YES

N. V. Fedoroff et al.

Radically Rethinking Agriculture for the 21st Century

Population experts anticipate the addition of another roughly 3 billion people to the planet's population by the mid-21st century. However, the amount of arable land has not changed appreciably in more than half a century. It is unlikely to increase much in the future because we are losing it to urbanization, salinization, and desertification as fast as or faster than we are adding it.[1] Water scarcity is already a critical concern in parts of the world.[2]

Climate change also has important implications for agriculture. The European heat wave of 2003 killed some 30,000 to 50,000 people.[3] The average temperature that summer was only about 3.5°C above the average for the last century. The 20 to 36% decrease in the yields of grains and fruits that summer drew little attention. But if the climate scientists are right, summers will be that hot on average by midcentury, and by 2090 much of the world will be experiencing summers hotter than the hottest summer now on record.

The yields of our most important food, feed, and fiber crops decline precipitously at temperatures much above 30°C.[4] Among other reasons, this is because photosynthesis has a temperature optimum in the range of 20° to 25°C for our major temperate crops, and plants develop faster as temperature increases, leaving less time to accumulate the carbohydrates, fats, and proteins that constitute the bulk of fruits and grains.[5] Widespread adoption of more effective and sustainable agronomic practices can help buffer crops against warmer and drier environments,[6] but it will be increasingly difficult to maintain, much less increase, yields of our current major crops as temperatures rise and drylands expand.[7]

Climate change will further affect agriculture as the sea level rises, submerging low-lying cropland, and as glaciers melt, causing river systems to experience shorter and more intense seasonal flows, as well as more flooding.[7]

Recent reports on food security emphasize the gains that can be made by bringing existing agronomic and food science technology and know-how to people who do not yet have it,[8,9] as well as by exploring the genetic variability in our existing food crops and developing more ecologically sound farming practices.[10] This requires building local educational, technical, and research capacity, food processing capability, storage capacity, and other aspects of agribusiness, as well as rural transportation and water and communications infrastructure. It also necessitates addressing the many trade, subsidy, intellectual property, and regulatory issues that interfere with trade and inhibit the use of technology.

What people are talking about today, both in the private and public research sectors, is the use and improvement of conventional and molecular breeding, as well as molecular genetic modification (GM), to adapt our existing food crops to increasing temperatures, decreased water availability in some places and flooding in others, rising salinity, [8,9] and changing pathogen and insect threats.[11] Another important goal of such research is increasing crops' nitrogen uptake and use efficiency, because nitrogenous compounds in fertilizers are major contributors to waterway eutrophication and greenhouse gas emissions.

There is a critical need to get beyond popular biases against the use of agricultural biotechnology and develop forward-looking regulatory frameworks based on scientific evidence. In 2008, the most recent year for which statistics are available, GM crops were grown on almost 300 million acres in 25 countries, of which 15 were developing countries.[12] The world has consumed GM crops for 13 years without incident. The first few GM crops that have been grown very widely, including insect-resistant and herbicide-tolerant corn, cotton, canola, and soybeans, have increased agricultural productivity and farmers' incomes. They have also had environmental and health benefits, such as decreased use of pesticides and herbicides and increased use of no-till farming.[13]

Despite the excellent safety and efficacy record of GM crops, regulatory policies remain almost as restrictive

Fedoroff et al., N. V. From *Science Magazine*, February 12, 2010, pp. 833–844. Copyright © 2010 by American Association for the Advancement of Science. Reprinted by permission via Rightslink. www.sciencemag.org

as they were when GM crops were first introduced. In the United States, case-by-case review by at least two and sometimes three regulatory agencies (USDA, EPA, and FDA) is still commonly the rule rather than the exception. Perhaps the most detrimental effect of this complex, costly, and time-intensive regulatory apparatus is the virtual exclusion of public-sector researchers from the use of molecular methods to improve crops for farmers. As a result, there are still only a few GM crops, primarily those for which there is a large seed market,[12] and the benefits of biotechnology have not been realized for the vast majority of food crops.

What is needed is a serious reevaluation of the existing regulatory framework in the light of accumulated evidence and experience. An authoritative assessment of existing data on GM crop safety is timely and should encompass protein safety, gene stability, acute toxicity, composition, nutritional value, allergenicity, gene flow, and effects on nontarget organisms. This would establish a foundation for reducing the complexity of the regulatory process without affecting the integrity of the safety assessment. Such an evolution of the regulatory process in the United States would be a welcome precedent globally.

