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Organic Farming a viable option for the global food supply and livelihood sustainability

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Abstract

The key obstacles to the proposition that organic farming will make a substantial difference to the global food supply are poor yields and inadequate organically appropriate fertilizer amounts. We evaluated the universality of both statements. Regarding the first argument, we compared the yields of organic versus conventional or low-intensive food production for a global dataset of 293 examples and calculated the average yield ratio (organic: non-organic) for developed and developing worlds of various food categories. The average yield ratio for most food categories was marginally < 1.0 for developed world studies, and > 1.0 for developing world studies.

With the average yield ratios, we were modelling the global supply of food that could be organically produced on the existing agricultural land base. Model projections suggest that organic methods could generate enough food per capita worldwide to support the current human population, and probably even a greater population, without growing the agricultural land base. We also measured the amount of nitrogen likely available from leguminous cover crops used as fertilizer from fixation. Evidence from temperate and tropical agroe-cosystem show that leguminous cover crops will fix enough nitrogen to offset the amount of currently used synthetic fertilizer.

Evidence from temperate and tropical agro ecosystems show that leguminous cover crops will fix enough nitrogen to offset the amount of currently used synthetic fertilizer. Such findings suggest that organic farming has the potential to make a significant contribution to global food supply, while reducing traditional agriculture's negative environmental impacts. Evaluation and analysis of this paper addressed important concerns about crop rotations in organic versus traditional agriculture and the reliability of sources of grey-literature. A continuing discussion on these issues can be found in this issue's Forum editorial.

Keywords

Organic agriculture, Conventional agriculture, Organic yields, global Food supply, cover crop

Introduction

Organic farming promises to be a more sustainable type of farming which aims to produce food in a more environmentally friendly and socially just manner. Organic agriculture thus offers possible means to address both human and environmental predicaments. This policy brief discusses the challenges and advantages of organic farming in developing countries, and examines the possible contribution of organic farming to sustainable agricultural growth. It will conclude with detailed suggestions on ways of enhancing organic farming efficiency and its suitability to poor farmers.

Agriculture is vital to human survival-it provides food and fuel and other resources to the environment, is an essential source of livelihood and plays a crucial role in economic growth. However, agriculture is also a major cause of environmental degradation that contributes to climate change, depletes freshwater resources, degrades soil fertility and pollutes the atmosphere through fertilizer and pesticide use. Interestingly, food production depends crucially on the very natural resources it degrades. Therefore, sustainable food protection demands not only that all people have access to sufficient and healthy food at all times but also that this food be processed with minimal environmental effects. Instead, sustainable agricultural development requires that agriculture satisfy the needs of the present without compromising future generations' ability to meet their own needs.

Current agriculture fails to achieve these goals for many purposes: today's agriculture is not only a leading driver of environmental destruction and a significant driver of the Earth system outside the 'safe-operating space' of humanity (Parrott et al. 2006; Rockström et al. 2009) — it also does not sufficiently feed people, as one in six people in developing countries is still undernourished. Since we are not achieving adequate food security today, and considering that we are likely to need to double food production by 2050 to feed 9 billion people with growing demand for meat and dairy products (Foley et al. 2011), there is a urgent need for improvements in the food system. From an agricultural perspective, we need to produce more food in the right places at reasonable prices, ensuring farmers' livelihoods and reducing the agricultural environmental expense. Given the enormous challenge ahead of us, it is important to assess the potential contribution of various types of farming systems to sustainable food health. 'Alternative' agricultural systems which attempt to mimic ecological processes while minimizing external inputs are often suggested as more sustainable forms of food production. Organic farming-a method aimed at producing food with minimal harm to habitats, animals or humans (see box 1 for a description of organic farming)-is the most common of such alternative farming systems (see box 2 for organic farming in numbers) and is also suggested as a solution for more sustainable farming.

During the G8 summit in 2009, in a joint statement, the Heads of Government decided to "act with the speed and urgency required to achieve sustainable global food security." However, the capacity to provide sufficient, affordable and nutritious food at all times is increasingly limited by reduced crop yields due to climate change, insufficient water availability, and widespread land degradation. Sustainable food security is therefore a compromise between taking advantage of the ecosystem function of food production for human use, thus avoiding natural resource exploitation to a degree that undermines the ecosystem's capacity to produce that food. Agriculture must face the triple challenge of rising food production and supplying affordable and nutritious food while reducing the impacts of farming on the environment. It will entail major improvements in the food system, as well as a thorough assessment of how different agricultural methods can help meet it challenge.

We need radical improvements to the global food system to achieve a more sustainable agriculture that adequately feeds people, contributes to rural development and provides farmers with livelihoods without damaging the natural resource base. Organic farming was introduced as an effective means of achieving those objectives. Organic farming actually covers only a limited area in developing countries but its distribution is increasingly increasing as demand for organic products is growing.Can organic farming therefore become a development policy priority and be placed on the international aid agenda as a means of achieving sustainable agricultural production? Could organic farming lead to sustainable food security in developed worlds? To address these questions this policy brief aims to assess the cultural, social and environmental viability of organic farming and to recognize its challenges and benefits in developing countries.

Organic farming has many advantages because it eliminates many of the environmental effects of traditional farming, it can improve productivity in the fields of small farmers, it decreases reliance on expensive foreign inputs and it guarantees price discounts for organic goods. Organic farmers often benefit from forming cooperatives within farmers and creating social networks that give them greater access to training, credit, and health services.Organic agriculture typically reduces farmers 'vulnerability as the higher organic prices serve as a hedge against traditional markets' low prices and demand uncertainty, as organic systems are also more resilient to severe weather events, and as the also complex organic crop-livestock systems provide a diverse range of outputs.

