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Organic agriculture in the twenty-first century

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Organic agriculture has a history of being contentious and is considered by some as an inefficient approach to food production. Yet organic foods and beverages are a rapidly growing market segment in the global food industry. Here, we examine the performance of organic farming in light of four key sustainability metrics: productivity, environmental impact, economic viability and social wellbeing. Organic farming systems produce lower yields compared with conventional agriculture. However, they are more profitable and environmentally friendly, and deliver equally or more nutritious foods that contain less (or no) pesticide residues, compared with conventional farming. Moreover, initial evidence indicates that organic agricultural systems deliver greater ecosystem services and social benefits. Although organic agriculture has an untapped role to play when it comes to the establishment of sustainable farming systems, no single approach will safely feed the planet. Rather, a blend of organic and other innovative farming systems is needed. Significant barriers exist to adopting these systems, however, and a diversity of policy instruments will be required to facilitate their development and implementation.

Organic agriculture has a history of being contentious. Emblematic of this, and representing the prevailing attitudes of many farmers and scientists in the 1970s and 1980s, are the unsympathetic words uttered in 1971 by then US Secretary of Agriculture Earl Butz: "Before we go back to organic agriculture in this country, somebody must decide which 50 million Americans we are going to let starve or go hungry"[1]. At the turn of the twenty-first century, sceptics considered organic agriculture to be ideologically driven and inefficient[2,3]. They argued that organic agriculture relies on more land to produce the same amount of food as conventional agriculture and that adopting organic agriculture on too large a scale could potentially threaten the world's forests, wetlands and grasslands[2,3]. They also asserted that organic agriculture has too many shortcomings and poor solutions to agricultural problems[2,4]. Organic agriculture is still considered by some critics as being an inefficient approach to food security[5,6] and a farming system that will become less relevant in the future[6].

Yet the number of organic farms, the extent of organically farmed land, the amount of research funding devoted to organic farming and the market size for organic foods have steadily increased[7]. Sales of organic foods and beverages are rapidly growing, increasing almost fivefold between 1999 and 2013 to US$72 billion (ref. 7; Fig. 1); this 2013 figure is projected to double by 2018. Moreover, recent international reports recognize organic agriculture as an innovative farming system that balances multiple sustainability goals and will be of increasing importance in global food and ecosystem security[8–10].

Here, we review the performance of organic farming systems in the context of sustainability metrics and global challenges, and examine some of the barriers to the adoption of organic farming systems and the policies needed to overcome them.

Organic practices and certification

Organic agriculture, sometimes called biological or ecological agriculture, combines traditional conservation-minded farming methods with modern farming technologies. It emphasizes rotating crops, managing pests naturally, diversifying crops and livestock, and improving the soil with compost additions and animal and green manures (Fig. 2). Organic farmers use modern equipment, improved crop varieties, soil and water conservation practices, and the latest innovations in feeding and handling livestock. Organic farming systems range from strict closed-cycle systems that go beyond organic certification guidelines by limiting external inputs as much as possible to more standard systems that simply follow organic certification guidelines.

Rudolf Steiner's 1924 course on biodynamic agriculture sparked the evolution of organic agriculture in Europe[1]. Organic agriculture was established in its own right in the 1930s and 1940s, being developed in Britain by Lady Eve Balfour and Sir Albert Howard, in Switzerland by Hans Mueller, in the United States by J. I. Rodale and in Japan by Masanobu Fukuoka[1]. By the 1970s, organic foods had grown in popularity, prompting the first organic certification standards to be drafted in Europe and the United States, and commencing an ongoing evolution of certifiers that now includes 283 organic certification bodies worldwide operating in 170 countries[7]. This proliferation of certifiers reflects both a complex history of sometimes competing independent standards and the demand for access to certifiers around the world.

Many farms in both developed and less-developed countries implement organic practices but are not certified organic. However, growers are increasingly turning to certified organic farming systems as a way to provide verification of production methods, decrease reliance on non-renewable resources, capture high-value markets and premium prices, and boost farm income. Although requirements vary slightly between certifying agencies, they promote soil quality, crop rotations, animal and plant diversity, biological processes, and animal welfare, while generally prohibiting irradiation, sewage sludge, genetic engineering, the prophylactic use of antibiotics, and virtually all synthetic pesticides and fertilizers. Standards continue to evolve with changing technologies and socioecological conditions; some requirements are based on scientific evidence, whereas others are driven by ideology.

