Manaaki Whenua
Landcare Research

Productivity: Indicators and associated methodologies to quantify production

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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 who 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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Productivity: Indicators and associated methodologies to quantify production

Contract Report: LC3954-9

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Contents

1 Introduction

Farm productivity is the yield or output from a farm system and usually a ratio of output per unit of input (e.g. kg pasture dry matter/hectare). This chapter examines how to assess the productivity of different systems in multiple sectors using measures of quality and quantity of farm product. The balance between the quantity and quality of products varies in importance depending on the contracts for supply, target markets, farmers' values, management systems, and the sectors involved. Here, the focus is on-farm productivity, we do not address how to assess productivity beyond the farm gate (e.g. at the processor and retailer end of the food and fibre distribution and supply chains).

The assessment of productivity using measures of quantity and quality is based on extensive research and protocol development, mainly focused on farm systems under conventional management. Applying the same methodologies to systems that align with regenerative agriculture (e.g. diverse pastures, high grazing residuals, cover crops, reduced cultivation) may be challenging. Further challenges arise since our knowledge of productivity under regenerative systems is limited by lack of quantitative data. We draw on studies that explore systems design and farm management practices that are similar to, or overlapping with, those found in regenerative agriculture (e.g. organic, minimum tillage, diverse pastures, grazing management) to highlight potential knowledge gaps. However, we recognise that regenerative systems are complex and context-specific, so systems-level comparisons will be required to fully understand the productivity of these different agricultural systems.

This chapter focuses on the measurement of productivity per unit area, or per livestock equivalent, over a particular time period, as is standard practice across the primary sectors. We highlight some of the challenges with using these assessments across different farm systems. Further, we acknowledge the importance of alternative ways to view farm productivity, although these are out of the scope of this report (e.g. nutrient use efficiency, water use efficiency, and greenhouse gas mitigation, nutrient density of foods, animal health, and welfare). Assessing productivity through these different lenses may be of greater importance under regenerative agriculture practices because farming systems are altered and particular consumers targeted with branded products. Changes in policy may also make some of these indicators increasingly important.

2 Assessing productivity in the pastoral sector

2.1 Primary production

Across the pastoral sector, primary production is typically measured as the amount of plant material grown (Table 1), both in terms of quantity (e.g. tonnes Dry Matter/ha/yr) and quality (e.g. MJ Metabolisable Energy/ha). Assessment is typically conducted at the paddock scale to determine available feed. The number of stock units supported per land unit on pastoral farms is another way productivity can be assessed, and this approach should also account for the application of external inputs (e.g. supplements).

Under conventional pastoral management, the assessment of the quantity of herbage production often uses tools that are calibrated to ryegrass/clover systems (Table 1). However, these tools (e.g. rising plate meter) may not provide accurate assessment of pasture quantity beyond the species and systems for which they are calibrated. Under regenerative systems, changes in the diversity of species present in the sward, variable herbage heights, and unique plant characteristics or traits make this assessment difficult. The standard for determining primary productivity in any pastoral system will remain yield measured from harvesting a known area of pasture (quadrat cuts) to ground level (or grazing height), followed by dissection of the sample into each species if required. Beyond field-based measurements, proximal and remote sensing tools have been developed; however, there are significant challenges in developing robust algorithms for measurement (Hilker et al. 2008; Harpold et al. 2015; Feilhauer et al. 2017; Gerhards et al. 2019). In New Zealand, few commercial options exist, and they would likely require recalibration for diverse pastures compared to ryegrass/clover systems.

