Environmentally Friendly Agriculture: Global Perspectives and Local Challenges

C Jerry Nelson
Agronomy Department, 210 Waters Hall
University of Missouri, Columbia, MO 65211 USA

It is appropriate that environment-friendly agriculture be the focus of a symposium on technologies and crop production as there is a growing list on new technologies, and the manner in which crops are produced is changing rapidly. This is caused largely by a set of external economic factors and a greater expectation from the public for the agriculturalists and producers, who are the managers and caretakers of the landscape Thus, in the immediate future most of the emphasis on agriculture and new technologies in developed countries will need to focus less on increasing production and more on value-added traits for marketing and on environmental and biodiversity issues. Developing countries will continue to focus on developing and adopting technologies to increase food production with no negative effects on the environment

Terminology on this subject can be both polarizing and compromising. *Organic agriculture* considers mainly the source of inputs used, does not allow chemical fertilizers or pesticides, and precludes insertion of foreign materials such as DNA via biotechnology. Most of the public assumes organic agriculture is sustainable, but that is not assured. Organic certification assures only that no pesticides, biotechnology, or chemical fertilizers have been used. *Sustainable agriculture* has been used to describe systems and cropping strategies that are economically viable, socially acceptable, and environmentally sound. This is a relatively broad definition that is less restrictive in terms of inputs, but is very hard to quantify in scientific or social terms. In contrast, *environment-friendly agriculture* allows chemical and biotechnology inputs that are either consumed or stored in the cropping system in such a way that the environment is not altered negatively or, in fact, is improved. In most cases the environment includes quality of soil, air and water, but in some cases includes aesthetic values which are not easily defined. *Eco-friendly agriculture* is more inclusive and considers the environment and the total ecosystem in terms of its biodiversity and function.

While environment-friendly agriculture is an honorable goal, it is not without its challenges and the need for development and use of modern technologies. In addition, while being more input and technology oriented than organic agriculture it needs to embrace and honor the culture and perspectives of the general public who, along with the agricultural producers, have a vital interest in the well-being and sound management of the landscape. My goal is to address some of the key issues at the international, national, and local levels. While it is largely an overview, the purpose is to form a framework or reference point for further understanding and decision-making regarding the management of the land resources in a way that maintains or increases production while also maintaining or improving the environment.

Economic Development and Environmental Preservation

Often it is assumed that strong economic growth will be at the expense of the environment, but that is not usually the case (Ekins, 1999). Recently that concept has been evaluated using an Environmental Kuznets Curve (Harbaugh et al., 2002) with good sources of data that show a different response, one that actually indicates that the environment improves with economic growth (Figure 1). The Environmental Stability Index is a composite of 13 environmental quality indicators, including air quality, water quality, and environmental health, each given equal weight. The world average is about 50 with Finland, Norway, Uruguay, Sweden and Iceland having the highest scores and North Korea, Iraq, Taiwan, Turkmenistan, and Uzbekistan having the lowest scores.

The general conclusion is that higher income countries are more capable of maintaining or improving environmental conditions as the economy improves. Yet, less than 25% of the variance is associated with economic factors suggesting other factors, e.g., education level or government priorities also have an influence. Of interest is the fact that South Korea is below expectation, perhaps due to the rapid economic growth that preceded the implementation of governmental policies and the development of a strong public concern.

When economic status is related to biodiversity issues, however, the relationship is negative and inverse from that on the environment alone (Figure 2). The Biodiversity Index includes threat to endangered species and changes in land use. As mentioned above, maintenance of biodiversity is different from maintenance of the environment, but in many ways is linked, and use of the same agricultural technologies may not be beneficial to both. Secondly, the importance of biodiversity to the public is more futuristic than is the importance of the environment, and is emphasized mainly in the most developed countries. On the other hand, developed countries generally have had major reductions in the rural populace being involved in commercial agriculture, usually leading to larger field sizes and the increase in monocultures. Both are known to have negative effects on plant, animal and microbe biodiversity.

