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Policy Alternatives in Sustainable Agriculture

Modern agriculture is a very recent development when considered in terms of evolution and human history. It is best considered as an experiment in progress. Its contrasts with the agriculture that has fed humankind for most of its history are quite dramatic. The land-races of major food crops that were grown for centuries in subsistence farming agroecosystems were genetically very diverse, environmentally stable, and carried polygenic disease and pest resistance, but were very low-yielding by today's standards. Farms were small, labor-intensive and characterized by a mix of species, both plant and animal. It is generally held that the agriculture of primitive humans and even of the early decades of industrialized agriculture in the late nineteenth century were less damaging to the environment than today's agriculture has proven to be. Whether or not this is so, it is indisputable that modern agricultural practices are among the many factors that threaten the long-term stability of the earth's environment. Changes are called for in adjusting agricultural practices to serve the long-term need fora more sustainable agriculture.

Economic and environmental concerns about sustainability and agricultural practices of today come at the same time that scientific advances have occurred in our understanding and control over genetics. The consequences of this new knowledge are already beginning to work their way into agriculture. Practical application comes with the ability to isolate specific genes and transfer them between organisms that are unrelated, providing the recipient organisms with new traits.

Equally powerful are new technologies that bring new power to traditional breeding, from restriction fragment length polymorphism (RFLP) mapping to somatic embryogenesis.

Sustainable agriculture requires a system of farming based on the premise that agriculture, first and foremost, is a biological process. In practice, this means that a sustainable agriculture attempts to mimic the key characteristics of the natural ecosystem while still maximizing the yield of one or more components. To do this, it strives to build complexity into the agroecosystem, to cycle nutrients efficiently, and to maintain the primacy of the sun as the energy source driving the system. The management focus on sustainable agriculture is on long-term optimization of the system as a whole, rather than its short-term exploitation. The farmer and the researcher must select strategies that balance the need for high yields each year with the longer-term biological requirements that contribute to ecological stability. This requires a sophisticated approach that emphasizes stewardship, and also requires an understanding of the internal relationships of the agroecosystem with special emphasis on population dynamics and nutrient monitoring.

Pesticides, when used, are used with caution, and in such a way as to avoid disruption. When they are employed, they must meet the criteria of low toxicity against mammals, limited persistence in the environment, low environmental mobility, and be specific to target organisms. Both management and technological components need to be called upon to make sustainability work.

Any realistic agenda for sustainable agriculture must provide a safe, abundant, and affordable source of food and fiber for a growing population while redressing the adverse effects of past practices. The challenge is great and the outcome desired will not be achieved quickly. All technology, not just biotechnology, is a component of the answer. Consumer demands, land use planning, the skills and abilities of farm managers, the research agenda, and the incentives under which companies and public technology development will work, all need to be addressed in the policy arena.

To achieve a sustainable agriculture that embodies ecological values, the national agricultural and economic policy must encourage or mandate practices consistent with these values. Many of the longer-term benefits of sustainable agriculture, such as reduced damage to soils and to water quality will not be reflected in the short-term economic calculations of farmers, whether they are industrial farmers or small family farmers, unless policies are in place that provide the possibility of short-term economic success as well.

CENETIC MANIPULATION

Genetic manipulation is a proven technology that can be used to address whatever the future agenda is for agriculture. Plant genetic manipulation responded to, rather than dictated the changes in agricultural production imperatives in the past. As in the example of the modern, mechanically harvested tomato crop, the history of the development of processing tomatoes illustrates how modern plant breeding has tended to reduce genetic variability as a crop is genetically modified to fit a particular agricultural management system. It was done very successfully. The range of genetic variability found in primitive tomato cultivars was distilled to yield a relatively narrow breeding germ plasm base and homogeneous varieties required to fit into that production system. Genes already present within the genus of Lycopersicon have been recombined by a cross-pollination and selective breeding with those traits necessary for mechanical harvesting; single genes as well as polygenic traits. Traits that would decrease reliance on the use of chemicals were not among the many improvements that were made in modern tomato cultivars. The history of the development of modern tomato cultivars indicates that genetic manipulation is a powerful tool that can be used to modify plants to fit the requirements of management systems in agriculture.

