

Application of circular economy principles to New Zealand pastoral farming systems

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Abstract

Global food production is under pressure to produce more from limited resources, with further expectations to reduce waste and pollution and improve social outcomes. Circular economy principles aim to design out waste and pollution, minimise the use of non-renewable external inputs and increase the lifespan of products and materials. Waste sources on New Zealand farms and options to reduce waste and improve circularity were reviewed. Waste reduction should begin with systems design, while recycling should be at the bottom of the hierarchy. On-farm resource use efficiency has been widely studied, but there are also opportunities to repurpose waste and integrate systems. The use of organic waste products as fertiliser and supplementary feed occurs to some extent, as does use of excess dairy calves in the beef industry, but they present both opportunities and challenges. More farm waste recycling opportunities are becoming available, with new products available from waste processing, such as plastic fence posts. Circular strategies in New Zealand agriculture require more analysis to determine economic, social, cultural and environmental outcomes.

Keywords: material flow, plastic, recycling, resource use efficiency, waste management

Background

Producing enough safe and nutritious food for future populations without exhausting resources or degrading ecosystems is a major global challenge (Rockström et al. 2017). New Zealand agriculture has become increasingly reliant on external inputs such as synthetic fertilisers, irrigation, imported feed, agrichemicals and infrastructure. These inputs can enable productivity gains but can also lead to increased waste and environmental degradation.

Circular economy business models could help tackle such pressures (Purnell et al. 2019). Although there is no single agreed definition of the circular economy, the general principles are “designing out waste and pollution, keeping products and materials in use, and regenerating natural systems” (Ellen MacArthur

Foundation 2019). “Designing out” waste and pollution includes investigating renewable and sustainable inputs, including the use of waste products to replace the use of primary resources and prioritising local inputs where feasible (Murray et al. 2017). “Keeping in use” aims to extend the life of products and inputs, reducing demand for new inputs. Principles such as longevity (Figge et al. 2018), product stewardship, and business models (Rizos et al. 2016) that enable redistribution of resources are all part of this stage. To this list of important elements, Murray et al. (2017) adds the design and management of systems to maximise ecosystem function and human well-being.

de Boer and van Ittersum (2018) defined principles, barriers and incentives for circularity in food production, focusing on nutrient use in systems dominated by arable land use. An opportunity exists for New Zealand to capture the benefits of this global phenomenon of increased circularity in food production, however, its application in pastoral agriculture is not well documented. Here, we give an overview of current examples of application of circular economy principles in New Zealand pastoral farming, noting some costs and benefits, and outlining the gaps in knowledge that need addressing to improve circularity in New Zealand agriculture. Circularity post farm gate is outside of the scope of this review.

Approach

We searched literature using the Scopus database, with the search terms in the title of “circular economy” and “review”, producing 69 articles. Titles were assessed for their potential application to agriculture. Relevant articles from this search, along with those referenced within them, information sourced via the Ellen MacArthur Foundation (<https://www.ellenmacarthurfoundation.org/>) and from a search of circular bioeconomy on the Wageningen University website were used to define the principles of a circular economy, as related to agriculture. Applications of these principles to New Zealand pastoral agriculture were reviewed, using both Scopus and Google and searching within the *New Zealand Journal of Agricultural*

Research, *Journal of New Zealand Grasslands* and publications from the New Zealand Society of Animal Production, including terms such as farm waste and recycling, nutrient, water and energy efficiency, organic fertiliser and integrated enterprises. StatsNZ, Ministry for the Environment and Ministry for Primary Industry websites were searched for specific data on resource use and regulatory requirements.

Results and Discussion

Resource use and waste on New Zealand farms

“Waste” can be viewed as anything that ends up in landfill but can also refer to resources and nutrients that cannot be recovered or are used inefficiently. Wheeler et al. (2004) showed that many New Zealand dairy farms had soil test phosphorus (P) levels above optimum for pasture production as a result of excess P inputs. Furthermore, New Zealand farms with greater inputs of N and P risk greater loss of these nutrients, contributing to declining water quality, and for N, greenhouse gas emissions (Monaghan et al. 2007). Sediment loss is a waste of the soil resource and is typically greatest in catchments where deer are farmed, followed by sheep and beef then dairy (McDowell & Wilcock 2008), with the risk increased under forage cropping (McDowell & Houlbrooke 2009).

