CAN ORGANIC AGRICULTURE FEED THE WORLD?©

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Abstract

The global food crisis has resulted in calls for a second "Green Revolution" that uses genetically engineered crops to boost agricultural yields. Like the first "Green Revolution", the second depends upon petroleum to manufacture and spread fertilizers, pesticides and herbicides and to power irrigation systems that act upon crops selected to increase agricultural yield. The rising costs and eventual scarcity of petroleum, and the pollution caused by agricultural chemicals may preclude this approach to feed the world.

Agriculture that relies more upon the services of nature and less upon petroleum presents an alternative. This type of agriculture promotes the activity of beneficial soil micro-organisms that tighten the nutrient cycle, the planting of leguminous crops to supply nitrogen, and the presence of beneficial insects that prey upon pest species. One term for such agriculture is "organic", but there are other terms that capture the spirit of organic agriculture such as sustainable agriculture, alternative agriculture, ecological agriculture and regenerative agriculture. But can this type of agriculture feed the world? In order to answer the question, this article develops a perspective concerning: a) the conflict among agronomists and policy makers over the future of agriculture; b) the arguments for a second green revolution; c) the evidence for unsustainability of industrial agriculture; d) the evidence for the productive potential of organic agriculture; e) the economic and political roadblocks to an organic transition; and f) the steps that can be taken to facilitate a transition.

Agriculture at a Crossroads

The era of cheap and abundant food appears to be drawing to a close (1,2). The Green Revolution of the 1970s is stalling, and the problem of food insecurity is worsened by increases in the price of rice, wheat, and other food staples (3,4). Approximately one sixth of the world's population is in danger of starvation (5). The situation differs from region to region, and changes with time as economic and political conditions change, but in general, over much of the world, there is a serious problem of food security. Agronomists and ecologists working at the field level, as well as economists and political analysts in multi-national banks, development agencies, and non-governmental organizations agree that action must be taken to stave off immediate problems of hunger as well as action to ensure long-term stability of the world's food supply. However, there is sharp disagreement as to what these actions should be (6,7).

One side of the debate is that a "Second Green Revolution" (industrial agriculture based on inorganic fertilizers, pesticides, and genetically modified crops) will be necessary to feed the world (8-10). Yields must be increased, and increases can be obtained only through more intensive application of inorganic nitrogen and other nutrients, increased irrigation, greater application of petroleum-based chemicals to control insect pests and weeds, and through the use of genetically modified crops that are programmed to take advantage of these subsidies (11).

Opponents of this approach argue that industrial agriculture is unsustainable for a number of reasons:

1. It is highly dependent upon petroleum to synthesize the fertilizers, pesticides, and herbicides, and for fuel for the airplanes, trucks, and tractors that deliver and spread these compounds. Because petroleum supply is erratic and limited (12) , agriculture based on these compounds is unsustainable. As the price of petroleum increases, prices for agricultural chemicals will increase (13). As prices increase, less fertilizer will be used, resulting in greater soil degradation and declining yield of agriculture (14).
2. Use of genetically modified crops can increase yield (15). However increasing yield requires an energy tradeoff against ability to resist pests, and compete with weeds for nutrients and water. Genetic engineering does not increase the photosynthetic energy available to plants. It just redirects it (16).
3. Use of genetically modified crops can put the farmer under the control of international corporations that own patents on the crops. As use of

these crops spreads, the world's food supply becomes increasingly dependent on the economic goals of a handful of corporations and not on the needs and desires of consumers (17).

4. The simple, vertically integrated economic food chain common in industrial agriculture can be highly susceptible to disturbances (18). For example, terrorists can disrupt the world's food supply by introducing pathogens and other biological weapons into a few key links in food chain (19, 20).
5. Industrial agriculture is leading to a depletion of water resources. For example, center pivot irrigation has led to a significant depletion of the Ogallala Aquifer in the western U.S. (21).
6. Prevalence of monocultures in industrial food production systems leads to loss of genetic diversity (21). Low genetic diversity increases the risk of disease or insect outbreak (22).
7. Inorganic nitrogen leached from fertilizers spread on agricultural fields enters waterways and causes hypoxia that results in kills of fish, crustaceans and other marine life (23). Dead zones have been reported from more than 400 regions throughout the world (24).
8. Nitrogen volatilized from fertilizers enters the troposphere and poses direct health threats to humans and causes substantial losses in agricultural production (25).
9. Animal waste lagoons and sprayfields near aquatic environments can significantly degrade water quality and endanger health (26).
10. Overuse of antibioitics in the livestock industry has resulted in increasing resistance of pathogens (27).
11. Increasing resistance of weeds to a single type of herbicide is resulting in the need for an expensive series of herbicides (28).
12. Use of pesticides kills beneficial insects that can help control pest species (21).
13. Plowing and other methods of tillage that disrupt the structure of the soil result in erosion that is destroying croplands throughout the world (29).

