

## Potential for a New Generation of Biodiversity in Agroecosystems of the Future

Frederick L. Kirschenmann\*

### ABSTRACT

**Industrial agriculture, which is grounded in the industrial principles—specialization, simplification and concentration—that inform all industrial economies, has been exceptionally successful for the past half century. But, as we enter the 21st century this modern agriculture will be facing a number of serious challenges that may force the abandonment of these principles in favor of a more diversified, complex system of food and fiber production.**

THE ROOTS OF INDUSTRIAL AGRICULTURE are embedded in the historic publication of Justus Liebig's *Organic Chemistry in Its Application to Agriculture and Physiology* (1840). Liebig argued that we could sustain the productivity of agriculture without continuing mixed farming practices and the laborious task of manuring soils. Substituting synthetic fertilizers for such nutrient cycling practices substantially simplified farming practices, and the ability to substitute synthetic fertilizers for nutrient cycling led farmers to specialize in the production of a few high-value crops and abandon the mixed farming practices that incorporated green manures and livestock into farming systems.

As the industrialization of agriculture took hold in the mid-20th Century, several assumptions began to be taken for granted. It was assumed that: (i) production efficiency could best be achieved through specialization, simplification and concentration; (ii) therapeutic intervention was the most effective way to control undesirable events; (iii) technological innovation would always be able to overcome production challenges; (iv) control management was the most effective way to achieve production results; and (v) cheap energy to fuel this energy intensive system would always be available.

Based on these assumptions, our entire agricultural production system was transformed into large-scale, specialized, energy-intensive farming.

As we enter the 21st century most, if not all, of these assumptions are under fire.

The world is experiencing a major energy transformation that is bound to have a profound effect on our industrialized farming systems. At the same time that the global demand for fossil fuels is skyrocketing, the global production capacity of oil and natural gas either has peaked or will shortly do so. Oil and natural gas constitute two-thirds of our hydrocarbon-based economy and provide almost *all* of the energy used on industrial

farms. Fertilizers, pesticides, farm equipment, tractor fuel, and irrigation operations, which constitute the very core of all industrialized farming systems, are derived almost entirely from fossil fuels.

Even without any other challenges, this new energy situation may force agriculture, as well as most of the rest of our economy, to change rather significantly and imminently. As Paul Roberts (2004) put it, "the real question, for anyone truly concerned about our future, is not *whether* change is going to come, but whether the shift will be peaceful and orderly or chaotic and violent because we waited too long to begin planning for it" (p.14).

In addition to the energy transition, there are numerous other challenges that will force agriculture to change. Among them are ecological degradation (much of it caused by industrial agricultural practices), climate change and a severely impaired farm economy.

The degraded condition of the ecosystem services on which agriculture is heavily dependent was described succinctly in the recently issued UN "Millennium Ecosystem Assessment Synthesis Report" (2005). The report detailed some disturbing conclusions about the state of our global ecological resources.

Produced by 1360 of our leading scientists from 95 countries, the report's core findings cannot help but alarm us. The report found that over the last one-half century, humans have polluted or overexploited two-thirds of the earth's ecological systems on which life depends, dramatically increasing the potential for unprecedented and abrupt ecological collapses. And the report determined that most of these ecosystem damages were the direct or indirect result of changes made to meet rising demands for ecosystem services—in particular the growing demands for food, water, timber, fiber, and fuel.

In other words, the means by which we have met our basic human needs during the past half century have now become the bane of our existence. And the agriculture we have practiced played a key role in that unhappy outcome.

The report goes on to stress that there is no simple fix for these impending consequences. We now have set in motion a series of changes—climate change, biodiversity loss and land degradation—that make it extremely difficult to *restore* ecological health. These changes, together with the loss of both species diversity and genetic diversity, now have severely damaged the *resilience* of ecosystems—the level of disturbance that an ecosystem can undergo without crossing a threshold to a different kind of structure or functioning. So, not only have we degraded the productive capacity of the planet, we also have undermined the planet's capacity for self-renewal and self-regulation.

