Nutrient density and food quality in the context of regenerative agriculture

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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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Nutrient density and food quality in the context of regenerative agriculture

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Contents

1 What is food quality?

Food quality is a complex function of a number of factors including:

- the chemical composition of a food – the concentrations of nutrients (e.g. nutrient density), phytochemicals (also often referred to as secondary metabolite profiles or bioactives)
- the forms in which they exist (e.g. glycosylation status), as well as their associated health attributes
- food safety – freedom from pathogens, mycotoxins, chemical contaminants, and toxic levels of minerals or phytochemicals
- organoleptic quality – including taste, flavour, aroma, colour/visual appearance, texture/mouth feel, and storage stability
- other properties allowing handling and distribution along the supply chain.

There are many subjective aspects of quality ('process' attributes and consumer values) that could influence the price or perception of a product. These include certification, branding and endorsements – was it produced organically, locally, seasonally, ethically, or is it free from undesirable attributes (e.g. residues, animal products, allergens). Another category is 'value' or 'function' attributes such as size, packaging and shelf life of a product. Using the narrow definition of 'quality' at the outset of this paper seems unhelpful. Also, when considering the 'quality' of food produced from a production system, it is critical to consider the harvestable yield and its profitability, ensuring economically sustainable production as well as aspects such as carbon and water footprint are acceptable.

The current regenerative agriculture (RA) narrative evolves around 'nutrient-density' and thus in this report, we will focus mostly on defining and assessing food composition=nutritional value of individual food items, and how this might or not be affected by the way the food items are grown on farm. When evaluating nutritional composition it is important to determine if any differences in concentrations of nutrients between RA and conventional growing practices are of dietary significance. For, example a mineral could be two-fold different but if it is less than one percent of the recommended dietary intake, the difference would not be significant in terms of human health. Once we have addressed these questions, then other aspects of 'quality' (including yield per hectare, profitability, safety, sensory quality, environmental and economic sustainability) can be considered. Some of these later aspects are outside the scope of this report and are instead discussed in accompanying reports (e.g. Schon et al. 2021a, 2021b; Grelet et al. 2021).

For this report, additional 'out of scope' topics includes:

- what optimal diet looks like in terms of what food items need to be consumed and in which proportion
- how well food produce travel along the value chain (e.g. fruit blemish, capacity to survive transport and storage)
- quality of fibre produce
- food security (availability of all required food items to all).

There are also questions relating to how to measure quality, the weight to place on various quality parameters, and how to deal with gaps in knowledge and data on various food quality indicators.

The author acknowledges that in this space there is a lack of high-quality, peer-reviewed science articles. Thus, this chapter draws on articles from low impact or non-peer reviewed articles and citizen science. This highlights the need for more credible research in this space.

2 The nutritional quality of crops is variable

Numerous factors can directly or indirectly affect the nutritional quality of crops and their safety. These include:

- soil factors, such as pH, available nutrients, texture, organic matter content and soil–water relationships
- weather and climatic factors, including temperature, rainfall and light intensity
- the crop and cultivar
- post-harvest handling and storage
- fertiliser applications and other management and cultural practices (Hornick 1992, 2005; Dangour et al. 2009).

What do we know about the effect of management on the quality of key crops?

At present there are still too few datasets to decide whether RA increases food nutritional quality. In addition, we are still not even sure which indicators should be used to determine the impact of RA on food quality. To understand what aspects may be important in the context of RA, we need to consider the aspects that may be particularly relevant. Very little peer-reviewed research appears to have been published on the impacts of RA on food quality and safety, and in particular on the nutritional and phytochemical composition of crops. This applies to crops grown for human and for animal consumption.

The Bionutrient Institute (formerly the Real -Food Campaign) in the United States, seeks to test whether crop nutritional quality varies with soil health properties and management practices. A study they conducted analysed 298 wheat and 372 oat samples for protein, total antioxidants, polyphenols, and mineral content, sourced from 45 farms across 13 states (https://our-sci.gitlab.io/bionutrient-institute/bi-docs/Grains_Report/). The study also analysed soil carbon concentration and details of farming practices deployed where crop samples were taken. Because farm management practices can increase the concentration of one nutrient whilst reducing the concentration of another, the study developed the Bionutrient Quality Index (BQI). This index was developed to simplify interpretation of complex nutrient density data and aggregates multiple analytes into a single value. The BQI is calculated by summing antioxidants, polyphenols, protein, magnesium, sulphur, potassium, calcium, iron and zinc concentrations in the crop tissue. The formula calculation for BQI is still in development with the help of a community of food scientists, nutritionists, and other experts. Initial results from the study indicated that (i) grains grown by producers identifying with RA had higher BQI compared to grain grown by producers who did not; (ii) no-till or 'light' tillage practices increased both soil carbon concentration and BQI. It should be noted that this study is still subject to formal publication and peer review and further work is needed to validate this and determine if the same holds true in the New Zealand context. In addition, the concept of nutrient density / quality is complex. There is more to it than simply measuring concentrations of selected nutrients and this will / may depend on the food/feed under investigation. This use of the BQI was one of multiple ways to go about it, but there might be others. Below we dive more deeply in the food properties we ought to measure and why.

There may be some lessons from nutrition-sensitive agriculture, but even here evidence on what and how agriculture can contribute to nutrition is extremely scant (reviewed in Ruel et al. 2018). There is also the issue that this work looks at how agricultural interventions in a development context can improve population health, focusing on communities at real risk of nutrient deprivation (and consequential problems such as stunting). It specifically excludes the opposite problem: overweight, obesity, and non-communicable diseases that characterise nutrition-related problems in affluent countries. Yet it is these affluent countries that may be more interested in discussions about 'regenerative agriculture'. There may also be some lessons to be learned from the body of literature on organically grown products (e.g. recent reviews by Mie et al. 2017; Vigar et al. 2019). However, again some of these studies lack scientific rigour and it is often very difficult to control factors to ensure direct comparisons are robust or ultimately determine what factors are actually impacting any differences in nutrient composition.

