World Food System Challenges and Opportunities: GMOs, Biodiversity, and Lessons from America's Heartland

By

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Abstract

Most people accept that world food production must grow at a steady pace in order to meet the twin challenges of population growth and economic development. Nearly all productive land is already growing food and water resources accessible to agriculture are, if anything, shrinking. Intensification of production emerges as the most promising option. Different paths to intensification, with vastly different consequences, are now competing for public and private sector research and development dollars.

The rising prominence of the private sector in setting R+D priorities and shaping farming systems is shifting emphasis from problem-solving and societal needs to preserving and creating high profit margins on proprietary technologies. Biotechnology and the integration of the seed and pesticide industries are expanding private sector options for exploiting intellectual property. Some significant on-farm economic, R+D, and ecological consequences are already apparent and deserve more attention, especially within the farm community.

Two biotechnologies now used on thousands of Illinois farms, herbicide tolerant and *Bt*-transgenic plant varieties, will be assessed to provide real world context for discussion of the consequences of current efforts to intensify agricultural production. Over time changes in technology, profitability, and consumer preferences may change the clientele, and the private organizations and institutions willing and able to exercise leadership in directing the flow of public and private investment capital within the U.S. food system.

A. Sustainable Agriculture within the Global Food System

Sustainable agricultural and food systems must –

- Provide a reasonable rate of return to farmers to sustain farm families, agricultural infrastructure, and rural communities;

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- Assure a reasonable rate of return to public and private providers of farm inputs, information, services and technologies;
- Meet society's food needs;
- Preserve and regenerate soil, water and biological resources upon which production depends, and avoid adverse impacts on the environment;
- Increase productivity and yields at least in step with growth in demand; and
- Adhere to social norms and expectations in terms of fairness and equity, regulations, food safety, and ethical treatment of workers, animals and other creatures sharing agricultural landscapes.

Agricultural systems and technology become unsustainable for a variety of reasons, but loss of profitability is almost always the most immediate. When an agricultural system or technology becomes unsustainable, agriculture evolves through changes in ownership or management, or by an infusion of technology, capital or new enterprises. It has done so for decades, and in some countries, for centuries. All too often in the U.S. in recent decades, the only thing that really changes is that energetic and ambitious managers willing to accept lower returns per bushel find the capital to expand, maintaining their income only by expanding their acreage base.

One of the tragic dimensions of recent changes in U.S. agriculture is that forces beyond the control of producers can drive even the best operators, with generations of hard-won equity in a farm, off the land. Hundreds if not thousands of Illinois hog producers may not make it through the winter. Their loss will be the state's loss, and another undeserved opportunity for vertically integrated corporate hog farms and processors to expand their market share and drive up profit margins when supply falls and prices recover, as they surely will.

On conventional and sustainable farms alike since the 1980s, the slide toward unsustainability has typically been triggered by excessive optimism and misguided investments when prices are high, or changes in market conditions or policy that trigger significant price swings. In some regions the ravages of bad weather and flooding, or a decision to close a processing plant or livestock auction, have taken a toll. But now another generic pitfall is emerging -- poor judgement in the selection and use of agricultural technologies. For two reasons this new source of instability may rise in prominence in the years ahead.

First, increasingly serious economics surprises and setbacks. Many emerging biotechnologies are more expensive to bring to market. The costs of creating and protecting intellectual property are already high and bound to rise, as are the steps required in overcoming regulatory hurdles. Many new technologies cost more per acre at the grower level and require more management, information, and skill to use to best advantage. When they fail, they tend do so more profoundly than past technologies, imposing greater losses on growers. And some biotechnologies will constrain marketing options – the last thing farmers need as input suppliers, the grain trade, and processors compete to gain a larger share of the consumer food dollar, often at the expense of farm-level profit margins.

Second, a growing array of sources of genetic, ecological and biological instability. Both the nature of many new technologies and how they are being marketed are setting the ecological foundation for trouble. The pesticide treadmill is giving way to the technology package treadmill. But now, instead of just destabilizing the interactions of pests, beneficials and crops, technology packages are throwing crop genetics and physiology into the mix, as well as the potential for a new generation of highly mobile ecological problems.

Instances of erratic performance will no doubt continue to plague some transgenic varieties. Problems arising in areas where transgenics are used will occasionally move onto surrounding farms where the technology may not have been used. Sorting out who caused what, the magnitude of losses and who must pay will be costly and contentious. These costs will be factored into per acre expenditures in one way or another. Who will bear the economic burden of these costs and risks remains unclear, but recent developments suggest most companies will be aggressive, arguing that problems arose because of bad weather or management shortcomings. Hence, farmers are likely to bear the burden of proving harm and causality, a burden not always easy to sustain near the frontiers of agricultural biotechnology, as some farmers are learning.

Meeting Global Food Needs

According to the FAO over two billion people suffer from deficiencies in micronutrients and close to a billion people remain undernourished, yet farmers worldwide struggle with low prices caused by over-production. What gives?

Dietary deficiencies and hunger persist because of poverty, politics, and the design of food systems, not because of a lack of production. In the developing world natural resource degradation continues to worsen as more and more people try to survive on less and less land. The number of people living in harm's way -- flood plains, beneath or on steep hillsides, in arid regions -- is growing, exposing countries and ecosystems to new sorts of natural calamity.

Gus Speth, then the outgoing Administrator of United Nations Development Program (UNDP), gave a compelling "swan song" speech in October 1998 before the National Press Club in Washington, D.C. Since the early 1970s I have known Gus and admired his energy and optimism. He accomplished much during his seven years running UNDP. I was interested in how he would recap his experiences and "lessons learned" with UNDP and so listened intently to the speech, which was, in a word, depressing.