In developed countries, on the other hand, organic farmers need to enter foreign markets, they also need expensive certification and have increased labour demand. In general, organic farming therefore offers promises for sustainable agricultural production, but its limitations do need to be recognized. Therefore, this policy brief ends with a collection of concrete suggestions on what policy options would better resolve the current problems of organic farming and ensure the success of an organic farm growth strategy.

Since Malthus, there has been a challenge to the sufficiency of global food supply for feeding the human population. One side of the current debate claims that green-revolution methods — involving high-yielding varieties of plants and animals, mechanized tillage, synthetic fertilizers and biocides, and now transgenic crops — are essential for producing adequate food for the growing human population1–4. Agriculture was a remarkable technical success in the Green-Revolution. Even with the doubling of human populations over the past 40 years, more than enough food has been generated to fulfill the caloric needs for all people around the world, if food has been distributed more fairly5.

And Malthusian concerns on the future remain. Nonetheless, considering the prediction of 9 to 10 billion people by 20506 and the global patterns of rising meat consumption and declining grain production per capita4, advocates argue that our only hope of feeding the planet is a more concentrated form of green-revolution agriculture. Another side of the debate states that these food processing processes have incurred considerable direct and indirect costs and may constitute a Faustian offer. Green-revolution agriculture's environmental price includes increased soil degradation, pollution of the land and groundwater, release of greenhouse gases, increased resistance to pests and depletion of biodiversity.

Alternative types of farming, such as organic methods, are incapable of producing as much food as traditional intensive methods do1,3,5. A corollary is that organic farming requires more land for food production than conventional farming does, thereby offsetting any environmental benefits from organic production18. Some have also argued that there is insufficient organically suitable fertilizer to produce enough organic food without substantially rising the land area devoted to farming3.

We evaluate here the future contribution of organic farming to the global food supply. In particular we examine the key objections to organic farming

The word 'organic' here applies to farming practices that can be called agroecological, sustainable, or ecological; use natural (non-synthetic) processes of nutrient cycling; avoid or seldom use synthetic pesticides; and preserve or regenerate soil quality; Such activities that include crops, manures, compost, crop rotation, intercropping and the control of bio-logical pests. We do not adhere to any particular certification requirements, and include organic examples that are not certified in our data.

Methods

We collected data on the current global food supply, comparative yields between organic and non-organic production methods, and biological nitrogen fixation by leguminous crops from the published literature. These data formed the basis for estimating the global availability of food that could be produced using organic methods and the amount of nitrogen that could become available through increased use of cover crops as green manure.

Estimation of the global food supply

Estimation of the global food supply grown by organic methods involved compiling data about current global food production, deriving ratios of the yields obtained from organic versus non-organic production methods, and apply-ing these yield ratios to current global production values.

Production of global foodstuffs. Food and Agriculture Organization (FAO) overview data for 200119 document the current global food supply — growing primarily through traditional methods in most of the developed world, and primarily through low-intensive methods in most of the devel-oping world. The FAO offers estimates of the current supply of foods in 20 general categories of foods19 which we updated for our analysis.

We combined three pairs of cate-gories (into sugars and sweeteners, vegetable oils and oil-crops, meat and offals). We omitted from consideration three categories (spices, stimulants, and 'miscellaneous'), because they contribute few calories and little nutritional value to the daily diet and lack comparative data for organic versus non-organic production. In addition, we reported data for seafood and 'other aquatic products' but did not estimate yield ratios for these categories, since most of these foods are currently harvested from the wild.

Alcoholic beverages have been identified as they contribute significantly to the average daily caloric intake but no organic yield assessment has been made. The data for yield ratios provided belong to ten groups covering the major components of human diets in plants and animals.

FAO's data on food production includes both commercial and domestic production, and excludes losses during harvest. Pre-harvest crop losses are not included in the estimates; such losses can be substantial20 but not necessarily more severe for organic production, as a number of pest control approaches are available21,22.The FAO data for the food supply available for human consumption take into account food production, exports, imports, and stocks for each country or region, as well as production losses to become livestock feed, seed, or waste19. 'Waste' refers to loss of after harvest during storage, transportation and processing. After the FAO classification of countries as developed or developing, we gathered this information for the world, for developed countries and for developing countries.

Deriving yield ratios.

We estimated the global organic food supply by multiplying the amount of food in the current (2001) food supply by a ratio comparing average organic : non-organic yields. Comparisons of organic to non-organic production are available for many plant foods and a few animal foods. For each of 293 comparisons of organic or semi-organic production to locally prevalent methods under field conditions, the yield ratio is the ratio of organic : non-organic prFor example, a ratio of 0.96 means that the organic yield for the same crop is 96 per cent that of the conventional yield. The compari-sons include 160 cases with conventional methods, and 133 cases with methods of low intensity. Most examples come from peer-reviewed, written literature; a minority comes from conference proceedings, technical papers, or a farm research station's website. Unlike the 1990 organic and traditional pro-duction survey by Stanhill,23 our data provide various comparisons from paired farms and controlled trials at research stations.oduction.

The studies vary in duration of observation from a single growing season to more than 20 years. Despite the ob-servation that results from conversion from traditional to organic output initially declines and then that increase with time24,25 (but see ref. 23), we have included studies irrespective of length. All of Stanhill's examples (included here) come from the developed world, while our dataset contains numerous examples from the developing world as well. There was no effort to skew the findings in favor of organic yields; various examples from developed and developing countries indicate low comparative yield. We also avoided generalizations based on national or regional average yields

We have grouped examples into 10 general food categories and estimated the average yield ratio in each food category for all cases. See Appendix 1, for the full dataset and references. Table 1 describes the average yield ratios for all combined (world) studies of these food

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groups, studies in developed countries, and studies in developing nations. When no data (e.g. tree nuts) were available to estimate global organic production then we used the average

Table 1. Average yield ratio (organic : non-organic) and standard error (S.E.) for ten individual food categories recognized by the FAO[19] and three summary categories. Average yield ratio based on data from 91 studies (see Appendix 1 for data and sources). (A) All countries. (B) Developed countries. (C) Developing countries.