3 The premise of RA and how it may affect food quality and safety

The goal of RA is to apply the concept of more from less (McAfee 2019). Lal (2020) recently discussed some of the premises of RA. This raises a series of questions (in bullets) on how these might relate to impacts on food quality and safety.

1. Managing soil fertility by enhancing SOM content, biological nitrogen fixation, and relying on the recycling of nutrients instead or more than on inputs of chemical fertilisers.
    - Does this translate into increased yields, higher protein contents and therefore also alter 'nutrient density' ?
    - Do other nutrients/phytochemicals containing nitrogen also increase?
    - How do the relationships between minerals in the soil affect the final contents in the plant?
2. Improving soil structure by increasing activity and species diversity of biota (e.g. earthworms and micro-organisms) and prolific plant roots rather than by ploughing.
    - Are there larger amounts of nutrient resources available for uptake?
    - Do these benefits improve mineral uptake from the soil?
3. Increasing the availability of 'green' water by conserving precipitation, reducing losses by runoff and evaporation, moderating soil temperature, and encouraging deep root systems.

- How does water availability affect nutritional quality (can managing water avoid 'dilution' effects)?
- How does temperature affect nutrient concentrations (e.g. vitamin C is temperature sensitive in some crops at least)?

4 Controlling water and wind erosion through preventive measures of maintaining a continuous groundcover, cover cropping, and conservation agriculture (CA) rather than by curative land forming and engineering structures.

- Do these groundcover and cover crops affect the nutritional composition of co-occurring target crops and subsequent crops?

5 Managing soil acidification and elemental imbalance by biofertilisers (e.g. compost, manure, mycorrhiza) as opposed to over-fertilisation to mitigate against poor yields.

- Do these have benefits in the balance of nutrients (in particular minerals)?
- What safety concerns may arise through the use of these products?

6 Enhancing water infiltration rate by reducing crusting, compaction, hard-setting, and desiccation through retention of residue mulch, cover cropping, and creation of bio-pores through bioturbation of the rhizosphere.

- Can these improvements increase nutrient uptake from the soil?

4 The concept of nutrient density

In developed countries, it is often stated that we are overfed but undernourished, because many people are consuming diets that are energy dense but nutrient poor (Drewnowski 2005). The term 'nutrient density' is often bandied about, including in reference to RA. So what does it mean?

Nutrient density expresses the nutrient content of foods on the basis of a reference amount, typically 100 kcal (i.e. on the basis of energy), 100 g, or per serving (Drewnowski & Fulgoni 2014). Various nutrient profiling systems have been developed to quantify the healthiness of foods to use for labelling as well as for public health purposes in helping consumers with diet selections. Most calculations have relied on nutrient-to-calorie ratios, but the most relevant is probably per serve, because foods are consumed in varying amounts. Several different national and international standards have been developed and are in use for front-of-pack labels including 'traffic light' labels and Health Star Ratings. These differ in their breadth and depth of what components are included and some also differ in the scoring system used between food categories. The 'nutrient-density' concept used by the RA protagonist is "ug or mg X per 100 g produce" or "%RDA per 100 g produce". In addition to the BQI discussed above there are some other scoring systems that could be used.

In New Zealand, Food Standards Australia New Zealand (FSANZ) uses an online tool for determining whether health claims can be made for a food using the Nutrient Profiling

Scoring Criterion (NPSC).[1] However, this only includes macronutrients and a measure of fruit/vegetable content, and not vitamins and minerals (apart from sodium) or other bioactive components.

Another concept is the Nutrient Rich Food Index (NRF), which produces a score that can be applied to individual foods and to total diets (Drewnowski & Fulgoni 2020). This is a family of nutrient profiling models that balance nutrients to encourage against three nutrients to limit (saturated fats, sugars, and sodium), using 100 kcal as the basis of calculation. Various iterations of the score exist, which vary in the number of positive nutrients included, ranging from 6 (NRF 6.3) to 15 (NRF 15.3). However, even the NRF 15.3 is very limited.

A more recent tool recently published is Food Compass (Mozaffarian et al. 2021). This tool includes a broader range of attributes and domains than found in previous systems with uniform and transparent principles. Food Compass incorporates macronutrients, vitamins and minerals but also multiple health-related food ingredients, phytochemical contents, specific lipids and processing features. A key difference from some other tools is that Food Compass utilises updated evidence for the health effects of both established and emerging factors.

At present there is no perfect tool to consider all the factors that may be important in the RA context. The question also arises as to whether changes in growing practices resulting in changes in nutrient or phytochemical composition translate to changes in the score in any of these nutrient profiling scoring systems. The tools may easily discriminate a carrot and a chocolate bar in terms of healthiness, but do more subtle differences in composition translate to changes in a profiling score?

In considering the use of such tools, it is important to remember that no one food contains the whole array of nutrients and bioactives needed to sustain life and promote good health. We don't eat foods in isolation, and even a diet based on a great deal of high-nutrient density foods could still lack several essential nutrients and not allow optimal health to be achieved. These are important considerations when thinking about what should be measured when using any nutrient density score.

5 Has nutrient density changed over time?

Has the focus on increasing crop yields come at the cost of quality/nutrient density? In certain crops it does, or it might, in others it doesn't. This highlights the need to 'test' whether or not RA can increase quality for different crops, and if it is even sensible to ask that question.

According to multiple studies in several countries, the nutrient density of individual food items (not necessarily of the whole diet) has fallen in the last 50–70 years (Mayer 1997; Thomas 2003, 2007; Davis et al. 2004; Fan et al. 2008), although this is somewhat debated. In one of the larger studies, data gathered by the USDA in 1950 and 1999 on the nutrient

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[1] www.foodstandards.gov.au/industry/labelling/Pages/Consumer-guide-to-NPSC.aspx

content of 43 fruit and vegetable crops found that six out of 13 nutrients studied had declined by 9–38% (Davis et al. 2004). The nutrients affected were phosphorus, iron, calcium, protein, riboflavin (vitamin B2), and ascorbic acid (vitamin C). The other studies showed similar nutrients affected, but also magnesium, potassium, selenium, and zinc (Mayer 1997). The reasons for the changes were unclear and could include changes in methodology, sampling differences, changes in the food system, changes in the varieties grown, or changes in agricultural practice. There has been some debate over whether there has been a real decline (e.g. Marles 2017).