Pasture quality may be assessed through species composition or percent dead matter. In typical New Zealand pastoral grazing systems pasture quality is commonly measured as metabolisable energy (MJ ME/kg, or just ME) using Near-Infra Red analysis of plant samples (Table 1) or proximate analysis. Metabolisable energy provides information about the energy in the feed and its digestibility (Waghorn 2007). However, pasture quality is more than this, and includes its nutritive value as well as feeding value (Ulyatt 1978), which incorporates livestock ingestion and digestion dynamics. Gregorini (2007) redefines the feeding value of grazed herbage as a cluster of three main components: herbage chemical composition; nutrient requirements of the animal; and the availability and accessibility of particular morphological components of the sward plants to meet the 'desires/needs' of the grazer. This redefinition can help us evaluate productivity of alternative swards and grazing methods better than traditional assessments of pasture quality. Altering grazing management to induce higher grazing residuals increases pasture age, which can reduce ME (Waghorn & Clark 2004). Further, the species composition of diverse pasture swards is dynamic from season-to-season and year-to-year and grazing management systems to maintain the prevalence of desirable species in the sward have not been defined (Tozer et al. 2016).

Pasture productivity is influenced by climate, landscapes, and soils, as well as management of farm systems. Understanding how pasture productivity (including resilience and persistence) is influenced by adverse climate events will be crucial in our understanding of the performance of these systems. Further understanding how farm management might change soil–plant–animal interactions, in particular the impacts of soil biological health on plant performance, is a key knowledge gap.

2.2 Animal production

Changes in pasture quality and quantity will influence animal production. Animal production is an important driver of productivity in the pastoral sector, with income directly linked to the quantity of animal products (e.g. milk solids, meat, wool). Animal production is also important for the arable sector, and there is a greater emphasis on livestock as part of the crop rotation under regenerative agriculture. The indicators used to assess animal productivity are sector specific, based on information collected as part of the farm business, either on-farm or by the processors, expressed per unit area or per stock unit (Table 1).

In dairy systems the amount of milk solids (kgMS/ha/yr or kgMS /cow/yr) is an important measure of productivity (Table 1). Understanding the relationship between changes in primary productivity as a result of regenerative principles and animal performance is critical. For example, increased plant diversity can improve plant yields (Mueller et al. 2013; Mason et al. 2020) and may increase pasture production through drier periods (Nobilly et al. 2013; Woodward et al. 2013), but does not necessarily equate to increased milk production or affect product quality (Woodward et al. 2013; Gregorini et al. 2017; Beck & Gregorini 2020).

In the meat and fibre systems, offspring liveweight gain (gLW/day/animal or gLW/day/ha) is important, with the quality of product being assessed through measures such as carcass weight/grade and wool length/strength (Table 1). How farm systems are managed influences the growth of young stock and the reproductive performance of livestock, which drives the lifecycle of the farm system. For example, organically managed dairy systems have lower animal productivity than their conventional counterparts (Shadbolt et al. 2009; Apparao et al. 2013). In organic sheep-grazed systems, livestock performance is reduced due to lack of effective controls of livestock parasite burdens (Mackay et al. 2006). In systems where mixed age/species livestock flocks/herds are utilised, it will be important to investigate how young animals/low social order animals perform in terms of animal production.

Current metrics of quality for milk, meat and wool drive product prices and are determined by contracts for supply to specific markets. It will be important to determine which farm management practices have the biggest impacts on product quality (especially for animal products such as meat and milk) and how these might change flavour profiles and other processing aspects.

2.3 Assessing productivity across other sectors

Just as the pastoral sector measures productivity through quantity and quality, so too do the arable and viticulture sectors (

Table 2). Typically, this would be weighed (tonnes Dry Matter/ha/yr or tonnes Fresh Weight/ha/yr). Improving our understanding of how management influences crop quantity, alongside trade-offs with other farm indicators, is required. For example, greater length and diversity of crop rotations (as utilised under regenerative agriculture) can benefit harvested yields (Merfield 2019). However, biodynamic mixed cropping systems may not be as productive as conventional systems (Nguyen et al. 1995) and minimum tillage can have variable results on crop productivity (Fraser & Beare 2008).

The influence of regenerative systems on crop quality may be especially important. In arable systems, crop quality may be measured through grain quality or seed quality (

Table 2). The use of cover crops, rotations, and intercropping may diversify products grown on farm but may influence crop quality, especially in terms of foreign matter and seed purity. Understanding risks from the prscene of seeds or plants that impact nearby or subsequent crops needs to be considered. Currently, weed pressure and distance between flowering plants is controlled through an assurance programme for seed producers; however, increased crop diversity may influence this and impact seed purity.