As most certification standards originated in temperate developed countries, they are not always applicable in other regions, especially in less-developed countries. High demand for organic foods in Europe and North America has resulted in the import of organic foods from large farms in less-developed countries[7]. Although premium prices for exported foods may be beneficial to farmers, the inaccessibility of many of these foods to local consumers raises

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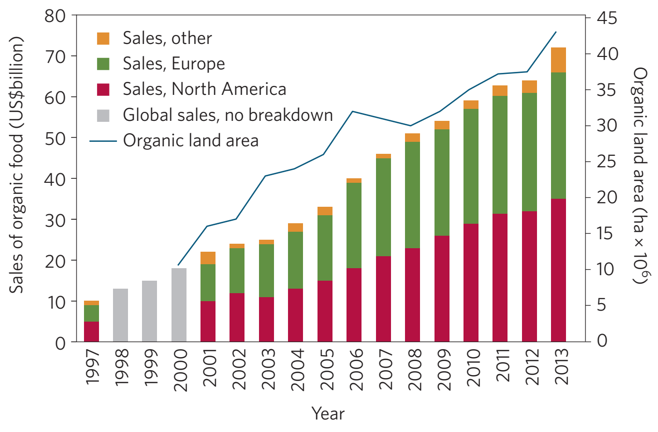

Figure 1 | Annual global market for organic foods and land area of organic production. Increasing sales of organic food in nominal billions of US dollars (bars), broken down by contributions from North America (red), Europe (green) and the rest of the world (orange), and increasing total global land area under organic production in millions of hectares (blue line)[7,96–98]. European and North American contributions were not available for the years 1998 through 2000, shown in grey.

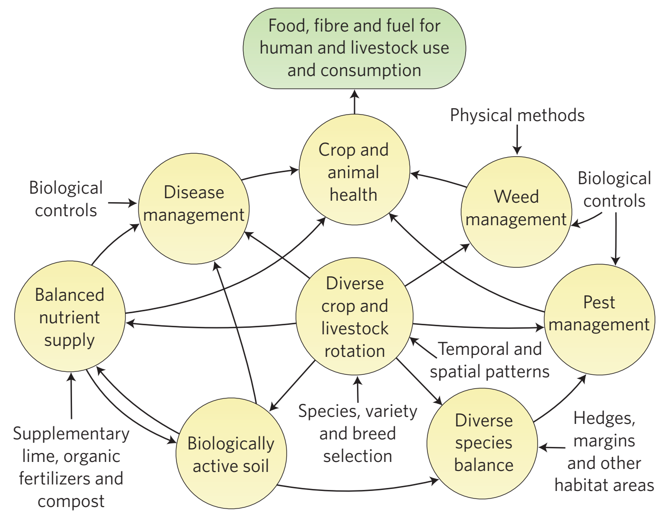

Figure 2 | Organic management practices. The complex interactions among structural factors and tactical management strategies on a diversified organic farm producing food, fibre and fuel for human and livestock use and consumption. Structural factors, represented by circles, are the foundation of organic management, with diverse crop and livestock rotations at the centre. Tactical management decisions are used to supplement the structural factors and include the use of: biological controls; supplementary lime, organic fertilizers and compost; hedges, margins and other habitat areas; species, variety and breed selection; temporal and spatial patterns; and physical weed management. Figure adapted from ref. 99, © 2001 Elsevier.

questions about food security and social equity. Participatory guarantee systems, which rely on local stakeholder verification, have emerged as a more locally focused alternative to traditional certification[7], and could lead to the development of more locally relevant visions for the production and consumption of organic foods.

Sustainability of organic agriculture

About 38% of Earth's land cover is occupied by agriculture[11]. Although agriculture provides growing supplies of food and other products, it is a major contributor to greenhouse gases, biodiversity loss, agrochemical pollution and soil degradation[12–14]. Most of these environmental consequences come from arable land, which comprises around 12% of the land cover[11]. The challenge of feeding a growing population expected to reach 9 to 10 billion people by 2050 while protecting the environment is daunting. Adopting truly sustainable farming systems on a wide scale is our best opportunity for meeting this grand challenge and ensuring future food and ecosystem security. Concerns about the unsustainability of conventional agriculture have promoted interest in other farming systems, such as organic, integrated and conservation agriculture[8–10].

According to a US National Academy of Sciences report[10], any farm, be it organic or conventional, can only be deemed sustainable if it produces adequate amounts of high-quality food, enhances the natural-resource base and environment, is financially viable, and contributes to the wellbeing of farmers and their communities. With the rise of organic farming in the past two decades, hundreds of research studies comparing different aspects of organic and conventional farming systems have been published. This section focuses on assessing such comparison studies across these four sustainability areas.