It is also important to consider differences in nutrient composition in terms of yield and potential serving sizes – after all, for much produce, we eat in portion sizes such as an apple. Marles (2017) argues persuasively that any small impact of 'nutrient dilution' from irrigation and fertiliser use is offset by the increased yield that results, allowing more people to benefit from the production system. Does a bigger apple from a conventionally produced orchard actually deliver the same total amounts of nutrients as a slightly smaller apple (that may be more nutrient dense on a per 100 g basis) from an RA orchard? We don't know the answer to that yet. A major issue is that Westernised populations consistently fail to consume the quantity of fruit and vegetables they know they ought to consume. We don't want people to fall into the trap of eating less of a fruit or vegetable just because they think it is more nutrient dense. However, conversely if fruits and vegs were more 'nutrient-dense', then there would be a gain in nutrition without the need to change habits. However It is important to note fruits and vegetables play a role in the diet beyond nutrient delivery in terms of displacing unhealthier food choices.

It has been suggested that breeding for the traditional metric of yield might result in a reduction in nutritional value (White & Broadley 2005; Benbrook et al. 2008; Murphy et al. 2008) and also less desirable organoleptic properties (Roth et al. 2005; Theuer 2006). The dilution of food components with sensory attributes has been noted in high-yield, high-nitrogen systems, resulting in a loss of the intensity of flavours (Theuer 2006). However, there are limited robust data to support this. This can be due to increases in sugar content dominating over other, more subtle flavours, changing the whole balance with the phytochemicals that have astringent, bitter and sour flavours, but also aroma attributes associated with volatile compounds (Perkins-Veazie & Collins 2001).

Plant and animal health and food safety have also been shown to be affected by the focus on crop yield and conventional farming practices (Baker et al. 2002; Benbrook 2004; Lu et al. 2006). Other studies demonstrate that decline in soil quality due to certain agricultural practices may result in lower nutrient density (Lal 2009; Hepperly & Seidel 2018). In reality, it is a complex system, and not just about the presence of soil nutrients but also whether they are available for uptake by the plant.

Could RA make a difference in terms of nutrient density? One key focus of RA is to improve soil health but there appears to be limited peer-reviewed research specifically on RA practices to prove if this translates into improvements in nutrient composition. However, in the wider literature, multiple studies have demonstrated that direct manipulation of plant root and soil microbial communities has the potential to increase food crop yield and improve nutritional quality (Martinez-Hidalgo et al. 2019; Brevik et al. 2020).

How valid are the concepts of nutrient density (e.g. an NRF score), and is there any relevance for RA? One important consideration, discussed below, is that food is more than a specific group of nutrients, and the health benefits may come from the diversity of phytochemicals present as well as the nutrients. Whether RA confers some advantages for human and animal health through improving nutrient density remains to be demonstrated. Under some conditions it is highly likely there will be impacts of RA on plant composition based on evidence from the wider literature but the extent, especially in relation to a New Zealand context, remains to be determined.

6 There is more to composition than nutrients

The traditional nutritional components measured include proteins, fats (including more detailed composition of fatty acids), carbohydrates (e.g. sugars, starch, dietary fibre), vitamins, and minerals. But plants contain another array of compounds, often collectively referred to as phytochemicals. The main classes of phytochemicals include carotenoids, phenolic compounds (e.g. anthocyanins), glucosinolates and other sulphur compounds, alkaloids, and terpenes, and these have been widely studied for their beneficial effects on human health (Barros & Ferreira 2017; Martel et al. 2019; Mena & Angelino 2020) and also animal health (Lee et al. 2017; Qin & Hou 2017; Lillehoj et al. 2018).

It is also important to note that many phytochemicals can be toxic when ingested in large amounts (particularly true for animals fed on a single crop), and the benefits are observed when they are consumed in moderation and in combinations as part of phytochemically diverse diets, in the case of both herbivores and humans (Provenza et al. 2003; Provenza 2018). As discussed by Provenza et al. (2019), it is the complementarities and synergies among both nutrients and phytochemicals within and among meals that promote health.

The concentrations and profile of phytochemicals in a given crop can be highly variable, and are influenced by many different factors and interactions as well as genetics (Gould & Lister 2006; Ku et al. 2020). The variations in phytochemical composition and concentrations are much greater than they are for the core nutrients. For example, in apple, vitamin and mineral contents typically only vary between 1 and 30%, but phytochemicals may vary multiple fold (C. Lister, Plant and Food Research, unpublished data). The literature contains many reports showing that phytochemicals can both increase and decrease as a function of a combination of genetics, soil quality, cropping systems, pest levels and pest management systems, and weather conditions (Woese et al. 1997; Benbrook 2005; Benbrook et al. 2008).

There is evidence that soil quality, the forms and levels of applied nutrients (particularly nitrogen), and farming system choices affect not just yield and nutritional composition, but also phytochemical composition in reasonably consistent ways (Mitchell et al. 2007; Benbrook et al. 2008). A growing body of research shows that organic farming can increase the concentration of phytochemicals, particularly phenolics and antioxidants, in crops (Brandt et al. 2011; Mie et al. 2017). These higher concentrations are possibly linked to greater plant stress, rhizosphere microbial communities, and/or lower available nitrogen. However, there is so much variation in management practices among farming systems that it is hard to be sure of the key factors responsible. Also, environmental and crop species and/or cultivar interactions may exert stronger effects than management (Reeve et al. 2016).

There is still considerable research required to sort out these interactions, what drives them, and how to channel them through farm management systems in ways that enhance food quality.