The first genes of agricultural interest to be tested using the new technology were those conferring tolerance to herbicides. Early attention was focused on the herbicide N-phosphonomethylglycine or glyphosate, a potent inhibitor of the pathway leading to synthesis of aromatic amino acids in bacteria and in plants. Two independent research groups set out to genetically modify resistance to this herbicide in the early 1980s and both have had some degree of success.

A field trial conducted by my colleagues last year examined tomato plants treated with the herbicide at the two to three leaf stage. The transgenic plants treated at a pound per acre with the active ingredient of the herbicide showed that the plants were essentially fully resistant to the herbicide. The expected weed control advantages were seen in these trials.

Contrary to the claims of some critics of biotechnology, some herbicide tolerances may result in lower overall uses of herbicidal chemicals and lower input costs for growers. Glyphosate tolerance in tomatoes grown for processing is one case in point. Herbicides currently play a major role in processing tomato production, because weed control is crucial to achieving satisfactory yields. Competition with weeds early in the season causes yield reduction and delays harvest. At harvest, weeds can hinder mechanical harvesting.

Current practices with processing tomatoes in the California Central Valley, which is about a quarter of a million acres and accounts for 80 percent or so of the nation's processing tomato crop, include at least one pre-plant and pre-emergent application, as well as a lay-by herbicide application next to the plant row after emergence. As many as nine different chemicals have been recommended for spray and soil incorporation, and typically at least three of those are applied on each acre. With the use of a glyphosate-tolerant tomato, a post-emergent application of the herbicide would economically control weeds without harming the tomato crop. The herbicide has a very wide phytotoxicity spectrum, but low mammalian toxicity, a relatively short environmental half-life, and is systemic in the plant. This could result in significant decreases in overall herbicide usage and because glyphosate is much less toxic than many other recommended chemicals, in use with tomatoes, it would also provide advantages in the environment. Fewer applications mean lower overhead costs in time spent and chemicals applied, landless traffic through the field would avoid soil compaction.

A colleague, Dave Stalker, has examined resistance to the contact herbicide Bromoxynil, which is widely used in small grains. Small grains are naturally tolerant to the herbicide because a non-phytotoxic product is made in the plant before the compound gets to its site of action in the chloroplasts. This herbicide has an extremely short half-life in the soil. There is some evidence, in certain formulations, of problems with transdermal exposure to applicators, but its environmental profile is very favorable. This resistant trait has recently been put in cotton, where it will increase weed control efficacy and markedly decrease the cost associated with using soil-incorporated pre-plant herbicides.

One of the most straightforward applications of genetic engineering to decrease crop plants' reliance on chemical protectants, are new uses of the toxin genes from Bacillus thuringiensis, or Bt. Bacillus thuringiensis is a bacterium that produces a group of related proteins that are lethal to many moth and butterfly larvae. Other groups of insects and other life forms are unaffected by the Bt proteins. The protein is encoded on plasmids within the bacterium. It is targeted against lepidopteran larvae, although there is some evidence of Bt strains that also have activity against certain coleopteran pests during their larval stages as well. In agriculture, insects are voracious and a problem during their larval stages. Bacillus thuringiensis toxin can currently be purchased for home garden use as an emulsion that is sprayed on plants. It has been in use in one way or another for about twenty years.

The Bt gene has been isolated and characterized in a number of labs over the last several years, and there are at least three ways in which genetic modification can be used to improve the use of Bt. The first is to attempt to do better than mother nature in designing improved, more efficacious toxins, perhaps having different modes of action or different spectra of activity against insect pests. The second is to put the toxin into different bacteria with the ability to colonize different parts of the plant that might, for example, not be accessible by the spraying of Bt itself. A third approach, which is related in its objective to the second, is to engineer the crop plant itself to produce Bt toxin levels that would make the plants insect tolerant.

Several strategies have been proposed to address the possibility of the development of pest-resistant populations after exposure to plants expressing Bt toxin. Several factors may deter development of pest resistance and their management would ensure success. There are a number of Bt toxin genes, and the range of susceptible insect species is somewhat different for each.