The statistics Gus rattled off described the scale and scope of deprivation and hopelessness around the world, and the slippage in society's capacity to make a meaningful difference in the lives of so many people. He pointed to many promising development efforts and praised the toughness and spirit of the poor, but chided the American public and Congress for turning its back on the rest of the world in a time of clearly growing need. He also warned of the consequences if recent trends are not soon reversed. These include rising costs of humanitarian and peacekeeping efforts, political unrest, global environmental decay, terrorism, and a loss of moral authority.

Speth noted that for some 3 billion people, strong and deeply set forces will continue to degrade quality of life and erode the chances for sustainable development, despite greater wisdom and commitment among those working to promote development. Our discussion tonight of how the global food system, technology, and the agricultural sciences can better help meet the needs of the world's poor must be grounded in this sobering context. The first key step in solving a problem is understanding its source.

We need to acknowledge that growing more corn and soybeans in Illinois is not going to do much in overcoming hunger among the world's poor. Those calling for more production in America as the only way to feed the world do so sincerely but fail to properly diagnose the roots of hunger. No wonder some proposed solutions miss the mark.

Different Visions of and Paths to "Intensification"

Last month in North Carolina I debated Dr. Dennis Avery, one of the speakers invited to this podium during your symposium two years ago. At the 1998 Southeast Vegetable Expo, we focused on technology, the environment, food safety and global food system challenges. We agreed that demand for food will continue rising and that intensification of production must bear most of the brunt in meeting demand growth. But we described very different notions of what "intensification" means, and where and how it can best be achieved.

Dennis favors more specialization and bigger factory farms. He favors more biotechnology and chemical use in farming, and he believes our farming systems are basically on the right course. He does see problems on the horizon in two areas – trade and regulation. On the trade front he wants more and on regulation, less. Unshackle the productive power of high-yield American agriculture and soon, according to Dennis, there will be a Big Mac on every table and more room for wildlife, or so the story goes.

I think of food system "intensification" as the process whereby more calories and nutrients are delivered to people per acre in production. If America, or the developed world, truly wishes to overcome world hunger we could accomplish a lot by changing our diets, especially if we also were willing to increase direct and indirect support for development and economic opportunity. Nutrition experts point out that a bushel of legumes or grains consumed directly by people in bread, pasta or other foods, instead of by livestock, would support about eight times the human population. I wonder what percent of Illinois's annual crop harvest humans directly consume – well less than 5 percent I bet.

Contrary to Avery's assertion, we do not need to become a nation of vegans to make a difference. If one-quarter of Illinois soybeans were consumed directly by people instead of by poultry and hogs, think of the changes in the supply and price of soybean-based protein products. But such changes in our food system are unimaginable to most people, and hence not worth thinking about.

American agriculture has never been comfortable with nor rewarded those inclined to think outside the box, whether in academia or industry. Most scientific and commercial breakthroughs have come from specialization and reductionism. As a result we suffer from a sort of “big picture” myopia.

The day may come when limited thinking will begin to undermine the inclination to innovate that runs so strong in American agriculture. There are many paths to intensification in agriculture yet only a few receive meaningful institutional and financial support. Different paths are likely to lead to different outcomes. No one path will work everywhere nor meet all needs. For sound ecological and economic reasons, the nation will benefit from multiple agricultural intensification choices and the knowledge and ability to choose wisely among them. Finding how to do so is one of the land grant system’s most daunting contemporary challenges.

I have studied the linkages between technology, policy, economics and the environment during most of my career. It is clear to me that the role of traditional farm policy is greatly diminished, that the private sector now largely controls the selection of technologies that are reaching farmers, and that the discipline of the open market is being undermined by industry consolidation and vertical integration. Most farmers seem to accept, if not welcome these changes. Down the road if views within the farm community change, will farmers still have ways to compel the system to shift gears?

How will the University of Illinois, a great land grant university, engage the farm community, consumers, environmentalists and the private sector in distinguishing between sustainable and unsustainable paths to intensification? And second, how will the university help the U.S. and global food systems steer away from one by consciously choosing the other?

B. Technology and Sustainable Agriculture

> “When I started farming 23 years ago we didn’t use the most powerful chemicals on the market, we didn’t flood the land with fertilizer, and we still made a good living. I felt that I was in control of my operation. Our gross revenue to expense ratio was 3 to 1. Today, we are on the cutting edge, using GMOs, changing crop varieties almost yearly, using chemicals as if we farmed in Europe, and our revenue to expense ratio has dropped to 1.25 to 1, on a good year, just enough to pay the grocery bill.”

Lloyd Fear
Red River Valley, Manitoba
@g Worldwide Correspondent

Lloyd Fear's January 13, 1999[2] commentary cuts to the core of grower concerns about technology. Is the nature of technology changing? For decades new technology has nearly always been welcomed on the farm as laborsaving, problem solving and income generating. In the last decade technology has become a mixed bag. It too often creates unforeseen problems and seems designed principally to accommodate specialization and bigness.

Some farmers sense that they have climbed on a treadmill and that the harder they run, the faster they must go to just stay even. Lloyd Fear notes that the more technology helps farmers increase production, the softer prices become, especially as governments pull out of the supply management business in deference to the need of the grain trade for maximum volumes and unconstrained price movement. Among the implications of changes underway in farming, Lloyd Fear believes that the "farmer is in an industry where his fortunes and future are being dictated by others with little thought to the impact of their actions."

So tonight let's do a "little thinking" about technology, what is driving it, and implications for farmers, consumers, and the country. I will make five major points –

- Biotechnology is fundamentally changing the nature of technological change, and in due course may reconfigure the economic, cultural and ecological genome of the farm community.