Production. Production includes crop and animal yield and their quality. Numerous individual studies have compared yield differences between organic and conventional systems. These data have been synthesized in several meta-analyses or reviews; according to these studies, yield averages are 8 to 25% lower in organic systems[15–19]. However, with certain crops, growing conditions and management practices, organic systems come closer to matching conventional systems in terms of yields. According to one such synthesis study, the best yielding organically grown crops or crop groups are rice, soybeans, corn and grass-clover, which yield 6 to 11% less than conventional systems; the lowest yielding are fruits and wheat, which yield 28 and 27% less, respectively[17]. Another meta-analysis found fruits, soybeans and oilseed to be the highest yielding organic crops, and wheat and vegetables the lowest, yielding 37 and 33% less than conventional systems respectively[18]. In cases where organic crop rotations depend on green manure crops, food production over the whole rotation may be lower than one-to-one crop yield comparisons suggest[17].

Although meta-analysis is a great tool that can describe broad patterns not immediately visible in primary field research[19,20], it must also be treated with caution, because no single farming system or practice works best everywhere. Still, these studies[15–19] give strength to the argument that adoption of organic agriculture under agroecological conditions where it performs best may close the yield gap between organic and conventional systems. Under severe drought conditions, which are expected to increase with climate change in many areas, organically managed farms have frequently been shown to produce higher yields than their conventional counterparts[21,22], due to the higher water-holding capacity of organically farmed soils[23]. In addition, improvements in management techniques and crop varieties for organic systems may also close this yield gap. For example, direct selection of wheat cultivars in organic systems has resulted in improved yields in organic systems when compared with indirect selection of wheat cultivars in conventional systems[24].

Whereas organic systems yield less food, organic foods have significantly less to no synthetic pesticide residues compared with conventionally produced foods[25–28]. Studies have also found that children who eat conventionally produced foods have significantly higher levels of organophosphate pesticide metabolites in their urine than children who eat organically produced foods[29,30]. In 2012, the American Academy of Pediatrics reported that an organic diet reduces children's exposure to pesticides, and provided resources for parents seeking guidance on which foods tend to have the highest pesticide residues[31]. Although these data show that organic foods

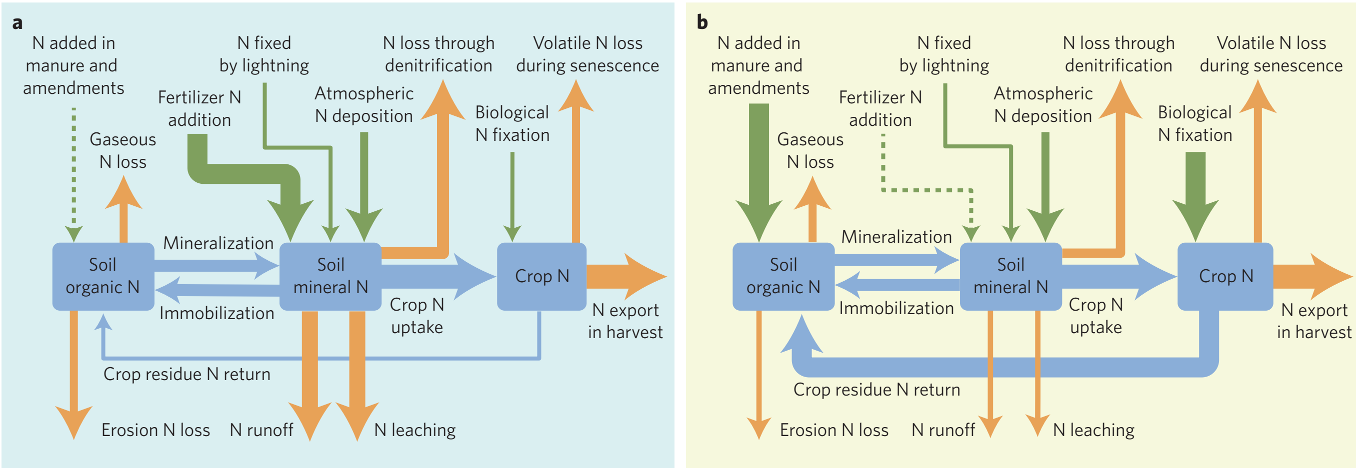

Figure 3 | Hypothetical nitrogen stocks and flows of two contrasting cropping systems. a,**b**, Cropping systems relying mainly on mineral nitrogen inputs (**a**) have relatively higher nitrogen losses to air and water than cropping systems with emphasis on biological N fixation, manure and other organic matter amendments, cover crops and perennial crops, and low reliance on mineral N fertilizer, such as organic and integrated systems (**b**). The width of the arrows is relative to the size of the nitrogen flux; boxes representing nitrogen stocks are not scaled to the pool size. Figure adapted from ref. 100, © 2015 The National Academies[100]. Arrows represent nitrogen inputs (green), losses (orange) and transformations (blue).

may present some clear advantages when it comes to synthetic pesticide residues, the human health impacts of pesticide exposure from food are not clear[26], and organically certified pesticides need to be better identified and taken into account[28].