The concurrent use of more than one engineered Bt toxin gene, each with a different toxicity profile, would be one approach to reduce the possibility of pest-resistance development. Using genetic engineering techniques, the expression of this and other toxin genes could limit the overall levels so as to control populations rather than kill insects outright, or to limit Bt to particular plant tissues during that time of development, when the protection of the plant is the most important.

It has been proposed that mixtures of transgenic and non-transgenic plants can be developed as multi-lines, thereby reducing the overall impact on the pest population but still controlling pest populations below economic threshold levels.

The concurrent use of different strategies with different modes of action, perhaps combined with integrated pest management (IPM) using of some of the more environmentally acceptable chemicals, could yield management systems to control insect pests, while reducing the reliance on the persistent and broad spectrum insecticides that are commonly used, but that also affect beneficial insects.

DISEASE RESISTANCE

Biotechnology can also contribute to sustainable agriculture in the area of disease resistance. An impressive example comes from the work of Roger Beachy and his colleagues. The coatprotein gene of the tobacco mosaic virus (TMV) was inserted into tomato plants. After inoculation with the virus, the transgenic plants are clearly tolerant to, if not resistant to, infection by this virus. This technique has been demonstrated now in at least six different plant virus families. It has been field tested in tomatoes against TMV resistance, and field trials are going on with potatoes for coat proteins of two different potato viruses.

Another strategy that has been used to show reduced damage, at least in greenhouse tests, is using the phenomenon of satellite viruses. This is an approach that could potentially be used in perennial crops where the satellite RNAs associated with some plant virus families can be used to ameliorate or reduce symptomatology.

When talking about disease resistance, the big issues with regard to chemical use are nematodes and fungi. Our knowledge base in this area is very small, and therefore it is an area that needs increased levels of research funding. Fungal resistance, especially, is a topic that requires a lot of work and once the genetic work is successful, some of the major products may be displaced.

Systemic acquired resistance has been recognized for twenty years or more and has been researched at Calgene Inc. for several years. Limited pathogen attack on the lower parts of the plant, confers a degree of resistance in the upper parts of the plant. There is a lot of work going on in a number of labs around the world to get a better understanding of the genetic basis of this resistance. It may not work adequately in the field yet, but improvements are expected.

RECOMBINANT DNA

A final example of the contribution of recombinant DNA and its associated technologies is the use of molecular markers in plant improvement and breeding programs. The DNA sequences of the genes of individuals within a species or from closely related sexually compatible species can differ in subtle ways. These differences can be revealed as variations in the pattern observed when total DNA is isolated and cut with restriction enzymes, then probed with specific probes for various genes. The technology can be useful in managing breeding programs, in identifying and manipulating single genes and chromosome regions contributing to quantitative traits, such as water use efficiency. Undoubtedly, this technology will be applied to other complex characters, such as horizontal disease resistance that facilitates the breeding of these complex traits.

These examples illustrate some, but not all of the targets and tools being used to approach goals that could be consistent with the sustainable agriculture agenda. There are encouraging signs that this agenda is gaining acceptance more and more broadly. As mentioned earlier, genetic solutions to problems now addressed by chemicals, are on the stated agenda even of the more progressive agricultural chemical players. And the press—both lay and business—is seeing the opportunity and promoting it. Any realistic agenda for sustainable agriculture must, in my view, take us forward from where we are today. It must provide a safe, abundant, and affordable source of food and fiber for a growing world population while redressing the adverse effects of past practices. That is to say, the challenge is great and the outcome desired will not be achieved quickly. We face a long and difficult future. That is why getting started today is urgent.

There is, in my view, however, a regrettable and unconstructive outlook on the future of agriculture that counsels reducing the level of technology rather than seeking to solve or avoid technological problems with different approaches. I find the recent remarks of two very different commentators on the future of science and technology in addressing humankind's needs encouraging—to restore the environment and maintain a productive agricultural base for economic growth.

In a wide ranging commentary first published in the Washington Post, Gus Spaeth of the World Resources Institute answered—"yes, it can and must"— to the question "Can technology save us from the pollution it has caused?"