Opponents of industrial agriculture argue that what is needed is a paradigm shift away from agriculture based on the premise that humans must conquer nature in order to survive to the premise that humans must learn to understand how nature works, and take advantage of the services of nature to produce food and fiber (30). One term for such agriculture is "organic", but there are other terms that capture the spirit of organic agriculture such as sustainable agriculture, biodynamic agriculture, alternative agriculture, ecological agriculture and regenerative agriculture.

Only a few studies have been carried out long enough to evaluate the potential of organic agriculture. Mäder et.al. (31) compared organic and conventional (industrial) farmed plots over a period of 21 years,. They found that while crop yields were 20 percent lower in the organic trials, fertilizer and energy inputs were up to 53 percent lower, and pesticide input was reduced by 97 percent. This means that while gross income from the organic fields was lower, net income may have been higher. Pimentel et.al. (32) reviewed the 21-year study of industrial and two types of organic treatments at the Rodale Institute in Kutztown, Pennsylvania. They concluded that organically managed crop yields on a per-ha basis can equal those from conventional agriculture, although there was high variability depending on the crop, soil, and weather conditions. Badgley et. al (33) compared yields of organic versus conventional food production for a global dataset of 293 examples and estimated the average yield ratio (organic:non-organic) of different food categories for the developed and the developing world. The average yield ratio for studies in the developed world was slightly less than 1.0, but greater than 1.0 for the developing world. Results of comparisons often depend upon the amount of farm chemicals used in the conventional system (34). Critics of organic agriculture such as Avery and Avery (35) assume that "organic" means replacing nitrogen in inorganic fertilizers with similar amounts of organic nitrogen from sources like animal and green (plant-based) manures. However, replacement with equivalent amounts is not necessary to achieve comparable production, since significant amounts of inorganic nitrogen are lost through volatilization and leaching. In organic systems, losses are much less due to nutrient recycling by soil micro-organisms that feed upon soil organic matter.

The relative yields of industrial vs. organic agriculture may not be the most important issue regarding hunger. There is evidence that hunger in some parts of the world is not caused by low agricultural yields, but rather because in some regions, people have insufficient income to purchase food (36). A 2007 conference entitled "Africa can Feed Itself" (37) concluded that organic agriculture could improve food security, but important obstacles are unfair trade regimes, market access, food dumping, border wars, unpredictable weather, dissembling government policies, access to land and land use, expensive credits, delays in receiving inputs and human disease. Other problems include the tendency for agricultural development projects often ignore or exclude women, yet they are often the primary agricultural producers. Food aid itself is a problem. It has diminished Africa's capacity to feed itself by undermining African farm production and local food markets.

Regenerating the earth's productive capacity

If we sacrifice the earth's regenerative capacities through exploitative agriculture, we will simultaneously destroy the earth's capacity to meet future needs. Short-term quick fixes through greater chemical warfare against weeds and disease will only lead to greater problems in the long term. To alleviate the problems of pollution caused by industrial chemicals, and to regenerate the productive capacity of the earth, industrial agriculture must be replaced by agriculture that is based on an understanding of how natural ecosystems maintain their productivity *and* sustainability. The following paragraphs illustrate some of the ways in which this can be done.

Restore and Preserve Soil Organic Matter. Building and maintaining soil organic matter (SOM) is critical to increasing the efficiency of nutrient recycling in agricultural ecosystems. The carbon compounds in soil organic matter are energy sources for the soil food web. The organisms in these food webs range from bacteria and fungi through protozoa, nematodes, and arthropods to earthworms (38). Nutrient-rich composts composed of manure, chicken litter, peanut hulls, and other natural products that feed the food web are an environmentally preferable alternative to inorganic fertilizers, because nutrient release into the soil is relatively slow. In contrast, mechanical tilling with plows and rototillers oxidizes and destroys SOM. In the absence of SOM, nutrients are held in the soil only by weak electrostatic exchange on mineral soil particles. As a result, nutrients are more readily leached to groundwater and streams and volatilized into the atmosphere.