7 Mixed cropping versus monocultures

A key focus of RA is growing diverse species rather than monocultures. There are at least two potential dimensions of benefit from growing crops in mixed plantings rather than monocultures. First, does the combination of plants growing together actually change the nutritional profile of the plants? The second aspect relates to those animals grazing on these mixtures and if there are benefits gained from ingesting more diverse mixtures of compounds.

Most of our understanding of the nutritional composition of crops/plant species comes from those grown in monocultures, so what happens to the composition when grown in mixtures? A recent study from the Netherlands showed grass–clover mixtures resulted in greater herbage dry matter, nitrogen and digestible dry matter yields than monocultures of these same forage species (de Haas et al. 2019). However, there appears to be little other solid work in this area. This raises the question, How widely are these benefits observed? Other questions are, Does the benefit come mainly from including a nitrogen-fixing crop in the mix? Are there other ways in which benefits may be arising?

Research is only just starting to elucidate the links among plant diversity in herbivore diets and human health, for either feedlot or pasture-based livestock production. Plant diversity is not necessarily reflected in the generic label 'grass-fed', which is why the flavours and biochemical characteristics of different 'grass-fed' beef differ (Neethling et al. 2016; Kilcawley et al. 2018; Rowntree et al. 2019). Work conducted by DairyNZ trial suggested that mixed species pastures could have a place on New Zealand dairy farms especially as more emphasis is placed on reducing leaching of nitrogen in farm systems (Woodward et al. 2013). Inclusion of diverse plant species in pastures has been shown to change the milk fatty acid profile in a potentially beneficial way (Strom 2012). A very recent paper has also shown a multiforage diet as opposed to a single forage diet on animal intake, performance, welfare, and urinary nitrogen excretion (Garrett et al. 2021).

In theory, plant diversity may also impact carbohydrate diversity in the diet and carbohydrate composition of the diet is known to influence the benefits in terms of microbiome impacts. More generally, a healthy gastrointestinal microbiome has also been shown to be dependent on dietary diversity (Heiman & Greenway 2016). This is yet another area where further research is needed in a RA context.

Provenza et al. (2019) reviewed circumstantial evidence that grazing systems have unrecognised benefits for health. The authors posed four very pertinent questions:

1. Are specific compounds (e.g. omega-3 fatty acids) etiologic in human health?
2. Does the phytochemical richness of herbivore diets influence the biochemical richness of meat and dairy, and if so, does that affect the flavour and satiating characteristics of meat and dairy?

3. Does biochemical richness of meat and dairy affect human health?
4. How do diets of herbivores and humans influence environmental health?

The authors concluded that circumstantial evidence does support the hypothesis that phytochemical richness of herbivore diets enhances biochemical richness of meat and dairy, which is linked with human and environmental health (Provenza et al. 2019). Figure 1 shows the overarching relationships that are hypothesised. However, this now needs more research and monitoring to determine if there is truth to this. Other research has shown that grass-fed animals produce beef with lower total fat and a higher omega-3/omega-6 ratio than grain-fed ones, which could potentially benefit consumer health (Carrillo et al. 2016). Note that this study also reported that blood cortisol levels strongly indicate that grass-fed animals may experience less stress than grain-fed individuals. There are also seasonal differences in omega-3 and omega-6 fatty acids, minerals and antioxidants in grass-finished beef (Daley et al. 2010; Jain et al. 2020). Further work is needed to fully elucidate the reasons for these differences and the implications in the context of RA.

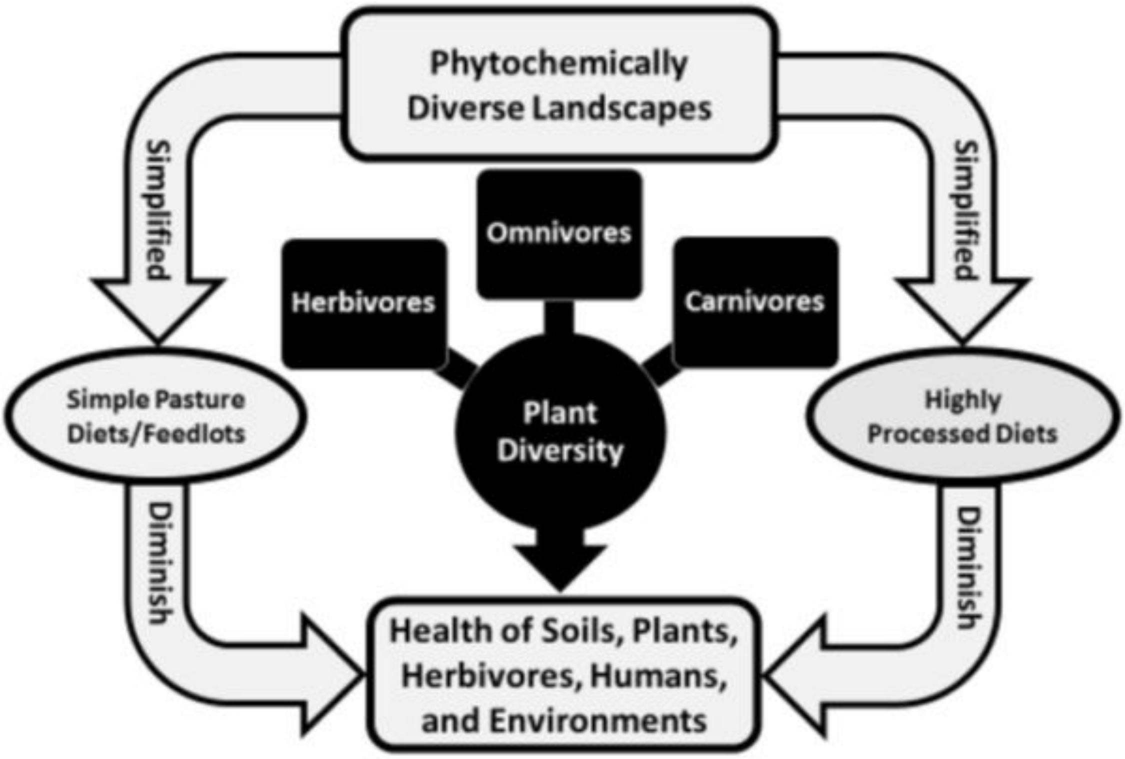

Figure 1. The health of life in soils, plants, herbivores, humans, and environments (land, water, and air) is tied to plant diversity – phytochemical richness – across landscapes. Reproduced from Provenza et al. 2019 under Creative Commons Attribution 4.0 International Licence (http://creativecommons.org/licenses/by/4.0/).