- Past agricultural science and technology revolutions have been largely public sector financed and driven, and for the most part, responsive to farmer-needs. The biotechnology revolution is private sector and corporate profit-driven.

- For at least another generation the real prices of most farm commodities are likely to remain flat, or at best rise modestly. Input industry and processing sector growth, debt-service and profits will have to come from somewhere. Expect further pressure on farm profits.

- Biotechnology is driving change at all levels of agriculture and at an unprecedented rate. The law of unintended consequences is likely to have many field days. The pace of change will bring upon rural America and our food system selection pressures unlike any in the past.

- If current trends continue, farmers and society may be able to do relatively little in shaping these changes, the genie is out of the bottle.

[2] Commentary appears on the Successful Farming website "@g World Wide" at (http://www.agworldwide.com).

Evaluating the Impacts of Biotechnology

Methods to project the various impacts of emerging biotechnologies are needed for many purposes. Which emerging biotechnologies deserve public support? When is it worth taking a gamble with a commercial application in the face of uncertain health or ecological risks? Which biotechnologies are likely to improve farm profit margins without imposing offsetting indirect costs?

Assessments of biotechnology should evolve from the principles and concepts of ecology and evolutionary biology rather than mechanistic, input-output, dose-response models. Conventional approaches to risk assessment pay little heed to adaptive forces and evolutionary biology. This needs to change since synergism between plant health, stress, genetic adaptation, and changes in biodiversity will trigger many unintended consequences.

It is also important to question who will benefit from various applications of biotechnology. Clearly the pesticide and seed industries are bullish on biotechnology, a reflection of expectations that they will benefit from the opportunity to offer farmers genetically engineered seeds and production inputs. Many academic scientists working on molecular genetics are also clearly eager to apply their skills in creating new plants.

In fact, all the public and private institutions of agriculture, both the USDA and EPA, the farm press and the private sector have, for all intents and purposes, embraced biotechnology as the wave of the future. For better or worse the row crop farmers of the Midwest are now riding that wave.

The Roots of Technological Change

Each generation of farmers has to deal with a set of yield, production and profit constraints. These include emerging and well-established pests, and maintaining and hopefully building soil quality. Ideally, the focus if R+D is on the generation of new technologies to overcome these problems.

Illinois farming systems have grown more productive per acre through integration, over many years, of a series of new technologies. Farmers will become more productive and prosperous in the years ahead if they are able to wisely choose among expanding technological options and are not overwhelmed by anti-competitive forces in the marketplace.

Farmers make a series of decisions each year that determine what will be grown, where and how. These decisions and how skillfully they are carried out join the weather and market prices in determining income from farm operations. They include –

- Farming Enterprise Design -- (1) whether to specialize in crops, livestock, or manage a mixed system; and (2) mix of crops and crop rotations, hence defining the farm's mix of marketable commodities.

- Selection of Genetics – complex tradeoffs arise in choosing between high yield potential, resistance to pests and stress, and output traits. The emergence of GMOs requires farmers to weigh new factors and tradeoffs in choosing varieties.

- Agronomic Systems – choices span tillage and planting systems, fertilization methods, weed and other pest management practices, soil and water conservation practices, and harvest timing and methods. Some decisions – adoption of no-till – forego certain options and heighten reliance on certain technologies and inputs.

Some decisions have long-run consequences – whether to diversity into livestock, or specialize in grain production, the purchase of no-till planting equipment or a second combine. Other decisions must be made quickly as a season unfolds and may, or may not improve profits in a given year. Examples include whether a second pass is needed with a cultivator or how much nitrogen to apply.

Technological innovation – the kind farmers welcome and society has been willing to support -- occurs when a farmer is able to make these interconnected decisions in a way which, on average over several years, increases yields more so than costs, or reduces costs more so than yields, while either improving or leaving unchanged the environmental and resource base impacts of farming operations.

In the last two decades there has been relatively little change in many aspects of farming system design in Illinois. Corn and soybeans dominate the landscape and have for years. Most farms specialize in crop or livestock production and the trend toward large-scale operations seems, if anything, to be gaining momentum. The effort to find a viable third crop for corn-soybean rotations is no one's priority; far too little R+D funding is committed, over the long haul, to the development of new crops and more diverse rotations and farm enterprises, a task only public sector investment can tackle.

Accordingly, innovation in farm system design appears not likely to be a major source of change, despite great potential to improve the performance of Midwestern farms. A third crop might largely solve the problem with several corn insects. Bringing cattle and alfalfa back into the Midwest could help improve the performance of farming systems in many ways, as reported in the important November 1998 paper by Dr. Laurie Drinkwater and colleagues in *Nature* magazine (Drinkwater, et al., 1998). The paper shows that crop rotations including legumes and cover crops combined with agronomic practices favoring biodiversity can markedly improve the efficiency of nitrogen and carbon cycles, thereby helping to meet U.S. obligations in the Kyoto Protocols. Such systems can, moreover, sustain high yield levels and lessen nitrogen losses to groundwater by over 50 percent compared to conventional systems. But with nitrogen priced so low and no rewards for lessening losses to the environment, sustainable farming systems remain at a competitive disadvantage. A provocative "News and Views" piece by University of Minnesota ecologist David Tilman accompanies the Drinkwater et al. paper and begins by saying –

> "It is not clear which are greater – the successes of modern high-intensity agriculture, or its shortcomings." (Tilman, 1998).

After reviewing why conventional agricultural systems have become so "leaky" and describing the technological foundations for the Green Revolution, Tilman goes on to say –

> "…a greener revolution is needed – a revolution that incorporates accumulated knowledge of ecological processes and feedbacks, disease dynamics, soil processes and microbial ecology."