	(A) World			(B) Developed countries			(C) Developing countries		
Food category	N	Av.	S.E.	N	Av.	S.E.	N	Av.	S.E.
Grain products	171	1.312	0.06 69		0.928	0.02	102	1.573	0.09
Starchy roots	25	1.686	0.27 14		0.891	0.04	11	2.697	0.46
Sugars and sweeteners	2	1.005	0.02 2		1.005	0.02			
Legumes (pulses)	9	1.522	0.55 7		0.816	0.07	2	3.995	1.68
Oil crops and veg. oils	15	1.078	0.07 13		0.991	0.05	2	1.645	0.00
Vegetables	37	1.064	0.10 31		0.876	0.03	6	2.038	0.44
Fruits, excl. wine	7	2.080	0.43 2		0.955	0.04	5	2.530	0.46
All plant foods	266	1.325	0.05 138		0.914	0.02	128	1.736	0.09
Meat and offal	8	0.988	0.03 8		0.988	0.03			
Milk, excl. butter	18	1.434	0.24 13		0.949	0.04	5	2.694	0.57
Eggs	1	1.060	1		1.060				
All animal foods	27	1.288	0.16 22		0.968	0.02	5	2.694	0.57
All plant and animal foods	293	1.321	0.05 160		0.922	0.01	133	1.802	0.09

Ratio of yields for all plant foods, or any animal food where relevant. For individual studies in which multiple yield ratios for a single crop (e.g., 0.80–2.00) grown under the same treatment were recorded, we took the average as the study value. When describing different treatments we listed a value for each treatment. Averaging the yield ratios across each general category of food has reduced the effects from individual studies of unusually high or low yield ratios. The average yield ratios are based on a wide variety of soils and environments, since these studies come from many regions in developed and developing countries.Global south studies typically show increases in yields following conversion to organic methods (Table 1C), but these studies are not comparable with developed world ones. Agriculture is typically less intensive in developing countries now than it is in the developed world. Organic output is often compared to local, resource-poor subsistence farming practices, which may exhibit low yields due to farmers' restricted access to natural resources, purchased inputs, or extension services. While adoption of green-revolution methods typically has increased yields, organic methods have intensified as well26.

Estimating the worldwide food supply.

Using the average yield ratio for each type of food, we calculated the amount of food that could be organically grown by multiplying the amount of food currently produced times the average yield ratio (Tables 2 and 3). Following the FAO methodology19, this amount was then decreased proportionally for imports, exports, and losses (e.g., Table 2, column D) to provide the total supply of organic food after losses (e.g., Table 2, column G), which is the food supply available for human use. We believed that all currently produced food is grown using non-organic techniques, as the global region of certified organic farming is just 0.3 per cent 28.

We developed two global food-producing models, grown using organic methods. Model 1 applied the organic: non-organic (conventional) yield ratios from developed-country studies to the entire agro-cultural land base (Table 2). This model essentially assumes that if converted to organic farming, the low-intensity agriculture present in much of the developing world will have the same or a small decrease in yields recorded for the developed world, where green-revolution methods dominate now.

Model 2 applied yield ratios derived from developed-world studies to developed-world food production, and yield ratios derived from developing-world studies to developing-world food production (Table 3). The sum of these different figures gives the total estimate

Table 2. Actual (2001) food supply and estimates for Model 1. Data for world food supply from FAO Statistical Database[19].

(A) Food category	(B) Actual world food production	(C) Actual food supply after losses	(D) Supply as proportion of production (C/B)	(E) Average yield ratio (Table 1)	(F) Estimated organic food production (BrE)	(G) Estimated organic food supply after losses (DrF)
Units	1000 Mg	1000 Mg			1000 Mg	1000 Mg
Grain products	1,906,393	944,611	0.50	0.928	1,769,133	876,599
Starchy roots	685,331	391,656	0.57	0.891	610,630	348,965
Sugars and sweeteners	1,666,418	187,040	0.11	1.005	1,674,917	187,975
Legumes (pulses)	52,751	32,400	0.61	0.816	43,044	26,438
Tree nuts	7,874	7,736	0.98	0.914[1]	7,213	7,070
Oil crops and vegetable oils	477,333	110,983	0.23	0.991	472,559	109,984
Vegetables	775,502	680,802	0.88	0.876	679,340	596,383
Fruits, excl. wine	470,095	372,291	0.79	0.955	448,940	355,538
Alcoholic beverages	230,547	199,843	0.87			
Meat and offal	252,620	247,446	0.98	0.988	249,588	244,476
Animal fats	32,128	19,776	0.62	0.968[2]	31,100	19,143
Milk, excl. butter	589,523	479,345	0.81	0.949	559,457	454,898
Eggs	56,965	50,340	0.88	1.060	60,383	53,360
Seafood	124,342	95,699	0.77			
Other aquatic products	10,579	8,514	0.80			

Average for all foods	0.922

[1] Average yield ratio for all plant foods (developed countries) was used, since no comparative yield data were available for this food category.

[2] Average yield ratio for all animal foods (developed countries) was used, since no comparative data were available for this food category.

Mg = megagram = metric ton.

Results and Discussion

Estimates of food and caloric production under organic agriculture

The projections from Models 1 and 2 are compared to the actual food supply in Figure 1. The predicted organic food supply for most food categories (grains, sweeteners, tree nuts, oil crops and palm oils, vegetables, foods, animal fats, milk, and eggs) is close in magnitude to the actual food supply according to Model 1. Such correlation exists because the average yield ratios ranged from 0.93 to 1.06 for these groups (Figure 1, Tables 1B and 2). The average yield ratios range from 0.82 to 0.89 for other food groups (starchy roots, legumes, and vegetables), resulting in slightly lower production rates.

