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Estimating the nutrient value of agricultural products

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Contents

Introduction

Responses to the Scottish Government target for Net Zero will increase demand for land in Scotland and potentially take land out of food production for example, for tree planting and green energy production. But land use changes could be measured in the loss of potential nutrients for human consumption that might otherwise have been produced. This matters for the supply sufficient food and nutrients to the population.

Food security is predominantly focused on averting hunger, and in this case a sufficient supply of calories for a population, but adequate nutrition goes beyond this to include nutrients as well as energy and the avoidance of nutrient deficiencies[1]. Imported foods contribute to the nutrient supply and current domestic Scottish does not meet the population needs. Approximately 46% of foods consumed in the UK are imported[2].

A substantial proportion of nutrients potentially produced are, however, used for other purposes (e.g., animal feed and alcohol) and illustrate nutrients foregone that might otherwise have been used by people. Understanding the potential and realised nutrient supply of domestic production of different foods highlights the opportunities to reimagine food production to maximise the supply of nutrients across Scotland.

1 Ingram J. Nutrition security is more than food security. Nat Food 2020;1:2–2.
2 DEFRA. United Kingdom Food Security Report 2021: Theme 2: UK Food Supply Sources. London, UK: DEFRA; 2023 Oct.

Vegetables and especially fruits are produced in small quantities and consequently contribute little to nutrient production. Although meat production requires a significant portion of agricultural land, their contribution to nutrients is only moderate. Cereal crops are grown in such large quantities that they are important sources of energy and fibre, although their contribution is constrained because most of the production is not for human consumption. Milk and eggs are key sources of nutrients and supply the majority of nutrients that are an important source of minerals.

No one commodity provides all the nutrients needed for a healthy life and a balance is required. Nutrients are, however, not eaten in isolation but as whole foods. The nutrients reaching consumers are often different from those of minimally processed foods but these results help articulate the relative contribution of commodities to the initial supply of nutrients.

Aim

To contextualise the value of Scottish agriculture from land by estimating the supply of nutrients for human consumption from agricultural products.

1 Background

Foods are not created equal. Food stuffs grown in Scotland have different economic worth, but also not all products contribute equally to the supply of nutrients. For example, some foods provide our energy needs and others provide essential nutrients. Other foods might contribute very few nutrients that benefit health but are profitable. A combination of foods make up diets and it is recognised that there are multiple factors driving the choice of farm produce.

What is grown in Scotland matters because, along with imports, it forms the basis of nutrients supplied to the Scottish diet. The UK is largely self-sufficient with a domestic supply of most nutrients that meets the needs of the population, but the UK-origin supply of nutrients at the point of consumption falls short of the population requirements for energy (30%), iron (20%), zinc (16%) and vitamin A (12%)[3,4]. These estimates are based on the food that reaches consumers and primary production on farms is only one part of the food chain. Processing commodities into food for consumption can substantially change the nutrient supply along the food chain.

But land is in high demand. The legal commitments to achieve Net Zero[5] increases pressure to use land efficiently. Afforestation, biofuels, solar and wind farms are examples of activities that require an increasing amount of land. These demands join a long list of other important public services from different sectors that we want from land including biodiversity, housing, and tourism[6]. Sometimes these land uses remove land from food production, which in turn could potentially lead to a reduction in the supply of nutrients. Whether the reduction in nutrient supply matters is in part a question of what could be produced. In other cases, there might mixed uses of land, such as agroforestry or grazing under solar panels, but in combinations that constrains choices about what can be produced.

We have to make choices about how we balance the many legitimate uses of land in a multifunctional landscape[6], for example where to prioritise nutrient security and food sovereignty, habitat restoration or renewables.

3 Examples of foods rich in iron include liver, red meat, beans, spinach and legumes; examples of zinc-rich foods include meat, cheese and bread; examples of vitamin A sources include cheese, eggs and liver, yellow, red, and green (leafy) vegetables and yellow fruits. https://www.nhs.uk/conditions/vitamins-and-minerals/

4 Macdiarmid JI, Clark H, Whybrow S, De Ruiter H, McNeill G. Assessing national nutrition security: The UK reliance on imports to meet population energy and nutrient recommendations. Struik PC, editor. PLOS ONE 2018;13:e0192649.

We also have choices about where different activities are best suited to get the best outcomes from land. Not all land is equally suited to all activities, e.g., by climate, soil and relief[7].

To better understand the value of what is produced and where, the focus of this report is the nutrient value of agricultural commodities. We estimate the nutrient value of commodities entering the food system, albeit domestic production from land alone.

We recognise that what is produced as raw commodities are often processed to foods that have different nutrient properties. Previous estimates of national[4,8], regional[9] and global[10,11,12] nutrient supply trace commodities through the food chain to the products that people consume. We, however, focus on estimating the rawest supply of nutrients from land before commodities are processed into foods or at least to estimate nutrients in foods that have had minimal processing into a state to be eaten by humans (e.g., wheat processed to whole wheat flour rather than bread or biscuits). The many ways of processing foods are complicated, often combining Scottish produce with ingredients imported from elsewhere and processing (e.g., cooking or diluting) that can reduce or increase nutrient quantities. We therefore aimed to estimate nutrients from the least processed form of a commodity to estimate the nutrients produced by Scottish farms and their potential value to the population even though we don't eat most agricultural produce straight from harvesting.

The results presented here represent potential nutrient supply rather than the supply realised by consumers in Scotland. Nutrient supply is changed through the food system, but the nutrients reported here are the starting point to that food chain.

5 Scottish Government Climate change policy

6 Royal Society. Multifunctional landscapes: Informing a long-term vision for managing the UK's land. London, UK: The Royal Society; 2023.

7 Brown I, Towers W, Rivington M, Black H. Influence of climate change on agricultural land-use potential: adapting and updating the land capability system for Scotland. Clim Res 2008;37:43–57.

8 Sheehy T, Sharma S. The nutrition transition in the Republic of Ireland: trends in energy and nutrient supply from 1961 to 2007 using Food and Agriculture Organization food balance sheets. Br J Nutr 2011;106:1078–89.

9 Enahoro D, Lannerstad M, Pfeifer C, Dominguez-Salas P. Contributions of livestock-derived foods to nutrient supply under changing demand in low- and middle-income countries. Glob Food Secur 2018;19:1–10.

10 Chen C, Chaudhary A, Mathys A. Nutrient Adequacy of Global Food Production. Front Nutr 2021;8:739755.

11 White RR, Gleason CB. Global human-edible nutrient supplies, their sources, and correlations with agricultural environmental impact. Sci Rep 2022;12:16781.

12 Smith MR, Micha R, Golden CD, Mozaffarian D, Myers SS. Global Expanded Nutrient Supply (GENuS) Model: A New Method for Estimating the Global Dietary Supply of Nutrients. Obukhov AG, editor. PLOS ONE 2016;11:e0146976.

2 Approach

The approach taken in this report is outlined in **Figure 1**.

Agricultural products are linked to a corresponding food that is associated with nutrient data (section 2.1). Some commodities will have a direct match, others may require multiple foods that are recombined.

Nutrient data are typically reported per 100g of food and these numbers need to be scaled to units that match those of production (e.g., tonnes) (section 2.2).

However, not all of a commodity produced are eaten, so the amounts produced need to be adjusted to account for nutrients that are foregone.

To support the interpretation of the supply of nutrients, the nutrients available (section 2.3) can be compared to national dietary guidelines that make recommendations about how much people need for a healthy life (section 2.4). The supply is presented for both realised production, i.e. the nutrients from current production levels, and theoretical, assuming the same commodities, but different levels of production.