> "Reconciling the economic and environmental goals societies have set for themselves will occur only if there is a transformation in technology—a shift, unprecedented in scope and

pace, to technologies, high and low, soft and hard, that facilitate economic growth while sharply reducing the pressures on the natural environment.

"In this limited sense at least, one might say that only technology can save us. That is a hard thing for a congenital Luddite like myself to say, but, in a small victory of nurture over nature, I do now believe it. I do not diminish the importance of lifestyle changes—some go hand-in-hand with technological change—and I applaud the spread of more voluntary simplicity in our wasteful society. But economic growth has its imperatives; it will occur. The key question is: with what technologies? Only the population explosion rivals this question in fundamental importance to the planetary environment.

"The good news is that many emerging technologies offer exciting opportunities and can help us move in the right direction. The bad news is that no 'hidden hand' is operating to guide technology. We must think hard about the interventions that will be needed to bring about this greening of technology.

"The two fundamental processes of technological transformation are discovery and application. The first is the realm of research and development. Science and engineering must have the financial support and the incentives to provide us with an accurate understanding of the Earth's systems and cycles and the effects of human actions. They must deliver to us a new agriculture, one redesigned to be sustainable both economically and ecologically, which stresses low inputs of commercial fertilizers, pesticides and energy. We must make the market mechanism work for us, guiding technological innovation that should not be micromanaged by government. Today, natural-resource depletion and pollution are being subsidized on a grand scale around the globe. To get the prices right, we must begin by removing subsidies and making private companies and governments 'internalize the externalities' so that prices reflect the true costs to society, including the costs of pollution. The world's emerging biotech industry provides many of the tools needed for environmentally sustainable growth."

The other commentary is from Lane Palmer, the wise editor emeritus of Farm Journal. In the concluding lines of an article entitled "Promises—and Threats— of Biotechnology", he wrote:

> "Once we have proved that a new product is safe and economic, we should adopt it. We cannot worry about which of the current producers—foreign or domestic—it will put out of business, or we risk becoming modern-day Luddites.
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> "The U.S. is blessed with an almost unlimited acreage of fertile land. Many other developed nations—especially Japan and Germany—are not. We can count on them to substitute technology for acres wherever they can. Our answer is to do likewise, whenever new technology will lower our costs. The answer is similar for competing with the developing countries. They will seek every opportunity to use their low-cost labor to a competitive advantage. Again, new technology is the most promising means of competing with them and maintaining our markets. Some will sacrifice their environment if necessary. We must pursue technology to keep both our markets and our environment.
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> "The last resort of the naysayers is to impugn the good name of science. They will try to frighten our citizenry into opposing change with the argument that we are placing too much reliance on science. They will cite anew other instances where 'science has been wrong'. People who make such accusations or implications have their own definition for the word 'science'. They think of it as a huge body of knowledge assembled over the years to which scientists turn for their answers. Well, it is not science that errs; it is our use of science, or more likely, our failure to use science, that leads us into errors.
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> "Science is not a huge body of truth. Science is a carefully constructed method or procedure by which we can discover our errors and move toward truth. Perhaps the best analogy I can offer involves another word that gives us the same kind of difficulty—'democracy'. Now the genius of our political system is not that our Constitution contains all the final laws and regulations for governing a nation. Rather, our Constitution is the best procedure ever devised for discovering and correcting our political errors and moving toward freedom and justice. The scientific method can serve the same function in maintaining and adapting

our physical and biological environment—that is if we will just use it."

And finally, in words of my own, I am convinced that the farm of the future will be more management intensive, and that management will require a wider range of tools—that is technology—to be successful in producing an abundant safe food supply. Genetic manipulation is the proven environmentally safe way to address production challenges—both economical and environmental. I am personally very concerned about the rural infrastructure of this country. I come from and live in a rural area. But the increasingly sophisticated management, the increasing capital intensity, and the increasing competitive nature of agriculture viewed globally clearly dictate difficulties for unsophisticated managers and undercapitalized farms. These are serious problems. Let us not make it worse by regulating science and technology at its source. This is a clumsy tool to accomplish an important social, ethical, and political agenda.