It is also critically important to develop a public facility within the USDA with the mission of conducting the requisite safety testing of GM crops developed in the public sector. This would make it possible for university and other public-sector researchers to use contemporary molecular knowledge and techniques to improve local crops for farmers.

However, it is not at all a foregone conclusion that our current crops can be pushed to perform as well as they do now at much higher temperatures and with much less water and other agricultural inputs. It will take new approaches, new methods, new technology—indeed, perhaps even new crops and new agricultural systems.

Aquaculture is part of the answer. A kilogram of fish can be produced in as little as 50 liters of water,[14] although the total water requirements depend on the feed source. Feed is now commonly derived from wild-caught fish, increasing pressure on marine fisheries. As well, much of the growing aquaculture industry is a source of nutrient pollution of coastal waters, but self-contained and isolated systems are increasingly used to buffer aqua-culture from pathogens and minimize its impact on the environment.[15]

Another part of the answer is in the scale-up of dryland and saline agriculture.[16] Among the research leaders are several centers of the Consultative Group on International Agricultural Research, the International Center for Biosaline Agriculture, and the Jacob Blaustein Institutes for Desert Research of the Ben-Gurion University of the Negev.

Systems that integrate agriculture and aquaculture are rapidly developing in scope and sophistication. A 2001 United Nations Food and Agriculture Organization report[17] describes the development of such systems in many Asian countries. Today, such systems increasingly integrate organisms from multiple trophic levels.[18] An approach particularly well suited for coastal deserts includes inland seawater ponds that support aquaculture, the nutrient efflux from which fertilizes the growth of halophytes, seaweed, salt-tolerant grasses, and mangroves useful for animal feed, human food, and biofuels, and as carbon sinks.[19] Such integrated systems can eliminate today's flow of agricultural nutrients from land to sea. If done on a sufficient scale, inland seawater systems could also compensate for rising sea levels.

The heart of new agricultural paradigms for a hotter and more populous world must be systems that close the loop of nutrient flows from microorganisms and plants to animals and back, powered and irrigated as much as possible by sunlight and seawater. This has the potential to decrease the land, energy, and freshwater demands of agriculture, while at the same time ameliorating the pollution currently associated with agricultural chemicals and animal waste. The design and large-scale implementation of farms based on nontraditional species in arid places will undoubtedly pose new research, engineering, monitoring, and regulatory challenges, with respect to food safety and ecological impacts as well as control of pests and pathogens. But if we are to resume progress toward eliminating hunger, we must scale up and further build on the innovative approaches already under development, and we must do so immediately.

References and Notes

1. *The Land Commodities Global Agriculture & Farmland Investment Report 2009* (Land Commodities Asset Management AG, Baar, Switzerland, 2009; www.landcommodities.com).
2. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management* (International Water Management Institute, Colombo, Sri Lanka, 2007).
3. D. S. Battisti, R. L. Naylor, Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 323, 240 (2009). [Abstract/Free Full Text]
4. W. Schlenker, M. J. Roberts, Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proc. Natl. Acad. Sci. U.S.A.* 106, 15594 (2009). [Abstract/Free Full Text]
5. M. M. Qaderi, D. M. Reid, in *Climate Change and Crops*, S. N. Singh, Ed. (Springer-Verlag, Berlin, 2009), pp. 1–9.
6. J. I. L. Morison, N. R. Baker, P. M. Mullineaux, W. J. Davies, Improving water use in crop production. *Philos.*

NO

Satish B. Aher, Bhaveshananda Swami, and B. Sengupta

Organic Agriculture: Way towards Sustainable Development

Introduction

Agriculture sector is vital for the food and nutritional security of the nation of India. The sector remains the principal source of livelihood for more than 58% of the population though its contribution (14.2%) to the national GDP. Compared to other countries, India faces a greater challenge, since with only 2.3% share in world's total land area; it has to ensure food security of its population which is about 17.5% of world population. This leads to excessive pressure on land and fragmentation of land holdings. On the other side the annual consumption of fertilizers in nutrient terms (N, P & K), has increased from 0.7 lakh [Lakh = 100,000] MT in 1951–52 to 264.86 lakh MT 2009–10, while per hectare consumption of fertilizers, which was less than 1 Kg in 1951–52 has risen to the level of 135.27 Kg (estimated) in 2009–10. Intensive use of inorganic fertilizers and pesticides has been an important tool in the drive for increased crop production. In fact more fertilizers consumption is a good indication of agricultural productivity but depletion of soil fertility is commonly observed in soils. This continuous and massive application of the agrochemicals causes degradation of environment in terms of reduction in soil fertility, water pollution and indirectly significant contribution to the global warming, climate change and ozone layer depletion. According to the National Bureau of Soil Survey and Land Use Planning (NBSSLUP) 21.97 million hectare (mha) of land is degraded in terms of acidity and alkalinity/salinity. Thus, the indiscriminate use of the fertilizer directly affects the soil health in terms of productivity and mineral composition.