Of all 160 examples from developing countries the average yield ratio is 0.92, similar to the average relative yield of Stanhill of 0.9123. According to Model 2, the future production of organic food exceeds the current supply of food in all food categories, with most projections being more than 50 per cent higher than the amount of food actually produced (Figure 1). The higher estimates in Model 2 are the result of high average organic yield ratios versus conventional production methods in developed world (Tables 1C and 3). Of the 133 cases from the developed world the average yield ratio is 1.80. We find Model 2 more practical because it uses defined average yield ratios for each area of the world.

These two models probably hold together the best estimate of global organic food production. Model 1 may underestimate the potential yield ratios of organic to conventional production, as years of tillage, synthetic fertilizers, and pesticide residues have degraded many agricultural soils in developed countries. Conversion to organic methods usually results in initial decrease on these soils

Table 4.Estimated nitrogen available for plant uptake from biological nitrogen fixation with leguminous cover crops, for the world and the US. For A, and F, data are from FAO Statistical Data Base[19] and USDA National Agriculture Statistics[35]; for B, data for the world are from Gallaway et al., 1995[36], and for the US from USDA-ERS[37] and the USDA National Agriculture Statistics[35]; for D, data are from sources listed in Appendix 2. Estimates are based on land area not currently in leguminous forage production.

		World	US
A	Area of total cropland	1513.2 million ha	177.3 million ha
B	Area in leguminous forage production	170.0 million ha	36.0 million ha
C	Area remaining for use in cover crops (A–B)	1362.1 million ha	141.3 million ha
D	Average N availability or fertilizer-equivalence from winter and off-season cover crops	102.8 kg N ha^{-1} yr^{-1} (n = 77, S.D. = 71.8)	95.1 kg N ha^{-1} yr^{-1} (n = 32, S.D. = 37.5)
E	Estimated N available from additional cover crops without displacing production (CrD)	140.0 million Mg N	13.4 million Mg N
F	Total synthetic N fertilizer in current use by conventional agriculture	82.0 million Mg N	10.9 million Mg N
G	Estimated N fixed by cover crops in excess of current synthetic fertilizer use (E–F)	58.0 million Mg N	2.5 million Mg N

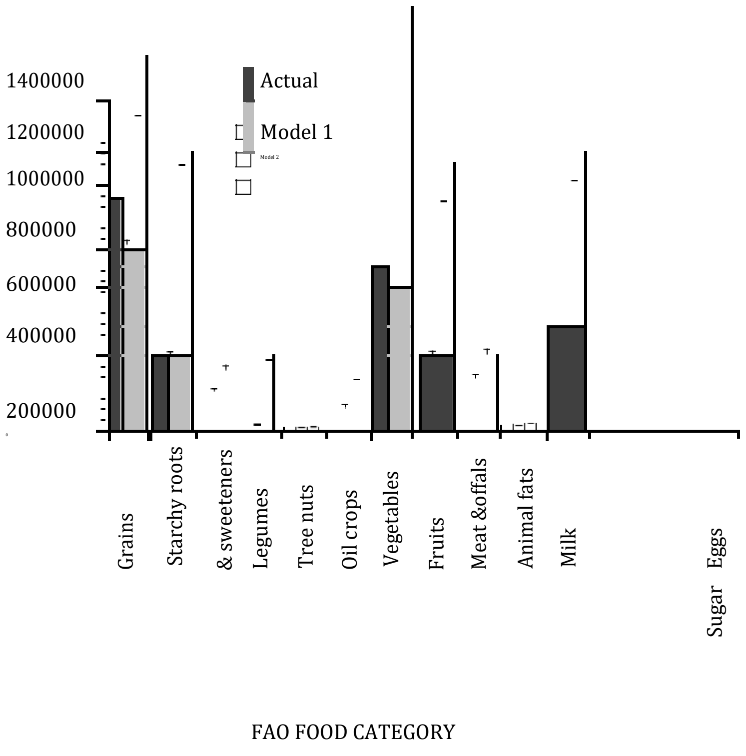

Figure 1. Estimates of the global food supply from two models of organic production compared with the actual food supply in 2001. Standard errors are given for food categories with multiple studies of yield ratios (see Table 1 and Appendix 1).

In yields, it is restored in relation to traditional methods, accompanied by an improvement in yields as the soil quality7,25. Model 2 will overestimate developed world yield ratios to the degree green-revolution methods are being practiced.

Both models indicate that organic approaches, in terms of daily caloric intake, could support the present human population (Table 5). After losses19, the existing world food supply provides for 2786 kcal person-1 day-1. For a healthy adult38 the average caloric intake is between 2200 and 2500 kcal day-1. Model 1 yielded 2641 kcal person-1 day-1, above the recommended value, but slightly below the current availability of c

Availability greater than currently available. This calculation indicates that organic production has the capacity to sustain a human population that is considerably greater than it currently exists.

Significantly, both models have high grain yields which make up the main caloric component of the human diet.

examples exceed the intrinsic yield limits set by crop genetics and the environmental context40. (Such contro-versy surrounds the 'SRI' and our data include studies from both sides of this controversy.) Yet alternative agricultural methods may elicit a different pathway of gene expression than conventional methods do41. Thus, yield limits for conventionally grExamples exceed the intrinsic yield limits defined by crop genetics and the environment40. (Such controversy surrounds the 'SRI' and our data includes studies on both sides of this controversy.) However, alternative farming methods that lead to a different gene expression pathway than traditional methods do41. Thus yield limits for conventionally grown crops under alternative methods may not predict yield limits. Own crops may not predict the yield limits under alternative methods.