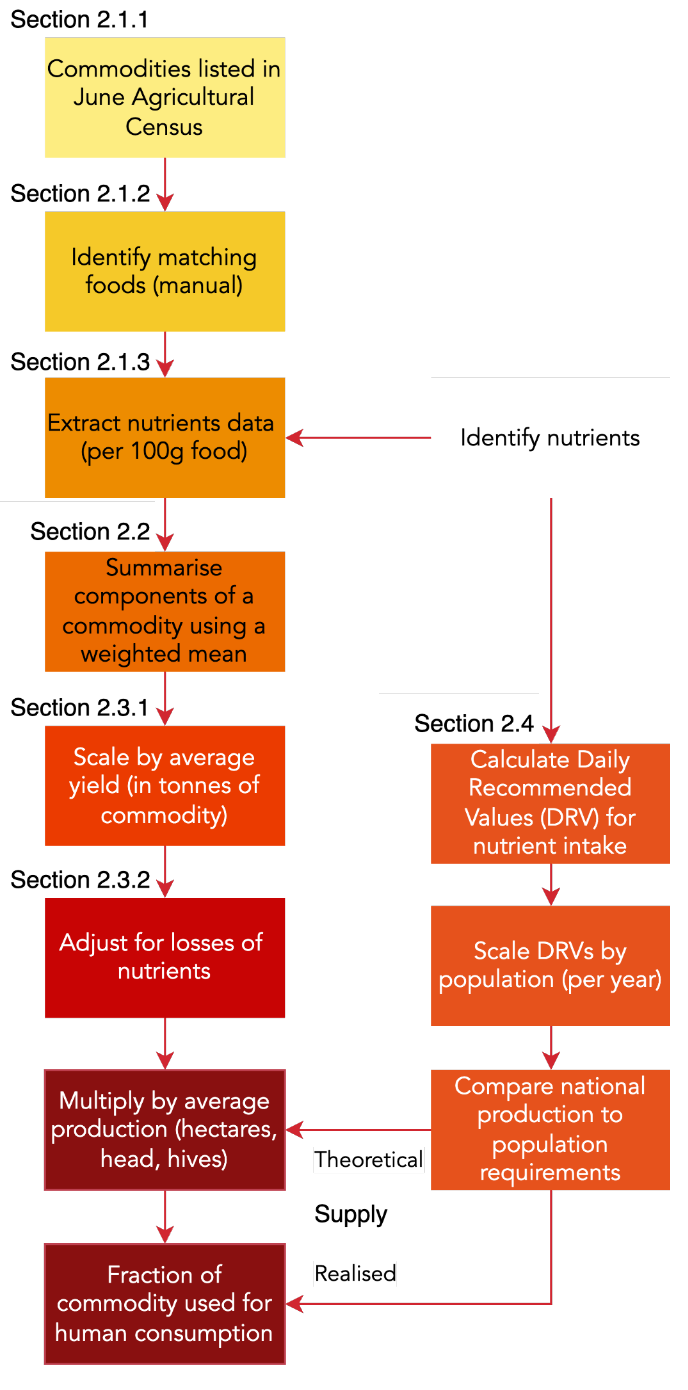


Figure 1 Description of the workflow used to estimate the nutrient supply from agricultural products

This work builds on analysis by the Rural and Environment Science and Analytical Services Division (RESAS)[13] that aimed to articulate the differences in food production across farms in Scotland. There are many ways in which farms differ, but one is to consider how they contribute to the food needs of the nation.

RESAS linked agricultural census data to published nutrient data from the Food and Agriculture Organization of the United Nations (FAO) Food Balance Sheets[14]. The FAO data include average estimates of calories, fat and protein per commodity that are based on detailed commodity trees that estimate how commodities are processed into food. These macronutrients and energy were made available in a recent edition[15] of the FAO's food balance sheets data.

The estimation of nutrients by the FAO includes derived foods that are processed along the whole food chain to capture where a raw commodity is processed. Additional nutrient data are not currently available in the FAO food balance sheets, and the source and analysis of nutrient data is not published. For example, the way that different countries contribute to a global average is unpublished. The FAO data are, therefore, derived from a different method to those used here and show the nutrient supply to consumers rather than the nutrients from primary production.

What the data demonstrated, however, was the utility of mapping calories, protein, and fat from agricultural products in Scotland to articulate the geographic variability in nutrient production.

In this section we describe the methods taken to estimate the nutrients value of commodities. The approach taken is broken into sequential steps: first, matching commodities to foods; second, estimating the quantity of nutrients from each commodity; third, estimating the supply of nutrients from commodities (Figure 1).

13 Scottish Government Agriculture and Rural Communities (Scotland) Bill: supporting evidence and analysis

14 Food and Agriculture Organization of the United Nations. Food balance sheets

15 Food and Agriculture Organization of the United Nations. Food balance sheets 2010–2021: Global, regional and country trends

2.1 Matching commodities to foods

2.1.1 Agricultural Commodities

The commodities produced in Scotland are taken from the Scottish June Agricultural Census (JAC), an annual census of land that is or could be used for agricultural activities that is routinely used to estimate the production of key agricultural commodities.

In the RESAS analysis, commodities from the JAC were manually linked to data published by the FAO. In some cases, the match was clear. Wheat, for example, can be matched by name. Other foods were grouped both in the JAC and by the FAO, for example in the JAC orchard fruits are a single category that would include apples, pears, and a variety of stone fruits, and in the FAO data, for example, carrots and turnips are grouped together.

Other foods are partitioned in the FAO data where, for example, a commodity is split into different products. Oil crops, for example, are split into both the oil (for human consumption) and cake (livestock fodder) and animal carcasses have line items for meat, offal and edible fats.

Where there were partial matches, expert judgement was used to link the data.

Exclusions of Commodities:

Some items in the JAC are not destined for human consumption, for example fodder crops, but that do use agricultural land. There are no nutritional data for such crops at the point of the farm gate and further assumptions would be required to attribute their nutrient value from the parent commodity to them (e.g., attributing nutrients to livestock based on the feed used). These products are excluded from analyses here to avoid double counting nutrients with animal products.

Other items are different forms of the same commodity, for example, different ages of cattle or spring versus winter cereals. In these cases, the nutritional data is assumed to be the same for all forms of the commodity because the data tend not to include details about varieties, types (e.g., the age or sex of an animal) or local variability. In terms of nutrient supply, however, the yield of these commodities will be different so in terms of supply the commodities will contribute a different amount of nutrient.

Lastly, commodities that are destined used the production of alcohol deserve a special mention given their economic importance. Given that alcohol, like other foods, requires additional processing the nutritional value of these commodities is taken at the least processed stage (i.e., grain) and not alcohol.

2.1.2 Linking commodities to food

Human food commodities, i.e., those commodities that could be destined for human food and not those food stuffs that are exclusively used as livestock feed or other uses, were identified from the Scottish JAC. Foods were identified manually based on knowledge of the items in the census. These commodities included major cereal crops, horticulture and livestock produced in Scotland.

Completing the census is a legal requirement of landowners or tenants of land capable of agricultural use and therefore coverage across the country is good.

Commodities are described by their type or origin (e.g., meat, offal, fruit and vegetable) rather than some nutritional classification[16]. Most also require some form of processing before they can be consumed (e.g., removing husk from cereals or butchering a carcass). The food stuff most closely resembling the raw commodity was manually identified.

One approach to understanding the link between commodities and foods is a food commodity tree which traces how a commodity is used in different products or processing steps[17]. For example, wheat requires at least some processing and components of the wheat are typically separated before grinding the germ into flour (e.g., Figure 2); wholegrain flour then recombines the ground germ with bran, but white flour is also processed into different forms used to make many derived products. White flour is also fortified to replace certain nutrients (calcium, iron, niacin and thiamine) that are lost by refining flour from wholegrain. A commodity tree tracks all the destinations of a commodity (including non-food uses) and what proportion goes to each use. The relative balance of different branches of the commodity tree reflects the frequency of different products in a given population.

16 Scarborough P, Rayner M, Stockley L. Developing nutrient profile models: a systematic approach. Public Health Nutr 2007;10:330–6.
17 Food and Agriculture Organization of the United Nations. Technical conversion factors for agricultural commodities. Rome: Food and Agriculture Organization of the United Nations Rome; 1972.

Much of the commodity tree is not relevant to our purposes, but some components are, for example the breakdown of an animal carcass into edible components that have different nutritional values (i.e., meat, offal and fats). The commodity tree is a useful tool to try to identify the least processed form of a commodity for human consumption (e.g., wheat goes to both flour and bran, whereas oats are rolled and although rape is processed into both oil and cake only the former is for human consumption). We stopped at level 1 processing where necessary, and only selected commodities for human consumption. To avoid double-counting, we did not include portions of a commodity that we used for animal feeds or other industrial processes, e.g., rapeseed cake or rendered tallow even though these do lead to nutrients in the human food chain as animal products.