I agree, but do not see such a greener revolution on the horizon because those now driving technological change in agriculture have little to do with ecology and limited interest in probing the environmental dimensions of farming system performance, beyond overcoming regulatory hurdles. Most academics raising ecological questions within colleges of agriculture are not given the institutional support needed to make sustained progress. Some pursue these issues at considerable risk of professional consequences.

What Drives Technological Change in Agriculture?

During the 20th century most major technological changes have emerged from research carried out within the land grant university system and USDA in response to natural resource, farming system, genetic or biological constraints. The private sector always played a vital supporting role in making new technologies commercially viable and delivering them to farmers. But until recently the needs of farmers and society as a whole have largely driven the public R+D agenda, and hence have shaped the nature of most emerging technologies.

The polarity has clearly shifted since the early 1980s. Agricultural R+D priorities and investments are now responding to the opportunity to increase historical rates of return on private sector investment. Private companies have always and will always work to make a profit, as farmers also work to earn profits. Profits keep the system vibrant and investment capital flowing into agriculture. But new issues are arising because technology and industrial restructuring are fundamentally shifting the "terms of trade," and hence the relative economic performance and power across sectors in the food system. In the past, seed, farm machinery and pesticide manufacturers depended directly on a healthy farm sector to assure that their customers would return to the marketplace every year, and agribusiness supported policies that helped keep farmers in business and eager to increase productivity. But now, across many fronts, input suppliers, processors and integrators are getting more directly involved in the management and control of farms, and blurring the line between farm and agribusiness income, profit, decision-making, and risks.

Public sector investment in the agricultural sciences and public institutions has lagged far behind need and even further behind private sector willingness to invest in new biotechnologies. Shrinking public research budgets have forced land grants to carry out work of interest to the private sector. In many public institutions, scientists are now actively encouraged to pursue partnerships, private grant funding, and royalty income by targeting research toward patentable discoveries of likely interest to the private sector.

In addition, a growing share of the research effort in the land grant system is problem or crisis driven and short-term, quick-fix oriented, as opposed to focusing on discovering the genetic or biological basis for inherently more productive and profitable farming systems over the long-run. The near-term problems demanding attention often arise from the combination of chemical technologies and homogenous, large-scale production systems. As we train students and conduct research to better address the biological and resource-base miscues of current production systems, we fail to pursue science that might open up wholly new avenues to improved farming systems and technologies that are inherently more productive, profitable and sustainable.

In the world of biotechnology, the land grant system is now struggling with a dual role. The system has been and remains a major developer and promoter of biotechnology. But second, it is also the only public institution with the expertise and ability to project and understand the myriad potential adverse ecological, biological and economic consequences of biotechnology. How will land grant universities reconcile these dual roles? How well it does so will no doubt influence the degree to which the system remains largely public or becomes increasingly private.

C. Herbicide Tolerant Plant Varieties

Roundup Ready soybeans, other herbicide-tolerant varieties and *Bt*-transgenics clearly comprise the first wave of the biotechnology revolution. After just two years of widespread commercial use, over one-third of U.S. soybean acreage will be planted to Roundup Ready varieties in crop season 1999 – a remarkable and unprecedented change in weed management system technology.

Given how fast Roundup Ready beans have gained marketshare, one might infer that farmers have recently been plagued by serious problems managing weeds in soybeans. But actually in the 1980s and the 1990s the range of soybean weed management systems and technologies has exploded.

Ridge tillage, no-till, banding, improved cultivators, newly registered post-emergent herbicides and new planting systems gave farmers many new options. The chemical toolbox is overflowing – more than two-dozen new active ingredients have been registered in several families of chemistry. The first herbicide-tolerant soybeans were planted on a commercial scale in 1996. The problem for farmers seeking herbicide-based solutions has become the complexity of choices and compatibility with soil types, varieties, and farming systems, along with containing cash costs.

Why the rush to develop and market RR soybeans? My guess is that in the mid-1980s Monsanto business managers recognized in biotechnology a way to extend high profit margins from Roundup sales beyond the end of patent protection in the year 2000. They knew the price of Roundup would come down as other manufacturers entered the market, a process that has already begun. But by developing and marketing Roundup Ready plant varieties, Monsanto could, in effect, transfer high profits from sale of the chemical to "seed plus technology packages" accompanied by a technology fee.

Indeed, the announcement a few weeks ago that Monsanto is lowering the price of Roundup but increasing the Roundup Ready technology fee is consistent with such an overall plan.

Evaluating Weed Management Systems

Three criteria should be applied in judging weed management systems and technology[3] –

- Long-term Effectiveness -- the scope and difficulty of weed management challenges over time.
  + The goal should be lower weed seed density and fewer outbreaks over time.

- Robustness -- the ability to respond to unexpected conditions and shifts in weed pressure.
  + The goal is more and better tools to deal with whatever problems emerge; in short, greater system resiliency.

- Weed Management System Costs.
  + The goal is lower weed management costs per bushel produced and as a percent of net crop income.

Applying these criteria in evaluating Roundup Ready beans is a reasonably straightforward exercise. When first introduced, Monsanto promised that Roundup Ready soybeans would greatly simplify weed management. Just plant, spray once and relax for the rest of the season. If the technology had lived up to this early billing, it would have satisfied the first two criteria. But in the field, nature's proclivity to adapt has made things much more complicated and the future uncertain for users of this technology.