Crop rotation and yield-time adjustment

Organic grain production frequently uses a system of rotation which differs from conventional production. For example, in organic systems a three- or four-year rotation (with legumes or other crops) for corn is common, whereas conventional rotation often involves maize planting every other year. Comparisons of yields between organic and conventional systems in situations like this are difficult to make without some sort of time adjustment.

Since the high variability among rotation systems around the world makes it impossible to provide a general adjustment of the time – yield, it is important to analyze potential performance differences. A detailed evaluation of the rotation effect includes knowledge of the differences in the plot-to-plot yield between organic and conventional production and the rateDecline of both organic and traditional development as a feature of the rotation sequence — information not yet confirmed experimentally. Although under a global organic production scheme rotations will certainly vary, we have no reason for believing that this scheme would not be able to produce enough grain to feed the planet.

Organic nitrogen fertilizer

Million Mg (metrical tonneau)19. Our global estimate of N produced by the use of additional leguminous crops as fertilizer is 140 million Mg, which is 58 million Mg higher than the amount of synthetic N currently in use (Table 4). Also in the US, where large quantities of synthetic N are used in agriculture, the calculation indicates a surplus of usable N by the increased use of leguminous cover crops during usual cropping cycles. The global calculation is based on an average usable N or equivalent N-fertilizer of 102.8 kg N ha-1 (S.D. 71.8, n = 76, Table A2, Appendix 2). The average for temperate regions is 95.1 kg N ha-1 (S.D. 36.9, n = 33), and for tropical regions;The mean N ha-1 (S.D. 99.2, n = 43) is 108.6 kg. These biological N fixation and release levels can balance N availability with crop uptake and achieve yields equal to those of conventionally grown crops with high yields42.

Winter cover crops grow well in temperate regions in autumn after harvest and in early spring before the main food crop is planted43. Work at the Rodale Institute (Pennsylvania, USA) showed that red clover and hairy vetch as winter covers with no additional fertilizer inputs in an oat / wheat – corn – soybean rotation produced yields comparable to those in traditional controls24,25,44.

Organic agriculture and the global food supply 93

Table 5. Caloric values for the actual food supply (2001, data from FAO[19]) and for the organic food supply estimated in Models 1 and 2 (Tables 2 and 3). For alcoholic beverages, seafood, and other aquatic products, no change in caloric intake was assumed.

Food category	Actual food supply after losses	Actual per capita Supply	Model 1 results	Ratio of model/ actual	Est. per Capita supply, Model 1	Model 2 results	Ratio of model/ actual	Est. per Capita supply, Model 2
Units	1000 Mg	Kcal day^{-1}	1000 Mg		Kcal day^{-1}	1000 Mg		Kcal day^{-1}
Grain products	944,611	1335.3	876,599	0.93	1239.1	1,370,435	1.45	1937.2
Starchy roots	391,656	146.8	348,965	0.89	130.8	881,559	2.25	330.4
Sugars and sweeteners	187,040	247.7	187,975	1.01	249.0	283,565	1.52	375.6
Legumes (pulses)	32,400	53.8	26,438	0.82	43.9	124,099	3.83	205.9
Tree nuts	7,736	8.9	7,070	0.91	8.2	10,687	1.38	12.3
Oil crops and veg. oils	110,983	326.4	109,984	0.99	323.1	166,010	1.50	488.2
Vegetables	680,802	72.7	596,383	0.88	63.7	1,213,027	1.78	129.6
Fruits, excl. wine	372,291	77.8	355,538	0.96	74.3	771,443	2.07	161.2
Alcoholic beverages	199,843	64.0			64.0			64.0
Meat and offals	247,446	211.1	244,476	0.99	208.6	358,909	1.45	306.2
Animal fats	19,776	61.2	19,143	0.97	59.2	26,561	1.34	82.2
Milk, excl. butter	479,345	119.7	454,898	0.95	113.6	836,434	1.74	208.9
Eggs	50,340	32.3	53,360	1.06	34.2	78,323	1.56	50.2
Seafood	95,699	27.4			27.4			27.4
Other aquatic prod.	8,514	1.4			1.4			1.4
Total		2786.4			2640.7			4380.6

Our estimates of N availability from leguminous cover crops do not include other practices to increase biologically fixed N, such as intercropping49, alley crop-ping with leguminous trees50, rotation of livestock with annual crops32, and inoculation of soil with free-living N-fixers51—practices that can add significant N productivity to plant and animal production52. In addition, rotation of food-crop legumes with grains, such as pulses, soy, or groundnuts, can contribute up to 75 kg N ha-1 to the grains that follow the legumes33.

Such methods can increase the efficiency of N-use through plants. Since N is readily leached from the soil or volatilized if not quickly taken up by plants, the use of N in agricultural systems can be as small as 50% 53. Organic N sources occur in carbon-based compounds in more stable forms, which create organic soil matter and increase the amount of N retained in the soil25,54. Consequently, the quantity of N to be added each year to sustain yields that actually decrease as the release of organic N fixed in one season takes place over several years30.

These findings indicate that in principle, no additional ground area is required to obtain adequate bioaccessible N to replace the current use of synthetic N fertilizers. While this biological N fixation scenario is simple, it provides an assessment of one type of organic production of N-fertility, which is widely used by organic farmers and is relatively easy to implement on a data basis.

This example is not intended to be prescriptive for any specific rotation or location but to illustrate the possibility of this form of cover-cropping system fixing large quantities of N without displacing food crops or extending land area. The Rodale Institute Farm Systems Trial uses legume cover crops grown between main crops every third year as the primary source of N fertility and records equivalent grain yields to those of conventionally controlled systems, while using non-legume winter cover crops in other years to preserve soil quality and fertility and suppress weeds (R. Seidel and P. Hepperly, personal correspondence, 200).

