Can organic agriculture feed the world?

Despite the growing momentum of the organic movement the naysayers still challenge its ability to feed the world's expanding population. ***Ivette Perfecto*** *and* ***Catherine Badgley*** *stop them dead in their tracks with well-researched information on yields and productivity.*

With a growing awareness of the negative environmental impacts of industrial agriculture and an increase in the consumption of organic foods, the question, 'Can organic agriculture feed the world?' seems more pressing than ever. Although we now produce more than enough food to feed the world, and have done so for the last 40 years, Malthusian doubts persist. With the world's population projected to grow to between 9 and 10 billion by 2050 and the global trends of increasing meat consumption and decreasing grain harvest per capita, some advocates argue that a more intensified version of the green revolution (including transgenic crops) represents our only hope to feed the world.

The main claims of those that proclaim that industrial agriculture is our only option to satisfy the world's food requirements is that organic agriculture is incapable of producing as much food as intensive conventional methods, and that there is insufficient organically acceptable fertilizer to produce enough food without substantially increasing the land area devoted to agriculture. However, growing evidence of the potential productivity of organic agriculture challenges this notion.

Our study evaluates the potential contribution of organic agriculture to the global food supply by examining these two claims: lower yields of the organic systems, and insufficient quantities of organic nitrogen fertilizers[1]. To examine these questions we compiled data from the published literature about the current food supply, compared yields between organic and non-organic production methods, estimated the potential food supply using these yield ratios, and estimated biological nitrogen fixation by leguminous crops (see box).

Food and caloric production

Our estimates show that organic agriculture has the potential to produce as much, or even more food, than is being produced today with conventional methods. Figure 1 compares the estimates from models 1 (applying the organic:non-organic yield ratios derived from studies in developed countries to the entire agricultural land base) and 2 (applying the yield ratios derived from studies in the developed world to food production in the developed world, and the yield ratios derived from studies in the developing world to food production in the developing world) to the current food supply (see box for explanation of models). According to Model 1, the estimated organic food supply is similar in magnitude to the current food supply for most food categories (grains, sweeteners, tree nuts, oil crops and vegetable oils, fruits, meat, animal fats, milk, and eggs). This similarity occurs because average yield ratios for these categories range from 0.93 to 1.06. For other food categories (starchy roots, legumes, and vegetables), the average yield ratios range from 0.82 to 0.89,

Estimating global food supply and organic fertilizer availability

Global food production

To estimate the global food supply grown by organic methods data about current global food production was compiled. The ratios of yields obtained from organic versus non-organic production methods was derived, and applied to current global production values.

Summary data from the Food and Agricultural Organization (FAO) document the current global food supply[2] – grown primarily by conventional methods in most of the developed world, and primarily by low-intensive methods in most of the developing world. The FAO provides estimates of the current food supply in 20 general food categories which we modified to ten categories for our study. We compiled this information for the world, for developed, and for developing countries (using the FAO classification of countries).

We estimated the global organic food supply by multiplying the amount of food in the current food supply by a ratio comparing average organic:non-organic yields obtained from 293 comparisons of organic or semi-organic production to locally prevalent methods. We grouped examples into ten general food categories and determined the average yield ratio for all cases in each food category. A ratio of 0.96, for example, signifies that the organic yield is 96% that of the conventional yield for the same food category. The comparisons include 160 cases with conventional methods and 133 cases with low-intensive methods. Most examples were from the peer-reviewed, published literature; a minority came from conference proceedings, technical reports, or the website of a research station.

Averaging the yield ratios across each general food category reduced the effects of unusually high or low yield ratios from individual studies. As these studies come from many regions in developed and developing countries, the average yield ratios are based on a broad range of soils and climates. They are a general indicator of the potential yield performance of organic relative to other methods of production.