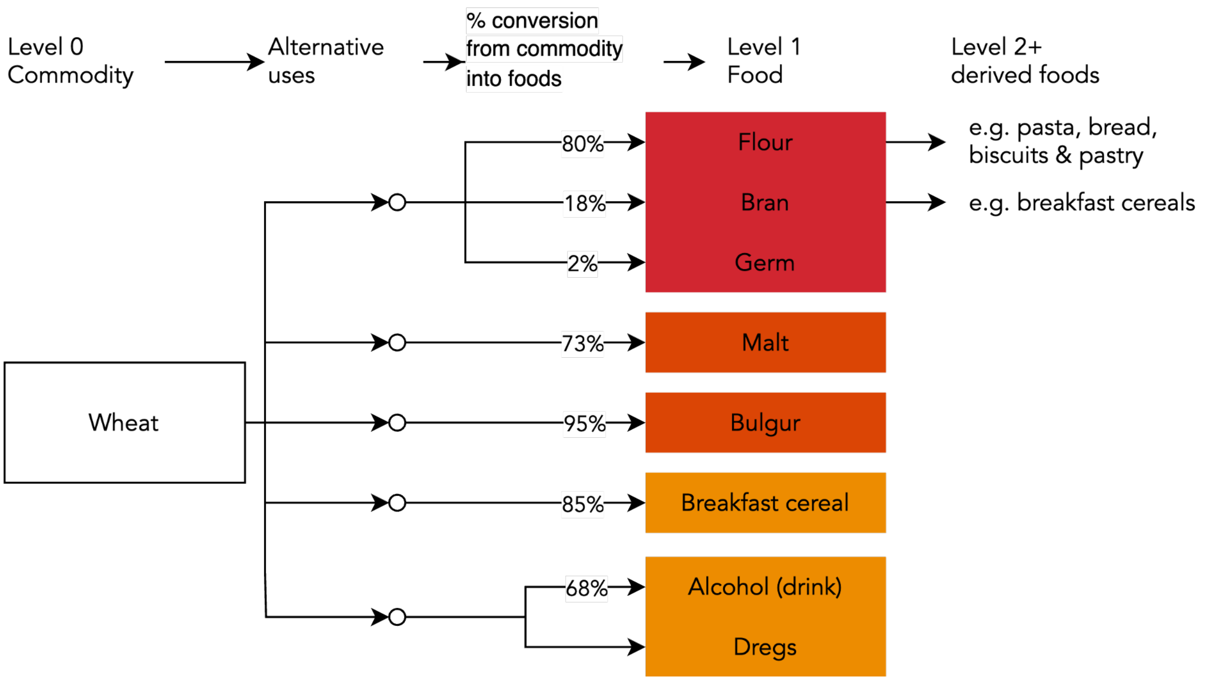


Figure 2 Example of a commodity tree for wheat based on FAO. Wheat can be converted into different products, for example wheat flour (the food used in this report) or alcohol. The numbers show the approximate conversion rate from the raw commodity into the food stuff. For example, 1 kg of wheat grain might generate approximately 800 g of flour along with 180 g bran and 20 g of wheat germ; alternatively, the same 1 kg of wheat grain could be used to generate 730 g of malt or 680 g alcohol. Some of the first level processed foods can be further processed into second level foods (that can themselves be further processed), for example using flour to make breads, pastries, and so on, but this report stops at minimally processed level 1 foods.

Commodities, or an appropriate minimally processed food, was then manually matched to an entry in a food composition table (FCT) to extract nutrient data. A FCT[18] is a database of food items with nutrient quantities that have been identified, usually by chemical analysis, but additionally through estimation[19]. FCTs are available for different countries and regions and contain information on foods eaten by that population. Unlike the FAO data that is presented at quite a high level of commodities, the FCT contains information on foods that are available to and eaten by consumers. The higher resolution of the FCT means that foods that are grouped in the JAC can be disaggregated in terms of nutrients (e.g., cauliflower and broccoli) or more specific (e.g., cabbage can be based on cabbages rather than an aggregated value for cauliflowers and broccoli).

18 McCance RA, Widdowson EM, Institute of Food Research (Great Britain), Public Health England, Royal Society of Chemistry (Great Britain). McCance and Widdowson's the composition of foods. Seventh summary edition. Cambridge: Royal Society of Chemistry

19 Schakel SF, Buzzard IM, Gebhardt SE. Procedures for Estimating Nutrient Values for Food Composition Databases. J Food Compos Anal 1997;10:102–14.

2.1.3 Nutrient data

The UK FCT is by McCance & Widdowson[18]. An electronic version of the database is available online (after registration)[20]. The FCT contains data on 35 nutrients including total energy, macro- and micro-nutrients. Foods are included in multiple forms reflective of how they are processed or prepared for consumption (e.g., raw, baked or fried). The nutrient values are typically based on the average of multiple food samples, where appropriate averaging across brands or varieties. Nutritional data are periodically updated, for example when new foods added. Some data can be decades old, but this is less likely to impact minimally processed foods than new recipes in composite dishes.

Where necessary, other FCT are necessary to fill in gaps where the food isn't included. In this case it was necessary to take three food items from the USDA FCT[21]. (for hulled barley, triticale and linseed).

The nutrients extracted from the FCT are shown in **Box 1**.

Box 1. Nutrients selected

Energy

- Energy (kcal)

Macronutrients

- Protein (% of total energy)
- Fat (% of total energy)
- Saturated fat (% of total energy)
- Monounsaturated fat (% of total energy)
- Polyunsaturated fat (% of total energy)
- Carbohydrate (% of total energy)
- Starch (g)
- Total sugars (g)
- Dietary fibre (g)

Vitamins

- Folate (μg)
- Niacin (mg)
- Retinol (μg)
- Vitamin A (μg)
- Riboflavin (mg)
- Vitamin B6 (mg)
- Vitamin B12 (μg)
- Vitamin C (mg)
- Vitamin D (μg)
- Vitamin E (mg)
- Thiamin (mg)

Minerals

- Sodium (mg)
- Potassium (mg)
- Calcium (mg)
- Magnesium (mg)
- Phosphorus (mg)
- Iron (mg)
- Zinc (mg)
- Selenium (μg)

20 Food and Nutrition - NBRI extended dataset based on PHE's McCance and Widdowson's Composition of Foods Integrated Dataset
21 U.S. Department of Agriculture: FoodData Central

The recommended intake of carbohydrates, fats and protein are made in terms of the percentage of the food energy. For these nutrients, the conversion was made to estimate absolute amounts.

Not all foods had complete data across the nutrients listed above, for example deer data were only available as meat, and animal fats and rapeseed oil lacked numeric data where nutrients were either not tested or only detected in trace quantities. When averaging across foods or food components (e.g., meat, offal, and edible fat), we excluded the missing values. The alternative would be to interpolate based either on the data that are available or based on similar foods, but in both cases, this requires additional assumptions.

Similarly, some nutrients had more missing data than others. For example, fibre, selenium and vitamin D had fewer values than other nutrients.

Where data were missing there is an under-estimate of the nutrient supply

2.2 Nutrient quantities

Where there were multiple foods matching the same commodity, the nutrient data were average using a weighted mean proportional to the relative frequency of the different commodity components, i.e.,

$$\text{Weighted mean quantity} = \frac{\sum_{i=1}^{n} \text{weight}_i * \text{food element}_i}{\sum_{i=1}^{n} \text{weight}_i}$$

for *i* foods. For example, an animal carcass is made up of meat, fat, and offal, but edible offal accounts around 4% of a live cow compared to 40% which is meat. The nutrient values used here were therefore the weighted average of these components to account for relative contribution of each component to the supply of nutrients.

Commodity trees from the UN Food and Agriculture Organization (FAO) provided details for most commodities, but other data were found when more detail was required, for example, from the Agriculture and Horticulture Development Board (AHDB)[22] yield data derived from abattoirs was used for the breakdown of an animal carcass because offal was not specific enough to match with foods in the FCT and because we wanted the relative weight of individual organs.