In many developing countries with very low GDPs, there is an acceptable short-term decrease in environmental quality for improved production, but once the rudimentary food needs are met the emphasis quickly changes to an environmental priority as well as production. The overall result is that the combined relationship (Figures 1 and 2) of environmental improvement and change in biodiversity is a curve with an apparent "optimization" at a middle range of GDP. But this is not the case in the long term and is the result of shifts in emphasis as the economy improves. Thus, as economic growth occurs there will be a shift in emphasis on technology adoption focused mainly on production to that which also improves the environment, and eventually to that which also maintains or enhances biodiversity. This is already evident in Europe where ecosystem levels of agricultural research are gaining strong momentum with minimal interest in increasing production, but to both improve the environment and increase biodiversity.

Dealing with Global Climate Change

Since the time of the industrial revolution the CO_2 concentration of the air has increased from about 280 ppm to about 370 ppm. Data suggest that about 2/3 of the increase is due to the burning of fossil fuels and about 1/3 is due to changes in land use and cultivation. The latter was associated with shifts from natural ecosystems to agricultural ecosystems which were subject to increased soil erosion and rapid decrease in soil organic matter (Lal et al., 2005).

If air temperatures were to remain similar, reports indicate that most C_3 crops will have reduced photorespiration at the higher CO_2 concentration, about 30% higher productivity and increased water-use efficiency (Kimball et al., 2002). Temperatures during the past 100 years are the warmest on record, however, and the rate of change over the past 50 years has accelerated indicating the direct effects of man's intervention (Rosenzweig and Hillel, 2005). The global models now suggest that by the year 2100 global temperatures will increase by a small amount near the equator to as much as $6^\circ C$ at the poles. The result will be melting of the polar ice with concomitant increase in the sea level and flooding of many low lying areas. The temperature increase will largely offset the positive effects of CO_2 by causing increased respiration and photorespiration of C_3 plants.

In addition, there will be more heat stress and transpiration. C_4 crops will be less affected than C_3 crops except for heat stress which will exacerbate problems when either type is grown in drought–prone environments. Annual rainfall is expected to increase slightly, but there will likely be more severe storms and increased soil erosion (Figure 3). The growing season for crops will be longer which may allow more areas to have double or relay cropping systems. There could be increased capacity for winter cover crops to protect the soil, but with more soil compaction due to increased animal and/or wheel traffic in the fields And, disease organisms and pests will have more rapid life cycles so there will be greater needs for genetic resistance through conventional breeding or biotechnology.

Technologies to offset global change will be focused on favorable crop sequencing, water conservation, soil conservation, soil temperature control, and water-use efficiency. Emphasis is likely going to be on environmental conservation, but ultimately on biodiversity as well. Use of technologies like precision agriculture and biotechnology will offer great potential for improving crop management, the environment, including tolerance to biotic and abiotic stresses. There will be emphasis on capturing CO_2 in the soil organic matter (Figure 4).

The Biotechnology Movement

Biotechnology in cropping systems came of age in the late 1990's and early 2000's, mainly through the use of the Bt gene in several crops to give resistance to several species of insects and the incorporation of glyphosate (Roundup) resistance into corn and soybean crops. Both were quickly adopted by farmers in some countries, while other developed and developing countries prohibited production or import of any genetically engineered crop (Hoban, 2004). Globally, more than 67 million hectares of transgenic crops were produced in 2003, and the trend was upward. Most was produced in the United States, Argentina and Canada, and consisted mainly of insect resistance and herbicide tolerance in three crops, namely soybean, cotton and maize.

Where adopted, biotechnology-derived crops have provided large economic benefits to farmers, by marked reduction in use of pesticides and improved efficacy of those that are used. It also helped to reduce the need for as much tillage. Application timing of needed pesticides is more flexible. In fact, use of Bt-cotton has likely been the greatest economic technology that has been developed for this crop (Traxler, 2004). And the environmental benefits due to the marked reduction of insecticide use in cotton and the use of glyphosate herbicide instead of more toxic and persistent herbicides are enormous. In addition, the reduced use of tillage for soybean and cotton crops has reduced energy consumption, left water-saving residue on the soil surface and has led to reduced soil erosion and associated effects on water quality.

