets and potential for development of harmonised indicators. International Journal of Environmental Research and Public Health 16: 1184.

FAO 2018. FAO and the 17 sustainable development goals. Food and Agriculture Organisation of the United Nations, Rome. http://www.fao.org/3/a-i4997e.pdf

Ford S 2018. Statement of evidence of Stuart Ford on behalf of Auckland Council. ENV-2016-AKL-304-000199 between Self Family Trust and Auckland Council.

Francis GS, Trimmer LA, Tregurtha CS, Williams PH, Butler RC 2003. Winter nitrate leaching losses from three land uses in the Pukekohe area of New Zealand. New Zealand Journal of Agricultural Research 46: 215–224.

Fransen P, Burkitt L, Bretherton M, Horne D, Singh R, Hickson R, Morris S 2017. Selection of cattle supplement feeding areas to reduce nutrient and sediment loss in surface runoff from hill country. Palmerston North, NZ: Fertilizer and Lime Research Centre, Massey University.

Gradwell MW, Arlidge EZ. 1971. Deterioration of soil structure in the market gardens of the Pukekohe District, New Zealand. New Zealand Journal of Agricultural Research 14: 288–306.

Gilbert N 2008. Agent-based models. Quantitative Applications in the Social Sciences. Number 07-153. Los Angeles, CA: Sage.

González-Chang M, Tiwari S, Sharma S, Wratten SD 2019. Habitat management for pest management: limitations and prospects. Annals of the Entomological Society of America 112: 302–317. doi:10.1093/aesa/saz020

Hancock GR, Ovenden M, Sharma K, Rowlands W, Gibson A, Wells T. 2020. Soil erosion – the impact of grazing and regrowth trees. Geoderma 361: 114102. doi:10.1016/j.geoderma.2019.114102.

Hawke MF, Maclaren JP 1990. Agroforestry - an opportunity overlooked? Proceedings of the New Zealand Grassland Association. Wanganui. Pp. 55–58.

Haynes R, Tregurtha R 1999. Effects of increasing periods under intensive arable vegetable production on biological, chemical and physical indices of soil quality. Biological Fertility of Soils 28: 259–266.

Hernández-Morcillo M, Burgess P, Mirck J, Pantera A, Plieninger T 2018. Scanning agroforestry-based solutions for climate change mitigation and adaptation in Europe. Environmental Science & Policy 80: 44–52. doi:10.1016/j.envsci.2017.11.013

Hicks DL, Vujcich V 2017. Farm-scale land use capability classification for Auckland. Auckland Council Technical Report TR2017/016.

Hunt DT 1959. Market gardening in metropolitan Auckland. New Zealand Geographer 15: 130–155.

Hutchings J, Smith J 2018. Evaluating the mana of soil through the Hua Parakore framework. MAI Journal 7: 92–102.

Hutchings J, Smith J 2020. Te mahi oneone hua parakore: A Māori soil sovereignty and wellbeing handbook. Christchurch, New Zealand: Freerange Press.

Kaiser J, Haase D, Krueger T 2021. Payments for ecosystem services: a review of definitions, the role of spatial scales, and critique. Ecology and Society 26: 12. doi:10.5751/ES-12307-260212

Komatsuzaki M, Wagger MG 2015. Nitrogen recovery by cover crops in relation to time of planting and growth termination. Journal of Soil and Water Conservation 70: 385–398. doi:10.2489/jswc.70.6.385

Lang S 2021. Regenerative principles applied in New Zealand. Manaaki Whenua – Landcare Research Contract Report LC3954-2 for Our Land and Water National Science Challenge & The NEXT Foundation. Downloadable at: https://ourlandandwater.nz/regenag and https://www.landcareresearch.co.nz/publications/regenag

Lange M, Eisenhauer N, Sierra CA, Bessler H, Engels C, Griffiths RI, Mellado-Vázquez PG, Malik AA, Roy J, Scheu S, et al. 2015. Plant diversity increases soil microbial activity and soil carbon storage. Nature Communications 6: 6707. doi:10.1038/ncomms7707

Laurenson S, Wall A, Monaghan R, Orchiston T 2018. Sediment losses from intensively grazed forage crops in New Zealand. Invermay, NZ: AgResearch.

Lavorel S, Grelet GA 2021. Ecosystem-based solutions for climate change adaptation in rural landscapes of New Zealand. Manaaki Whenua – Landcare Research Contract Report LC3954-20 for Our Land and Water National Science Challenge & The NEXT Foundation. Downloadable at: https://ourlandandwater.nz/regenag and https://www.landcareresearch.co.nz/publications/regenag

Ledgard SF, Boyes M, Brentrup F 2011. Life cycle assessment of local and imported fertilisers used on New Zealand farms. In: Currie LD, Christensen CL eds Adding to the knowledge base for the nutrient manager. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp. 1–13.

Ledgard SF, Crush JR, Ouyang L, Sprosen M, Rajendram GS 1997. Nitrate leaching under spinach, onion and potato crops in the Pukekohe region during 1996. Report for BOP Fertiliser Ltd. www.fertresearch.org.nz.