Where commodities differed by production (e.g., spring or winter cereals) or variety (e.g., cherry tomatoes or standard tomatoes) but for which there were no available data the weights were assumed to be equal.

22 AHDB

2.3 Nutrient supply

Using estimates of yields, the supply of each nutrient can be estimated. This gives an indication of how much of each nutrient is available from minimally processed domestic foods. The calculations for the potential supply of a nutrient can be given by:

$$\text{Potential Supply}_i = (\text{Nutrient}_i per\ 100g)(\text{Yield}_i)\left(100\% - \%\,\text{Loss in production}_i\right)(\%\text{Edible}_i)$$

in which the nutrients per 100g of food (which is how the FCT present nutrient data) is scaled by the yield.

However, not all a harvest is fit for consumption, and some is lost in production and the realised supply may be even less as some commodities are destined for other industries (such as malting, livestock feed or biofuels) rather than human consumption:

$$\text{Realised Supply}_i = \text{Potential Supply}_i * (\%\,\text{Human consumption}_i)$$

2.3.1 Production data

The production (area or headage), yield (tonnes) and human consumption data came from a variety of sources. Most of the production and yield data were based on agricultural statistics published by Scottish Government or using UK averages from Defra (e.g., the JAC[23], Economic Report on Scottish Agriculture[24] or Pesticide usage report[25]).

Production data was averaged across multiple years where data were available, e.g., the five-year average (2017-2021) cropping areas available in the 2023 JAC or five-year average headage of livestock in the 2021 Economic Report on Scottish Agriculture (2015-2019).

The extractable edible fraction was also sourced from a variety of data sets. Most foods have an edible fraction recorded in the FCT.

For livestock commodities, liveweights were used (rather than carcass weight previously used by RESAS), The edible fraction was estimated based on the proportional weight of edible components of a live animal (i.e., the proportion of a animal that is meat, edible fats and offal).

23 Scottish Government June Agricultural Census (2023)

24 Scottish Government Economic report on Scottish agriculture(2020)

25 Scottish Government Pesticide usage in Scotland: Outdoor Vegetable Crops (2021)

2.3.2 Estimating losses of nutrients

The production data used here, the JAC, reports area of crops (hectares) and the number of animals. From this we then estimated the production in tonnes of each commodity before accounting for any loses.

It is relatively unusual that all of a minimally processed food is fit for human consumption. Losses of nutrients occur at three stages of production[26]: (i) loss during harvesting, (ii) conversion between forms of food, and (iii) removal of inedible components.

We were interested in the least processed state of each commodity, for example, whole milk or hulled barley (the inedible outer husk is removed, but it is less processed than pearled barley that also removes the bran layer). The aim here is to retain the supply of nutrients from primary production before nutrient quantities are changed through food processing.

Losses from processing are classified depending on where in the process they occur: for example, wastage (loss because of agricultural practice, like misshapen vegetables), processing or extraction (e.g., removal of inedible components, e.g., a cereal husk).

The FAO commodity trees include global and national averages for wastage rates (13) that capture the loss of a commodity through harvesting, for example, 11% of a potato harvest is lost during harvesting.

Conversion between forms of a food are derived from the FCT. For example, one tonne (1,000kg) of raw wheat produces approximately 800 kg milled flour (using the FAO UK average extraction rate).

Further, some of the weight of a food is inedible (e.g. a peach stone) and the FCT contain data on the edible fraction of food items.

These losses, though individually small, are important when scaling from the nutrients of a FCT (per 100g of food) to units of production (e.g., per 1 tonne of cereal).

26 Alexander P, Brown C, Arneth A, Finnigan J, Moran D, Rounsevell MDA. Losses, inefficiencies and waste in the global food system. Agricultural Systems 2017; 153: 190–200.

Additionally, some commodities are broken down into multiple parts of which, some are inedible, and others have different nutrient profiles. For example, an animal carcass yields meat, edible fats and offal (internal organs) that can be eaten by humans in addition to inedible components (e.g., skin, bone, and blood). To fully account for the nutrient value of the whole commodity, each of these components needs to be identified and the commodity tree can help quantify these parts.

2.4 Nutrients relative to requirements

Nutrients are needed in different quantities. The amount needed is given by a dietary reference values (DRVs) for each nutrient. These reference values are based on the health implications of too little or too much of a given nutrient for an individual person. In the UK, the DRVs for how much of a nutrient is required were set by the Committee on Medical Aspects of Food and Nutrition Policy in the 1991[27] and updated by Scientific Advisory Committee on Nutrition in 2011[28] followed by specific recommendations, for example on sugar.

The dietary requirements for a healthy life change with age and differ by sex so we used a weighted average DRV for each nutrient based on the age and sex demographics of the 2023 population in Scotland[29]. The calculation did not adjust for pregnant or lactating women, both of whom need more or certain nutrients and do have modified different DRVs.

Dietary Reference Values (DRVs) define as the quantity of energy and nutrients required for groups of individuals. They are defined with reference to a population and are usually calculated for specific ages and sexes. Recommended intakes can be either a minimum or a maximum. Four common measurements that are used include:

Estimated Average Requirements (EARs): the average requirement of energy or nutrient needed for half a population to be healthy. In the UK energy (kcal) is defined by an EAR.

Reference Nutrient Intakes (RNIs): the amount of a nutrient needed for most of the population (e.g., 97.5%) to be healthy. In the UK, both vitamins and minerals have RNI thresholds.

Lower Reference Nutrient Intakes (LRNIs): the minimum amount nutrient necessary and regarded as inadequate for most individuals (e.g., 2.5% of the population).

27 Department of Health. Dietary Reference Values for Food Energy and Nutrients for the United Kingdom: Report of the Panel on Dietary Reference Values of the Committee on Medical Aspects of Food Policy. London, UK: The Stationary Office; 1991.

28 Scientific Advisory Committee on Nutrition. Dietary reference values for energy [Internet]. London, UK: The Stationery Office; 2012.

29 National Records of Scotland. Projected population of Scotland (2020 base)

3 Results

3.1 Nutrient quantities

3.1.1 Comparison with FAO data

This report builds on a RESAS study linking Scottish agricultural commodities to the FAO food balance sheets to estimate the supply of energy (kcal), protein and fat from food commodities. There are two principle sources of difference in the calculation of nutrients – how foods were matched to commodities to extract nutrient data and the estimation of yields (i.e., the quantity of food produced per hectare or head of livestock).

The calculation of nutrients used by the FAO include all foods derived from commodities at the point of sale and are based on a single global value. There are inevitably differences in the estimated nutrient value of foods (**Figure 3**). However, nutrient values are very similar. The significant differences are because of how foods were matched to commodities rather than their estimated nutrient value.

Some commodities are only an approximate match to the JAC data, for example, orchard fruits are an aggregated JAC category from which there are multiple food matches and in other cases there are some differences in the matching between commodity and food item. The matching differences do not reflect errors so much as practical choices in linking data, for example, to find a single best-fitting match to the least-processed form of food.