According to the above, so far most use of genetically engineered crops has been environmentally friendly and it has improved the economic situation for the producers and for private industry, the other major economic benefactor. Unfortunately, the combination has not been made available to farmers in developing countries and in several of the most developed countries, which is an interesting dichotomy. Use of biotechnology in developing countries will be slow because many do not have the necessary patent and intellectual property protection that encourages private investment. This is brought out in the Roundup-ready soybean situation in Argentina that allowed biotechnology crops, whereas its neighbor Brazil had policies to prohibit the same crops. Soon it was discovered that nearly half of the Brazilian soybean crop included the Roundup-ready gene that had been smuggled from Argentina. It could easily be utilized in the self-pollinated crop, although it was "illegal" according to both Brazilian law and patent rights of Monsanto Corporation. Fortunately, most countries are addressing the patent issues.

Issues regarding food safety and potential effects on biodiversity are other factors. A lack of education of the public in some developing countries will further delay the use of biotechnology as the populace has difficulty evaluating the science associated with food safety and biodiversity implications. Having conflict among the developed nations does not improve the situation, and action groups can have a disproportional effect on public opinion and eventual government policy. Most countries have implemented food safety criteria and testing procedures for crops improved by non-sexual gene transfer that are much more stringent than those for crops improved by sexual crosses and conventional breeding techniques. This has forced the industry to invest millions of dollars to gain approval. It is generally agreed by scientists that foods derived from biotechnology are actually safer than those from conventional breeding.

Attitudes of consumers differ among and within countries, and the attitudes gradually change (Hoban, 2004). Those in the US and in Asia tend to be more favorable toward genetically engineered crops, whereas those in Europe tend to be much less favorable But there are significant numbers in all countries with reservations. The exact reasons for the differences in opinion are difficult to discern, but range from food safety, effects on biodiversity, and general political issues, mainly the ultimate control by private industry and the concentration of those industries in certain countries. Attitudes gradually change in both positive and negative directions, but again the reasons for the change are largely not known. For example, it was felt that the food safety issues were being resolved, the reduced pesticide use and other environmental benefits were recognized, and lower food prices were being accomplished. But then issues related to pharmaceutical plants and biopharming raised a new higher level of concern, mainly on safety factors and biodiversity issues.

World Trade Organization (GATT)

Looming on the horizon is full implementation of the WTO agreements. Currently there is a great interest in working out the various market classes and their criteria for each product. This will likely take some time for complex products, but will go quickly for general commodities such as maize, soybean, and rice. The need for technologies to be in place for quality of the raw product or some value-added factor will be useful for establishing a separate market channel that can reflect the true value of the commodity in comparison to the general commodity. Likely, there will be separate market channels for biotechnology-derived crops, but the details are yet to be worked out. New value-added crops will need separate channels

Value-added traits such as those of golden rice may command a higher price on the global market than conventional food-grade rice, and rice of a certain starch composition may have enough difference in quality to demand a higher global market price Technologies associated with producing the crop and preserving the value-added trait during processing, transporting, and storage until the purchase by the global consumer will be important. These technologies, including post-harvest physiology will likely need cooperative efforts involving food scientists and marketing specialists. In addition, there may be opportunities for other value-added designations such as organic, sustainable, environment-friendly, or eco-friendly although they may not have the same importance or perceived value in an international marketing system as in local systems.

Water, Energy, and Biodiversity

Emerging rapidly are conflicts and potential solutions on the usages of water and energy resources for agriculture and other public uses. This is also linked to the desire for biodiversity, which becomes an important component of managed and natural ecosystems as income levels increase and environmental problems are being addressed. Water is a universal issue as agriculture is a major user; from 70-80% of the water being used in agriculture, largely for irrigation. Energy is an international problem already and new technologies are emerging. Emphasis on biodiversity is already clearly evident in Europe, with the concept and priority in addressing this in association with agriculture is emerging in other countries as well.

Technological advances in agriculture are often perceived to be detrimental to biodiversity (Figure 2) because they disturb the natural environment by increased energy use by mechanization that promotes use of larger fields and more monocultures. Other advances in pesticides or fertilizers also tend to cause shifts in land usage leading to fewer wooded or forested areas and more intensive land use. They, along with mechanization, also increase the use of fossil fuels for the manufacture and application. With energy prices increasing, the energy budgets for crop production relative to the energy captured in the products, are being questioned. As income levels rise there is more pressure for use of the limited water resources, and agriculture is generally considered to reduce water quality rather than improve it.