To build up SOM, cover crops in combination with conservation tillage can be used. Leguminous cover crops are especially desirable, because they also add nitrogen to the soil (39). Just before a cover crop reaches maturity, it is rolled flat and forms a mulch. Then a no-till planter is used to inject seeds through mulch. The mulch helps build up the SOM (40). It also helps to suppresses weeds, but further weed control is often necessary. Herbicides are not permitted by organic rules, but if a farmer chooses to use them in combination with no-till cultivation, he or she is still accomplishing a major improvement over conventional tillage.

Perennial grains now under development (41) can help build up SOM because annual tillage is not required. Agroforestry also helps to maintain SOM because of the tree overstory (42). Shade-grown coffee may be less vulnerable to global warming than more intensive production methods because leaf litter from the overstory trees increases SOM (43). Perennial leguminous shrubs planted in hedgerows that alternate with "alleys" of economic crops (44) can reduce input costs where land is not a limiting factor.

Other benefits of SOM include:

- The activity of soil fauna that feeds upon SOM results in improvement of the physical characteristics of the soil such as porosity and permeability.
- Organic acids released from composts chelate iron and aluminum in highly weathered soils, thereby solubilizing phosphorus bound in iron and aluminum phosphates and rendering the phosphorus available to crops (45).

Increase and preserve diversity: Maintaining species and genetic crop diversity through intercropping (46) can, on average, lead to greater productivity in plant communities, less nutrient leaching and volatilization, and greater ecosystem stability (47). Greater productivity and nutrient retention comes about through resource partitioning (48). When different species have different resource requirements, complimentary interactions between individuals become more important competition (49-51).

Greater stability also results from greater diversity because diversity helps slow the spread of disease. Genetically uniform monocultures are susceptible to rapid outbreaks of disease. For example, a mutation in black stem rust of wheat resulted in a new outbreak of the disease in Northeast Africa (52). The “Yellow shoot disease”, spread by the Asian citrus psyllid, is devastating citrus groves in Florida (53). In contrast to monocultures, a diverse cropland does not present an unlimited opportunity for growth and reproduction of pest species. In China, the level of rice blast caused by the fungus *Magnaporthe grisea* was hugely decreased by planting several varieties of rice together instead of just a single variety (54). Managing rangelands for a diversity of grass and forb species can reduce grasshopper populations (55). Because of their more complex structure, agroforestry systems help conserve biodiversity of fauna. In southwest India, 90 percent of the birds species of the native forest were found in an arecanut palm production system (56).

Maintenance of diversity at the economic level is also important. Compared to vertically integrated food systems, diverse food production and delivery systems with many independent local producers are much less susceptible to agroterrorism and other disturbances such as disease and climate change. If one pathway is disturbed in such a system, another can take up the slack. However a disturbance to a system where most of the food passes through a single chain of storage and delivery can be crippling (57, 58).

Use beneficial species to control pests. Ecologically based pest management helps cut down on poisons in the environment by taking advantage of interactions between pests and naturally occurring pest-controlling organisms. Population outbreaks of pests often occur because there are no predator populations to control them. Natural enemies such as ladybird beetles and parasitic wasps can sometimes be used in place of pesticides against insect pests (59). Bats have been found to control insects in tropical Agroforestry systems (60). Natural insecticides such as pyrethrum that is extracted from the flower of *Chrysanthemum coccineum* can be used when high levels of chemicals are not acceptable (61). Use of rotational schemes so that two crops from the same botanical family are not planted in the same field in successive years can be a big step toward reducing crop enemies such as parasitic nematodes. Close monitoring of pest populations and spraying only when a build-up is noticed can reduce pesticide use as compared to spraying regularly throughout the season.