Mackay A, Dominati E, Taylor M 2013. Soil Quality Indicators: The Next Generation. Report prepared for Land Monitoring Forum of Regional Councils. Client report number: RE500/2012/025.

McDowell RW, Drewry JJ, Muirhead RW, Paton RJ 2005. Restricting the grazing time of cattle to decrease phosphorus, sediment and E. coli losses in overland flow from cropland. Soil Research 43: 61–66. doi:10.1071/SR04041.

McDowell RW, Houlbrooke DJ 2009. Management options to decrease phosphorus and sediment losses from irrigated cropland grazed by cattle and sheep. Soil Use and Management 25: 224–233. doi:10.1111/j.1475-2743.2009.00231.x.

McDowell RW 2006. Phosphorus and sediment loss in a catchment with winter forage grazing of cropland by dairy cattle. Journal of Environmental Quality 35: 575–583. doi:10.2134/jeq2005.0364.

Meijer K, Buckthought L, Curran-Cournane F, Martindale M, Prebble N, Long L 2016. Elevated nitrate concentrations in Franklin surface and groundwater: a review. Auckland Council Technical Report 2016/015.

Ministry for the Environment 2018. Climate change projections for New Zealand: atmosphere projections based on simulations from the IPCC fifth assessment. 2nd edn. Wellington, New Zealand: National Institute of Water and Atmospheric Research (NIWA). 131 p.

Ministry for the Environment 2020. Decisions on the national direction for freshwater. An at-a-glance summary. https://environment.govt.nz/publications/action-for-healthy-waterways-decisions-on-national-direction-and-regulations-for-freshwater-management/

Monaghan RM, Laurenson S, Dalley DE, Orchiston TS 2017. Grazing strategies for reducing contaminant losses to water from forage crop fields grazed by cattle during winter. New Zealand Journal of Agricultural Research 60: 333–348. doi:10.1080/00288233.2017.1345763.

Monaghan RM, Semadeni-Davies A, Muirhead RW, Elliott S, Shankar U 2010. Land use and land management risks to water quality in Southland. Southland, New Zealand: AgResearch.

Montgomery DR 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences 104: 13268–13272. doi:10.1073/pnas.0611508104.

Myers R, Watts C 2015. Progress and perspectives with cover crops: interpreting three years of farmer surveys on cover crops. Journal of Soil and Water Conservation 70: 125A–133A. doi:10.2489/jswc.70.6.125A

Norton BG, Hannon B 1997. Environmental values: a place-based approach. Environmental ethics 19: 227–245. doi:10.5840/enviroethics199719313

Omokanye AT 2013. Soil nutrient trends and forage production following years of bale grazing in parts of the Peace Region of Alberta, Canada. American-Eurasian Journal of Agriculture & Environment Science. 13(6): 877–84. doi:10.5829/idosi.aejaes.2013.13.06.11011

Omokanye A, Yoder C, Sreekumar L, Vihvelin L, Benoit M 2018. On-farm assessments of pasture rejuvenation methods on soil quality indicators in northern Alberta (Canada). Sustainable Agriculture Research 7(2): 74–93. doi:10.5539/sar.v7n2p74

Provenza FD, Meuret M, Gregorini P 2015. Our landscapes, our livestock, ourselves: restoring broken linkages among plants, herbivores, and humans with diets that nourish and satiate. Appetite 95: 500–519. doi:10.1016/j.appet.2015.08.004

Reed MS, Allen K, Attlee A, Dougill AJ, Evans KL, Kenter JO, Hoy J, McNab D, Stead SM, Twyman C, Scott AS, Smyth MA, Stringer LC, Whittingham MJ 2017. A place-based approach to payments for ecosystem services. Global Environmental Change 43: 92–106. doi:10.1016/j.gloenvcha.2016.12.009

Schwalm D, Epps CW, Rodhouse TJ, Monahan WB, Castillo JA, Ray C, Jeffress MR 2015. Habitat availability and gene flow influence diverging local population trajectories under scenarios of climate change: a place-based approach. Global Change Biology 22: 1572–1584. doi:10.1111/gcb.13189

Schweizer S, Davis S, Thompson JL 2013. Changing the conversation about climate change: a theoretical framework for place-based climate change engagement. Environmental Communication 7: 42–62. doi:10.1080/17524032.2012.753634

Seymour M 2021. Caring food systems? The transformative potential of regenerative agriculture in New Zealand. Unpublished MSc., University of Otago. https://ourarchive.otago.ac.nz/handle/10523/12218

Sim RE, Brown HE, Teixeira EI, Moot DJ 2017. Soil water extraction patterns of lucerne grown on stony soils. Plant and Soil 414: 95–112. doi:10.1007/s11104-016-3112-x

Sim RE, Moot DJ 2019. The influence of spring grazing management on yield and water use of rainfed lucerne. Journal of New Zealand Grasslands 81: 187-194. doi:10.33584/jnzg.2019.81.403

Soloviev ER, Landua G 2016. Levels of regenerative agriculture. Terra Genesis International. 24 p. http://www.terra-genesis.com/wp-content/uploads/2017/03/Levels-of-Regenerative-Agriculture-1.pdf

Sparling G, Lilburne L, Vojvodic-Vucovic M 2008. Provisional targets for soil quality indicators in New Zealand. Landcare Research Science Series No. 34. Manaaki Whenua Press. Lincoln Canterbury, New Zealand.