At least 15 reviews or meta-analyses[26,27,32–44] of the scientific literature comparing the nutrition of organic and conventional foods have been published in the past 15 years. Twelve of these studies[27,32–34,36–39,41–44] found some evidence of organic food being more nutritious (for instance, having higher concentrations of vitamin C, total antioxidants and total omega-3 fatty acids, and higher omega-3 to -6 ratios). Whether or not these are nutritionally meaningful differences continues to be debated[26,43]. The other three studies[26,35,40] concluded that there were no consistent nutritional differences between organic and conventional foods. However, one of the three studies found that conventional chicken and pork had a 33% higher risk for contamination with antibiotic-resistant bacteria compared with organic alternatives[26].

Environment. Reviews and meta-analyses generally support the perception that organic farming systems are more environmentally friendly than conventional farming systems[45–58]. For example, such aggregate studies have found that organic farming systems consistently have greater soil carbon levels, better soil quality and less soil erosion compared with conventional systems[45–51]. In addition, organic farms generally have more plant diversity, greater faunal diversity (insects, soil fauna and microbes, birds) and often more habitat and landscape diversity[46–55]. Most functional groups, such as herbivores, pollinators, predators and producers (plants), are more diverse in organic farming systems[51–53]. Moreover, in a study covering eight western and eastern European countries, insecticides and fungicides had consistently negative effects on biodiversity, with insecticides also reducing the biological control potential in farming systems[56].

As organic agriculture uses virtually no synthetic pesticides, there is little to no risk of synthetic pesticide pollution of ground and surface waters[46]. With respect to nitrate and phosphorous leaching and greenhouse gas emissions, organic farming systems score better than conventional farming when expressed per unit production area[46,49,51,57,58]; however, given the lower land-use efficiency of organic farming in developed countries, this positive effect is less pronounced and in some cases reversed when expressed per unit product[49,57,58]. In a meta-analysis of environmental quality parameters, organic farms were found to have lower nitrate leaching, nitrous oxide emissions and ammonia emissions per unit of field area, but higher leaching and emissions per unit product[48]. Severe degradation of freshwater and marine ecosystems around the world is linked to excessive use of nitrogen and phosphorous fertilizers[12,59], leading to eutrophication of freshwater and the production of hypoxic zones in coastal waters. Lower nutrient pollution from organic compared with conventional systems can be illustrated by differences in their nitrogen cycling and losses (Fig. 3).

Organic systems are usually more energy efficient than their conventional counterparts[46–48,51,54,58]. For example, in Germany, Italy, Sweden and Switzerland, organic farms were found to use significantly less energy on a per-hectare basis than their conventional counterparts, and 70% of organic farms and 30% of conventional farms had significantly lower energy consumption per unit of output[45]. The generally lower energy use[46–48,54] and higher soil organic matter[45–49] of organic systems make them ideal blueprints for developing methods to limit fossil fuel emissions and build soil carbon stores, important tools in addressing climate change.

Economics. Whether organic agriculture can continue to expand globally will primarily be determined by its financial performance compared with conventional agriculture[17,60]. The main factors that determine the profitability of organic agriculture include crop yields, labour and total costs, price premiums for organic products, the potential for reduced income during the organic transition period (usually three years), and potential cost savings from the reduced reliance on non-renewable resources and purchased inputs[61].

To the best of our knowledge, only one meta-analysis has analysed the financial performance of organic and conventional agriculture[20]. The analysis combines findings from 40 years of studies covering 55 crops grown on five continents. When actual price premiums (higher prices awarded to organic foods) were included, organic agriculture proved significantly more profitable (22 to 35% greater net present values) and had higher benefit/cost ratios (20 to 24%) than conventional agriculture. When organic premiums were taken away, net present values (−27 to −23%) — net returns accounting for the time value of money — and benefit/cost ratios (−8 to −7%) of organic agriculture were significantly lower than conventional agriculture[20].