Two weed scientists in Iowa, Dr. Bob Hartzler and Dr. Doug Buhler, have studied one reason -- weed emergence patterns. They have found, not surprisingly, that different

[3] I thank Dr. Matt Liebman, Iowa State University, for suggesting these criteria.

weeds emerge at different points during the season (see this and other excellent weed management resources on the Iowa State University Extension weed management site at <http://www.weeds.iastate.edu/mgmt/qtr98-4/emergencepatterns.htm>; and Buhler, et al., 1997). Use of an over-the-top non-residual systemic herbicide like Roundup will generally work well in managing the weeds that have recently germinated, but will miss weeds that germinate either earlier or later. Growers planting RR soybeans have, as a result, three choices –

- Apply early to avoid early-season yield losses from fast growing grasses, possibly suffering yield losses from late season weeds;

- Delay applications until most weeds have germinated, risking loss of yield to early weeds; or,

- Apply Roundup twice or more, and/or a residual herbicide at planting or when Roundup is applied.

Most are choosing the third option, since there is a very low tolerance among growers for either weeds in fields or yield losses.

The emergence of tolerant and/or resistant weeds is a second mechanism likely to undermine the long-term effectiveness of Roundup Ready soybean systems. Indeed it is already happening. Researchers have documented glyphosate resistance in a rye grass species. Tolerant populations of waterhemp, sometimes called pigweed, are emerging across the Corn Belt. This particular species of weed is highlighted in the 1998 edition of the Weed Control Manual as the most worrisome "Up and Coming Weed" both nationwide and in the North Central region (Meister, 1998). Reasons why include the emergence of resistance to triazine and ALS herbicides and its ability to withstand Roundup applications (for an up to date overview by Iowa weed scientist Bob Hartzler, see <http://www.weeds.iastate.edu/mgmt/qtr98-4/roundupfuture.htm>).

Because of resistance and weed shifts, Roundup Ready soybeans clearly flunk the first criterion since weed management problems are already getting worse on farms relying on Roundup Ready technology. Much evidence, ecological theory, and practical pest management experience suggests such problems will worsen on farms that continue to rely mostly on Roundup Ready varieties. The combination of Roundup Ready beans and Roundup Ready corn in a rotation will further torque the ecology of weed populations and will eventually bring on the loss of commercial viability of this technology.

The second criterion involves the robustness of weed management systems – the capacity of farmers to respond to unexpected circumstances, whether brought on by weather, the evolution of a new weed biotype, or a change in tillage systems. On this criterion, Roundup Ready systems get a passing grade because the systems do not force farmers to forego most other weed management options. Farmers can still choose to apply other herbicides. Early season cultivation remains an option, as does diversifying rotations and use of cover crops.

Cost is the final criterion and the one most likely to limit adoption. Coverage in the farm press makes it clear that Roundup Ready systems offer farmers modest potential to reduce costs per bushel IF everything works well – i.e., there is no yield drag and one application of Roundup is sufficient in managing weeds. When a second application of Roundup is added, or another herbicide, the economic advantage largely disappears.

In parts of the Midwest the costs of Roundup Ready soybean systems have taken off. At a recent field day the Adair County Soybean Association released its projection of the costs of a "total" Roundup Ready system[4] in 1999 --

- Burndown with Prowl, 2,4,-D and Roundup Ultra, $19.40 per acre.

- June spray with 2 pints/acre Roundup Ultra and adjuvants, $15.31.

- July respray with 1 pint Roundup Ultra, $9.06.

- Seed cost per acre (includes $5.00 technology fee), $25.00.

Even after the recent price discounts announced by Monsanto, the full Roundup Ready system will cost an amazing $68.77 per acre in 1999, about 50 percent more than the cost of seed plus weed management systems in the Midwest in recent years, as shown in Table 1.

Many farmers have been willing to accept such increases in costs in return for the perceived advantages in managing weeds. But with crop prices heading down, several new herbicides gaining registration, and growing evidence of a yield drag, farmers will begin to look elsewhere for weed management options. Monsanto is already taking steps to preserve its marketshare by lowering the cost of technology, and further price reductions can be expected in the future. How this will play out for farmers and the seed-pesticide industry remains to be scene.

Table 1 shows clearly that soybean chemical costs – the vast majority for herbicides -- jumped dramatically between 1988 and 1990 in the Corn Belt region. Over the last decade, soybean seed plus chemical costs have risen $20.07 per acre, or 80 percent. Total costs rose just 22 percent over the same 10-year period.

The impact of the higher per acre cost of Roundup Ready and other herbicide-tolerant soybeans begins to show up in the 1997 data; note the 25 percent increase in seed prices from 1996 to 1997 – I believe, the largest annual jump in history. Increases in herbicide costs account for about one-third, and seeds two-thirds of the total increase in seed plus chemical expenditures.

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[4] Contact Dean Stormer, Adair County Soybean Association for details at 515-337-5436.

