What is sustainable agriculture?

Leslie Firbank
(University of Leeds, UK)

We all want to eat food that is produced sustainably. But it's not at all clear what that means in practice. Fundamentally, agriculture can be regarded as sustainable if it can continue to meet human needs whilst avoiding irreversible harm to the planet. The human needs are not just food, but include employment, leisure, social cohesion and the many ecosystem services provided by agricultural land that benefit people, including regulating water quantity and quality, carbon storage, maintaining landscapes of cultural and spiritual value, and providing homes for wildlife. Agriculture causes harm to the planet from habitat loss, carbon emissions, and pollution of air and water. Meeting these challenges is tough now, but it will only become more difficult as the human population rises and climate change becomes more difficult to cope with.

The key human need from agriculture is the provision of food for people. *Homo sapiens* is an omnivore, with requirements for carbohydrate, protein, fat, minerals and vitamins. One index of a healthy diet is the diversity of food items that one consumes; a simplified diet is likely to be low in certain elements and too high in others. Globally, there is more than enough food produced to feed everyone, yet an estimated 815 million people were undernourished in 2016, as a result of conflicts, inequality and economic slowdown. Malnutrition is not just about having too little food per se, it can be food of the wrong type. Obesity is becoming a chronic problem across the world, with an estimated 41 million overweight children under 5 in 2016, and adult obesity increasing everywhere. 28% of adults were classified as obese in North America and Europe in 2014, compared with around 13% across the globe.

One way of dealing with food shortages and dietary imbalances is to grow more food. Indeed, it has been suggested that global food production must increase by around 60%. Yet this is becoming more difficult, as most of the land that is suitable for food production is already in use. Future growth in crop production therefore depends on increasing yields. For crops, this is likely to be where current yields are well below the potential, especially in sub-Saharan Africa. For livestock, yield increases seem most likely to come from increased output per animal and larger herds. Such increases in productivity have to be achieved in the face of problems including climate change, soil erosion, water shortages and declines in insect pollinators.

Agriculture is already having a huge impact on the global environment. One measure is the Human Appropriate Net Primary Production, the proportion of plant production that is being used to support people. The estimates are highly uncertain, but it seems that around a quarter of net primary production was used by people in 2005, a value that is increasing. An estimated 37% of all land is used for agriculture, concentrated, of course, in areas with adequate climate and soils. The biomass of people and livestock combined outweighs that of all mammals and birds combined: the biomass of domestic poultry is about three times that of wild birds, while the biomass of livestock is over ten times greater than that of wild mammals. In most regions of the world, agriculture takes over 70% of freshwater, and emits around 24% of greenhouse gases. Clearly, agriculture needs to change if we are to keep the earth within a safe and just operating space. But how?

Let's go vegan

In the last few decades, the global demand for meat has risen. Around one-third of croplands are now used to grow feed for livestock, areas that could be used to grow crops for people. The greenhouse gas emissions (GHG) from the livestock sector account for around 14.5% of all human-induced emissions, and there are health risks involved in a high-meat diet.

It's not surprising that there are suggestions that a vegan diet will help make farming more sustainable. Yet there are strong arguments for not going 100% vegan globally. First of all, unless the diet is carefully managed with supplements, children on vegan diets are prone to nutritional deficiencies. Secondly, around 1 billion poor people around the world depend on livestock economically and for food. A reduction in livestock

Figure 1. Urban farming in action. In Nairobi, a community fish farm uses wastes from a nearby brewery to feed flies, which are food for fish in these ponds. An urban fruit and vegetable smallholding is seen in the background. Photo credit: L.G. Firbank.

numbers, whilst avoiding competing for food that could be used by people (i.e. restricting to grazing land and food wastes) may result in a healthier diet, improved efficiency of land use and reduced GHG emissions. A recent study suggests that if this approach were applied to the US, cattle production would fall to around 45% of current levels; another one suggested that organic farming could feed the world in 2050, but only if diets changed and food waste reduced.

A related discussion is about factory farming of livestock. The concentration of livestock into large units concentrates environmental impact, and is associated with low animal welfare. However, because the environment for the animals can be controlled, environmental impact per unit food can be lower than in free-range systems, while incidence of animal health problems can often be better controlled. The concentration of livestock like this also keeps the costs down, making meat and dairy products easier to afford.