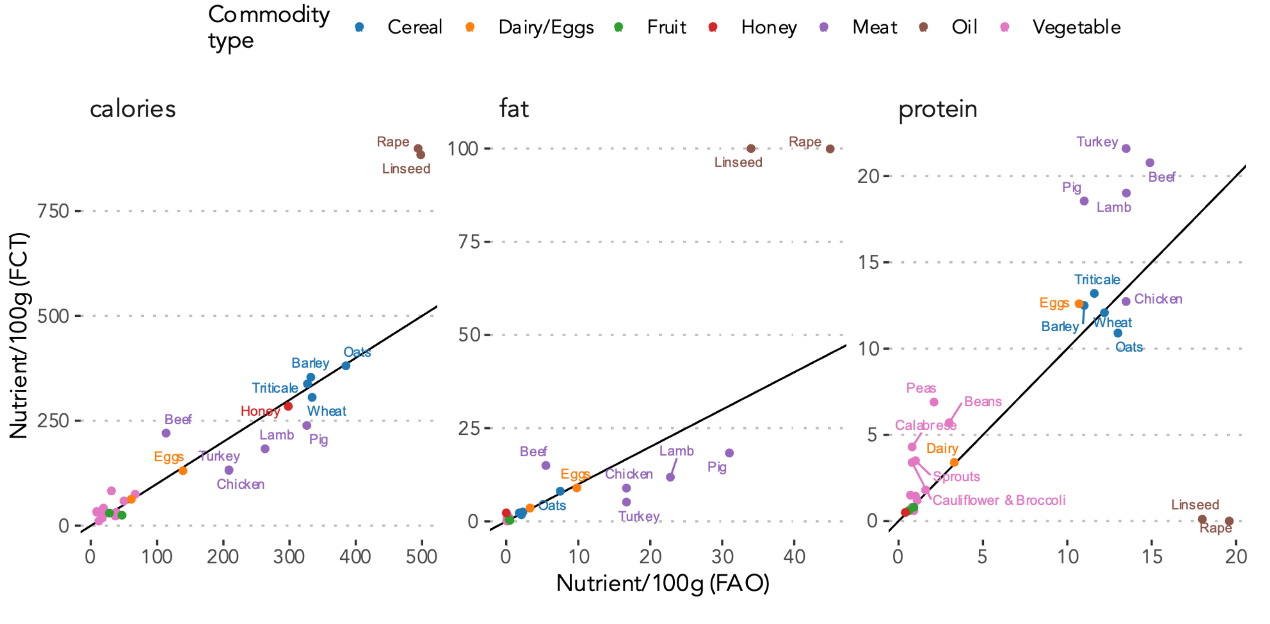


Figure 3

Comparison of the calories (energy), fat and protein per 100g of food between the FAO data used in the RESAS study and the data using food composition tables (FCT). The solid line indicates a one-to-one relationship.

One wouldn't expect a perfect match between the FAO data used in RESAS report and the FCT data used here (Figure 3) because of the assumptions used.

The most striking differences between the estimated energy, fat and protein are for rape and linseed (Figure 3, brown dots). This is because we selected different forms of these commodities compared to the RESAS study. Both are consumed by humans as oil that has highly concentrated fat and energy and has no protein content. Linseed seeds can also be consumed, but for consistency with rape, oil was used for this report as linseed is not available in the UK FCT as either oil or seed. The inedible seed cake is used as livestock feed and the FAO have line items for both cake and oil components, but in the original RESAS work only the solid cake was matched to the JAC data. We have taken only the nutrient values for oil in both cases despite it reflecting an additional processing step, but it is a human-consumable form. As illustration of the difference, the energy content of rapeseed oil is 899 kcal or 840 kcal per 100g in the FCT and FAO data respectively compared to 494 kcal for the seed and similarly the protein content is 0 versus 19.6g per 100g of rapeseed oil versus seed (FAO data only).

The estimates of protein are also different for meats (Figure 3, purple dots), with higher estimated protein in the data calculated here compared to the published estimates from the FAO. The FAO describe entries for all these commodities as meat, however this excludes edible offal and fats that have been factored for the FCT data. The FAO data are presented without information on exactly how data were derived. In contrast, the FCT data describe the source and any potential treatment of food samples, which aids selection of items. For example, the nutrient data for beef meat is described as "Beef, lean, average, raw. Average of 10 different cuts, trimmed of fat", which clarifies what was included and that the nutrient data for fat needs to be added back (from another entry in the FCT). The FAO likely take an average cut of meat, including the edible fat.

The pea protein content was also different, likely based on the type of peas considered (only green pea data were used from the FCT) and how they are processed in the FAO food chain. The same can be seen with calabrese, a variety of broccoli. The best matching value from the FAO data was the combined value of cauliflowers and broccoli, whereas the FCT data was a little more precise matching to broccoli on its own.

Foods that had little processing and for which there is a direct match between a food and a commodity, for example, eggs and whole milk, the agreement is close between the data from the FAO and the data gathered here. Despite this, the protein content of 100g of eggs was 12% higher in the UK FCT compared to the FAO data (12.6g compared to 10.7g of protein per 100g of egg) even though the calories and fat were nearly identical.

Although the nutrient values per 100g are similar, small differences are magnified when scaled to units of production (e.g., tonnes rather than 100g of food) and more so when scaled to national production (e.g., thousands of hectares).

3.1.2 Estimated nutrient quantities

Nutrients and energy per 100g of food for each commodity are shown in **Figure 4**. The brighter the colour, the more of a nutrient that a commodity provides.

Some nutrients, such as vitamin E typically have low concentrations for most foods (dark cells), but are abundant in rape oil (yellow). In contrast, potassium is well distributed across lots of commodities (light orange).

By weight of food (the nutrients in Figure 4 are per 100g), some foods that have a high water content, such as fruits and vegetables, tend to have low quantities of nutrients.

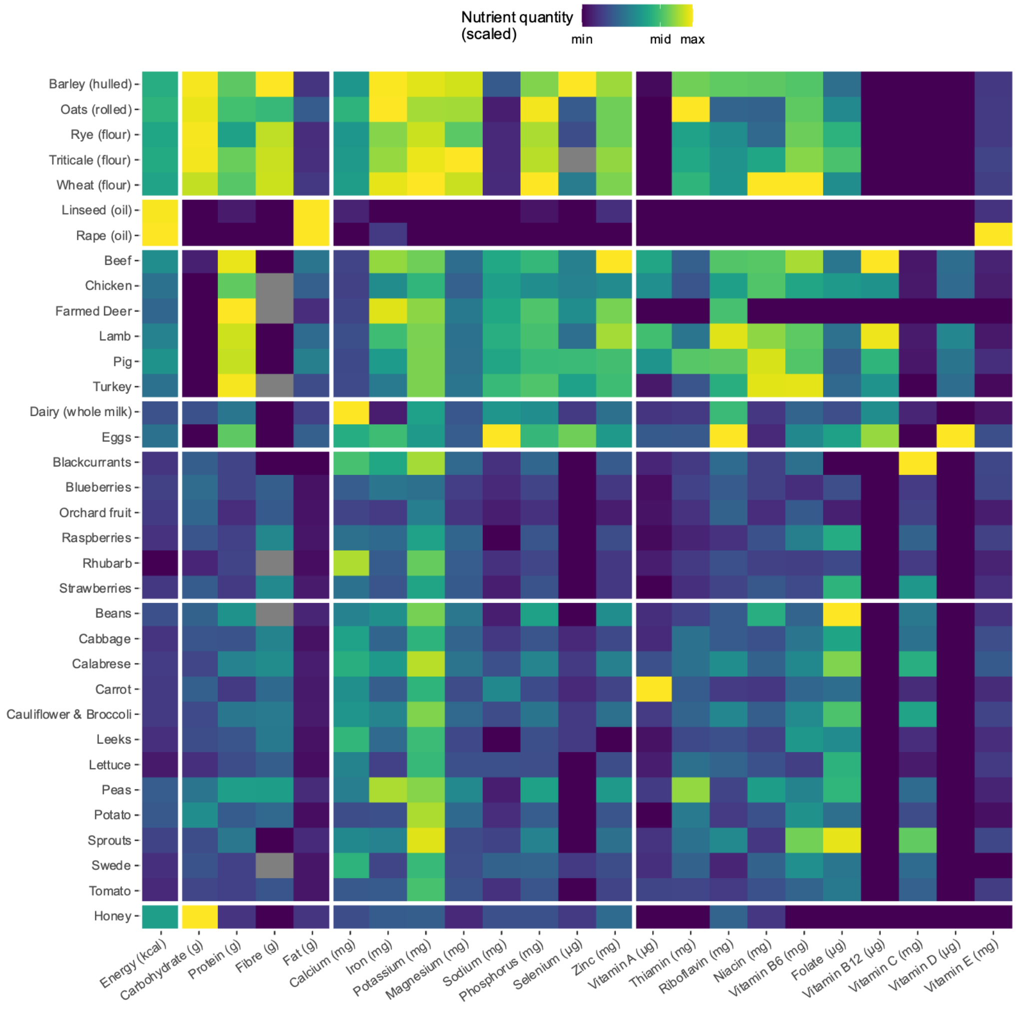


Figure 4

Estimated nutrient content per 100g of food using the food composition table data. Values are scaled between the minimum (dark blue) and maximum (yellow) observed content for each nutrient and energy (columns) to visualise the relative difference between commodities (rows). Note that the colour scale is square-root transformed. Missing data are shown in grey. Horizontal lines divide items into cereals, oils, meat, dairy and eggs, fruit, vegetables, and honey. Vertical lines divide energy, macronutrients, minerals and vitamins.