In practice, a number of appropriate approaches in organic farming offer crucial versatility in N-management32, including many sources other than cover crops. While certain environmental and economic circumstances pose challenges in relying on leguminous fertilizers55, the full potential of leguminous cover crops still remains to be exploited in agriculture. Implementing existing knowledge may increase the use of green manures in many parts of the world56.

Future selection of crop varieties and green manures with higher N-fixing levels, especially in arid or semi-arid regions, and good performance under N-limiting conditions, as well as improved N-fixing symbiont strains, combined with reductions in N losses from legume-based production systems and increases in leguminous planting, hold great promise to increase leguminous production. With major improvements in the food system, such as reduction of food waste and feeding less grain to livestock, the potential for increased dependence on legume fertilizers will be even greater56.

Prospects for More Sustainable Food Production

Our findings indicate that organic food production practices, while preserving soil fertility, may contribute significantly to feeding the present and future human population on the current agricultural land base. Indeed, the models indicate the possibility that if organic production methods were employed, the agricultural land base might eventually be reduced, while additional intensification would have the same impact in the tropics through conventional methods. Possibly, our estimates underestimate real production in many organic farms.

Yield ratios for individual crops have been registered, but many organic farmers use polycultures and multiple cropping systems, from which total production per unit area is often significantly higher than for single crops48,58. There is also room for increased production on organic farms, as most of the past 50 years' agri-cultural work has been based on traditional methods. It is arguable that comparable activities based on organic practices will contribute to more yield im-provings as well as soil fertility and pest management.

Production per unit area is greater on smallFarms than large-scale farms in both developed and developing countries59; an increase in the number of small farms would therefore also increase food production. Lastly, organic production on average requires more hand labour than traditional agriculture, but labor is also more uniformly spread over the rising season25,60–62. This requirement has the potential to mitigate rural unemployment in many areas and raising the pattern of building shantytowns around many of the developing world's major cities.The Millennium Ecosystem Assessment17 recommends promoting agricultural methods that increase food production through excessive use of water, nutrients or pesticides without adverse tradeoffs. The models show that organic farming can make a significant contribution to a more sustainable food production system. They say not only that organic farming, properly expanded, could provide most of the world's food, but also that developing countries with organic agriculture could improve their food security.However, the findings are not meant to be forecasts of immediate local or global output following conversion to organic methods. Neither do we say that organic method yields are consistently greater than green-revolution process yields. The findings demonstrate instead the potential for serious alternatives to green-revolution farming as the dominant mode of food production.Given our positive prognosis for organic farming, we acknowledge that there are various obstacles to the transition to and practice of organic farming — agronomic ally, socially, and educationally. The large-scale practice of organic farming needs funding from research institutions dedicated to agro-ecological fertility and pest management practices, a robust extension program and a committed public. Yet it's time to rest the argument on whether or not organic farming will make a major difference to food supply. Locally and internationally, it can.The discussion will turn towards how to devote more money to research into agro ecological food production methods and how to increase opportunities for farmers and consumers to participate in a more sustainable production system. Last but not least, production methods are only one part of a sustainable food system. In evaluating and promoting a sustainable food system, economic viability of farming practices, land tenure for farmers, market accessibility, water quality, food consumption patterns and poverty alleviation are important.

Organic Farming in brief

Organic farming is a farming system which aims to produce food with minimal harm to ecosystems, animals or humans (FAO & WHO 2007). Organic agriculture, according to its initial concepts, includes not just environmentally sustainable agricultural practices but also a socially just and economically responsible farming system. However, the growing demand for organic products and the rapid growth of the organic sector contributed to the need for organic production to be regulated. This resulted in the development of organic standards which were deemed best environmental practices, such as improved crop rotations and crop diversity, use of organic fertilizers, and control of biological pests.

Organic agriculture and the environment

A sustainable farming system would provide food alongside other ecosystem services such as controlling water flow and water quality, climate control and maintaining biodiversity (Foley et al., 2005). Organic farming has been developed as a farming method primarily oriented towards producing food in a more environmentally friendly way. Organic farming has been shown to have many environmental benefits compared with traditional agriculture on a per unit area basis1.

This decreases the use of pesticides, can increase the abundance and diversity of biodiversity (Bengtsson et al. 2005; Hole et al. 2005), reduce soil erosion (Siegrist et al. 1998), increase soil fertility (Leifeld& Fuhrer 2010), use less energy and minimize greenhouse gas emissions from agriculture (Gomiero et al. 2008), and minimize the system's nitrogen losses (Drinkwater et al. 1998). Nonetheless, on some environmental issues, such as soil carbon storage or water contamination from nitrate and phosphorus leaching, the improved environmental performance of organic farming is not entirely unambiguous (Kirchmann&Bergström 2001; Mondelaers et al. 2009).

One of the main aims of organic farming is to improve soil fertility by adding organic matter back to the soil. Thus, soils maintained using organic techniques usually have a higher content of organic matter, resulting in soils that can retain more water (Colla et al. 2000; Lotter et al. 2003) and that are less likely to suffer from erosion (Siegrist et al. 1998). Organic management approaches may also potentially provide valuable ways to restore degraded soils or avoid further soil degradation in land-prone regions.

However, the vast majority of research on the environmental effects of organic farming have been carried out in developing countries and in temperate regimes. Thus, the environmental efficiency of organic farming in tropical systems and in developing countries remains to be thoroughly examined.

Organic farm yields are also at the forefront of controversy regarding the environmental effects of organic and traditional farming. Critics of organic farming claim that organic farming would need considerably more land to produce the same amount of food because of its lower yields, resulting in broader deforestation, greenhouse gas emissions and loss of biodiversity (Trewavas, 2001). Instead, proponents of organic farming say that organic yields are comparable with those from conventional farming. Current evidence shows that organic yields in general are usually lower than traditional yields, but under some conditions (e.g. legumes and perennials in

Nonetheless, most data relating to organic yields comes from developing countries. The proof is much less evident in developed countries (see Box 3 for a debate about organic yields in developing countries).