Conflicts on water use have occurred for a long time and there are international agreements recommending integrating the water needs for agriculture and the natural ecosystems. Improvements in water-use efficiency by cultural practices such as tillage, residue management, weed control and more specific times of irrigation have increased water-use efficiency of crop production. There will be continued efforts by plant breeders and cropping systems specialists to further improve the efficiency, but major breakthroughs will require biotechnology or switches to use of more drought-resistant crops.

Agriculture will likely be reduced in priority as water needs for urban areas increase. Desalinization of sea water may be a technology to provide water for public uses as most large cities and population centers are located within 75 km of the sea. There is a great interest in use of agriculture to produce biofuels and industrial feedstocks that would reduce dependence on petroleum sources. In addition, there will be a need for continued efforts to decrease energy and water use on a global and local basis. At the same time there will be needs to increase biodiversity, mainly in developed countries, but it is gradually becoming a higher priority issue in developing countries. This is seemingly a great challenge as the methodologies for measuring and understanding the intrinsic value of biodiversity are not yet clear. So new technologies, likely involving social scientists and ecologists will be necessary.

The rapid development of precision agriculture will be a good foundation for dealing with these issues. To-date, precision agriculture has been studied and applied to deal with in-field variation in terms of crop management based on soil properties and the localization and treatment of areas with biotic stresses from weeds, insects and diseases. In the US the early adopters have used yield monitors to evaluate potentials for dealing with the inherent spatial variability, and have learned that soil hydrology is highly variable and is likely the major factor regulating crop growth (Hamza and Anderson, 2005). Adjusting soil fertility applications based on soil tests and targeting localized areas for pesticides has decreased the potentials for pollutants entering the environment. But the scientists have also learned that general soil testing is often not precise enough for application of specific rates of fertilizers. This has increased the interest in remote systems of tissue testing such as use of chlorophyll meters at specific growth stages, especially for nitrogen (e.g., Fox et al., 1994).

An expanded approach to precision agriculture may be useful for understanding the relationships of soil properties, water use, and energy needs for integrating crop production and biodiversity across a watershed or landscape. Using appropriate models and good soils and cropping systems data should allow a diverse landscape of crops, trees, grasslands, and livestock in a spatial pattern that optimizes the land use in such a way to improve the environment and biodiversity while maintaining high crop productivity in an environmentally friendly way. The new technologies in spatial statistics should assist in determining where in the landscape each component in the overall system should be located. For example, in a Missouri watershed, switching crops among field locations that are located near and more distant from a stream had a major effect on the water quality.

Many countries are investing heavily in use of crops or animal wastes as biofuels and the use of wind energy sources to generate electricity. Clearly there are advantages and disadvantages to uses of these renewable or sustainable sources of energy. And soil and crop management strategies will need to be developed to optimize sequestration of the CO_2 that continues to be produced by burning of fuels. But again the best soils for CO2 storage may be site specific (Figure 4). New technologies will also be needed to reduce the energy needs of agriculture such as in tillage systems, irrigation, fertilizer production, and pesticide production. Similarly, new technologies will be needed to reduce energy costs for application, and also for reducing the soil compaction that occurs with wheel or foot traffic (Hanza and Anderson, 2005).

Summary and Conclusions

New technologies will be needed to continue to improve environmentally friendly agriculture, and the problems will be more complex to address and more difficult to solve. Nevertheless, agriculture is positioned to provide the leadership for such an effort and the emerging issues of biodiversity. Agriculture and ecosystems are linked in resource use and biological processes, so it is natural that food production and improving the environment and ecosystem can be achieved. In an FAO statement they suggest a win-win situation for food production and environmental services, especially if market sources are available for economic benefit to the land managers. How that economic benefit is generated will be a topic of considerable international discussion to determine if and how government subsidies are used to give stability to the overall system.