3.2 Estimated nutrient supply from commodities

To estimate the realised supply of nutrients, the nutrient data from food (Section 3.1.2, Figure 4) was scaled to the tonnes of food produced in an average year, i.e. the average yield in tonnes multiplied by the number of hectares, hives or head of animals for each commodity.

The supply shown in **Figure 5** also adjusts for the food lost in production, the fraction of food that is inedible, and the proportion of food destined for human consumption (see equations in Section 2.3).

Figure 5 shows the relative contribution of a commodity (rows) to the supply of a nutrient (columns). The brighter the colour, the more a commodity contributes to the nutrient supply.

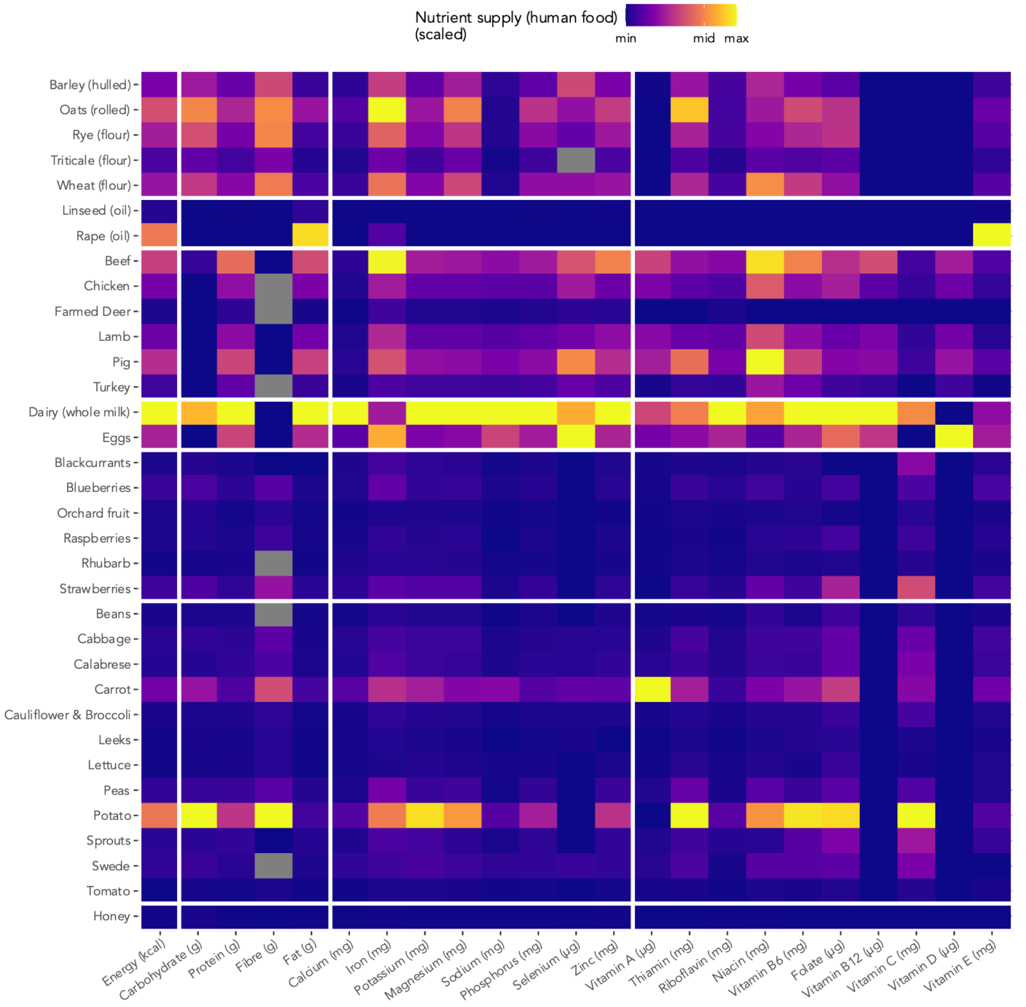


Figure 5

Estimated supply of nutrient for human consumption using the food composition table data. The calculation multiplied the nutrients from food by the average quantity produced (in tonnes) and adjusted for the loss of nutrients from harvesting waste, the edible fraction of food, and the fraction of the commodity that was used for human consumption. The supply of each nutrient (column) was scaled between the minimum (dark blue) and maximum (yellow) supply across commodities (rows). Missing data are shown in grey.

In contrast with the nutrients by weight of food (Figure 4), dairy products and potatoes rather than cereals contribute most to the current supply of nutrients (Figure 5).

Cereals are grown in large quantities, but little is used for human consumption (e.g., approximately 5% of wheat, 1% of barley and 50% of oats are sent by merchants to be milled[30]) and therefore their contribution to the supply of nutrients is comparatively low. Fruit and vegetables are grown in relatively low quantities so their contribution to the supply of nutrients is limited. Similarly, although lamb and beef have similar nutrient profiles, lamb is produced in smaller quantities and therefore contributes less to the overall supply of nutrients.

30 Scottish Government Cereal and oilseed rape harvest (2022)

3.3 Nutrient supply compared to dietary requirements

The nutrient content of each commodity produced can be compared to the averaged DRVs to describe a nutrient profile. This is a comparison with food production in Scotland and does not include imported food, hence where nutrients do not achieve the population requirements one should not interpret the supply to the population as below requirements.

The DRVs are calculated for an individual of a given age and sex. We have calculated a total sum for each nutrient required for the population in Scotland. Summing the supply of nutrients from agricultural produce that are used for human consumption, we can then examine the relative supply compared to the population nutritional needs (**Figure 6**). Dairy (orange) contribute most to the supply of nutrients given their large yields and on their own provide an excess of several nutrients (calcium, phosphorous, riboflavin, and vitamin B12).

Cereals, wheat and barley, are the main crops in Scotland and provide significant quantities of nutrients.

Although fruit and vegetables have high nutrient density (nutrients relative to energy rather than weight of the food), their production is limited in Scotland.

However, Figure 6 adjusts for how much of each harvest is used for human consumption. For example, the majority of the barley and wheat harvests are not produced for human consumption but rather for livestock feed and production of alcohol. This significantly reduces the supply of nutrients that could potentially be produced for humans (**Figure 7**). The nutrients foregone, largely from cereal crops, are significant. However, it is not necessarily the case that the same land could produce cereals for human consumption that are currently used for other purposes (e.g., due to the grain quality).

Vitamin B12 supply is unaffected by the reduction in the cereal harvest as it mostly comes from eggs, lamb and beef and has a large supply. Vitamin C is also largely unaffected by the different uses of cereals given that it is absent from cereals though is extremely concentrated in blackcurrants, but also found in milk and other vegetables.

