Lifecycle analysis of dairy vs plant-based GHG production.

Public discourse about food system sustainability has been restricted to emissions before the farm gate, but of course, different food ingredients are likely to generate different emissions all the way from seed to sewer. My concern in this discourse is to try to assess the relative sustainability of nutrient provision systems when all aspects are taken into account. This concern is jurisdiction-independent: while land and water use are local concerns, GHG emissions have distributed global effects.

I was previously able to show (to my surprise, I have to confess) that dairy production is a far more efficient use of land and water than any plant-derived food **when the correct metric is employed.** (see https://peerJ.com/articles/2100) (Coles, Porter & Wratten, 2016) This metric is not correct just because it gives a specific result but because it covers the widest possible range of emissions and factors. If we start with that, it will make the following discussion a bit easier to follow.

A global food-security-focused metric.

The purpose of any modern food system is to deliver an adequate supply of essential nutrients in the most effective way. It follows, therefore, that the metric we use for judging efficacy must be based on the first-limiting nutrient in the diet, and for humans, that is the essential amino acid in shortest supply in the diet. (Coles, Porter & Wratten, 2016, Davies & Jakeman 2020, Reeds 2000.) For instance, among the cereals, lysine is the first limiting amino acid, normally present at around 2 mole % in cereal protein, whereas the normal monogastric (humans, pigs and poultry) requirement is for about 5 mole %. This means that cereal protein has to be consumed at 2.5 times the rate that, say egg protein (the reference protein) must be, to ensure that the consumer obtains enough of this essential nutrient. With plant protein generally, we can’t win. Legume protein (if you can digest it) has less inadequate lysine but is rather deficient in the sulfur amino acids. This does mean that it is possible to compensate, to some degree by blending plant-derived ingredients, but invariably, this simply exposes the deficiency in the next limiting essential amino acid, of which there are nine or ten, depending on whether you count selenomethionine separately from methionine.

The evolutionary history behind all this is largely due to the fact that plants can’t run away, so alternative mechanisms have evolved to protect the highly valuable nitrogenous materials they gather up to provide for their progeny. More on the implications of this later!

It follows that the amount of protein that must be consumed is inversely proportional to the deficiency of the first limiting amino acid. Therefore, the appropriate metric to judge the impact, efficiency and sustainability of a food production system is

“The amount of resource required to provide for the nutrition needs of the average consumer in a certain time.”

This is sufficiently obvious that it is surprising that this metric has failed to gain currency (yet).

Broadly speaking, animal protein is markedly more nutritious than plant protein, based on this metric, although obviously hair, horn and feathers are a bit off the pace in this regard. On the other hand, potato tuber protein does have a relatively useful amino acid profile. but is only found at low concentration in the tuber, and is protected by a number of antinutritional factors, not least of which is that you would have to eat about 3.5kg of potatoes, and 25Mj of energy daily to get an adequate intake of your first limiting essential amino acid. Mind you, the Irish managed it before the famine…

Note that the discussion so far has been around **essential** amino acids. Proteins are composed of around 20 amino acids, of which nine are essential (Reeds, 2000; Trolle et al., 2022). The remainder are called **dispensable**: monogastrics need them for protein synthesis, but can generate them from their own metabolism, including using the components from catabolism of protein previously used for “maintenance”. Thus, it is reasonable, when comparing food ingredients, to assess them for their ability to provide **essential amino acids**. Thus, the metric on which this analysis is based is:

“The amount of resource required to meet the annual requirements for essential amino acids of the average consumer.”

So who is the average consumer? We work with an adult male weighing 70kg for reasons of convenience, but this is a reasonable choice to avoid the complications of menarche, menopause, pregnancies of different frequency and so forth. We assume this average consumer to require daily intake of 56g of egg protein (the baseline for quality) and 9.6 MJ of dietary energy. Egg protein is assumed to have the ideal amino acid composition (of both essential and dispensible amino acids) and for our model, the WHO-approved intake is 0.8g/kg of body weight (Anon (United Nations University), 2007).

The USDA used to provide access to an excellent nutrition database, with information about over 7,000 foodstuffs and ingredients, and they provided a metric for foods called Biological Value (BV). Regrettably, the link now directs one to an online magazine! However, I was able to capture their estimate of BV for some key foodstuffs, and they were used in the paper cited above. Essentially, their version of BV was a number that reflected the concentration of the first-limiting EAA compared to egg protein, which is what we need to know to compare foods using our favoured metric.

It may not be surprising that on this basis, dairy protein has a very high value: 137, compared to egg protein at 100, soy protein at around 80 and wheat protein at 41. So to meet the average consumer’s EAA needs, we can see the figures in the following table.

Foodstuff	***BV***	***Protein intake relative to egg protein at 56g/day (g)***
Dairy	137	41
Egg protein	100	56
Whole-Soy protein	80	70
Whole-wheat protein	41	137

Clearly, from this table, wheat is a very poor source of EAA’s, soy average and dairy very effective. Thus, we see that using the proposed metric is pretty important, and already makes a big difference when the GHG intensity of feeding people is considered.