Resource waste also occurs via incursion of pasture and crop pests, weeds and diseases. Soil-borne nematodes attacking white clover may reduce total pasture yield by 15% (Watson & Mercer 2000) and increase the need for N fertiliser and pasture renewal. Such incursions can also require use of additional agrichemicals, with approximately 79 tonnes (t) of active ingredients from pesticides applied to New Zealand pastures in 2004 (Mansfield et al. 2019). Although conserved pasture reduces pasture waste and provides supplementary feed with a relatively low carbon footprint (see below), silage requires 1.3 kg plastic per round bale, or 40 g plastic per m² of pit silage (Pers. comm. Tony MacDonald, Donaghy's Crop Packaging), whilst feeding silage and other supplements typically requires additional machinery and fuel use. The nutritive value of pasture declines by 10–20% during hay making, with a smaller decline for silage (Litherland & Lambert 2007). Supplements may be wasted due to poor utilisation and/or spoilage, but this is reduced with appropriate infrastructure.

Approximately 8% of dairy farm operating expenditure is on animal health and breeding costs (DairyNZ 2019). Animal health issues also result in reduced production, discarded milk and condemned carcasses. However, in 2019, less than 1% of the total New Zealand cattle and sheep kill were condemned at slaughter (StatsNZ 2019). In addition, reproductive inefficiency is a form of waste in all livestock systems.

Approximately 17% of dairy cows do not conceive within the timeframe desired by farmers (LIC 2019). These cows are normally culled, with the total culled typically greater than optimum for profitability (Lopez-Villalobos & Holmes 2010). Culled cows are typically processed for meat and by-products, but additional resources are required to raise their replacements.

Efficient water and energy use are also important considerations in circular economies. In 2006, 78% of New Zealand's extracted water was used for irrigation, 3% for livestock drinking, with the remainder for public and industry use (New Zealand Parliament 2011). An estimated 26% of stock drinking water is lost through leaks, which, in turn, can damage pasture and increase energy use for pumping water (Higham et al. 2017). Electricity use in New Zealand produces average emissions in CO₂ equivalents (CO₂e), of approximately 150 g CO₂e/kWh (unpublished data S. Falconer and S. Ledgard 2020), compared to 2,990 g CO₂e/L diesel and 2,760 g CO₂e/L petrol (Ledgard et al. 2020).

In a survey of 53 rural Canterbury properties, including dairy, drystock, cropping and horticulture, more than 50 types of material wastes were identified, with an average of 9 t of inorganic and 14 t of organic waste per farm each year (Hepburn 2013). A similar survey in Waikato and Bay of Plenty found widespread use of on-farm dumps and burning of waste, with 20% of dumps adjacent to a watercourse (Matthews 2014). That survey reported dairy farm annual average farm waste streams of approximately 18 t timber and building waste, 4 t of animals and plant material, 0.7 t vehicle and machinery waste, 0.7 t packaging and containers and 1.2 t of other materials.

Circular strategies for New Zealand agriculture

Circularity principles in agriculture can be applied to one production sector but often involves integration of multiple enterprises (Jeffries 2019) to provide more opportunities to keep resources in circulation. The nutrients exported in food and fibre-based products can be partially replenished on the farm by co-products or waste streams from other enterprises, whilst minimising losses to the environment and using economically viable processes and procedures to increase food value (Jurgilevich et al. 2016; Toop et al. 2017). Whether by-products are used for animal feed, soil fertility or to generate energy should be driven by optimisation of the entire food system (de Boer & van Ittersum 2018). However, without regulations promoting circular economies, these decisions will likely be driven by economics.

Circular New Zealand farming systems can be characterised by minimised inputs of unsustainable resources, maximised resource use efficiency on-farm and repurposing of waste from, and to, other systems.

This approach should simultaneously lead to reduced environmental emissions.

Opportunities to minimise inputs or increase efficiency

In order to reduce the use of pesticides, integrated pest management strategies have been proposed, with training and education required to aid adoption (Mansfield et al. 2019). It is acknowledged that this method will not completely control pests and the overall impact on circularity would require assessment of economic, environmental and social outcomes. While N can be sourced from the atmosphere *via* biological fixation, conventional agriculture is dependent on mining more finite resources for other nutrients. The use of precision agriculture has optimised the requirement for these inputs, ensuring fertiliser and other agrichemicals are applied only when and where needed (Dennis et al. 2015; Ward et al. 2016).