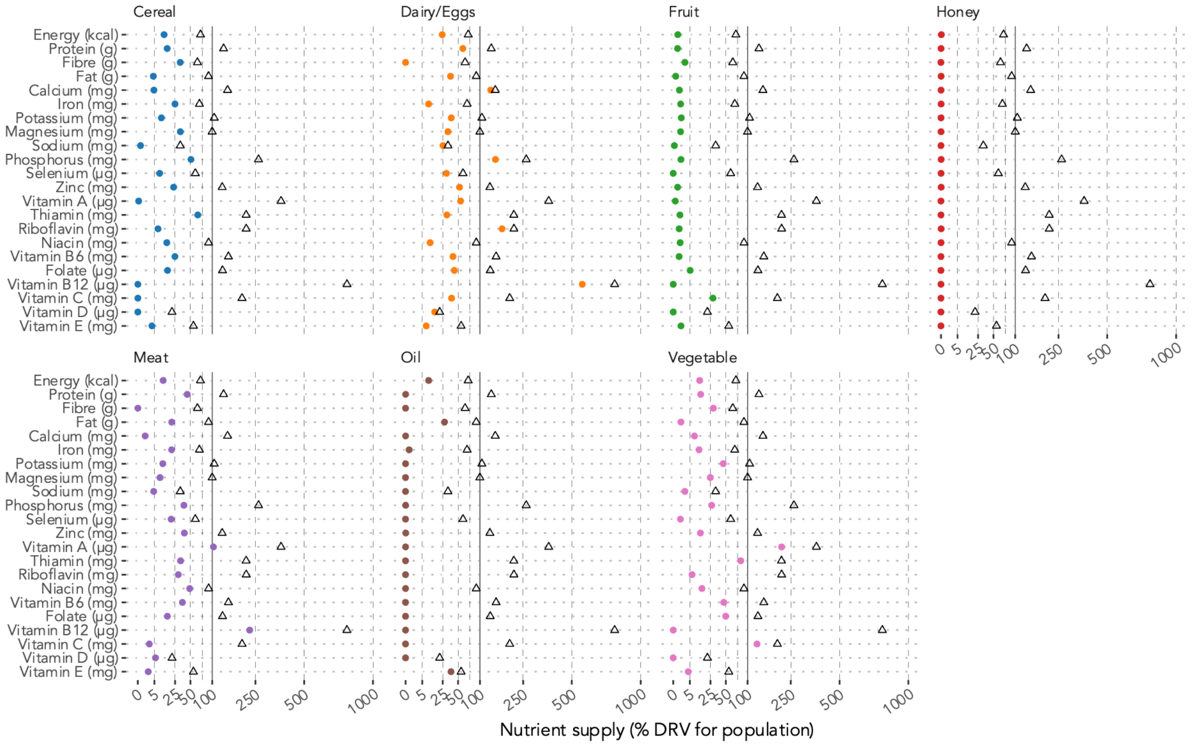


Figure 6

Estimated nutrient supply of minimal processed commodities as a percentage of the whole population daily reference values by agricultural sectors. The total realised supply is shown with black triangles. Assumes averaged cropping area or number of animals and average yields of edible commodities.

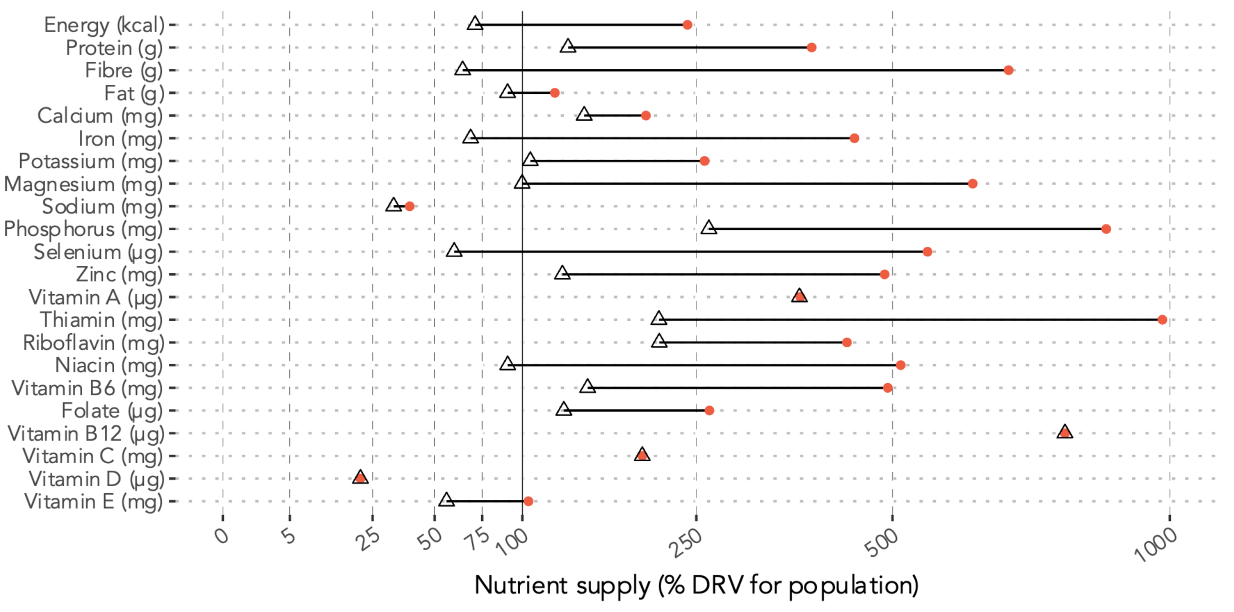


Figure 7

Estimated nutrient supply of minimally processed commodities as a percentage of the whole population daily reference values. Assumes averaged cropping area or number of animals and average yields of edible commodities. Black triangles show the proportion produced for human consumption (i.e., removing the fraction of cereals for animal feed) and red circles indicate the total potential production that includes non-food uses.

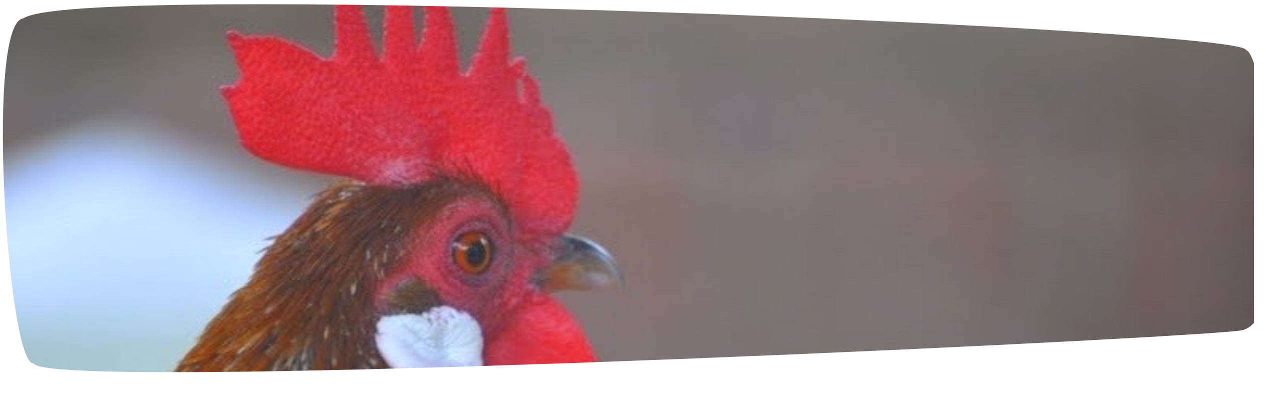
4 Discussion

4.1 Nutrients from Scottish agriculture

Agricultural products each contribute a different amount to the supply of nutrients. Commodities are nutritionally not all the same and consequently the farm outputs from different management choices of what is grown have consequences for the supply of nutrients for human consumption.

Here we explore the supply of nutrients from raw or minimally processed foods that best match agricultural commodities produced in Scotland. Previous estimates of nutrition supply (e.g.,[4]) have examined the supply of nutrients foods available to consumers and therefore accounting for the whole food chain. Here we focus on the primary production of nutrients from land.

We first manually matched minimally processed foods to agricultural commodities that are routinely recorded in the Scottish June Agricultural Census. The choice of food was based on representing the least processed form of the commodity that could still be eaten by humans. Other commodities are produced, but for example are exclusively for livestock feed (e.g., stubble neeps or forage rape), production of alcohol (e.g., most barley grown in Scotland), biofuels (e.g., oil seed rape grown for fuel) and other industrial processes. The same land that is used for non-food products could potentially be used for human food. Equally, land that is used to supply nutrients could be taken out of food production and used for other purposes. Understanding the nutrients of different products can help to model how choices about what is grown can contribute to the supply of nutrients.



As an illustration of choices for land use, the targets for Net Zero likely require a reduction in the number of ruminants. This would reduce the domestic nutrient supply from beef, lamb and dairy, but could free land that is currently used to produce livestock feed for other purposes.