Table 1. Soybeans -- Seed and Chemical Production Expenses in Corn Belt States, 1975-1997	1975	1980	1985	1988	1990	1992	1994	1996	1997
Production Expenditures									
Seed	$8.09	$8.09	$13.82	$12.60	$13.52	$13.30	$14.65	$16.11	$20.12
Chemicals	8.68	12.24	12.90	12.78	21.51	24.59	25.63	26.16	28.33
Seed+Chemicals	16.77	20.33	26.72	25.38	35.03	37.89	40.28	42.27	48.45
Other	16.23	29.87	28.85	28.09	32.27	33.15	33.75	36.27	30.41
Total variable	33.00	50.20	55.57	53.47	67.30	71.04	74.03	78.54	78.86
Total Cash Expenses	$68.50	$104.32	$101.06	$105.03	$111.14	$115.67	$123.04	$131.58	$128.15
Yield (bushels)	31.52	33.19	38.01	27.46	37.59	39.35	43.96	38.43	45.75
Harvest Period Price	$4.91	$7.62	$4.83	$7.54	$5.87	$5.24	$5.34	$6.91	$6.51
Gross Value of Production	$154.76	$252.91	$183.59	$207.05	$220.65	$206.19	$234.75	$265.55	$297.83
Total Costs	$125.28	$205.16	$182.37	$196.46	$200.79	$210.27	$226.35	$241.19	$249.58
Net Income	$29.48	$47.75	$1.22	$10.59	$19.86	($4.08)	$8.40	$24.36	$48.25
Chemicals as Percent of Total Variable Costs	26.3%	24.4%	23.2%	23.9%	32.0%	34.6%	34.6%	33.3%	35.9%
Chemicals as Percent of Total Costs	6.9%	6.0%	7.1%	6.5%	10.7%	11.7%	11.3%	10.8%	11.4%
Chemical Expenditures per Bushel	$0.28	$0.37	$0.34	$0.47	$0.57	$0.62	$0.58	$0.68	$0.62
Seed and Chemicals as Percent of Variable Costs	50.8%	40.5%	48.1%	47.5%	52.1%	53.3%	54.4%	53.8%	61.4%
Seed and Chemicals as Percent of Total Costs	13.4%	9.9%	14.7%	12.9%	17.4%	18.0%	17.8%	17.5%	19.4%
Seed and Chemicals per Bushel	$0.53	$0.61	$0.70	$0.92	$0.93	$0.96	$0.92	$1.10	105.9%
Seed Expenditures as a Percent of Gross Income	5.2%	3.2%	7.5%	6.1%	6.1%	6.5%	6.2%	6.1%	6.8%
Chemical Expenditures as a Percent of Gross Income	5.6%	4.8%	7.0%	6.2%	9.7%	11.9%	10.9%	9.9%	9.5%
Seed plus Chemical Expenditures as a Percent of Gross Income	10.8%	8.0%	14.6%	12.3%	15.9%	18.4%	17.2%	15.9%	16.3%

Source: Returns and cost of production data series from the National Agricultural Statistics Service, USDA. Calculations by Benbrook Consulting Services.

As a percent of variable costs, herbicide expenditures have risen from 24 percent to 36 percent over the past decade. Seed plus chemical costs rose from 47 percent to 61 percent over the same period.

Since 1975, seed plus chemical costs have doubled per bushel harvested – rising from $0.53 per bushel harvested to $1.06. The share of the a farmer’s income per acre devoted to seed and chemical expenditures has risen over 50 percent since 1975 -- from 10.8 percent in 1975 to 16.3 percent in 1997.

In the next few years, seed plus herbicide costs are bound to rise further. Everyone expects that a higher percentage of soybean acres will be planted to GMO varieties and that most farmers doing so will need to apply two or three applications of two or more herbicides. Weed shifts, resistance and aggressive marketing programs will work together in unpredictable ways driving further change in weed management systems.

Table 2 presents the same data on corn seed and weed management costs. Just as the case with soybeans, seed costs started to increase at a rate well above historical trends between 1995 and 1997, corresponding to the increases in R+D expenditures and the first releases of herbicide-tolerant varieties and *Bt*-transgenics. Over the last two decades, seed and chemical costs as a percent of production costs have risen marginally, but costs have almost doubled per bushel. Costs as a percent of gross income have grown about 50 percent since 1975.

For a variety of reasons, the costs of seed corn plus weed management are also likely to rise sharply in the next few years. Consider the implications of one just-announced corn program, sure to serve as a model for future soybean programs. AgrEvo and Novartis are offering a "guaranteed" corn weed control for farmers planting AgrEvo's Liberty-Link corn who also buy and apply Novartis' Dual Magnum II (S-metalochlor + benoxacor) or Bicep II (S-metalochlor + benoxacor + atrazine) herbicide.

That's up to four active ingredients in managing weeds after planting a variety that supposedly makes weed control easier. Offering guarantees as a marketing ploy has been strongly criticized in the past for establishing unreasonable expectations among farmers, ratcheting up cash expenditures, and encouraging excessive herbicide use, which can trigger resistance and other problems. Despite some progress in recent years in constraining the scope and expense of herbicide guarantee programs, some companies envious of Monsanto's successes with Roundup Ready varieties are bound to offer farmers a range of incentives to switch to their "technology package." Monsanto also continues to carry out an aggressive marketing campaign that earned the company two of the four "Herbicide Advertising Hall of Shame" awards given out by Iowa State University Extension weed management experts (http://www.weeds.iastate.edu/weednews/adhallofshame.htm>).

Higher weed management costs, weed shifts and resistance are not the only problem that may evolve from widespread planting of herbicide-tolerant crops. Research shows that changes in soil microbial communities caused by Roundup and other low-dose herbicides can both increase the vulnerability of beans to Pythium and reduce the uptake of phosphorous (Forlani et al., 1995). And research continues into the cause of this year's serious die-back problems in Missouri.