Resource use efficiency has already received much attention, and guidance has been given for effluent management, alternative feeds, animal stocking and replacement rates, and fecundity to improve efficiency and lower environmental impacts (Dynes et al. 2011, van der Weerden et al. 2018, Beukes et al. 2019). In many cases, these improvements in efficiency improve farm profit, but this is dependent on season, feed price, product price and the requirement for capital investment and new skills (Dalley et al. 2018).

Renewable energy sources should be considered over fossil fuels and tools are available to increase energy use efficiency, such as heat recovery systems and milk vat insulation. Methane produced from dairy effluent ponds represents a potential energy source, although most of New Zealand pasture-based farms do not generate enough effluent to make this economically viable (Milet et al. 2015). A 900-cow Southland dairy farm has implemented a biogas plant. Gas from the covered pond is filtered and stored in gas bottles and is used to generate all of the hot water and most of the power required at the dairy. With a capital cost of approximately \$0.2M, estimated pay-back is seven years. Additional claimed benefits include reduced odour and the conversion of methane to carbon dioxide, which has a lower global warming potential (McVeagh 2017).

Opportunities for re-use

Circular water use includes capture of rainwater and reuse of milk cooling water for washing yards. Compliance rules must be followed when recycling effluent water (Ministry for Primary Industries 2017). Technology and best management practices could increase water use efficiency for irrigation (Martin et al. 2008), but the capital cost of adopting such technology can be a barrier (Clark et al. 2007) and may be best

achieved when infrastructure is due for replacement.

The nutrients in livestock excreta are also reused, both from that returned to the land during grazing and during spreading of effluent. However, nutrient losses occur during this recycling, but they can be reduced by appropriate management practices (Shepherd et al. 2017). Efficient use of this resource also reduces the costs and requirements for external inputs of soil nutrients.

Regenerative use of waste products

Ruminant livestock can have a critical role in circular economies through utilising crop residues and wastes from human food production and processing. Although this can provide cheap feed supplements, the overall economics depends on transport distances, feed nutritive value, palatability and wastage and the ability to incorporate such waste products into the farming system when required whilst minimising risks to animal health. There is a lack of current data on regional availability of organic waste streams and the economics of their use. Many horticultural waste products have a high feeding value for ruminants but increase the risk of acidosis. Their use might also be limited by pesticide contamination or limited storage life (de Ruiter et al. 2007).

Replacing raw materials with waste products as inputs is generally assumed to reduce a farm's carbon footprint, as emissions associated with waste product use are largely allocated to the main products. However, the waste product palm kernel expeller has emissions of 515 g CO₂e/kg DM; considerably higher than the alternative supplementary feeds of pasture silage, maize silage and barley, at 70, 172 and 403 g CO₂e/kg DM, respectively (Ledgard et al. 2020). This is due to the largest contributing sources of emissions of palm kernel expeller being associated with shipping to New Zealand and deforestation in the last 20 years. The relative impact on nitrate leaching will largely depend on the nitrogen concentration of the feed (Dalley et al. 2018).

The nutrients found in organic wastes have the potential to be recovered and reused in food production systems to reduce the reliance on fertiliser inputs and increase overall nutrient use efficiency. With mineral fertiliser and lime manufacture and transport contributing approximately 6% of New Zealand dairy farm greenhouse gas emissions (Ledgard et al. 2020) and organic wastes potentially adding to soil carbon, there may be small benefits to carbon balances by replacing some of these inputs with organic waste. However, manure must be appropriately managed or processed to prevent transfer of pathogens and contaminants (Mossa et al. 2020) and to reduce methane and nitrous oxide emissions and issues with smell (Bos et al. 2017).

Current New Zealand regulations (Ministry for Primary Industries 2017) state that human waste, meat processing waste and waste from tanneries and pulp and paper mills cannot be applied to land for grazing milking animals. Furthermore, organic waste has a variable composition and releases minerals slowly, potentially reducing nutrient losses but not necessarily matching plant demand. However, Taupo sewage wastewater is applied to land used for silage production, but the wastewater is low in nutrients, averaging 40 g/m³ N and 9 g/m³ P (O'Connor et al. 2002). The current cost-effectiveness of use of biological wastes for farm soil nutrients is not known.