Making the big assumption that nothing else would change in agricultural production (e.g., imports and exports) except the removal of all meats (beef, lamb, chicken, and turkey) which were not replaced with other commodities, the supply of nutrients would decrease, but only three additional nutrients would have inadequate domestic supply (protein, potassium and zinc). Removal of dairy and eggs, however, would dramatically reduce the domestic nutrient supply and in addition to the three nutrients that meat would reduce, calcium, riboflavin, and folate would also decrease below population needs. If dairy, eggs, and meats were removed from production, the domestic supply of all nutrients except for fibre, vitamins A, C and thiamine would all be inadequate.

A substantial proportion of the barley and wheat harvest are used to feed livestock. If animal numbers were changed, the area of land required to support them would also change. Even with limited production for human consumption, cereal crops have relatively large concentrations of minerals (e.g., magnesium, potassium and iron) and macronutrients (e.g., carbohydrate, fibre and protein). Given the large absolute quantities grown, their contribution to nutrient supply is substantial. The lower supply of saturated fat and sodium from cereals are positive given that these two nutrients should be limited in the diet.

At current production levels, fruit does not contribute significantly to the supply of nutrients except for vitamin C. Vegetables are grown in larger quantities and contribute significantly to vitamins A (e.g., from carrots) and C (e.g., from potatoes, not because they have a lot of vitamin C so much as lots are grown) both of which exceed the population requirements. Vegetables also contribute substantially to the supply of fibre, potassium, magnesium, phosphorous, thiamine, vitamin B6 and folate.

Each nutrient is necessary for health. No one commodity provides all the nutrients required for a theoretically healthy population. Milk, for example, provides many nutrients, but does not provide all of them. Consequently, a balance of products is necessary. If production of these commodities were reduced, then careful consideration would need to be given to the foods that would be produced as an alternative to maximise the supply of nutrients.

4.2 Other considerations

The commodities included here are minimally processed and in some cases that means that they are quite far removed from how people might consume them. Wheat, for example, is less often consumed as wholegrain flour and more often eaten as fortified white flour in the form of baked goods. Most of the flour grown in Scotland for human consumption is graded (based on protein content) for use in biscuits rather than bread or pasta. Accounting for the full food chain would change the nutritional value of a commodity as it is consumed rather than from primary production. The nutrient data from the FAO in theory accounts for this and while the differences for 100g of food might be small, when scales up to national production in thousands of tonnes makes for wide variability in supply.

This work focuses on nutrients from agriculture in Scotland, but it is worth noting that nutrients also come from the sea. Within the whole diet, these are important. They are not the only source of nutrients either, as almost half of what is eaten in Scotland is imported, although it is not clear whether this accounts for the source of ingredients so much as whole foods. Across the whole the food chain, the provenance of ingredients and thereby nutrients is largely unknown.

However, aside from where a food comes from the identify of the food matters. There is no automated way to link commodities to the derived foods in FCTs and this requires expert judgement that can differ. The FAO commodity trees do help as an internationally recognised data set, but their derivation is not transparent and at present, the range of nutritional information is limited. Use of global averages, for example, may give an unrepresentative picture of the nutrient value of Scottish products.

It seems a small detail to match a commodity to a food, but with something like beef cattle, meat is only part of the nutrient value. Fat includes many more calories and organs like the liver have much larger quantities of nutrients including vitamin A, thiamin and phosphorous. But even so, there are additional components of a cow that could be eaten but are not typically eaten in the UK and therefore have no associated nutritional data in the UK FCT (e.g., lungs and thymus). Other international FCTs could be examined for such data, which may be more important when considering nutrient import and export, but unless there is a domestic market these are more likely to be nutrients that are routinely discarded.

In terms of data, FCTs do not report variability around nutrient estimates. This means that it is not possible to quantify the uncertainty or variation from the nutrients in foods. Some FCTs, like the US one, do link to individual samples when analysed and multiple samples may be used to estimate the reported average. The minimally processed foods included in this report are unlikely to substantially change over time, but the FCTs are periodically updated[31].

31 Traka MH, Plumb J, Berry R, Pinchen H, Finglas PM. Maintaining and updating food composition datasets for multiple users and novel technologies: Current challenges from a UK perspective. Nutrition Bulletin 2020; 45: 230–240.

Samples, however, may or not reflect current productions. Furthermore, there are many determinants of the nutrient profile of agricultural produce including variation in management, location, genotype and the environment, for example, red meat[31] or wheat[32]. These nutrient variations may be small, but the relative supply of nutrients from different places may vary in ways that we do not current know.

National production data too do not give uncertainty. We have tried to mitigate this by using averaged across five years. There is considerable variation year to year and in some cases secular trends.

Published production data is also aggregated to whole of Scotland or in some cases UK. Where possible, Scottish data have been used, but some data, for example, the average yield per hectare of some vegetables, come from UK averages. The regional Scottish data that do exist demonstrate that nutrient supply might vary substantially within given that farms can be very diverse.

In time, higher resolution data (e.g., by farm) may become available to permit more detailed discussion about issues such as land use.

The estimated nutrient supplies reported here is sensitive to the data if scaled to national production because small differences can be multiplied by thousands of tonnes for a commodity. The data used are the best available, but are subject to change (e.g., yields vary due to weather).

We also make assumptions about extraction and waste that come from a variety of sources. There is no single source for such information. Some commodities have industry bodies that report averages, for example AHDB gives representative data on the breakdown of a carcass (for beef, lamb and pork, but not other meat). Other products, such as horticultural crops, do not have large representative bodies to collate standardised information. However, like other sources of information used here, there is no uncertainty in the numbers presented and therefore the final estimated nutrient supply under-estimates variability.

32 Juárez M, Lam S, Bohrer BM, Dugan MER, Vahmani P, Aalhus J *et al.* Enhancing the Nutritional Value of Red Meat through Genetic and Feeding Strategies. *Foods* 2021; **10**: 872.
33 Zhang X, Ma X, Li Y, Ju H. Geographical detector-based wheat quality attribution under genotype, environment, and crop management frameworks. Front Environ Sci 2022; 10: 1037979.

A big consideration is the nutrient supply, especially compared with the DRVs. First, we only estimate what is produced in Scotland. We do not account for nutrients that are imported and exported. Even more specifically we only account for nutrients from land-based agriculture and nutrients also come from aquaculture.

When we estimate the nutrient supply relative to DRVs under different scenarios, we have not accounted for what would be produced in place of current commodities. For example, if livestock were to be reduced, land would be used for other purposes. Not all alternative uses would necessarily include food production, but some might, and these nutrients would offset those lost from reduced livestock production.

Finally, foods provide different nutrients, and a balance of foods is necessary. Even though some foods dominate supply because of their levels of production, diets needs to include a balance from different foods.

Conclusions

The global food system has been estimated to account for a third of all greenhouse gas emissions[34] and is the primary cause of biodiversity loss[35]. Given this, and the growing need to balance demands on land, it is useful to acknowledge the relative nutritional value of different agricultural products both to consider what would best ensure food and nutrition security needs but also where land needs to be protected for agriculture over other functions. To that end, the work presented here is an attempt to capture the ways in which agricultural products contribute to the supply of different nutrients for the population of Scotland.

The nutrients quantities by weight of food suggests a theoretical supply, for example, which commodities would contribute to the supply of nutrients. This theoretical supply is not matched by the realised supply of nutrients when adjusting for levels of production. Milk and potatoes, for example contribute more to the supply of nutrients than might be expected because of high yields. Cereals contribute less than might be expected because much of the production is used for livestock feed and making alcohol.

Animal products are an important sources of nutrients and the replacing these nutrients from plant sources would necessitate a substantial increase in the production of horticultural crops beyond current levels. Land that is currently used to support livestock might be made available for alternative products to replace nutrients from animal-based foods.

Different geographic locations, however, have different capability to produce human foods. Modelling where commodities can be grown highlights the contribution of different locations to the supply of nutrients and can be balanced with the choice of commodities to optimise theoretical nutrient supply.

34 Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello FN, Leip A. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat Food 2021;2:198–209.
35 Benton T, Bieg C, Harwatt H, Pudasaini R, Wellesley L. Food system impacts on biodiversity loss: Three levers for food system transformation in support of nature. London, UK: Chatham House; 2021 Feb.

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