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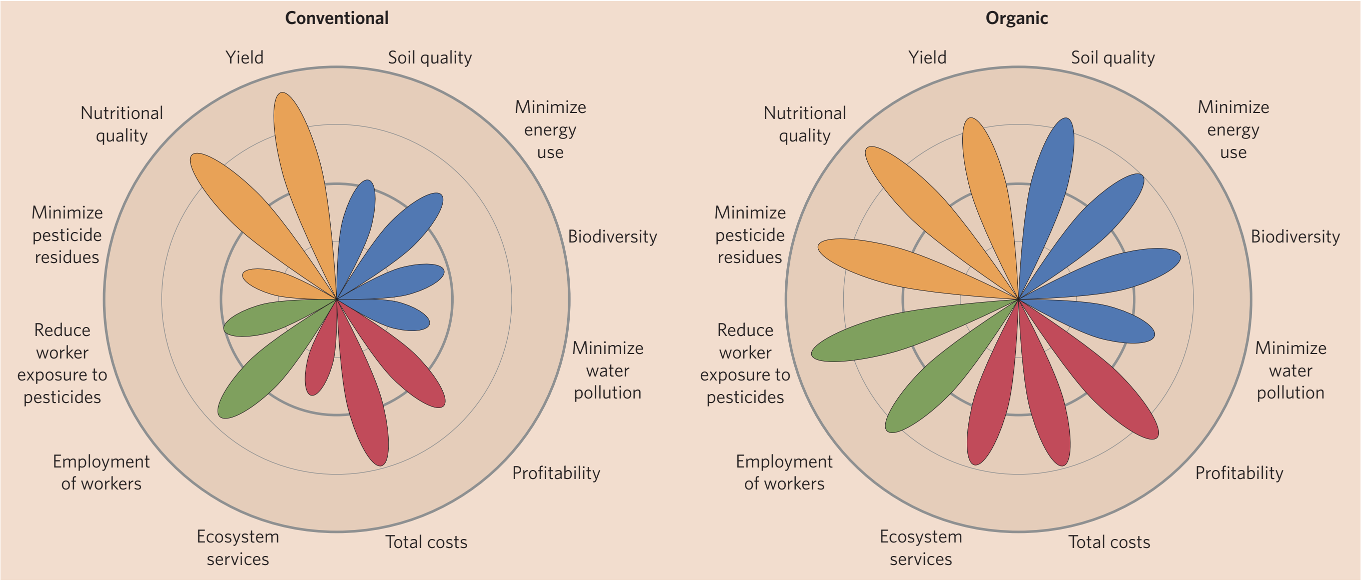

Figure 4 | Assessment of organic farming relative to conventional farming in the four major areas of sustainability. Lengths of the 12 flower petals are qualitatively based on the studies discussed in this Review[15–23,25–29,32–56,58,62–74] and indicate the level of performance of specific sustainability metrics relative to the four circles representing 25, 50, 75 and 100%. Orange petals represent areas of production; blue petals represent areas of environmental sustainability; red petals represent areas of economic sustainability; green petals represent areas of wellbeing. The lengths of the petals illustrate that organic farming systems better balance the four areas of sustainability.

Although price premiums were 29 to 32%, breakeven premiums necessary for organic profits to match conventional profits were only 5 to 7%, even with organic yields being 10 to 18% lower. The size of organic premiums awarded, and the difference between organic premiums and breakeven premiums, were consistent during the 40-year study period. The fact that organic premiums were significantly higher than breakeven premiums suggests that organic agriculture can continue to expand even if premiums decline. The study also found that total costs were not significantly different, but labour costs were significantly (7 to 13%) higher with organic farming practices[20]. Although one of the successes of conventional agriculture has been its ability to produce more with less labour, some have found the extra labour of organic agriculture to be beneficial in providing rural employment and development opportunities[62,63].

Few economic studies have accounted for negative externalities (such as environmental costs) or positive externalities (such as ecosystem services), with associated monetary values, in organic and conventional comparison studies. Putting a price on the negative externalities caused by farming, such as soil erosion or nitrate leaching into groundwater, would make organic agriculture even more profitable, given that its environmental impact is less than that of conventional agriculture[45–58]. Indeed, it has been estimated that a switch to organic production would lower the external costs of agricultural production in the United Kingdom by 75%, from £1,514 million yr^{-1} to £385 million yr^{-1} (ref. 64).

A number of studies (for example, refs 65,66) have compared ecosystem services in organic and conventional farming systems. A few of these studies have accounted for the monetary value of ecosystem services; these studies generally show that conventional practices decrease the ability of farms to provide some economically significant ecosystem services relative to organic practices[67–69]. For example, in a study comparing 14 organic arable fields with 15 conventional ones in New Zealand[70], the total economic value of three ecosystem services (biological pest control, soil formation and the mineralization of plant nutrients) in the organic fields was significantly greater at US\$232 ha^{-1} yr^{-1} compared with the conventional fields at US\$146 ha^{-1} yr^{-1}. Factoring in such differences in economic comparison studies would probably make up for price premiums awarded to organic products. Price premiums and European subsidies for organic farms are often justified on the grounds that they compensate farmers for providing ecosystem services or avoiding damage to the environment.