Organic agriculture and farmers' livelihoods

Nonetheless, most data relating to organic yields comes from developing countries. The proof is much less evident in developed countries (see Box 3 for a debate about organic yields in developing countries).In developing countries, where three out of four poor people live in rural areas and where more than 80 per cent of rural people live in agricultural households, improving livelihoods for poor farmers is key to addressing rural development (World Bank 2007). Many studies have indicated that 'organic' agriculture could make a major contribution to food security for farmers and boost livelihoods for farmers (Scialabba&Hattam 2002; IFAD 2003; IFAD 2005; Parrott et al. 2006; UNCTAD & UNEP 2008).Yet many of these studies do not differentiate between 'true' organic (see Box 1) and other 'agroecological' or 'sustainable' types of farming. Scientific evidence on the livelihood impact of 'really' organic farming, which is primarily an export-oriented farming system in developing countries , is more mixed, instead.

Organic farming has many benefits for farmers including cheaper materials, higher and more stable prices, and farmer cooperative organization. However, organic cash crop production is often associated with problems like potentially decreased yields compared to traditional intensive methods, certification costs and high labour requirements. Whether the advantages of organic farming outweigh the problems depends on the socioeconomic and agronomic background, such as the extent of the organic price premium, certification costs, availability of agricultural labour, and organic inputs.

If organic farming is to play a role in providing sustainable food security and livelihoods, it needs to be open to poor farmers. The adoption or non-adoption of an agricultural technology or practice is affected by the farmer's demographic and socio-economic characteristics, by the political, institutional and economic background and by the essence of the technology itself.

The economic implications of organic agriculture

For smallholder farmers the feasibility of organic farming depends on organic yields (see Box 3), organic production costs, and the size of the organic price premium. All these factors can differ greatly from system to year (see case study 2 on organic coffee production in Nicaragua for example). At the one hand, organic farmers also earn higher and more sustainable prices for their products (Bacon 2005; Bolwig et al. 2009; Valkila 2009) and organic inputs are cheaper as well, thus lowering overall production costs (Eyhorn et al. 2007; Valkila 2009).

On the other hand, organic production is followed by high entry costs, including higher labor demands that household resources sometimes can not meet, the need for increased expertise and training, considerable certification costs and often the need to buy costly organic inputs (Bray et al. 2002; Calo& Wise 2005; Chongtham et al. 2010). During the transition period, these costs are exacerbated during the conversion to organic farming mandated by organic regulations – organic practices are introduced in this time but the goods can not yet be marketed with the organic price premium.

Consequently, the net impact of organic cultivation on production costs depends on whether the usually lower input costs exceed the traditionally higher labor and certification costs. Some studies indicate that overall organic farming output costs are lower than traditional farming costs (Margasagayam&Jebaraj Norman 1997; Eyhorn et al. 2007; Valkila 2009; Panneerselvam et al. 2011), although other studies found that lower input costs did not always compensate for higher labor costs (Lyngbaek et al. 2001; Bolwig et al. 2009).

Often premium rates are not needed (Eyhorn et al. 2007; Panneerselvam et al. 2011), whereas in other cases they are necessary and not always appropriate to compensate for conversion and certification costs (Lyngbaek et al. 2001; Bray et al. 2002; Calo& Wise 2005).

The social implications of organic agriculture

Organic farming can also have advantages, irrespective of organic cash crop profitability. Organic production in the South can generate social capital, and as they combine into cooperatives, can empower small producers (Rice 2001). Organic cooperatives also promote social networks, provide training and extension resources, and access to health and credit programs (Valkila 2009; Méndez et al. 2010).Organic farming can also provide opportunities in many areas for the use of local resources and for the incorporation of conventional knowledge, as many aspects of organic management are reminiscent of traditional farming methods in developing countries. Organic pioneers such as Sir Albert Howard, Robert McCarrison or Richard St. Barbe Baker were influenced by peasant farming practices in Asia and Africa and attempted to incorporate them through organic management into Western industrial agriculture (Conford 2001). Rural areas may also benefit from work creation in labour-intensive organic farming (Bray et al. 2002; Bakewell-Stone et al. 2008).In addition, organic cash crops are often part of a diverse mixed farming system including livestock and other subsistence or local market cultivation (Bacon 2005). By reducing economic dependence on a single crop, such a diverse system can help reduce vulnerability. Last but not least, agroecologically based farming systems also have more robust yields and are more resilient to severe weather events compared to traditional systems (Holt-Gimÿnez 2002; Lotter et al. 2003). This could be especially important under a changing climate.Organic farming can also offer significant health benefits by reducing the sensitivity of farm workers to pesticides. It is estimated that up to 25 million farm workers in developing countries may each year suffer from an episode of pesticide poisoning (Jeyaratnam 1990). Thus, by reducing the use of pesticides, organic management will provide an effective way for farm workers and rural communities to reduce the health risk from pesticide exposure.

While agriculture's nutritional position has often been ignored, it can be a valuable tool for addressing nutritional and health problems (Welch & Graham 1999). Organic farming would provide safer and more nutritious food and therefore may theoretically lead to dietary and nutritional needs. However, due to the low consistency and conflicting findings of several studies, the empirical evidence on the nutritional content of organic and conventional foods is somewhat unclear (Bourn & Prescott 2002; Magkos et al., 2003).

Nutritional value of organic food

It does not appear that the nutrient content of organically and conventionally processed foods varies significantly (Dangour et al. 2009). However, in organic foods, their bioavailability and the nutrient content may be higher (Magkos et al. 2003). This has also been proposed that non-nutrient elements, such as secondary plant metabolites, could be higher in organic food and could offer the most important health advantage to organic food (Brandt &Mølgaard 2001).