Food processing

The gross content of EAA’s is just the first step, however. As noted above, **all** plants have evolved effective mechanisms to protect the amino acids (and other desirable nutrients) they accumulate for the benefit of their progeny. Storage proteins have very poor EAA content. In the legumes, a high proportion of the storage proteins are trypsin inhibitors! The plants can metabolise them but predators can’t. Cereals store most of their grain nitrogen as prolamines that have structures rendering them very difficult to digest. On top of this, plants contain at least 12 other classes of antinutritional factors, from the tannins that are found in the hulls of seeds, to the phytohaemagglutinens of soy and very toxic materials such as the ricin of castor bean seeds.

It has not been beyond the wit of man to find ways to reduce the impact of these antinutritional factors. Dehulling, milling, fermentation, cooking and blending with other materials are just some of the ways we process food raw materials to make them at least adequately nutritious. However, these processes are all energy-demanding, and may themselves reduce EAA availability. As just one example, cooking converts lysine, particularly, to Maillard products, which are nice contributors to baked goods flavour and appearance, but which are not nutritious!

Post-farm-gate processing is said to add 11% to the GHG cost of dairy protein, counting freight, processing and storage. For plant-based foods, the first cost is getting rid of unwanted components, such as soy hulls, wheat bran and so forth, then subsequent processing – milling, drying, fermentation, baking, packaging and preservation, and on it goes. So far as I can find, no-one is owning up to the GHG cost, but to a first approximation, once the useful fraction is obtained, the GHG cost of the energy used might be a good surrogate.

Consumption and excretion

The excreta component of principal concern in discussing dietary nitrogen is urinary urea, rather than faecal nitrogen. Humans excrete urea as a compromise between the really nasty consequences of trying to excrete ammonia and the energy cost of excreting uric acid (evolution at work!) Relative to the nitrogen in faeces, (which is tied up in refractory protein, mucins, etc) urea is pretty labile. Furthermore, when urea comes into contact with faecal urease in an aqueous environment, it is very rapidly converted back to ammonia – hence the attention paid to slurry ponds on dairy farms. And this is what happens when the s**t hits the pan!

According to the Christchurch Council wastewater managers, about 1.6 tonnes of elemental nitrogen arrives at Bromley daily – about 5.3 g/person. However, from the NZ nutrition survey, the average daily protein intake is 79g, providing 12.64gN/person/day. That means about 7.5gN/person is going missing. Since the goal of the sewage engineer is to avoid leaks (of liquid), this N, on the face of it, is being lost as ammonia gas!

Ammonia is, itself, a GHG, in that it forms aerosols that are $PM_{2.5}$ contributors, but in the atmosphere, it is reasonably rapidly oxidised to, first, N_2O, then to NO_2, both long-lived gases. Using an arbitrary average composition of NO, I assume all this ammonia eventually contributes 1.76 **tonnes** GHG_e per person per year. That's 8.8 million tonnes of CO_2 equivalent for NZ annually. Gross that up for global impact if you dare!

As discussed above, dairy **could** allow for a significant reduction in dietary protein consumption necessary for adequate nutrition, but what is clear is that a vegan diet has significantly greater impact. Even switching to an exclusively soy-based diet requires a **minimum** of 70g of protein daily, without accounting for the impact of activities between the farmgate and the lavatory pan. If, instead, one relies on the 29g difference between dairy and soy shown in the table above, the excess GHG production from such a consumer will be 1.1 tonnes of CO_2 equivalent annually. Go figure!

Other essential nutrients

Smith et al (Smith et al., 2021) present, in considerable detail, the use of the DELTA model for determining the sustainability of food systems calculated as the efficiency of provision of nutrient requirements. However, they note that, with the exception of Davies & Jakeman, (Davies & Jakeman, 2020) little to no attention is paid to efficient provision of **individual** digestible indispensable amino acids. Davies and Jakeman (op.cit) argue cogently for the relative importance of the DIAA's when considering the overall nutritional efficiency of plant-sourced protein, noting that almost invariably, consuming enough, even of a combinations of PSP sources, to achieve adequate intake of DIAA's will lead to overconsumption of other macronutrients.

Micronutrients

Human requirements for micronutrients are unique, not only to our species, but to individual lifestages, health status and so forth. It is now widely accepted that our relatively sedentary lifestyle and our longevity means that micronutrients that might have been provided sufficiently well by a 19th Century diet supplying 14.4Mj of energy are functionally deficient in a modern diet not leading to obesity. A number of micronutrients must be supplied by supplementation in a diet where EAA's and energy needs are perfectly well met. These include iodine, Vitamins B12 and C and the essential fatty acids. It is no longer the case, as was claimed by McLaren (McLaren, 1974) that nutrition needs can be met simply by supplying enough money that consumers can fulfil traditional dietary intakes.

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