And if that news were not sobering enough, the report goes on to suggest that additional *new* challenges are on

Leopold Center for Sustainable Agriculture, and Iowa State Univ., 209 Curtiss Hall, Ames, IA 50011-1050. Received 4 Apr. 2006. \*Corresponding author (leopold1@iastate.edu).

Published in *Agron. J.* 99:373–376 (2007).

Symposium Papers

doi:10.2134/agronj2006.0104

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677 S. Segoe Rd., Madison, WI 53711 USA



the way. The report anticipates that during the next 50 yr demand for food crops will grow by 70 to 85% and demand for water by between 30 and 85% (Millennium Ecosystem Assessment, 2005).

Climate change is likely to be a third driver forcing agriculture to restructure in the decades ahead. Climate change is, of course, partly caused by ecological degradation, as the UN report suggests. But even apart from human-induced changes, the climate on our planet seldom is stable or consistently favorable to agricultural production. As Stephen Schneider (1976, p. 103–112.) noted several decades ago, while favorable, stable climate plays at least as big a role as technology in producing consistently high crop yields, such favorable climate conditions are not the norm. Industrial agriculture features highly specialized production systems that rely on climate conditions that remain hospitable to those few crops. When 92% of Iowa's cultivated land is planted to just two crops—corn (*Zea mays* L.) and soybeans [*Glycine max* (L.) Merr.]—climate conditions that are consistently favorable to corn and soybean production will be vitally necessary to maintain productivity. As climate becomes more unstable, such specialized systems will become increasingly vulnerable to climate fluctuations.

While there are still a few policymakers and agriculturalists who assert that the UN report's analysis is alarmist, the overwhelming evidence would indicate that it is on target. Jim Hansen's recent review (2006) of four prominent climate studies in the July 13 *New York Review of Books* provides some context for understanding the gravity of the situation. Hansen suggests that, "If human beings follow a business-as-usual course... the eventual effects on climate and life may be comparable to those at the time of mass extinctions. Life will survive, but it will do so on a transformed planet." So those who assume that agriculture can largely continue business as usual with 50% of the world's species gone, no fisheries, no tropical forests, etc., may want to rethink their positions, especially if these cataclysmic changes also mean general chaos and mayhem everywhere. In his "Sustainable Developments" column in a recent issue of *Scientific American*, Jeffrey Sachs (2006) provides clear evidence that social and political chaos in Darfur was directly attributable to global warming.

In his *The Weather Makers*, Tim Flannery (2005) similarly points out that social and economic chaos likely will result from the effects of climate change. Flannery, who is a mammalogist, concludes that the speed at which animals and plants need to migrate to remain in their preferred thermoclines—and the speed at which they have to migrate *is* accelerating—will simply not allow them to move fast enough to stay ahead of the changing climate and survive. Given the interdependence of species, such species loss will likely cause severe devastation to the biodiversity of the planet—a biodiversity on which agriculture ultimately depends.

How does agriculture operate in a world with significant biodiversity eviscerated? Will we have pollinators? We just have no good idea how this unraveling will play out in terms of the feasibility of farming any-

where. Can we reasonably continue to assume that we can sustain our agricultural productivity under these changing conditions simply by inventing a few more new technologies?

If agriculture is to remain productive, farmers need to be able to adjust quickly to these changing conditions. Since the farm economy has gradually worsened during most of the last half-century, farmers may find it very difficult to respond quickly or nimbly. Net farm income has gradually declined since the 1940s, despite an increasing infusion of government subsidies since the mid-1980s (Fig. 1).

While some argue that such shrinking of net income is of little consequence since the income is shared by a shrinking number of farmers, that argument fails to consider the fact that the larger farms also bear a significantly increased amount of risk. The fact is that almost all net farm income today comes from government subsidies and off-farm income—hardly circumstances that stimulate on-farm innovation.