Three basic issues, namely *knowledge*, *values*, and *institutions* are important and will need to be in the forefront of decision to harmonize crop production and the ecosystem. Broader and more specific knowledge about systems will be needed along with the appropriate technologies to change or improve the conditions. Values are harder to define, and will require assistance from social scientists to quantify and interpret. This is critical as values will determine which technologies the public will allow to be used. And institutions will have a major role, especially in terms of public and private research relationships. Institutions will also be responsible for educational programs for the producer to aid in adoption of new technologies and to the public about the positive attributes of agriculture and crop production that are consistent with the environment and ecosystem improvement.

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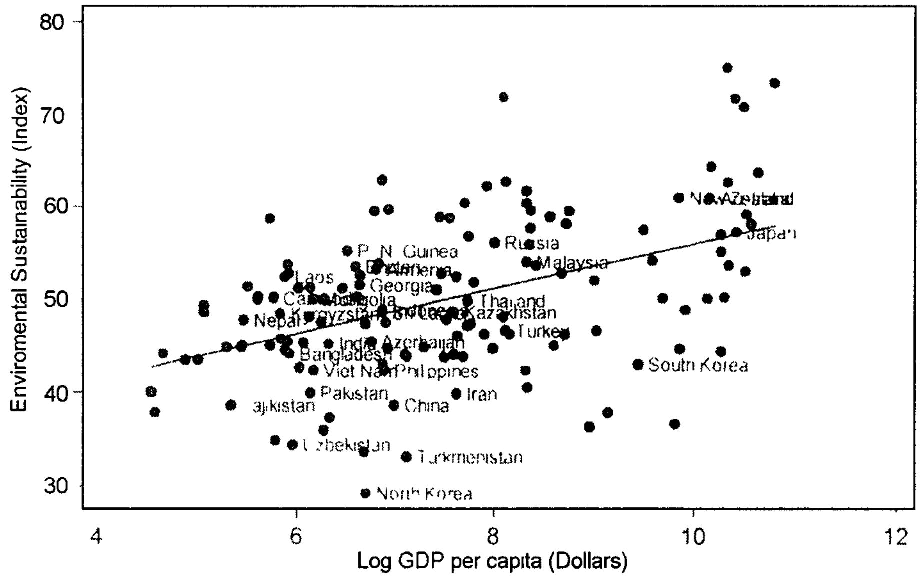

Figure1. Effect of gross domestic product (GDP) on the index of environmental stability. Data are labeled for some Asian countries. The index includes several measures of soil, air and water quality. Adapted from Lee and Koo (2005).

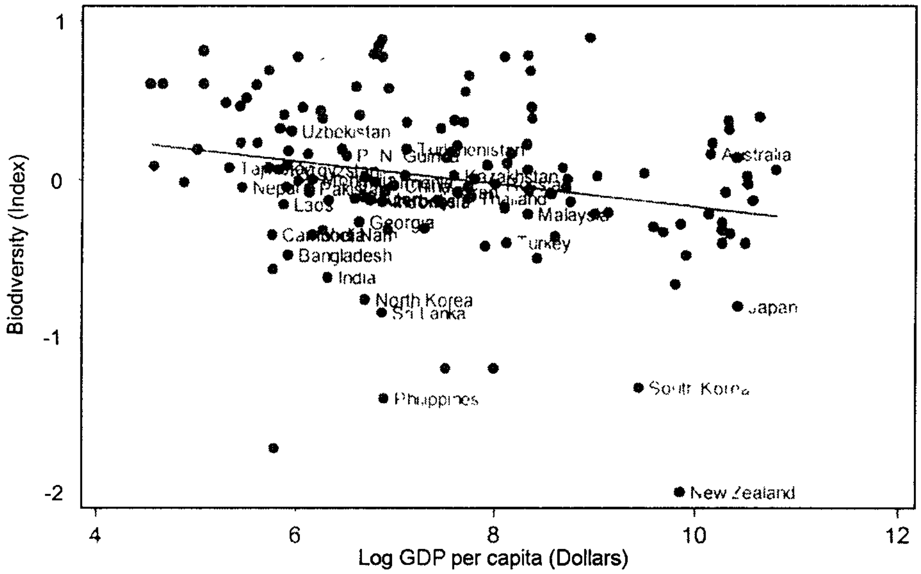

Figure 2. Effect of gross domestic product (GDP) on the index of ecosystem biodiversity. Data are labeled for some Asian countries. The index presented includes the National Biodiversity Index and the proportion of bird, mammal, and amphibian species that are considered threatened. Adapted from Lee and Koo (2005).