Let's go organic

Organic farming does not rely on the artificial fertilizers and pesticides that underwrite much of intensive agriculture. The intention is to manage the natural processes, especially by improving soil quality. It does so by using crop rotations that include periods of grass, ideally with livestock, to rebuild soil nutrient levels and structure (note a global organic, vegan farming system would be difficult to achieve…where would all the plant nutrients come from?). These improvements in soil structure confer resilience against more extreme weather conditions. Grass in rotations also help control weeds and diseases. The more varied landscapes that result tend to be richer in wildlife. Organic farming therefore should help reduce the environmental footprint and increase the resilience of farming against climate change.

The main downside of organic farming is that yields are lower, especially across the whole rotation. The key argument against organic farming is therefore that, if adopted on a large scale, food production would fall. This point can also affect how the environmental footprint is perceived; if GHG emissions are measured per unit land, they are smaller on organic systems, but the difference pretty much disappears if measured per unit of food produced. Other distinctions between organic and non-organic systems are harder to determine, especially now that pollution from pesticides and fertilisers can be much reduced thanks to new technology that applies pesticides and fertilisers precisely where they are needed. Evidence that organic food is of higher quality than conventional food, or that animal welfare is better, is patchy, and depends on how the particular farm is managed.

This kind of discussion suggests that practices in organic and conventional agriculture are mutually exclusive, which is far from the case. If anything, best

practice in organic farming is being adopted more widely anyway. In Europe, bans in agrochemicals are encouraging the renewed uptake of cultural pest and weed control. In China, concerns about nitrate pollution are encouraging the use of organic manures instead of inorganic compounds, and in many parts of the world agricultural development is being steered towards Climate Smart Agriculture, which involves adapting to climate change by building soil resilience and ecosystem service delivery, often using techniques that are compatible with organic farming.

Let's go GM

One of the key engines of improved agricultural performance is the advancement of crop and livestock genetics. This development has relied on fixing beneficial mutations into the organism's genetic code. In the 1920s, it was discovered that the rate of mutations can be increased by exposure to radiation of chemicals, but the resultant changes were impossible to predict. Improvements in molecular methods in the late 20th century allowed a much more precise approach to plant breeding, of transferring desirable genes across species barriers into crop plants. The first such genetically modified crops were made available for commercial use in the 1990s. However, there was a great deal of public opposition, especially in Europe where few GM food products are sold directly to consumers. The new crops were seen as unnatural, posing risks to human health and environment, reduced the diversity of crops, and were associated with increasing hold of multinationals on the agrifood system. On the other hand, GM has the potential to accelerate plant breeding to allow much more timely responses to changing pest and disease challenges, and to changing soil and climate conditions. Regulatory systems were installed around the world to manage their introduction. Regulatory systems were installed around the world to manage their introduction.

The debate about GM remains lively. The technology has now moved on; it is now possible to edit genomes much more precisely using techniques including CRISPR/Cas9, avoiding the need to move genes between species. CRISPR involves using an enzyme, Cas9, to edit DNA precisely and very cheaply, to insert or remove particular sequences. Such techniques are much cheaper and much more flexible than GM, and need not leave any

Figure 2. Cattle, Embrapa Research Station, Brazil. Photo credit: L.G. Firbank.

Figure 3. Intensive dairy unit. The cattle are milked and fed with individualized rations on a rotary unit, which also checks weight and can provide an opportunity for health checks. Note the fans in the background to maintain temperature. Photo credit: L.G. Firbank.

imprints that are detectable in the progeny. Regulators are considering their response to CRISPR; in the US, they are not currently regulated, as they do not contain foreign DNA, although this situation is being reviewed. In Europe, the situation will be decided later in 2018, although a formal opinion earlier this year suggests that they need not be regarded as subject to GMO regulations. Whether this relaxed regulatory approach accords with public views remains to be seen.

In truth, both the benefits and risks associated with the commercial production of GM crops have turned out to be rather muted. GM crops have neither saved the world nor put it at risk, but they have been commercial successes. However, the stakes will be higher in the future, as the technology allows a much wider range of modifications to a much wider range of plants and animals. For example, new modifications of biochemical pathways have enhanced the efficiency of photosynthesis of tobacco in the field by 15%. This has been achieved by speeding up the adaptation to fluctuating light by accelerating the conversion between violaxanthin and zeathanxin, and increasing the amount of photosystem II subunit.