Wellbeing. How well organic, conventional and other farming systems are performing in areas such as social equity (for instance, issues of gender, race, ethnicity and class) and quality of life for farm families and communities remains unclear due to limited research. Available data indicate that both organic and conventional farming systems need to make significant progress to meet social sustainability goals[10]. However, organic farming has been shown to have some sociocultural strengths, such as positive shifts in community economic development, increased social interactions between farmers and consumers[71,72], and greater employment of farm workers and cooperation among farmers[62,63].

Although organic farming often requires additional manual work on the farm, it reduces the exposure of farm workers to pesticides and other chemicals. Such exposure can be particularly problematic in less-developed countries, where illnesses and death have resulted from occupational and accidental exposure (due in part to the fact that it is impractical and expensive for workers to use safety equipment)[73,74].

Organic certification programmes have adopted social wellbeing goals. Guidelines of the International Federation of Organic Agriculture Movements (IFOAM) stipulate that organic farmers should be able to support themselves and other workers with fair incomes, while maintaining safe and dignified working conditions[75]. Furthermore, organically certified animals must be raised humanely under conditions that allow for the expression of their natural behaviours and needs[75]. For example, European Union, US and Japanese rules on organic production require livestock to have access to open air or grazing whenever possible, and that sick animals be treated as needed, even with the use of antibiotics if required[76–78].

Organic farming can improve food security by diversifying on-farm crop and livestock operations, which diversifies income sources and improves variety in diets[79]. Organic farming necessitates diverse crop and livestock rotations, encourages the integration of multiple farm enterprises and encourages the use of leguminous crops for biological nitrogen fixation. By growing a higher diversity of more nutrient-rich (such as vegetables) and more protein-rich (such as legumes and meats) foods, whether for export or subsistence, a farmer has access to at least a portion of these foods. For example, following 840 small organic and non-organic farms in the Philippines, researchers found the increase in vegetable and protein consumption from 2000 to 2007 to be two to three times greater for the more diversified organic farmers than conventional farmers[80].

Balancing sustainability metrics. Some argue that significantly scaling-up organic land area may increase nitrogen and other nutrient limitations on yields[17], and question whether the greater land area required by organic agriculture to maintain yields counteracts its environmental gains[2,3]. Probably the biggest criticism of organic agriculture is its lower yields compared with conventional agriculture[4,5], a particularly salient challenge given the task of feeding a growing world population without further agricultural expansion[13]. Conversely, some contend that the environmental advantages of organic agriculture far outweigh the lower yields, and that increasing research and breeding resources for organic systems would reduce the yield gap[16,17,24,81]. Others suggest that multifunctional farming systems, such as organic, coupled with more plant-based diets and reduced food waste, are necessary elements of a more sustainable food system[16,54,65]. Sometimes excluded from these arguments is the fact that we already produce adequate kilocalories of food to more than feed the world but do not provide adequate access to all individuals[82]. Globally, 1.9 billion adults are overweight and of these 600 million are obese[83], while 793 million people are undernourished and more than 28% of children under the age of five are stunted due to malnourishment[82,84].

Debates aside, although yield is an important sustainability metric, the issue is more complicated than kilograms of food per hectare. Mainstream conventional farming systems have provided growing supplies of food and other products but often at the expense of the other three sustainability goals. Environmental degradation, public health problems, loss of crop variety and genetic biodiversity, and severe impacts on ecosystem services have not only accompanied conventional farming systems but have often extended well beyond their field boundaries. Such negative externalities are not accounted for.

The performance of organic farming systems in the context of sustainability metrics indicates that they better balance multiple sustainability goals than their conventional counterparts (Fig. 4). Based on present evidence, we argue that although organic farming systems produce lower yields compared with conventional agriculture, they are more profitable and environmentally friendly, and deliver equal or more nutritious foods with less to no pesticide residues. In addition, initial evidence indicates that organic agriculture is better at enhancing the delivery of ecosystem services, other than yield, as well as some social sustainability benefits. Importantly, the body of research studies has been heavily biased towards developed countries, whereas studies in the less-developed world, especially in tropical and subtropical climates, need to be greatly increased.

With only 1% of global agricultural land in organic production[7], and with its multiple sustainability benefits, organic agriculture can contribute a larger share in feeding the world. Yet, significant barriers to farmers adopting organic practices remain in both developed and less-developed countries.