Use locally proven techniques. Integrating local or indigenous knowledge into farming can improve the sustainability of cropping systems. For example, in the Amazon region of Brazil, the cropping system of the Kayapó Indians which mimics natural successional processes can be continued indefinitely, in contrast to the slash and burn agriculture of migrant farmers which depletes the soil in two or three years (62). In the taungya system for reforestation of teak in Thailand, peasant farmers cultivate upland rice in between the widely spaced seedlings for the first two or three years. This results in decreased weed competition for the seedlings (63). A spiny legume used in fallows in the Philippines improves soil fertility while at the same time, repelling grazing animals (64). An innovative system of rice production that conserves water and results in plants that are less susceptible to lodging is the System of Rice Intensification (65)). Soil is actively aerated, resulting in improved growth and functioning of root systems and the soil biota that contribute to increased productivity.

Any one or more of these techniques can be adopted by farmers to improve environmental sustainability without necessarily becoming organically certified.

In fact, agriculture that is certified "organic" may not necessarily be the best route to sustainability. One can be certified "organic" in the U.S., and still farm unsustainably. The organic label says nothing about monocultures, tillage of the soil, nor the amount of petroleum consumed in bringing the crop to the consumer. For example, National Organic Program standards (66) permit plowing of the soil, rather than requiring conservation tillage. On the other hand, it forbids composted sewage sludge, even though it is composted at temperatures high enough to kill all harmful bacteria and is tested for absence of toxic heavy metals.

Barriers to adoption of sustainable techniques

Despite the advantages of sustainable techniques, there are powerful economic and political barriers to accomplishing a transition to ecologically sustainable agriculture. Pathways to overcoming barriers to sustainable agriculture will vary, depending upon countries, regions within countries, and urban vs. rural situations.

In the U.S., a subsidy farm bill was passed during the Great Depression, to keep small farmers afloat and ensure a food supply for Americans (67). However, the effect of recent farm bills has been to promote huge industrial monocultures that can exist only with massive inputs of synthetic chemicals (68). The federal government spends billions subsidizing mega farms. These subsidies hide the real cost of agricultural production, and make profitability more difficult for farmers using more ecologically sustainable methods (69). The National Institute of Food and Agriculture established by the Farm Bill of 2008 may help promote agriculture that is less dependent on petroleum-derived chemicals (70). The difficulty in changing this system lies in the effectiveness of the lobbying efforts of industrial agricultural corporations. Their control over production and marketing of farm chemicals, and genetically modified crops has been an important factor in the evolution of the industrialized bio-tech vertical system, and they resist efforts to change (18,71).

The trend away from smaller family farms to larger corporate owned farms has resulted in economic stagnation of many rural areas. The mechanistic and simplistic approach of industrial agriculture requires fewer farmers and farm workers, and often less skilled workers. Another problem of small scale farmers, whether organic or not, is that of price competition with their neighbors. Various types of farmer's cooperatives try to address this problem, but economic muscle still resides in the large corporations that control marketing and distribution, and the prices paid to farmers.

The migration of young people from farming communities has left much of the countryside without a population base and economic infrastructure that is essential to establishing agriculture in a more sustainable mode. The social and economic survival of farm communities hinges on the willingness of residents to participate in, and to lead community organizations, -farm, religious, civic, youth, and professional (72). This will come only with an economic incentive. It requires a realignment of priorities by the federal government. Such change may be coming. President elect Barack Obama, when asked on Nov. 25, 2008, where he would start cutting spending once he becomes President, he immediately pointed to abuse of farm subsidies (73).

However, an immediate and complete change from industrial to organic agriculture is not practical in the U.S. A conversion period from conventional to organic almost invariably leads to a temporary decline in yields (32) For fields in transition from conventional to organic, it may take a number of years for levels of production to regain their previous output, because of the time required to build up a healthy topsoil (74). To ease a short-term economic sacrifice, farmers highly invested in industrial agriculture but interested in changing to organic techniques could convert just a portion of their land each year.

Another problem in developed countries is that organic agriculture is labor intensive and knowledge intensive. Many more skilled farmers would be needed to feed the major urban centers of the U.S. than exist now. Even if training in organic methods were to be widely available, it would be unrealistic to believe that there would there be a significant migration of urban populations back to the countryside. Nevertheless, there are significant numbers of urbanites who would aspire to become organic farmers, but lack the access to the land and capital necessary to begin. Organizations such as Land for Good (75) have begun to address this problem by facilitating information exchange between landowners with idle land and potential organic farmers who are looking for land to cultivate.