Dead stock that are not fit for human consumption can be converted to protein meal for animal feeds, tallow and hides (Wallace Corporation 2020). Adoption of this practice is limited by lack of availability in some areas and by the cost of collection for cows of \$75 each (pers. comm. S. Lawton, Wallace Corporation 7 May 2020). Protein meals from ruminants cannot be fed back to ruminants in New Zealand and many other countries, because of the risk of bovine spongiform encephalopathy (Biosecurity New Zealand 2019). Although dead stock can also be composted, regulation prevents spreading the compost on grazed pastures or feral cropping areas (DairyNZ 2012).

Opportunities for recycling

The last tool in the circularity hierarchy is recycling of waste. Schemes are available for reuse and/or recycling of metal and plastic waste. Participating brands for over 3000 products pay a levy, enabling plastic container collection and safe chemical disposal (AgRecovery 2018). Stringent cleaning and transport requirements are barriers to adoption for some farmers (Rankin 2019) but AgRecovery claim to have recycled 2,427 t of containers since 2007. Plasback provides additional recycling of silage wrap, twine and polypropylene bags (Plasback 2013).

New technology can aid in infrastructure longevity and recycling. DairyFlo produce plastic milk liners from 20% recycled plastic, which may last twice as long as rubber liners and can be reprocessed at the end of life (DairyFlo 2018). Future Post makes fence posts from 100% recycled plastic, taking back damaged posts for further recycling (Future Post Ltd 2020). They can be used on organic farms, where copper, chromium and arsenic treated (i.e. Tannalised®) wooden posts cannot be used. Perceived adoption barriers are a higher purchase cost than standard wooden posts and more care required during installation.

Integrating systems

Expanding the geographical boundaries of circularity beyond the single farm to allow low-value products or

wastes from one system to replace 'linear' inputs for another provides greater possibilities for circularity and thus improved nutrient cycling (Garrett et al. 2017, Moraine et al. 2017). Integrated crop and livestock systems can reduce some costs, labour and agrichemical use and increase soil carbon, but these responses are highly variable and in some cases are less profitable (Niles et al. 2018).

An example in Marlborough is the grazing of sheep in vineyards for understory control and leaf plucking to promote grape quality. This largely occurs in winter, when pastoral farms are feed limited. The understory control also reduces mowing and agrichemical use (Niles et al. 2018). The viticulturalists typically pay for the sheep to graze, but overall financial outcomes for the sheep farmer rely on the grape grower's sheep management skills.

Another example is the use of surplus calves from the dairy sector to replace the breeding cow/calf component of traditional sheep and beef systems (Burggraaf & Lineham 2016). Replacement of a breeding cow and its calf by a surplus dairy calf that otherwise might be slaughtered at 4-days-old, avoids the feed requirement for a breeding cow and its associated environmental emissions and provides better value from surplus calves for dairy farmers. Payen et al. (2019) showed that greenhouse gas emissions per kg beef are approximately one-third lower from dairy-derived calves than from traditional beef, whilst Ledgard et al. (2016) showed the nitrogen footprint can be reduced by 7 to 13%. However, the number of surplus dairy calves is greater than can be used by the beef industry (Hunt et al. 2019) and demand depends on beef prices. Calves with apparent Jersey genetics are largely unwanted by beef farmers due to perceptions of poorer growth and yield. Alternative beef systems for these calves are being investigated, with slaughter at 8 to 12 months of age, enabling use of more bobby calves, but modelling suggests an 11–27% price premium is required to be competitive with Friesian bull beef (Hunt et al. 2019).

Regions vary in their resource availability and suitability for producing certain foods, and degree of processing and population size for food consumption. Taking advantage of this variability and sharing resources across regions may outweigh the carbon emissions associated with longer transport distances, but adoption also depends on transport costs (McCabe et al. 2020). Life cycle assessment should be used to evaluate the implications of waste use within a 'circular economy' to ensure whole-system efficiency gains and avoid environmental trade-offs (Ward et al. 2016).

Conclusions

New Zealand farmers have a suite of options available to follow circular economy principles that

design out waste and reduce harm to the environment. Resource use efficiency will continue to improve on farm as new knowledge and technology becomes available that improves profit, lifestyle or helps to meet environmental regulations. For agriculture to address circularity at a larger scale, more research is required to quantify and determine the best use of biological resources and their associated waste across enterprise types, determining the skills and technologies required and the economic, social, cultural and environmental impact of this amongst the associated supply chains. However, optimal benefits may not be achieved unless industries work together, and appropriate policies are implemented to reduce waste.

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