8 Mineral composition

The mineral composition of crops is a very important consideration for both animal and human health. There are so many factors that influence the final composition and concentrations in the plant. These include genetic properties of the crop species, climatic conditions, soil characteristics (including microbes), management practices, and the degree of maturity of the plant at harvesting (Hornick 1992; Martinez-Ballesta et al. 2010; Welch & House 2015). For example, abiotic stresses such as high salt levels, low water availability, and extreme temperatures can severely modify the mineral composition (Meena et al. 2017).

The long-term use of organic composts (vegetal compost and green residue of previous crops) on greenhouse soils induced few differences in the mineral concentrations in the edible parts of food crops compared with the experiments using mineral fertilisation, although there was a trend of showing higher nitrogen concentration in minerally grown crops and higher potassium concentration in organically grown crops (Herencia et al. 2007). Nevertheless, the results were variable depending on the crop, season cycle, and year (Martinez-Ballesta et al. 2010).

9 Chlorophyll: the power of green?

Fruits, vegetables, nuts, seeds, and grains are ‘packaged sunlight’ derived from photosynthesis. Through photosynthesis, the plant uses the stored energy to convert carbon dioxide (absorbed from the air) and water into sugar. These simple sugars, commonly referred to as photosynthates, are the building blocks of life. Plants use glucose together with nutrients taken from the soil to make new leaves and other plant parts. A great diversity of compounds are formed, including starch, proteins, organic acids, cellulose, lignin, waxes, and oils.

It is sometimes stated that chlorophyll content is an indicator of plants having a higher nutrient content (e.g. California Bioresources Alliance 2017). Part of the argument for this is that plants need mineral nutrients in order to produce chlorophyll, and that in turn chlorophyll drives the uptake of nutrients. Differences in the nutrient content of the soil significantly affect the photochemical process of photosynthesis, thereby playing a crucial role in plants’ growth and development (Kalaji et al. 2018). These authors showed that differences in the mineral content of soil and plant leaves resulted in functional changes in the photosynthetic machinery that can be measured by chlorophyll a fluorescent signals. However, the situation is complex and will depend on a raft of factors, including the plant species and part. Photosynthetic rates may also be important, as plants rapidly release photo-assimilated carbon to the soil via direct root exudation and associated mycorrhizal fungi, resulting in improved nutrient availability for the plant (Kaiser et al. 2015).

The relationship between chlorophyll and phytochemical concentrations in a plant is unclear. This may be more complex because of the diversity of compounds and the fact that some of them, such as the carotenoids, can act as accessory pigments in photosynthesis. The carotenoids can absorb and dissipate excess light energy as well as functioning as antioxidants (McElroy & Kopsell 2009). Thus, the validity of chlorophyll as a marker of nutrient density is highly questionable. Nonetheless, the relationship between rubisco, chlorophyl and plant N has been demonstrated in many plants. So Chlorophyl is also an indicator of N status and also correlates with plant photosynthetic capability, which then drives plant carbohydrate concentration. Does that make chlorophyl a good candidate indicator for plant tissue quality?

10 Can Brix be a simple measure of nutrient density?

Brix (°Bx) is a unit of measure that has traditionally been used in the wine, sugar, fruit, and honey industries to estimate the sugar (sucrose) or water-soluble content, but it does have limitations for wider use, such as for forage crops (Lemus & White 2014). As with chlorophyll, some in the RA community suggest using Brix as a measure of quality (and in some cases nutrient density) and crop health.[2] However, the applicability of using Brix will depend on the crop, application, and wider considerations.

The Brix level measures the solutes (including sugars) in the plant. In fruits, such as apple and grapes, most of the 'solutes' are sugars. However in other plant tissues such as leaves, what is extracted from the plant tissue are 'solutes' includes a mix of dissolve sugars, amino acids and any ions travelling within the phloem and xylem system. The relationship between Brix values and sap concentration in any of these compounds has not yet been established. However some labs (e.g. via Farmlands Co-operative) are now offering sap testing to assess nutritional status of plants (in contrast to tissue analyses). These tests are actually more than Brix values as they determine concentrations of specific minerals. But again these still need validation in terms of links to human or animal health as at present they are being considered in terms of plant health.

Brix is sometimes used as an indicator of consumer acceptability as it may indicate sweetness. However, the relationship of Brix to human taste perception is more direct in some crops than in others. There are numerous other compounds that contribute to flavour and palatability. Therefore, linking Brix levels to mineral and other nutrient levels currently lacks scientific evidence, and it is unlikely that there would be a simple relationship.

Many genetic and management factors interact to influence crop Brix levels. Similar varieties and management (e.g. fertility, irrigation) will not always result in similar Brix values (Kleinhenz & Bumgarner 2013). Brix values will vary with year, season, environment, and other factors. Indeed, there is a whole range of other factors that influence Brix readings, including the following:

- The method of extracting sap can have a large influence on the reading. This is why it is important to use the same sample preparation methods.
- Brix may change throughout the day: it is generally lowest at dawn and highest after midday. Thus, measuring Brix at the same time each day is important in order to compare varieties, fields, crops, etc. Temperature may have an effect, so it is also good practice to record temperature.
- Generally, Brix readings will drop with low atmospheric pressure (e.g. the onset of a storm).

As result, there is no solid scientific evidence that Brix values alone can be used to describe a food's nutritional value (Kleinhenz & Bumgarner 2013).