Greenhouse gas (GHG) emissions from the agricultural sector account for 10–12% or 5.1–6.1 Gt of the total anthropogenic annual emissions of CO2-equivalents. However, this accounting includes only direct agricultural emissions; emissions due to the production of agricultural inputs such as nitrogen fertilizers, synthetic pesticides and fossil fuels used for agricultural machinery and irrigation are not calculated. Furthermore, land changes in carbon stocks caused by some agricultural practices are not taken into account, e.g., clearing of primary forests. Emissions by deforestation due to land conversion to agriculture, which account for an additional 12% of the global GHG emissions, can be additionally allocated to agriculture. Thus, agriculture production practices emit at least one-quarter of global anthropogenic GHG emissions and, if food handling and processing activities were to be accounted for, the total share of emissions from the agriculture and food sector would be at least one-third of total emissions. Considering the high contribution of agriculture to anthropogenic GHG emissions, the choice of food production practices can be a problem or a solution in addressing global warming. Recent studies have highlighted the substantial contribution of organic agriculture to climate change mitigation and adaptation. The potential of organic agriculture to mitigate climate change is mostly claimed on the basis of assumptions concerning the soil carbon sequestration potential of organic management.

Organic agriculture offers a unique combination of environmentally-sound practices with low external inputs while contributing to food availability. The objective is to describe the potential of the organic agriculture to provide an alternative way for conventional agricultural practices which leads to a sustainable resource utilization and contributes in mitigating global problems like climate change.

Concept of Organic Agriculture

A large number of terms are used as an alternative to organic farming. These are: biological agriculture, ecological agriculture, bio-dynamic, organic-biological agriculture and natural agriculture. According to the National Organic Standards Board of the US Department of Agriculture (USDA) the word 'Organic' has the following official definition: *"An ecological production management system*

Aher, Satish B., Swami, Bhaveshananda, and Sengupta, B. From *International Journal of Environmental Sciences*, July 2012, pp. 209–214.

that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on the minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony."

According to the Codex Alimentarius Commission, *"organic agriculture is a holistic production management system that avoids use of synthetic fertilizers, pesticides and genetically modified organisms, minimizes pollution of air, soil and water, and optimizes the health and productivity of interdependent communities of plants, animals and people."* To meet these objectives, organic agriculture farmers need to implement a series of practices that optimize nutrient and energy flows and minimize risk, such as: crop rotations and enhanced crop diversity; different combinations of livestock and plants; symbiotic nitrogen fixation with legumes; application of organic manure; and biological pest control. All these strategies seek to make the best use of local resources.

Organic farming is distinguished from conventional agriculture by exercising particular respect for human values, the environment, nature, and animal welfare, etc. This regard is incorporated in the basic principles of organic farming, as formulated by the International Federation of Organic Agriculture Movements. The main principles for organic farming and food processing include:

1. The production of food of high quality in sufficient quantities,
2. Operation within natural cycles and closed systems as far as possible, drawing upon local resources,
3. The maintenance and long term improvement of the fertility and sustainability of soils,
4. The creation of a harmonious balance between crop production and animal husbandry,
5. The securing of high levels of animal welfare,
6. The fostering of local and regional production and supply chains, and
7. The provision of support for the establishment of an entire production, processing and distribution chain that is both socially and ecologically justifiable.

These basic principles provide organic farming with a platform for ensuring the health of the environment for sustainable development, even though the sustainable development of mankind is not directly specified in the principles.

Organic Agriculture and Sustainable Development

When the World Commission on Environment and Development presented their 1987 report, *Our Common Future* they sought to address the problem of conflicts between environment and development goals by formulating a definition of sustainable development:

> *Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs.*

An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of renewable resource systems or environmental sink functions, and depleting non-renewable resources only to the extent that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources. The United Nations report stated: 'All case studies which focused on food production in this research where data have been reported have shown increases in per hectare productivity of food crops, which challenges the popular myth that organic agriculture cannot increase agricultural productivity.'