The quality of harvest may be of greatest importance to the viticulture sector. 'Brix' meters (refractometers) were originally developed to measure sugar levels in harvested grapes and are an important indicator of the quality of grapes harvested in the viticulture sector. However, a comparison of organic and conventional vineyards found comparable grape yields with no distinctive differences in wine quality (Reider & Arnst 2015). Hence, understanding which managements may have the biggest impact on product quality will be important to ensure reliable products into the future.

3 Knowledge/technological gaps

In order to advance our understanding of productivity under different management systems, there are key areas that need to be addressed. The knowledge gaps listed below are focused on farm productivity and do not include aspects of other outcome working groups such as profitability, animal health, soil health, and water quality. Farm system comparisons are likely to be required,.

Investigating the impacts and trade-offs of different management on productivity and its relationship with other farm indicators (e.g. farm profitability, food nutrient density and on-farm nutrient use efficiency, water use efficiency and greenhouse gas mitigation) will be important to improve our understanding of different management systems.

- Key knowledge gaps include: determining which tools require further development to estimate the quantity and quality of diverse pastures
- developing an understanding of grazing principles in highly diverse pasture swards, and how selective and competitive grazing affects pasture performance, including feeding and nutritive values
- determining how the productivity of regenerative systems is influenced by adverse climate events in comparison to conventional systems, including resilience and persistence of pastures
- understanding how farm management might change soil–plant–animal interactions, in particular the impacts of soil biological health on plant performance
- investigating how production of young animals/low social order animals is impacted in mixed age/species livestock flocks/herds
- establishing the impacts of farm management (diverse pastures/cover-crops/biostimulants) on product quality (meat/milk/wine) and quantity

understanding risks from the presence of seeds or plants that impact on the production of other crops (e.g. certified seed production).

Table 1. Indicators and methods used to assess productivity in the pastoral sector (D=dairy; S= sheep & beef). All indicators shown are used for sector benchmarking methodologies used may vary from farm to farm. Priority measurements for research purposes are rated 1, other measures are rated 2 to all measures are applicable across all sectors (na)

Indicator	*Method*	*Use: C = cheap; A = accurate; S = scalable; R = more research req.*				*Reference*	*Priority: 1 = must; 2 = maybe; na = not applicable*		*Potential issues under regen agriculture*
		A	*C*	*S*	*R*		*D*	*S*	
Primary production									
Pasture quantity									Difficult to assess diverse pastures. Control of weeds.
How much pasture is grown/consumed (tDM/ha/yr)	Visual assessment		✓			(Lile et al. 2001)	2	2	
	Sward stick		✓				2	2	
	Plate meter		✓	✓		(Lile et al. 2001)	2	2	
	Pasture cages/cuts	✓				(Lile et al. 2001)	1	1	
	Rapid plate meter			✓		(Dalley et al. 2009)	2	2	
	Automatic pasture reader			✓	✓	(Dalley et al. 2009)	2	2	
	Remote sensing			✓	✓	(Dalley et al. 2009)	2	2	
Pasture quality									Changes through time.
Botanical/species composition	Visual assessment/ herbage dissection		✓			(Lambert & Litherland 2000)	2	2	
	Dead matter (%)		✓				2	2	
Metabolisable energy	Herbage analysis (wet chemistry or NRIS)	✓		✓		(Waghorn 2007)	1	1	Standard assessment using ME (MJME/ha) but nutritive and feeding value may provide more information.
Protein content	Herbage analysis	✓		✓			2	2	
	Remote sensing			✓	✓	(Yule et al. 2013)	2	2	
Fibre content	Herbage analysis	✓		✓			2	2	