Let's spare land for biodiversity

One of the big debates about farming is summed up as land sparing versus land sharing. The focus of debate is whether land should be used either for food or conservation, or for both. Organic farming is seen as land sharing, as the levels of production are lower, the demand for land is higher, but wildlife can live on the land. Under land sparing, the idea is some land is used very intensively for food production, making it possible to free up land elsewhere that can be devoted to habitat and biodiversity conservation. The two models address different species; the farmland birds that might benefit from land sharing would not thrive in the spared tropical forests, or vice versa. Also, the land sparing model assumes that there is a simple trade-off over land. It's not clear that the real world obeys these models. The link between agricultural production and biodiversity is not an inversely linear one, it is far more complex. In some situations, low levels of agriculture enhance biodiversity (this is especially true in the traditional, extensively farmed landscapes in Europe), and in others, biodiversity can enhance agricultural production (especially if the range of food products is increased to include some of the indigenous species). Nor is it clear that land allocation for the creation of nature reserves is influenced by agricultural prices. A more nuanced look at this issue recognizes that different parcels of land have different potentials; some are good for food production, some for supporting ecosystem services like flood management, some are good for biodiversity conservation. The trick is to find mechanisms so that different parcels of land are used appropriately, but at a larger scale the different requirements for food, housing, leisure and ecosystem services are provided.

Figure 4. Arable landscape, East Anglia. Photo credit: L.G. Firbank.

Let's use other ways of producing food

There is increasing interest is developing new ways of producing food. The combination of hydroponics and LED lights is allowing indoor plant production at scale in urban settings; current emphasis is on high-value, small items, such as salad leaves. Such systems have the potential to provide dietary diversity at very local scales, just as smallholder systems involving feeding fish or chickens on food wastes (via insects) may be able to deliver protein. These systems demand little land or natural resources, and are creating opportunities for innovators around the world. The increasing success of culturing meat in a lab may also provide a commercially viable alternative to livestock production.

Looking ahead

Something has to change over the next few decades if we are to meet our societal needs for food without going beyond the earth's capacity. But there is no single off-the-shelf answer. First of all, food consumption needs to be smarter; eating a balanced diet with less waste. But this is not a simple a decision for the individual, as dietary choices are related to poverty and quality of life. Sustainable agriculture cannot fix this problem. We need more responsibility for the whole food chain at more local levels; currently it feels too remote for many people to really care about it. On the farm, there is no single pathway to sustainability, no single label that gives us the assurance we would like. But all pathways will involve the more intensive application of knowledge to land management, recognizing that land, soil and water are vital natural resources to be nurtured. ■

Further reading

- Clark, M. and Tilman, D. (2017) Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environmental Research Letters **12**, 064016
- Eshel, G., Shepon, A., Shaket, T., Cotler, B.D., Gilutz, S., Giddings, D., Raymo, M.E. and Milo, R. (2017) A model for 'sustainable' US beef production. Nature Ecology and Evolution **2**, 81–85
- FAO World Agriculture Towards 2030/2015, the 2012 revision.
- Gao, C.X. (2018) The future of CRISPR technologies in agriculture. Nature Reviews Molecular Cell Biology **19**, 275–276
- Intergovernmental Science: Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2017) The assessment report on pollinators, pollination and food production of the intergovernmental science-policy platform on biodiversity and ecosystem services www.ipbes.net/system/tdf/downloads/pdf/individual_chapters_pollination_20170305.pdf?file=1&type=node&id=15248
- Kromdijk, J. Głowacka, K., Leonelli, L. Gabilly, S.T., Iwai, M. Niyogi, K.K. and Long, S.P. (2016) Improving photosynthesis and crop productivity by accelerating recovery from photoprotection. Science **354**, 857–861
- OECD FAO Agricultural Outlook www.agri-outlook.org/.
- UN Sustainable Development Goals www.un.org/sustainabledevelopment/sustainable-development-goals/
- Kumar, S., Chen, W., and Novak S. (2017) Trait stacking in modern agriculture: application of genome editing tools. Emerging Topics in Life Sciences **1** (2) 151-160

Les Firbank is an agro-ecologist. He was brought up on a small farm in northern England, took a degree in zoology before researching into interactions between farming and the environment. His early work focussed on weeds and crops, before moving to the Centre for Ecology and Hydrology where he led large scale studies on the environmental effects of set-aside, organic farming and GM crops. He moved to North Wyke Research where he developed the concept of an intensive, farm-scale research platform to look at the mechanisms underpinning more sustainable farming. He is now Professor in Sustainable Agriculture at the University of Leeds, addressing the sustainable intensification of agriculture. Email: L.Firbank@leeds.ac.uk