Barriers and policies

Obstacles to farmers adopting organic agriculture include powerful vested interests and existing policies, a lack of information and knowledge, weak infrastructure and other economic challenges, and misperceptions and cultural biases (Fig. 5). Global and national agribusiness corporations, agrochemical industries, commodity groups and food companies have a strong vested interest in the conventional agroindustrial model, command ever-greater market power in the food system and have heavily influenced public policy to favour this model[10,85]. The consolidation of industries, the concentration of market power, and many past and current agricultural policies have led to decreased agricultural diversity[10] and have disincentivized agricultural innovation[81].

Considerably less public and private funding has been put towards research and development for organic systems than towards conventional systems worldwide; this has resulted in a lack of crop and livestock breeding for organic farming conditions and a dearth of knowledge and information resources supporting organic farmers[17,19]. Historically, public funding for research on organic systems has been higher in Europe than in the United States[7]. Moreover, research on organic agriculture in less-developed countries represents only a small fraction of the overall scientific literature on the topic[17,19,52].

Some farmers face infrastructure and economic barriers, which include certification costs and access to markets, loans and insurance. Many areas, especially rural regions and less-developed countries, lack access to additional labour, markets for organic foods, infrastructure for storage and distribution, or appropriate certification requirements[86,87]. Finally, strong cultural biases against the connotations of organic agriculture, and conventional mindsets held by some individuals and organizations, limit the spread of organic practices[86,87].

With these obstacles in mind, governments should focus on creating an enabling environment for the development and adoption of not just organic but also other innovative and more sustainable farming systems[88]. These efforts must be targeted at improving agricultural performance in all four areas of sustainability and will require a diversity of knowledge-based, legal and financial policy instruments[89].

Knowledge-based policy instruments are needed to create an enabling environment for agricultural innovation, education and outreach. Specifically, policy instruments must: ensure farmer and scientist engagement in research and development decision-making; improve farmer knowledge and capacity through effective extension and outreach infrastructure, such as the use of farmer field schools and communication technologies; and enhance women's educational and leadership opportunities[90].

Legal instruments must play a stronger role in ensuring open and competitive markets, limiting commercial influence in government and increasing transparency in the food production system. In addition, they are needed to reduce food waste, to improve the security of land tenure for farmers, and to develop national targets for trade policies that promote food and ecosystem security.

Financial instruments are needed to give monetary value to the externalities that arise from agricultural practices and to empower farmers through access to capital, infrastructure and competitive markets[88]. In developed countries, direct and indirect crop subsidies and biofuel incentives should be replaced by targeted agro-environmental incentives, such as payments for biodiversity protection and soil conservation. Some policy organizations have found that raising the costs of fossil fuels, irrigation water and other limited resources strongly encourages more efficient farming systems[91]. In less-developed countries, targeted input subsidies and investment in rural infrastructure are key financial instruments. For example, subsidizing organic nutrient inputs alongside mineral fertilizer inputs for the poorest farmers can be an effective strategy for increasing yields and building soils[92].

Beyond organic

More than 40 years after Earl Butz's comment, we are in a new era of agriculture, as reflected in the words of current US Secretary of Agriculture Tom Vilsack: "Organic agriculture is one of the