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[2] https://bionutrient.org/site/bionutrient-rich-food/brix; https://koanga.org.nz/wp-content/uploads/2018/10/Refractometer-Lit1-1.pdf

Although there is no evidence that Brix alone is a good indicator of food nutrient density, can Brix together with other indicators be used as a proxy of plant-based food quality?

11 Impacts on taste and visual appeal

Organoleptic quality is also important in terms of food and includes taste, flavour, aroma, colour/visual appearance, texture/mouth feel, and storage stability (Benbrook 2009; Ahmed & Stepp 2016). As noted earlier, there is some evidence that the way plant-based foods taste is influenced by growing condition. In the case of animal-based food products, what plants those animals eat also affects taste. Like many of the other aspects discussed above, this area is very complex. Brix has some influence on flavour, especially for fruit, but isn't the only factor. Phytochemicals are likely to have a large influence because they often contribute to bitterness and astringency (Oliveira et al. 2014). Some of the phenolics also contribute to browning reactions (Taranto et al. 2017). Some also contribute to visual appeal, such as the carotenoids, which contribute to yellow, orange and some red colours, and anthocyanins (a class of phenolics), which give red, blue and purple colours (Barnes et al. 2013). Because phytochemical composition and concentrations are affected by so many factors, it is entirely possible that RA may have an impact on sensory profiles.

Compared with dairy products from cows fed a predominantly grain-based diet, dairy products from pasture-fed cows tend to be more yellow in colour (Grigionia et al. 2011). There may also be flavour impacts. Some studies have highlighted a potential correlation of pasture with enhanced 'barny' or 'cowy' sensory attributes, and subsequently linked these to accumulation of p-cresol from the metabolism of beta-carotene and aromatic amino acids, or possibly isoflavones in the rumen (Kilcawley et al. 2018). However, it may be that unless differences are significant, and consumers may not pick up the differences that arise through RA practices.

There are a number of aspects to meat-eating quality. Tenderness, juiciness, and flavour are usually assessed by consumer panels. Intra-muscular fat (IMF), pH and tenderness are technological attributes (measured with some sort of technology, or by a trained grader) that correlate to tenderness, juiciness, and flavour. IMF is the only factor that is solely determined on farm. All the other factors are influenced by factors like transport, lairage, slaughter practices, electrical stimulation, chilling, packaging, and aging (time and temperature). Aspects of meat quality may be impacted by the raising practices used. For example, differences in fatty acid content can give grass-fed beef a distinct grass flavour and unique cooking qualities (Daley et al. 2010). In addition, the fat from grass-finished beef may have a yellowish appearance from the elevated carotenoid content (a precursor to vitamin A).

Keys et al. (2020) suggested that carcasses from 'naturally raised' and organically raised cattle are typically fatter and lighter muscled than conventionally fed cattle. However, fatness is related to management of animals, maturity, breed type feed rations, readiness for slaughter etc. It has also been suggested that marbling scores, and the resulting quality grade, are generally greater in carcasses from 'naturally raised' than conventionally fed cattle (Keys et al. 2020). There is no validated evidence of this as marbling score has a strong genetic component, and relates to energy intake and management.

There is a view that RA may support consistent moderate live weight gains due to feed types and grazing management. However, unless there were extreme circumstances (like a drought) prime beef cattle farmers do everything they can to avoid growth checks. Such circumstances would have the same impact on any farm system in a NZ context.

Many variables are used to assess fruit and vegetable sensory quality. Some quality metrics such as size, shape, and colour are relatively easy to measure. Others, such as flavour, texture, and aroma, are more subjective and therefore not so simple to assess. These attributes are usually regarded as best assessed by trained panellists because the human olfactory system is superior to all other 'technology' or systems in its ability to differentiate samples based on key sensory properties (Kleinhenz & Bumgarner 2013). Yet, this is time-consuming and costly, and it remains to be seen if RA may result in changes that make the investment in these aspects worthwhile. However, experimentation is required to determine if there are real differences in fruit or veg composition delivered by RA and that it impacts on sensory quality.

12 Food safety

As in many other areas, there appears to be little work specifically on RA and food safety. The concept of food safety being increased in RA is mostly pertaining to reduced agricultural chemical residuals – if less biocides and fertilisers containing heavy metals are used, then the assumption is that less residuals will be detected in the harvest food produce. There may be benefits from lower nitrogen applications (which reduce nitrate concentrations in food and in ground water) and chemical use. On the other hand, the use of biofertilisers (e.g. compost, manure) may pose a higher risk of microbial contamination. Changes in mineral uptake may also increase concentrations of those elements that present a risk to human health (e.g. heavy metals). It is, however, possible to reduce these risks through management and remediation processes.

Plants also contain natural toxins (e.g. glycoalkaloids in potatoes), and their concentrations are determined by a range of factors, including growing conditions. Like many other plant components the concentration can be the critical factor turning something that may be safe, and in fact have a health benefit, into something that is potentially harmful.

13 What should we be measuring?

As is evident from the above discussions, there are many components that can be measured and that may be relevant. There may be differences in what should be measured in crops depending on whether they are for animal or human consumption. With crops for animal consumption, where these are the sole or major nutrition source, the spectrum of components measured needs to be broad (ideally, everything that is an essential nutrient and potential phytochemicals too). Where there is mixed cropping, it may be sufficient to complete analysis on the mixture rather than individual species, although this will depend on any scientific questions that need to be answered.

Crops for human nutrition or processing may be considered a bit differently. In these cases, the selection of nutrients may depend on other factors, including marketing attributes. For example, kiwifruit are marketed on the basis of selected nutritional components such as vitamin C, dietary fibre, folate, and potassium.