Table 2. Corn -- Seed and Chemical Production Expenses in Corn Belt States, 1975-1997									
	1975	**1980**	**1985**	**1988**	**1990**	**1992**	**1994**	**1996**	**1997**
Production Expenditures									
Seed	$9.51	$14.66	$18.84	$19.21	$20.70	$21.96	$22.19	$27.38	$29.60
Chemicals	12.13	15.13	20.29	22.59	24.88	23.91	25.52	28.66	28.07
Seed+Chemicals	21.64	29.79	39.13	41.80	45.58	45.87	47.71	56.04	57.67
Other	59.39	89.47	96.19	81.41	89.29	85.54	89.69	102.07	102.15
Total Variable	81.03	119.26	135.32	123.21	134.87	131.41	137.40	158.11	159.82
Total Cash Expenses	$131.00	$186.81	$199.09	$168.89	$184.30	$173.37	$184.89	$212.20	$208.89
Yield (bushels)	91.80	98.50	121.96	77.19	122.71	135.77	145.46	132.12	134.92
Harvest Period Price	$2.49	$3.04	$2.09	$2.56	$2.16	$2.01	$2.02	$2.78	$2.50
Gross Value of Production	$228.58	$299.44	$254.90	$197.61	$265.05	$272.90	$293.83	$370.85	$341.26
Total Costs	$189.11	$268.41	$281.32	$261.33	$299.89	$296.26	$313.35	$362.39	$357.67
Net Income	$39.47	$31.03	($26.42)	($63.72)	($34.84)	($23.36)	($19.52)	$8.46	($16.41)
Chemicals as Percent of Total Variable Costs	15.0%	12.7%	15.0%	18.3%	18.4%	18.2%	18.6%	18.1%	17.6%
Chemical Expenditures per Bushel	$0.13	$0.15	$0.17	$0.29	$0.20	$0.18	$0.18	$0.22	$0.21
Percent of Total Variable Costs	11.7%	12.3%	13.9%	15.6%	15.3%	16.7%	16.1%	17.3%	18.5%
Seed Expenditures per Bushel	$0.10	$0.15	$0.15	$0.25	$0.17	$0.16	$0.15	$0.21	$0.22
Seed and Chemicals as Percent of Variable Costs	26.7%	25.0%	28.9%	33.9%	33.8%	34.9%	34.7%	35.4%	36.1%
Seed and Chemicals as Percent of Total Costs	11.4%	11.1%	13.9%	16.0%	15.2%	15.5%	15.2%	15.5%	16.1%
Seed and Chemicals per Bushel	$0.24	$0.30	$0.32	$0.54	$0.37	$0.34	$0.33	$0.42	$0.43
Seed and Chemical Expenditures as Percent of Gross Income	9.5%	9.9%	15.4%	21.2%	17.2%	16.8%	16.2%	15.1%	16.9%
Source: Returns and cost of production data series from the National Agricultural Statistics Service, USDA. Calculations by Benbrook Consulting Services.									

Lessons Learned

There is clearly much left to learn about how herbicide-tolerant varieties will change agricultural systems, pest pressure, crop physiology, and soil health. Midwestern farmers are "learning by doing."

There are strong linkages forged by immutable laws of nature between weed management systems, reliance on and the costs of technology, and the impacts of weed management on yields, the environment and profitability. Three are inescapable.

- First, count on nature to find ways to evolve around any weed management system that rests upon one or a few closely related weed management practices or technologies.

- Second, the key to keeping weed management systems effective and costs down is to diversify the systems over time and space.

- Third, relying on genetic changes to deal with management problems can pose unexpected drains on system productivity.

Last, it now seems clear that the major driving force behind efforts to develop herbicide tolerant varieties was the desire to hold onto or create higher profit margins from the sale of proprietary herbicides. While an understandable strategy for the companies pursuing it, the larger question is whether it will deliver benefits to farmers and society as a whole.

D. Evolving Insect Pest Management Challenges

New insect and weed management problems in the corn-soybean rotation arise through one of several mechanisms from selection pressures inherent in common row-crop agricultural systems. Each new challenge reflects the success of adaptive forces that will, in the years ahead, work to undermine the effectiveness of emerging technologies.

Cost-effective use of pest management technology, regardless of its genesis, depends upon the degree to which it helps diversify and complicate the challenges faced by pest species within farm fields. Many technologies once heralded as major innovations have failed because of agriculture's tendency to rely on technology to simplify and homogenize systems rather than to diversify them.

To correct the underlying problem, farmers need to look at their farms and fields through the lens of evolutionary biology. Farmers will either learn to manage selection pressure or will continue to be managed by it.

Turning selection pressure into a positive force will pose many new challenges for land grant scientists and farmer-networks. A new generation of diagnostic tools are needed. The chemical cues governing soil microbial interactions with roots and pathogens will need to be isolated, along with threshold levels that seem associated with disease suppressive or conducive soils. Others will then need to work on the discovery of genetic, biopesticide and cultural practices that can help trigger resistance mechanisms sooner and more effectively.

Evolutionary Biology in Action

The most important recent change in insect pressure in the Midwest has arisen from the behavioral adaptation of the Western corn rootworm (WCR) to the long-effective corn-soybean rotation. This simple, moneymaking rotation has been one of the great success stories in the world of cultural pest management practices, reducing corn insecticide use by half, lessening water quality problems and reducing grower cash costs (for a solid overview, see Gray et al., 1998). On continuous corn in the 1990s, 90 percent or more of corn acres are treated with a soil insecticide while less than 15 percent of rotated corn has been treated.

The success of the corn-soybean rotation in limiting WCR losses set the stage for trouble, as farmers and scientists were lulled into thinking that little more was needed to be done in dealing with this pest.

Economically significant Western corn rootworm damage in first-year corn following soybeans was first documented in isolated fields in the mid-1980s. Over the next decade the pattern of infestation was uneven and episodic. Some seasons, like the wet crop year in 1998, do not favor WCRs and hence mask changes in pest behavior and damage potential. But over time it has become clear that in many parts of the Midwest, the Western corn rootworm had developed what scientists call behavioral resistance to a management-based control strategy, in this case crop rotation.

Western corn rootworm adaptation came on gradually. Its roots were subtle, hard to isolate from other dynamic factors affecting pest complexes. Both farmers and entomologists did not realize the significance of their observations of WCR damage in first year corn until the mid-1990s. In 1993 some farms in east-central Illinois suffered serious WCR larval injury in first year corn root systems. In both 1995 and 1997, damage was “severe and prevalent” in east-central Illinois (Department of Crop Sciences, 1998). Field research quickly ruled out extended diapause and repellency from use of synthetic pyrethroid insecticides as possible causes, leading to the realization that the rotation itself had broken down as an effective control strategy.