Indicator	*Method*	*Use: C = cheap; A = accurate; S = scalable; R = more research req.* A	C	S	R	*Reference*	*Priority: 1 = must; 2 = maybe; na = not applicable* D	S	*Potential issues under regen agriculture*
Mineral content	Herbage analysis	✓		✓			2	2	
Nutritive value	Models + herbage analysis	✓		✓		(Waghorn & Clark 2004)	1	1	
	Remote sensing			✓	✓	(Pullanagari et al. 2012)	2	2	
Feeding value	Models + herbage analysis	✓		✓		(Waghorn & Clark 2004)	1	1	
Stocking rate	Livestock (cows/ha or SU/ha or kg/ha or comparative/revised stocking rate)					(Crawford & Lowe 1994)	1	1	Accounting for livestock in non-pastoral sector for comparison
Animal production									
Milk production									
How much milk is produced (kgMS/ha/yr or kgMS/cow/yr)	Measured. Processor/herd test	✓	✓	✓			1	na	
	kgMS/cow at peak kgMS/cow/day, days in milk per cow	✓	✓	✓			2	na	
Cow efficiency	Production per cow in relation to average herd liveweight (MS as % liveweight)		✓	✓			2	na	
Milk quality	Somatic cell count	✓	✓	✓			1	na	
	Fat evaluation index	✓	✓	✓			1	na	
	Milk composition	✓				(Schwendel et al. 2015)	2	na	
Meat and fibre production									
Net production	Total liveweight production (kg/ha/yr)		✓	✓			na	2	
Liveweight gain	Offspring growth rate (gLW/day per animal or per ha)	✓	✓	✓			na	1	Susceptibility to disease, animal welfare issues.

Indicator	Method	Use: C = cheap; A = accurate; S = scalable; R = more research req.				Reference	Priority: 1 = must; 2 = maybe; na = not applicable		Potential issues under regen agriculture
		A	C	S	R		D	S	
Percentage offspring	Measure of reproductive performance (%)	✓	✓	✓			na	1	
Flock efficiency	Measure of fertility and feed management (%)		✓	✓			na	2	
Meat quality	Carcass weight/grade	✓	✓	✓			na	1	
	pHu	✓	✓	✓		(Lomiwes et al. 2014).	Na	2	
	Intramuscular fat content		✓	✓			na	2	
	Eating quality (seven indicators)		✓	✓			na	2	
Wool quality	Yield	✓	✓	✓			na	2	
	Fibre diameter	✓	✓	✓			na	2	
	Length and strength	✓	✓	✓			na	2	

Table 2. Indicators and methods used to assess productivity in other sectors (A=arable; V=viticulture). All indicators shown are used for sector benchmarking methodologies used may vary from farm to farm. Priority measurements for research purposes are rated 1, other measures are rated 2 to all measures are applicable across all sectors (na)

Indicator	*Method*	*Use: C = cheap; A = accurate; S = scalable; R = more research req.*				*Reference*	*Priority: 1 = must; 2 = maybe; na = not applicable*		*Potential issues under regen agriculture*
		A	*C*	*S*	*R*		*A*	*V*	
Primary production									
Crop quantity									Incorporating multiple crops/intercropping.
How much crop is produced (tDM/ha/yr or tFW/ha/yr)	Visual assessment		✓				2	2	Fresh or dry weight depending on the crop
	Weighing/yield monitors	✓	✓	✓			1	1	
	Remote sensing			✓	✓		2	2	Sub-annual timescales. Accuracy for plant health and nutrient status but not grain yield
Crop quality	Crop dependent								
Grain quality	Grain quality (protein %)	✓	✓	✓			1	1	Bulk density or 100 seed weight and foreign matter may be another important factor
	Moisture (%)	✓	✓	✓			2	2	
	Harvest Index	✓	✓	✓			1	1	Used for research
Seed quality	Seed purity	✓		✓			1	1	Intercropping effects of seed purity
	Seed germination	✓		✓			1	1	
Wine quality	Brix (%) refractometer	✓	✓	✓		(Reider & Arnst 2015)	1	1	pH, and total acidity, total soluble solids also important for wine quality

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