Pesticide residues

The limited use of pesticides in organic systems is one of the main reasons customers continue to purchase organic. However, residue levels of pesticides even on conventional foods are low in developed countries. While the non-use of chemical pesticides in organic systems is likely to result in organic products having lower levels of pesticide residues, studies are not adequate to provide strong empirical evidence for a substantial difference (Bourn & Prescott 2002). In developing countries, where many older and more dangerous pesticides are commonly used, residues of pesticides on conventionally grown crops are of greater concern (Ecobichon 2001) and organic products may be comparatively more important.

Dietary diversity

Dietary diversification is a significant way to address nutrient deficiencies. Agricultural biodiversity can contribute to the diversification of poor farmers 'diets (Johns &Eyzaguirre 2006), and the increased diversity of organic systems could potentially improve organic farmers' nutritional status. However, the contribution of organic farming to the farmers' dietary diversification has not been evaluated so far.

Organic food, nutrition & health

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Information and labour

Organic farming is a very information-intensive management system, or what was called an innovation based on 'software' (Rogers 2003). Including details about the definition of organic farming, organic certification andOrganic markets, information on how to use organic management methods is important for the organic program to work well. Good management practices in organics have been shown to be more critical than in traditional systems for achieving high yields (Seufert et al. 2012). Consequently, knowledge and awareness on organic farming is a critical precondition for the propagation of organic farming and the lack of it has often been shown to impede the acceptance and success of orgOrganic agriculture has mostly emerged from the ground up in developing countries, i.e. through initiatives and networks between farmers, rather than being promoted by government agencies, research agencies, or extensions (Padel 2001). In developing countries, information on organic farming is somewhat dependent on the involvement of government or non-governmental extension programs, while the actual adoption of organic farming is driven by both bottom-up (i.e. farmer-to-farmer) and top-down (i.e., NGO3-to-farmer) networks (Goldberger 2008; Thapa &Rattanasuteerakul 2011).anic farming (Goldberger 2008; Méndez et al. 2010).

Another key feature of organic farming is its tendency to replace labour-inputs. Instead of using herbicides, it relies on weeding and ploughing for weed management and relies on the incorporation of crop residues, cover cropping and compost for nutrient management instead of using chemical fertilizers. This high labor demand has also been described as an significant obstacle to the adoption of organic management or other low-input farming systems (Bray et al. 2002; Bachmann 2011) (Moser & Barrett 2003; Lee 2005).

Increased labour requirements can often not be met by household resources, particularly during peak labour demand times, and thus require additional cash spending (Bray et al. 2002; Bolwig et al. 2009). This is especially problematic in areas where agricultural labour supply is reduced due to worker emigration or labour movement to non-agricultural sectors (Bachmann 2011). On the other hand, by generating jobs in rural areas with minimal job opportunities (Goldberger 2008), the increased labour demand of organic production can also be an advantage

Dependence on international markets

In developing countries organic farming is an export-oriented farming method (see Box 2). Organic farmers are also dependent on access to international markets, must undertake and pay for an extensive certification process and are subject to international regulations often determined by foreign certification bodies and Northern markets. This reliance on foreign markets can pose significant obstacles to smallholder farmers and may potentially increase the vulnerability of farmers.

There can be significant delays in many developing countries until farmers obtain complete payments for their organic produce, and organic farmers also sell parts of their organic produce on lower-payiInstant Fees (Bacon 2005). They often bring goods to the traditional market that they are unable to sell to organic exporting firms, which often have relatively low demand and high quality requirements (Bacon 2005; Valkila 2009; Chongtham et al. 2010, sInternational organic trade has been criticized for reproducing the disparities of traditional North-South trade by concentrating market control in the hands of transnational organic buyers and certifiers, and placing additional certification costs on farmers (Mutersbaugh 2002; Raynolds 2004; Getz &Shreck 2006; Scott et al. 2009). It has also been said that the bureaucratic organic certification process benefits large producers and therefore raises the social disparities between small and big farmers (Gómez Tovar et al. 2005; Getz &Shreck 2006).ee case study 2).

Furthermore, the need for compliance with organic requirements established by Northern bodies (e.g. the EU or the USDAs National Organic Program) and supervised by local certifiers limits farmers and prevents them from 'trading on their own terms' (Mutersbaugh 2002).

Various characteristics of organic farming, such as its need for high management skills and more agricultural labour, as well as its penetration into the international commodity market, can create considerable barriers for small farmers to organic farming or benefit from organic farming.

Conclusions

- Organic farming and certification of environmentally sustainable and socially just practices offer a promising way of linking farmers and customers through great distances. On the one hand it will ensure that consumers are processing their food according to sustainable standards. On the other hand, it offers a way for farmers to engage customers in a share of the true cost of food production. However, turning the noble goals of organic farming into a practical change for poor farmers is a daunting challenge and evidence is conflicting on whether this is actually accomplished.
- Strong organic management practices need to be extended to achieving high yields and organic practices need to be adjusted to local conditions to achieve environmental sustainability. Organic agriculture's economic survival depends on sufficient prices for organic produce and on the accessibility of the international agricultural markets. To enhance the social sustainability of organic farming, the cost of certification should be held to a minimum and, even better, should be shared by consumers and producers alike.
- Organic farming provides CIDA with an opportunity to invest in sustainable agricultural production and thus facilitate the integration of environmental, economic and social sustainability in developing countries. Organic farming offers a range of development benefits, including likely increased productivity in low-input farming, empowerment of women, increased community organizational capability, reduced exposure to pesticides in farming communities, enhanced soil fertility in areas where land depletion is a problem and reduced farmers' vulnerability to market price fluctuations. But the challenges and constraints are to make organic farming beneficial to poor farmers

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