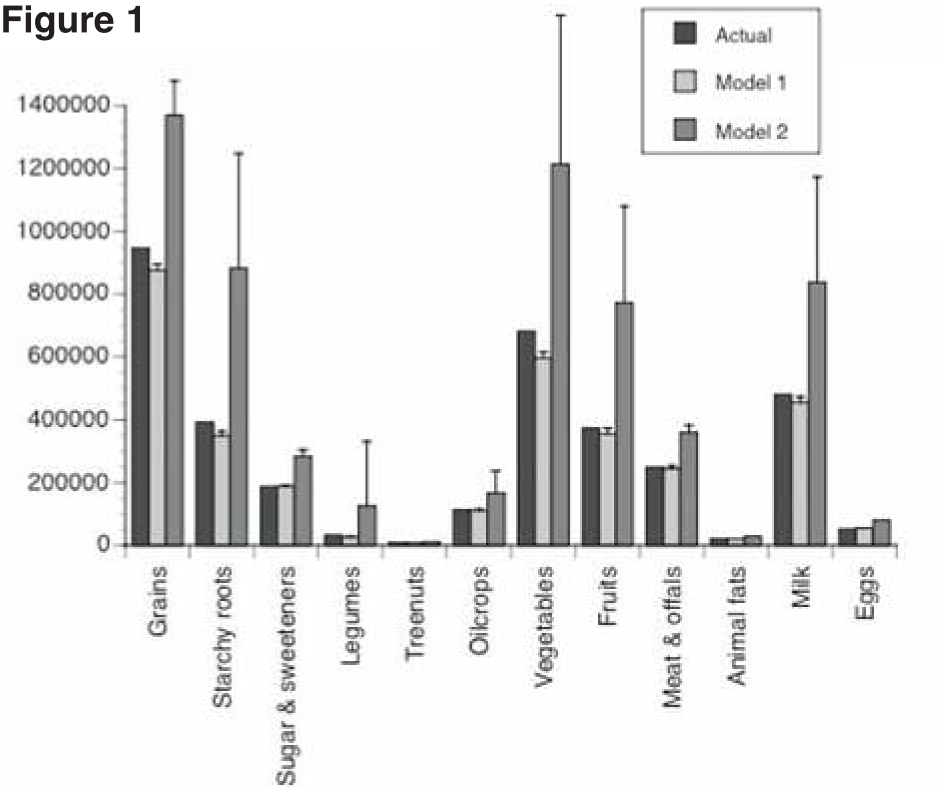
We constructed two models of global food production grown by organic methods. Model 1 applied the organic:non-organic (conventional) yield ratios derived from studies in developed countries to the entire agricultural land base. This model effectively assumes that, if converted to organic production, the low-intensity agriculture present in much of the developing world would have the same or a slight reduction in yields that has been reported for the developed world, where green-revolution methods now dominate. Model 2 applied the yield ratios derived from studies in the developed world to food production in the developed world, and the yield ratios derived from studies in the developing world to food production in the developing world. The sum of these separate estimates provides the global estimate.

Nitrogen availability with legume crop

The main limiting macronutrient to agricultural production is biologically available nitrogen (N) in most areas, with phosphorus limiting in certain tropical regions. For phosphorus and potassium, the raw materials for fertility in organic and conventional systems come largely from mineral sources and were not analyzed in our study.

Nitrogen amendments in organic farming derive from crop residues, animal manures, compost, and biologically fixed N from leguminous plants[3]. A common practice in temperate regions is to grow a leguminous cover crop during the winter fallow period, between food crops, or as a relay crop during the growing season. Such crops are called green manures when they are not harvested but ploughed back into the soil for the benefit of the subsequent crop. In tropical regions, leguminous cover crops can be grown between plantings of other crops. To estimate the amount of N that is potentially available for organic production, we considered only what could be derived from leguminous green manures grown between normal cropping periods. Nitrogen already derived from animal manure, compost, grain legume crops, or other methods was excluded from the calculations, as we assumed no change in their use. The global average of N availability was determined from the rates of N availability or N-fertilizer equivalency reported in 77 studies – 33 for temperate regions and 44 for tropical regions, including three studies from arid regions and 18 studies of paddy rice. N availability values in kg/ha were obtained from studies as either 'fertilizer-replacement value,' determined as the amount of N fertilizer needed to achieve equivalent yields to those obtained using N from cover crops, or calculated as 66% of N fixed by a cover crop becoming available for plant uptake during the growing season following the cover crop[4].

Figure 1



resulting in somewhat lower production levels. The average yield ratio for all 160 examples from developed countries is 0.92, close to the average yield ratio reported in another study (0.91)[5]. According to Model 2, the estimated organic food supply exceeds the current food supply in all food categories, with most estimates over 50% greater than the amount of food currently produced (Figure 1). The higher estimates in Model 2 result from the high average yield ratios of organic versus current methods of production in the developing world. The average yield ratio for the 133 examples from the developing world is 1.80.

The most unexpected aspect of this study is the consistently high yield ratios from the developing world. These high yields are obtained when farmers incorporate intensive agroecological techniques, such as crop rotation, cover cropping, agroforestry, addition of organic fertilizers, or more efficient water management[6]. In some instances, organic-intensive methods resulted in higher yields than conventional methods for the same crop in the same setting (for example, the system of rice intensification in 10 developing countries[7]).

Both models suggest that organic methods could sustain the current human population, in terms of daily caloric intake (Table 1). The current world food supply after losses provides 2786 kcal/person/day. The average caloric requirement for a healthy adult is between 2200 and 2500 kcal/day[8]. Model 1 yielded 2641 kcal/person/day, which is above the recommended value, even if slightly less than the current availability of calories. Model 2 yielded 4381 kcal/person/day, which is 57% greater than current availability. This estimate suggests that organic production has the potential to support a substantially larger human population than currently exists. Significantly, both models have high yields of grains, which constitute the major caloric component of the human diet.