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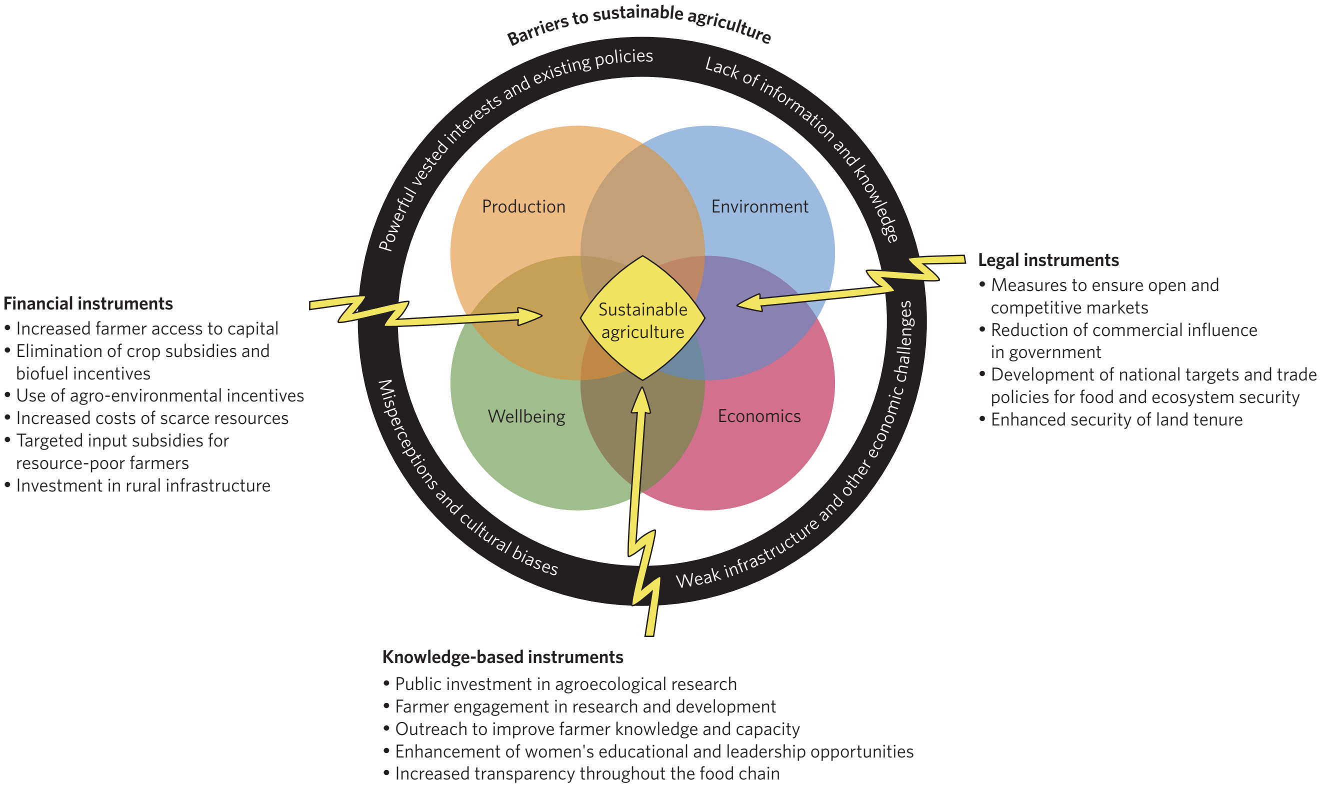

Figure 5 | Policy instruments for overcoming barriers to farmers adopting more sustainable farming systems. For any farm to be sustainable, it must meet four goals, shown in the centre: (1) produce adequate amounts of high-quality food (production); (2) enhance the natural-resource base and environment (environment); (3) be financially viable (economics); and (4) contribute to the wellbeing of farmers and their communities (wellbeing)[10]. Despite the appeal of a sustainable agriculture philosophy, the task for farmers to achieve agricultural sustainability is challenging. Just because a farm is organic does not mean that it is sustainable. However, research shows that organic farming systems better balance the four sustainability goals than their conventional counterparts and are more likely to achieve agricultural sustainability (overlapping area). Yet, significant barriers to adopting organic agriculture exist, including powerful vested interests and existing policies, lack of information and knowledge, weak infrastructure and other economic challenges, and misperceptions and cultural biases. In fact, many of these same barriers exist for other innovative systems, such as agroforestry, conservation agriculture, integrated farming and mixed crop–livestock systems. A diversity of policy instruments is needed to overcome these barriers, and can be categorized as financial, legal and knowledge-based instruments. Examples of these instruments are shown in the figure.

fastest growing segments of American agriculture and helps farmers receive a higher price for their product as they strive to meet growing consumer demand"[93]. Moreover, organic agriculture has been able to provide jobs, be profitable, benefit the soil and environment, and support social interactions between farmers and consumers.

Although organic agriculture has an untapped potential role in global food and ecosystem security, no one farming system alone will safely feed the planet. Rather, a blend of organic and other innovative farming systems, including agroforestry, integrated farming, conservation agriculture, mixed crop and livestock, and still undiscovered systems, will be needed for future global food and ecosystem security. For example, integrated farming systems that blend mostly organic with some conventional practices have been shown to be more sustainable than conventional farming systems[94,95] and are likely to play a central role. Achieving global food and ecosystem security requires more than just achieving sustainable farming systems worldwide. We need to reduce food waste, improve food distribution and access, stabilize the human population, eliminate the conversion of food into fuel, and change consumption patterns towards a more plant-based diet.

Equal adherence to all four sustainability goals of production, environment, economics and social wellbeing does not limit but encourages farmers and researchers to innovate. The challenge facing policymakers is to create an enabling environment for scaling-up organic and other innovative farming systems to move towards truly sustainable production systems. This is no small task, but the consequences for food and ecosystem security could not be bigger. To make this happen will require mobilizing the full arsenal of effective policies, scientific and socioeconomic advances, farmer ingenuity and public engagement.

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Competing interests
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