The changing age distribution of farmers may be an additional barrier to change. In 1950, nearly 20% of U.S. farmers were under age 35, whereas less than 15% were over age 65. By 2002, only 6% were under age 35, but 27% were over age 65 (Fig. 2). None of us like to make major changes in our lives once we reach age 60. Farmers may be no exception.

An aging farm population that operates on thinner margins of net income and increasingly rents rather than owns its farmland presents us with a scenario that could inhibit change. Nevertheless, the combination of a volatile energy situation, unstable climate, and degraded ecological resources will prove to be a powerful driver of change. And if we can design farming systems that are less energy intensive, more resilient in the face of unstable climates, and that begin to outproduce monocultures by virtue of their multispecies output, then the economic advantage of such complex farming operations over the dismal financial performance of specialized monocultures could be an additional incentive to change.

Furthermore, as we are learning from ecologists and social scientists, adaptive management, especially when

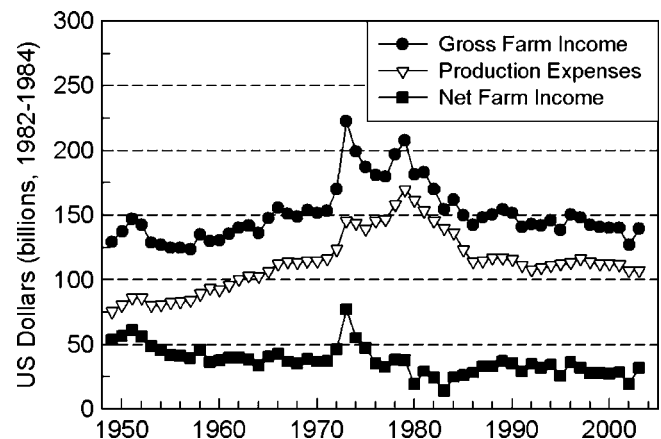


Fig. 1. Total gross farm income, farm expenses, and net farm income in the USA, expressed in constant dollars (1982–1984 basis; USDA, Economic Research Service).

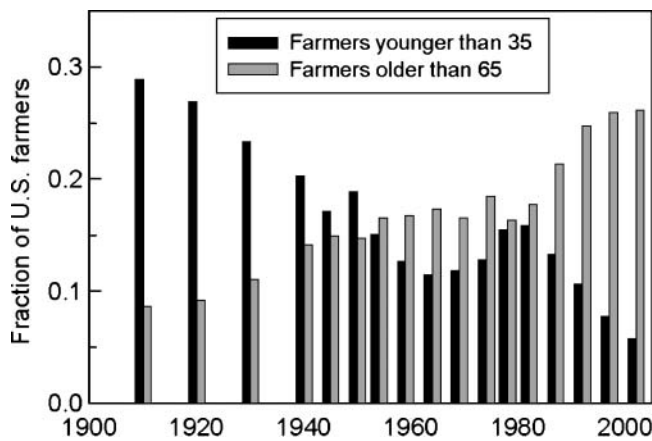


Fig. 2. Changing age distribution of U.S. farmers (1900–2000, U.S. Census of Agriculture).

emergent properties reign as they do in nature, is far more reliable than control management. Control management, which lies at the heart of industrial agriculture, operates under the assumption that constancy is the rule. But, as C.S. Holling (1995) reminds us, “Assumptions that such constancy is the rule might give a comfortable sense of certainty, but it is spurious. Such assumptions produce policies and science that contribute to a pathology of rigid and unseeing institutions, increasingly vulnerable natural systems and public dependencies.”