Estimates of organic nitrogen supplied by legume cover crops

In 2001, the global use of synthetic nitrogen (N) fertilizers was 82 million Mg (metric ton). Our global estimate of N fixed by the use of additional leguminous crops as fertilizer was 140 million Mg, which is 58 million Mg greater than the amount of synthetic N currently in use. Even in the United States, where substantial amounts of synthetic N are used in agriculture, the estimate shows a surplus of available N through the additional use of leguminous cover crops. The global estimate is based on an average N availability or N-fertilizer equivalency of 102.8 kg N/ha (st. dev. 71.8, n=77). For temperate regions, the average is 95.1 kg N/ha (st. dev. 36.9, n=33) and for tropical regions, the average is 108.6 kg N/ha (st. dev. 99.2, n=44). These rates of N fixation can deliver N rapidly enough to meet the demands of high-yielding corn, wheat, and rice. In temperate regions, winter cover crops grow well in fall after harvest and in early spring before planting of the main food crop[9]. Even in arid and semi-arid tropical regions, where water is limiting between periods of crop production, drought-resistant green manures, such as pigeon peas or groundnuts, can be used to fix N[10]. Areas in sub-Saharan Africa which currently use only very small amounts of N fertilizer could easily fix more N with the use of green manures leading to an increase in N availability and yields in these areas[11].

Our estimates of N availability from leguminous cover crops do not include other practices for increasing biologically fixed N, such as intercropping, alley cropping with leguminous trees, rotation of livestock with annual crops, and inoculation of soil with free-living N-fixers – practices which may add considerable N fertility to plant and animal production. In addition, rotation of food-crop legumes, such as pulses, soy, or groundnuts, with grains can contribute as much as 75 kg N/ha to the grains that follow the legumes.

These results imply that, in principle, no additional land area is required to obtain enough biologically available N to replace the current use of synthetic N fertilizers. In practice, a range of methods acceptable in organic agriculture provides critical flexibility in N-management, including many sources other than cover crops[12]. Although some environmental and economic circumstances pose challenges to reliance on leguminous fertilizers, the full potential of leguminous cover crops in agriculture remains to be utilized. Implementation of existing knowledge could increase the use of green manures in many regions of the world. Future selection for crop varieties and green manures that have high rates of N-fixation, especially in arid or semi-arid regions, and perform well under N-limiting conditions, as well as for improved strains of N-fixing symbionts, holds great promise for increasing the role of biological N-fixation in fertility management. The capacity for increased reliance on legume fertilizers would be even greater with substantive changes in the food system, such as reduction of food waste and feeding less grain to livestock.

Implications of our study

Our results suggest that organic methods of food production can contribute substantially to feeding the current and future human population on the current agricultural land base, while maintaining soil fertility. In fact, the models suggest the possibility that the agricultural land base could eventually be reduced if organic production methods were employed, although additional intensification via conventional methods in the tropics would have the same effect. Also, there is scope for increased production on organic farms, since most agricultural research of the last 50 years has focused on conventional methods. Arguably, comparable efforts focused on organic practices would lead to further improvements in yields as well as in soil fertility and pest management. Production per unit area is greater on small farms than on large farms in both developed and developing countries[13]; thus, an increase in the number of small farms would also enhance food production. Finally, organic production on average requires more hand labor than does conventional production, but the labour is often spread out more evenly over the growing season. This requirement has the potential to alleviate rural unemployment in many areas and to reduce the trend of shantytown construction surrounding many large cities of the developing world. On the other hand, the higher labour requirement can also represent a challenge to a transition to organic agriculture in some regions of the world.

Table 1. Caloric values for the actual food supply and the organic food supply estimated in models 1 and 2

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**	**1000 Mg**		**Kcal/day**	**1000 Mg**		**Kcal/day**
Grain products	944,611	1335.3	876,599	0.93	1241.8	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
Treenuts	7,736	8.9	7,070	0.91	8.2	10,687	1.38	12.3
Oilcrops 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**

For alcoholic beverages, seafood, and other aquatic products, no change in caloric intake was assumed.

The Millennium Ecosystem Assessment recommends the promotion of agricultural methods that increase food production without harmful tradeoffs from excessive use of water, nutrients, or pesticides. Our study demonstrate that organic agriculture can contribute substantially to a more sustainable system of food production. They suggest not only that organic agriculture, properly intensified, could produce much of the world's food, but also that developing countries could increase their food security with organic agriculture. The contribution of organic agriculture to food security has also been highlighted by the recent FAO-sponsored conference on organic agriculture and food security[15].

The results of our study are not intended as forecasts of instantaneous local or global production after conversion to organic methods. Neither do we claim that yields by organic methods are routinely higher than yields from green-revolution methods. Rather, the results show the potential for serious alternatives to green-revolution agriculture as the dominant mode of food production.

In spite of our optimistic prognosis for organic agriculture, we recognize that the transition to and practice of organic agriculture contain numerous challenges – agronomically, economically, and educationally. The practice of organic agriculture on a large scale requires support from research institutions dedicated to agroecological methods of fertility and pest management, a strong extension system, and a committed public. But it is time to put to rest the debate about whether or not organic agriculture can make a substantial contribution to the food supply. It CAN, both locally and globally. The debate should shift to how to allocate more resources for research on agroecological methods of food production and how to enhance the incentives for farmers and consumers to engage in a more sustainable production system. Finally, production methods are but one component of a sustainable food system. The economic viability of farming methods, land tenure for farmers, accessibility of markets, availability of water, trends in food consumption, and alleviation of poverty are essential to the assessment of a sustainable food system.

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