From a compositional viewpoint there are many different possible measures for crops in general:

- Brix: although it may not be a direct indicator of nutritional quality, there is some value in measuring Brix in some crops, but this needs further validation. However, it is critical that the sampling and measurement procedures be clearly defined.
- Chlorophyll: chlorophyll fluorescence has been routinely used for many years to monitor the photosynthetic performance of plants non-invasively. Recent work suggests that the chlorophyll fluorescent method, combined with machine-learning methods, can be highly informative, and in some cases can replace much more expensive and time-consuming procedures such as chemometric analyses (Kalaji et al. 2018). However, chlorophyll may not be a proxy for nutritional quality.
- Macronutrients: carbohydrates and protein are probably the most relevant components in this group. It is only in some food that fat and fatty acid content would be significant enough to be worth measuring.
- Vitamins: for crops destined for animal feed, analysis of the array of essential vitamins is probably necessary, but in crops for human consumption it may only be necessary to measure those of dietary significance or those used for marketing purposes.
- Minerals: these are important from both a health and, in some cases, a safety perspective. Measurements in the soil and in the plant are warranted. For crops for animal feed, analysis of the array of essential minerals is probably necessary, but in crops for human consumption it may only be necessary to measure those of dietary significance or used for marketing purposes.
- Phytochemicals: the challenge with phytochemicals is that there are thousands of components. Each different crop has its own spectrum, and some are important for positive health attributes while others may have anti-nutritional and/or sensory impacts. The selection of which compounds to measure will need to be on a crop-by-crop basis (e.g. in *Brassica* vegetables/crops the glucosinolates are a key group). Measuring total phenolics (e.g. by the Folin–Ciocalteu method) may have some value in many crops and is also a proxy for antioxidant activity. This is a cheaper option for screening purposes than extracting and quantifying individual compounds.

Looking from the perspective of end use, some key parameters must be considered (bearing in mind there may be additional considerations depending on end markets (e.g. food service/home use and domestic market vs international).

13.1 Plant-based produce

- For animal consumption, protein is a particularly important factor for animal growth, but the range of essential vitamins and minerals for the particular animal is also crucial. Brix measurements may have some application for overall plant health but are not sufficient.

- For human consumption the key measures are those nutrients that are of dietary significance or used for marketing the product. These will be different for each crop, but often include dietary fibre and selected vitamins and minerals. The New Zealand Food Composition database (NZFCD; https://www.foodcomposition.co.nz/search/food) can be used to search and identify potential nutrient claims for any crop in the database (an example for kiwifruit is shown in Figure 2). For fruit, in particular, Brix may be a useful measure because of its importance in terms of eating quality. Phenolic composition may also be important (e.g. in terms of impacts on the gut microbiome). Depending on management practices it may also be necessary to monitor chemical residues (e.g. from herbicides, pesticides, etc.).

13.2 Animal-based food produce

- *Meat*: meat quality and a good eating experience are traditionally measured by assessing intra-muscular fat, pH, tenderness, juiciness, succulence, and flavour. Like plant-based produce, those nutrients that are of dietary significance or are used for marketing the product are probably the key parameters to measure. Again, the NZFCD can be used to search for and identify these. Protein, along with, B-vitamins and minerals such as iron and zinc, may of particular significance for red meat. Instrumental colour, fatty acid analysis and antibiotic residue testing may be other important factors to measure.
- *Milk*: key nutrients are protein and fat (and fatty acid composition), as well as vitamins and minerals of dietary significance. Measurement of the somatic cell concentration of raw milk is a widely accepted indicator of mastitis and milk quality. Other considerations include sensory characteristics (e.g. colour and flavour) and presence of chemical residues.

Kiwifruit, Zespri Green Kiwifruit, Zespri, raw

FCDB food ID	L1026
Scientific name	*Actinidia deliciosa*
Food group	Fruit
Serving Size	148 g Update Reset
Recommended Serving Size	1 kiwifruit = 74 g

select component set to display

Potential Nutrient Claims

print this page save as CSV

If data is to be used for food labelling it is your responsibility to ensure you comply with FSANZ labelling requirements.
The potential nutrient claims provided here are based on conditions specified by FSANZ as at 1 June 2018. We make no assurances of legal compliance and should you intend making any claim on labels, promotional material or elsewhere it is your sole responsibility to ensure you meet current regulatory requirements.

* Percentage daily intakes are based on an average adult diet of 8700 kJ as specified by FSANZ.
■ denotes no data available

NUTRIENT	UNIT	QUANTITY PER SERVE	%DI* PER SERVE	QUANTITY PER 100 g	POTENTIAL CLAIM
NIP					
Energy, FSANZ	kJ	369	4 %	250	
Protein	g	1.7	3 %	1.2	
Fat, total	g	1.0	1 %	0.7	
Fat, saturated (SFA)	g	0.13	1 %	0.09	
Carbohydrate, available	g	13.5	4 %	9.1	
Sugars, total	g	13.0	14 %	8.8	
Dietary fibre	g	4.4	15 %	3.0	Good source
Sodium	mg	3	0 %	2	
OTHER POTENTIAL CLAIMABLE					
Folate	µg	57	28 %	38	Good Source
Potassium	mg	445		301	Source
Niacin (vitamin B3)	mg	1.23	12 %	0.83	Source
Vitamin C (ascorbic acid)	mg	126	315 %	85.1	Good Source
Vitamin E (tocopherols)	mg	1.27	13 %	0.86	Source
Vitamin K	µg	16.3	20 %	11.0	Source

Figure 2. Example of using the New Zealand Food Composition Database (https://www.foodcomposition.co.nz/search/food) to identify the nutrients of dietary significance in crops/foods.

One of the challenges in any of these areas is that testing is expensive, involving careful sampling and detailed analysis, or the use of sensory panels. However, for those components traditionally assessed by chemical methods, advanced testing techniques, such as hand-held spectrophotometers and other instruments (Prache et al. 2020), are being developed that will, it is hoped, allow in-field testing and reduce costs significantly in the future. The use of drones carrying such technology to assess overall crop health, and/or to determine composition using newer, non-destructive means is a possibility. Research is still required to validate non-destructive measures, including crop-specific research in some cases, but there appear to be significant opportunities in this area.