Springmann M, Spajic L, Clark MA, Poore J, Herforth A, Webb P, Rayner M, Scarborough P 2020. The healthiness and sustainability of national and global food based dietary guidelines: modelling study. British Medical Journal 370: m2322. doi:10.1136/bmj.m2322

Stockdale EA, Watson CA 2012. Managing soil biota to deliver ecosystem services. Natural England commissioned reports, number 100. 163 p. http://publications.naturalengland.org.uk/publication/2748107

Styles T, Laurenson S, Monaghan RM, Dalley DE, Chrystal JM 2013. Seasonal changes in soil structure under winter grazing in Southern New Zealand. Massey University, Palmerston North, NZ: Fertilizer and Lime Research Centre.

Swinburn B., Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR, Brinsden H, Calvillo A, De Schutter O, Devarajan R, et al. 2019. The global syndemic of obesity, undernutrition, and climate change: The Lancet Commission report. Lancet 393: 791–846. https://www.thelancet.com/commissions/global-syndemic

Tamburini G, Bommarco R, Wanger TC, Kremen C, van der Heijden MGA, Liebman M, Hallin S 2020. Agricultural diversification promotes multiple ecosystem services without compromising yield. Science Advances 6: eaba1715. doi:10.1126/sciadv.aba1715

Thomas AD, Elliott DR, Dougill AJ, Stringer LC, Hoon SR, Sen R 2018. The influence of trees, shrubs, and grasses on microclimate, soil carbon, nitrogen, and CO_2 efflux: potential implications of shrub encroachment for Kalahari rangelands. Land Degradation and Development 29: 1306–1316. doi:10.1002/ldr.2918.

Easdale T, Lavorel S, Mason N, Price R, Dominati E, Lucci G, Case B 2021. Environmental co-benefits of non-production vegetation on farm. Wellington, New Zealand: Ministry of Primary Industries. https://www.mpi.govt.nz/dmsdocument/46696-Environmental-co-benefits-of-non-production-vegetation-on-farm

Tozer KN, Müller K, Tarbotton I 2020. Deferred grazing handbook: messages from the sustainable farming fund project pasture management in a volatile world, July 2017 – September 2020. Hamilton, New Zealand: AgResearch Ltd. 32 p. https://www.agresearch.co.nz/assets/Uploads/Deferred-Grazing-Handbook-e-version-Dec-2020.pdf

Vukicevich E, Lowery T, Bowen P, Úrbez-Torres JR, Hart M 2016. Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture: a review. Agronomy for Sustainable Development 36(48): 1–14. doi:10.1007/s13593-016-0385-7

Wallace D, Sorensen I, Arnold N, van der Weyden J, van den Dijssel C, Dellow S, Wright P, Clark G, Cummins M, Green S, et al. 2020. Protecting our groundwater (FAR/MFE Fluxmeters): Plant and Food Research May 2020 report update.

Weisser WW, Roscher C, Meyer ST, Ebeling A, Luo G, Allan E, Beßler H, Barnard RL, Buchmann N, Buscot F, Engels C, et al. 2017. Biodiversity effects on ecosystem functioning in a 15-year grassland experiment: patterns, mechanisms, and open questions. Basic and Applied Ecology 23: 1–73. doi:10.1016/j.baae.2017.06.002

Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A, et al. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet 43: 447–492. https://www.thelancet.com/commissions/EAT

Williams PH, Tregurtha CS, Francis GS 2000. Strategies for reducing nitrate leaching from vegetable crops grown in Pukekohe. New Zealand Fertiliser Manufacturers' Research Association Technical Conference (26th, 2000 Lincoln NZ). Pp. 70–76.

Woolley J-M, Eager C, Jozaei J, Paul V, Paulik R, Pearce P, Sood A, Stuart S, Vincent A, Wadhwa S, Zammit C 2020. Climate change projections and impacts for Tairāwhiti and Hawke's Bay, prepared for Envirolink, Gisborne District Council and Hawke's Bay Regional Council. Auckland, New Zealand, National Institute of Water & Atmospheric Research Ltd (NIWA). 248 p.

Wright AJ, de Kroon H, Visser EJW, Buchmann T, Ebeling A, Eisenhauer N, Fischer C, Hildebrandt A, Ravenek J, Roscher C, et al. 2017. Plants are less negatively affected by flooding when growing in species-rich plant communities. New Phytologist 213: 645–656. doi:10.1111/nph.14185