A few farmers already operate new, complex farming systems based on biological synergies and adaptive management that are demonstrating incredible efficiencies and economic performance. Takao Furuno’s (2001) duck/fish/rice (*Oryza sativa* L.)/fruit farm in Japan serves as a prime example of such productivity and efficiency. He now produces duck meat, duck eggs, fish meat, fruit and rice in a highly synergistic system of production on the same acreage where he previously only produced rice—all without any purchased exogenous inputs. And, in this new production system, his rice yields have increased up to 50% over the yields he was getting from his former high-input, industrial, monocrop rice farm. His new farm, he writes, is based on the concept of producing “a variety of products within a limited space to achieve maximum overall productivity” by introducing multiple species into the same environment in ways that allow “all components to influence each other positively in a relationship of symbiotic production.” Such complex, synergistic systems are proving to be much more productive than monocropping systems, while using far fewer, potentially environmentally damaging inputs.

Many other examples can be cited. Joel Salatin, designer and operator of Polyface Farms near Swoope, VA, has developed a rotational grazing production system featuring pastures that contain at least 40 varieties of plants and support numerous animal species. Both plants and animals are linked in a symbiotic set of relationships that allows each species to make a contribution to the vitality of the system. Consequently, Salatin uses very little fossil fuel on his farm. And the farm is very productive. The 57-ha farm annually produces 30 000 dozen eggs, 10 000 to 12 000 broilers,

100 beef animals, 250 hogs, 800 turkeys and 600 rabbits (Purdum, 2005).

George Boody (2005) and his colleagues have calculated, on a watershed basis, that diverse, synergistic farms can be profitable and simultaneously benefit the environment. Their study demonstrates that when farms are converted from corn/soybean monocultures to more diverse farms consisting of five crops and include rotational grazing, riparian buffers, etc., net farm income can increase by as much as 108% while producing significant environmental and social benefits, despite increased production costs to purchase animals and install fencing.

As we enter the 21st century, mainstream agriculture faces many challenges that may propel agriculture in these new directions. As fossil fuels are depleted, the ratio of energy produced to energy required to produce it continues to diminish, making that source of energy increasingly costly. So agriculture will have to find an alternative energy source to sustain its productivity. Agro-ecologists increasingly are convinced that the most viable alternative technology will spring from the biological synergies inherent in multispecies systems and that additional research might make such systems the next new technology.

Masae Shiyomi and Hiroshi Koizumi make a strong case for exactly such a transformation in postmodern agriculture. I believe they raise one of the most important questions facing agriculture today (Shiyomi and Koizumi, 2001): “Is it possible to replace current technologies based on fossil energy with proper interactions operating between crops/livestock and other organisms to enhance agricultural production? If the answer is yes, then modern agriculture, which uses only the simplest biotic responses, can be transformed into an alternative system of agriculture, in which the use of complex biotic interactions becomes the key technology.” Farmers like Takao Furuno have already answered that question in the affirmative. Joel Salatin, who operates a similarly complex, synergistic farm in Virginia, concurs.

It would appear that these new farms of the future will operate on the basis of at least eight principles that are almost diametrically opposed to the assumptions industrial agriculture has taken for granted. Postmodern farms will likely need to: (i) be energy conserving; (ii) feature both biological and genetic diversity; (iii) be largely self-regulating and self-renewing; (iv) be knowledge intensive; (v) operate on biological synergies; (vi) employ adaptive management; (vii) feature ecological restoration rather than choosing between extraction and preservation; and (viii) achieve optimum productivity by featuring multiproduct, nutrient-dense, synergistic production on limited acreage.

Naturally, some modification in farm policy could help to increase the viability of these new generation farms. Most of today’s farm policies are designed to support monocultures. A modest shift in farm policy that would encourage transitions to these new synergistic systems might produce information that would make the transition more attractive. Designating a modest percentage of current research funding to further explore the potential

of biological synergies in agriculture in various watersheds would, I believe, reveal many additional models of farming in nature's image. Farming systems based on such biomimicry (Benyus, 1997) could dramatically reduce dependence on fossil fuel inputs, restore ecological capital, and put more diverse, resilient production systems on the landscape.

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