Comparison of Organic and Conventional Agricultural System

The study carried out in the Central Valley of California showed that tomato yields were quite similar in organic and conventional farms. However, significant differences were found in soil health indicators such as nitrogen mineralization potential and microbial abundance and diversity which were higher in the organic farms. Nitrogen mineralization potential was three times greater in organic compared to conventional fields. The organic fields also had 28% more organic carbon. One of the longest running agricultural trials on record (more than 150 years) [is] the Broadbalk Experiment at the Rothamsted Experimental Station in the United Kingdom. The trials compare a manure based fertilizer farming system (but not certified organic) to a synthetic chemical fertilizer farming system. Wheat yields are shown to be on average slightly higher in the organically fertilized plots (3.45 tones/hectare) than the plots receiving chemical fertilizers (3.40 tones/hectare). More importantly though, soil fertility, measured as soil organic matter and nitrogen levels, increased by 120% in the organic plots, compared with only 20% increase in chemically fertilized plots. Another trial's result from Sustainable Agriculture Farming Systems project (SFAS) at University of California, Davis showed the organic and low-input systems had yields comparable to the conventional systems in all crops which were tested—tomato, safflower, corn and bean, and in some instances yielding higher than conventional systems. Initially tomato yields in the organic system were lower in the first three years, but reached the levels of the conventional tomatoes in the subsequent years and had a higher yield during the last year of the experiment (80 t/ha in the organic compared to 68 t/ha in the conventional). In one such study at South Dakota in midwestern United States shows the higher average yields of soybeans (3.5%) and wheat (4.8%) in the organic compared to conventional farming system. 21 year study compared plots of cropland grown according to both organic and conventional methods at Institute of Organic Agriculture and the Swiss Federal Research Station for Agroecology and Agriculture found that organic yields were less by about 20% but fertilizer, energy and pesticide use were less by 34%, 53% and 97% respectively as compared to conventional. Also organic soils housed a larger and more diverse community of organisms. The study at Iowa State University assessed the agro ecosystem performance of farms which found initially the yield was slightly lower (organic corn & soybean yield averaged 91.8% & 99.6% of conventional respectively) in organic plots but in fourth year organic yield exceeded conventional for both corn and soybean crops. 30 Years Farming System Trial (FST) at Rodale Institute [showed] organic corn yields 31% higher than conventional in years of drought.

These drought yields are remarkable when compared to genetically engineered "drought tolerant" varieties which saw increases of only 6.7% to 13.3% over conventional (non-drought resistant) varieties. Corn and soybean crops in the organic systems tolerated much higher levels of weed competition than their conventional counterparts, while producing equivalent yields. This is especially significant given the rise of herbicide-resistant weeds in conventional systems, and speaks to the increased health and productivity of the organic soil (supporting both weeds and crop yield). The study conducted by ETC Organic Cotton Programme in the district of Karimnagar, Andrha Pradesh India [showed] organic cotton yielded on par at 232 Kg seed cotton/acre vs. conventional cotton at 105 Kg/acre. The pest control expenses was observed about Rs. 220 and Rs. 1624 per acre for organic and in conventional cotton respectively. Study at Washington State University compared yields, economics, soil quality, and other factors resulting from apples grown using organic, conventional, and integrated methods. After combining all of the sustainability indicators, the organic system ranked first in overall sustainability, the integrated second, and the conventional last. A survey conducted by Indian Institute of Soil Science on certified organic farms to evaluate the real benefits and feasibility of organic farming revealed that, on an average, the productivity of crops in organic farming was lower by 9.2% compared to conventional farming. But there was a reduction in the average cost of cultivation in organic farming by 11.7% compared to conventional farming. The average net profit of 22.0% higher in organic farming was observed where 20–40% premium provided. Besides this, overall improvement in soil quality was observed indicating an enhanced soil health and sustainability of crop production in organic farming systems.

Conclusion

A comprehensive review of a number of comparison studies on agricultural yields shows that in all of these studies organic production is equivalent to, and in many cases better than, conventional farming practices. In some, overall lower yield was also reported but the economy [was] still better than the conventional agriculture practices due to the lower external inputs. Besides the yield comparisons, organic practices show higher organic matter in soil, lower energy consumption, lower use of external inputs, better food quality, and also potential to address the global issues like climate change.

Satish B. Aher is affiliated with Environment and Disaster Management, IRDM Faculty Centre, Ramakrishna Mission, Vivekananda University, Narendrapur, Kolkata, West Bengal, India.

Bhaveshananda Swami is affiliated with Environment and Disaster Management, IRDM Faculty Centre, Ramakrishna Mission, Vivekananda University, Narendrapur, Kolkata, West Bengal, India.

B. Sengupta is a former Member Secretary, Central Pollution Control Board, Ministry of Environment and Forests, Government of India.