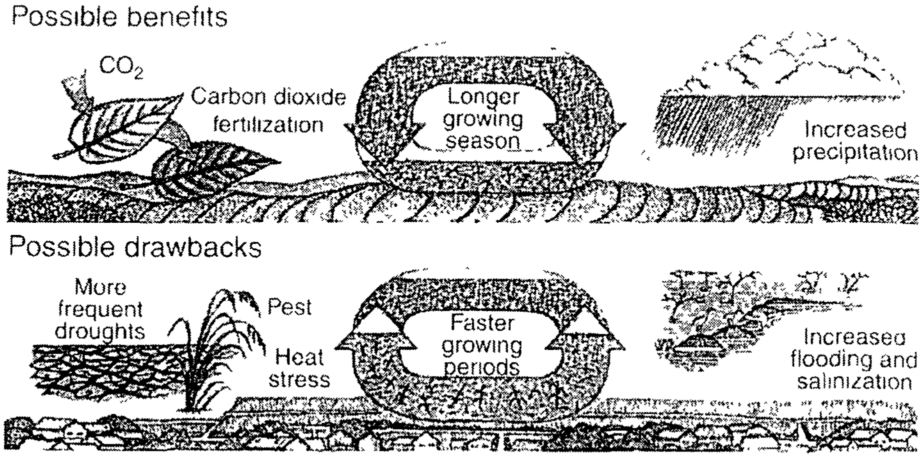

Figure 3. Possible benefits and drawbacks from climate change mediated by an increase in CO_2 and other greenhouse gases. The longer growing season and faster rate of development will allow more than one crop to be grown annually From Rosenzweig and Hillel (2005)

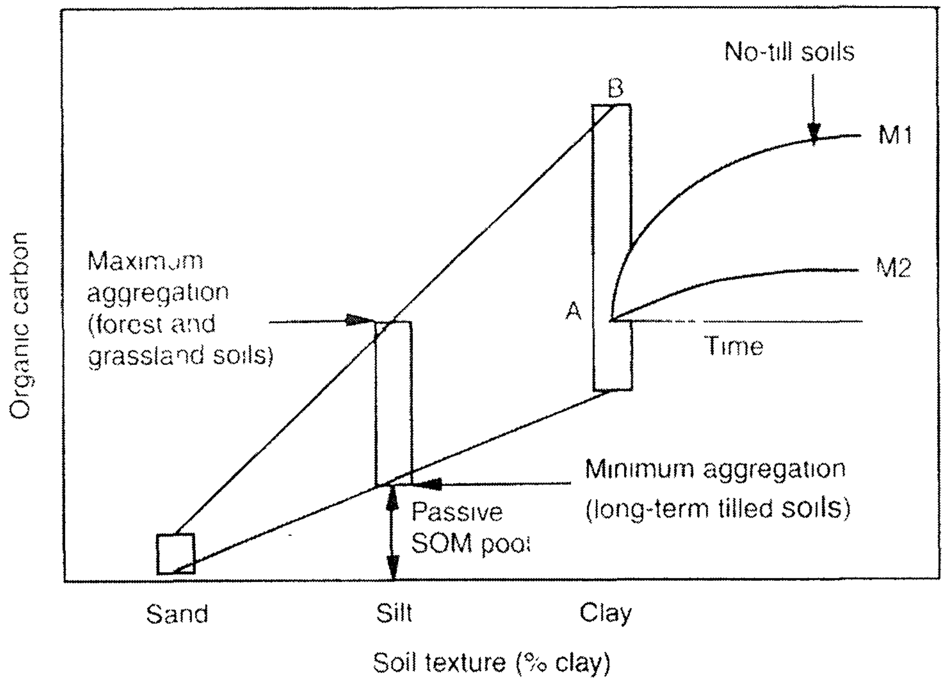

Figure 4 Effect of soil texture (actually percent clay in each class) and aggregation on carbon sequestration in soils. Inset shows the effect of tillage practices (M1=no tillage, M2=some tillage) on ability of soil to sequester organic carbon over time as soil organic matter (SOM) From Duxbury (2005).