14 Other aspects

An area of more recent focus is the microbiome, and this may also have implications for food quality and safety. Human pathogens are of relevance from a food safety perspective and are likely soil borne or from workers in the pre- and post-harvest supply chain.

Recent studies have suggested that the human (intestinal) microbiome plays an important role in modulating the risk of several chronic diseases, including inflammatory bowel disease, obesity, type 2 diabetes, cardiovascular disease, and cancer (Singh et al. 2017; Wang et al. 2018; Ding et al. 2019). Diet plays a significant role in shaping the microbiome, and dietary components including protein, fat, carbohydrates (sugars may impact negatively but dietary fibre positively), phenolics and pre/probiotics have all been shown to have an influence (Singh et al. 2017; Wu et al. 2019). It is complex, in that diet modulates the functionality of the intestinal microbiome, which, in turn, affects the human metabolic status and thus may change dietary requirements.

As an example, vegetable-rich diets may increase cell motility to access nutrients, increase catalytic activities for carbohydrates and food proteins, as well as affecting the synthesis and release of bioactive metabolites/proteins, thus resulting in potentially beneficial impacts on human health (De Angelis et al. 2020). Other food components, such as pesticides, may also impact negatively on the gut microbiota and thus be detrimental to health by that mechanism (Gamet-Payrastre 2020).

It has also been hypothesised that the edible plant microbiome and its diversity can be important for humans as (i) an additional contributor to the diversity of our gut microbiome, and (ii) as a stimulus for the human immune system (Berg et al. 2015). In addition, soil and faecal microbiomes may play a role in human health (Blum et al. 2019). Thus, there are complexities of interactions between microbiomes, and these have evolved over time (Figure 3). Diet and microbiome research is expanding and evolving, but the specifics of what to eat for a healthy microbiome are still undefined (Willis & Slavin 2020). RA may well have impacts on the human microbiome, but further work is required to determine what may be relevant. At present there is no evidence to suggest RA has impacts on the human microbiome. Plant carbohydrates have a big impact, as do antibiotic use and stress. Differences that may be seen in plants grown in a RA ecosystem compared with conventional growing are likely to be very small compared with the larger differences between human individuals. However, further research is needed and the methodology to study the microbiome aspect of food is beyond the scope of this report.

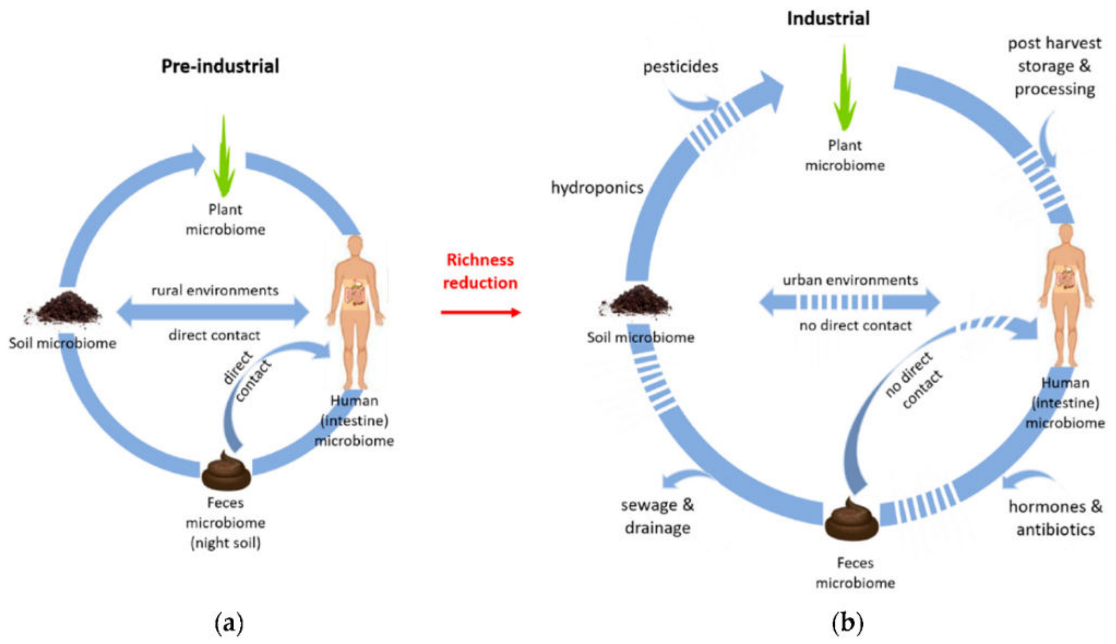

Figure 3. The microbiota in our environment influence the human intestine microbiome, via direct contact with soil and faeces as well as via food (quality). Our ancestors lived in close contact with the environment (a) a cycle for pre-industrial microbiota). In contrast, human activities such as urbanisation, industrialisation of agriculture, and the modern lifestyle, including the use of pesticides and antibiotics as well as hormones (medication), together with the loss of direct contact with soil and faeces, have depleted the richness of and overlapping with microbiota (b), a cycle for industrial microbiota). This depletion of microbial richness in all compartments can substantially affect human health. (Reproduced from Blum et al. 2019 under Creative Commons Attribution 4.0 International License http://creativecommons.org/licenses/by/4.0/).

15 Conclusions

Critical work is needed to assess the impacts of RA on food quality and safety in a New Zealand context. One of the premises of RA is that it can produce each individual food item at a higher quality, in particular, more nutrient dense. This needs to be substantiated through robust testing. The testing required will differ by crop and it will also be essential to consider what tool might be used to assess nutrient density (i.e. which profiling scoring system to use as to what domains should be captured). It will be important to test whether the nutrient/phytochemical concentrations in different individual farm produce is higher when produced under RA. Once that is determined and shown to differ, then nutrient profiling scores (such as Food Compass) could be used to compare an identical basket of foods (with quantities in proportion to their average consumption in a balanced diet) produced from RA or from 'conventional' agriculture. Other aspects of production can then be layered on to this to evaluate the wider aspects of quality and ensure economically sustainable production.

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