Part of the resistance to organic agriculture in the U.S. results from a wrongful belief that organic agriculture is equivalent to the agriculture prevalent in the U.S. at the time of the great depression and the dust bowl. Environmental education could help erase this misconception. As people move to urban areas from the countryside, they tend to lose a land ethic, that is, a realization that their subsistence depends upon maintaining healthy agricultural ecosystems, and that these ecosystems must be nourished and protected. One way to counter this loss of appreciation is to set aside a tract of land near each city to be used as an educational farm (76). The idea of setting aside certain portions of land within a county for the public good such as schools, parks, fire stations, and airports could be extended to the setting aside of community-owned land for an organic farm. A full time farmer could work the land, and residents of the town could help to the extent that they wanted. Such a system would benefit urban consumers who prefer produce that is “locally produced”, because it is fresher and tastes better than meals that are transported cross country. Redeveloping farmer’s markets also would help encourage local agriculture (77).

Conventional farmers are frequently resistant to change because of lack of information about sustainable agriculture. In a survey of farmers in South Georgia, Ellis and Gaskin (78) found that conventional fruit and vegetable farmers expressed significant interests in a wide array of sustainable agriculture practices, and expressed a willingness to consider adoption, especially if market data demonstrates increased economic opportunities. However, they reported that “only 30% of respondents agreed that clear/reliable information about sustainable agriculture is readily available, and there still appears to be widespread confusion regarding how sustainable agriculture is defined. Many respondents indicated that they rely on extension agents for sustainable agriculture information. Because extension agents often do not feel that adequate research is available to support recommendations for sustainable agriculture (particularly for small-scale farms) there appears to be an “information gap” between information demands and information availability”.

In developing countries, agencies have traditionally supported industrial agriculture rather than organic or traditional methods. In some cases, traditional agriculture that sustained populations for many generations was displaced when government incentives favored export agriculture (79). Since industrial agriculture often requires less labor (34), one result was a rise in unemployment. However, Nicholas Ahouissoussi, Senior Economist at the World Bank, in a lecture to the Agricultural Economics Dept. at the Univ. of Georgia, said the World Bank is no longer relying on Industrial Agriculture for its development projects, but rather is funding projects that employ a wide variety of approaches that are more environmentally and culturally friendly (80). Kareiva et. al. (81) found that World Bank projects with biodiversity goals were as successful in all development objectives, including poverty reduction and private sector development, as those that focused solely on development. A return to sustainable agriculture in developing regions will require substantial policy, institutional and professional reform (82). For example, tariffs are a key issue. They can either help or hinder development of sustainable food production (83,84). High tariffs imposed by the OECD (Organization for Economic Cooperation and Development) member countries on agricultural products limit the ability of farmers in developing countries to compete in world markets. On the other hand, tariffs by developing countries on commodities from industrialized nations protect local farmers and enable them to produce in a more environmentally friendly manner.

Nevertheless, “Organic agriculture is not going to do the trick” with regards to feeding Africa, said Roland Bunch, and agricultural extensionist quoted in Halweil (85). He suggests a “middle ground” of low-input agriculture that uses many of the principles of organic farming and depends on just a small fraction of the chemicals. “These systems can produce two or three times what smallholder farmers are currently producing.” Cuba is an example of how a transformation can occur from industrial to organic-like agriculture. Since the end of Russian subsidies to Cuba in 1991, small scale farmers and urban agriculture have played an increasingly important role in that Nation’s food supply (86). Through the reclamation of place-based land practices, local growers were empowered and aided in a shift to lower input methods without a great reduction in yields (87).

Conclusion

To feed the world on a sustainable basis, it is necessary for agriculture to become less environmentally and culturally damaging, and less dependent on fossil fuels. Techniques commonly used in organic agriculture have the potential to feed the world, although it could take several years for croplands in transition from conventional agriculture to organic to gain or regain their productive potential.. Economic and political barriers to changing the industrial agriculture paradigm may be more difficult to overcome than technical barriers. If we want everyone in the world to be sufficiently fed, we must not only adopt sustainable food production systems but also policy shifts that will address the real underlying causes of food insecurity. Nevertheless, historical social changes, though slow and difficult, give us hope that with continuous effort, agriculture can be changed from exploitative of nature to working with nature.

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