In retrospective, Dr. Mike Gray, a University of Illinois entomologist, suspects that the narrowness of the control strategy used against the rootworm explains, at least in part, its ability to adapt around it. If other control measures had helped spread out the control burden -- lessening the selection pressure, in effect managing resistance -- farmers might not be facing this new problem today.

There is an important lesson embedded in the events leading to WCR adaptation:

The more narrow the pest management system, the greater the selection pressure and hence the odds of adaptation to it through one or more mechanisms.

This lesson leads to a key first principle that farmers and scientists should heed in shaping pest management systems and fitting biotechnologies within them. The best way to preserve an effective and affordable pest management technology is to use it within a diversified system that spreads the annual control burden across differing mixes of cultural, genetic, chemical and biological tools and tactics.

Collective experience gained in managing (and mismanaging) hundreds of pests across thousands of cropping systems leads to some general hypothesis. While the number of tactics needed for stable control will vary across crops, pests and climatic conditions, four general hypotheses can be stated in simple terms as –

1. A pest management system that relies predominantly on one tactic is inherently vulnerable. The more generations of a pest in a season, and the longer the pest is subject to selection pressure from a single tactic, the greater the odds the pest will adapt around the tactic and adapt quickly.

2. Systems that spread control in a given crop cycle over two substantially different tactics remain vulnerable, but to a lesser degree. Two unrelated tactics used together in a given year will be more effective, in most circumstances, than two tactics used in isolation, one the first crop cycle, another during the second. Two different sets of two unrelated tactics in successive crop cycles will further tip the odds in favor of farmers and sustainability, and may be essential in the case of insects with multiple generations per season (i.e., most damaging species).

3. Systems with three or more distinct but significant control tactics are likely to be sustainable in the hands of good managers who act upon the first signs of trouble by further diversifying and complicating the tactics mixed within integrated control systems. By "significant," I mean a control tactic that in some years can be effective alone and which rarely fails when combined with another major tactic.

4. In all pest management systems, there is a minimal degree of redundancy in control tactics below which the odds of adaptation steadily improve toward certainty, as well as a degree of redundancy above which adaptation becomes unlikely and easily managed if it begins to appear.

Testing these hypotheses and establishing the thresholds noted in the fourth hypothesis should become an important focus of land grant pest management professionals. Imagine how helpful such information would have been in 1986 when problems first arose with the Western corn rootworm in first-year corn. If Illinois entomologists had known then that insects like the WCR are likely to adapt around a cultural control tactic when it is the sole tactic used, they might have realized more quickly what was happening in the field and how to avoid it becoming a stable, state-wide problem.

In 1999 Illinois entomologists are struggling, among other things, to deal with the prospect of resistance emerging to *Bt*-transgenic corn. The same knowledge about the linkages between the diversity of pest management systems and their resiliency would be very helpful in designing hopefully effective resistance management plans.

WCR and Biotech Drive Change in Corn Insect Pest Management Systems

Now that a new strain of the WCR has emerged, farmers and university IPM specialists have no choice but to manage it with the tools currently available. The response of Illinois agriculture to this new pest is an intriguing test of the system, conventional wisdom and openness to new technologies. The test is even more significant given the big push behind *Bt*-transgenics to manage European corn borers, as well as the rush to market seed genetically engineered to resist WCR.

While WCR levels were way down in 1998 because of the cool, wet spring, scientists warn that they will be back when conditions turn more favorable. By 1998 the university had developed new scouting techniques and thresholds to determine whether WCR levels in a soybean field were high enough to threaten the next year's corn crop. Working with consultants, coops and grower groups, university specialists quickly disseminated information on pheromone trap-based scouting techniques for use in soybean fields, along with economic thresholds for WCR adults caught in traps placed in soybean fields. Apparently the word got around. I have been told that Illinois corn growers almost single-handedly exhausted the world's supply of Pherocon AM yellow sticky traps last summer.

Table 3. Insecticide Use on Corn in Illinois in 1991 Ranked by Toxicity Units per Acre Treated (11.2 Million Acres Planted)

Active Ingredient	Percent Acres Treated	Acres Treated	Pounds Applied	Pounds per Acre Treated	Chronic Toxicity Units	Toxicity Units per Acre Treated
terbufos	7	784,000	839,000	1.07	1,678,000,000	2,140
chlorpyrifos	11	1,232,000	1,427,000	1.16	475,661,910	386
fonofos	5	560,000	662,000	1.18	33,100,000	59
tefluthrin	3	336,000	47,000	0.14	940,000	2.8
permethrin	3	336,000	63,000	0.19	667,800	2.0
Totals		3,248,000	3,038,000		2,188,369,710	
OPs as Percent of Total		**79.3%**	**96.4%**		**99.9%**	

Tables 3, 4, 5 show corn insecticide use in Illinois in 1991, 1994, and 1997. Organophosphate insecticides accounted for 70, 80 and 60 percent of the acres treated in 1991, 1994 and 1997. This family of chemistry accounted for over 96 percent of the pounds applied, and virtually all the toxicity units – a measure of the mammalian toxicity of pesticides applied (Benbrook et al., 1996). Chlorpyrifos was the most widely used product, accounting for about one-third of acres treated. While rising in recent years and a major cause of concern over environmental impacts, corn insecticide use is a fraction of what it once was. Use peaked in the mid-1970s at over 30 million pounds per year – more than seven-times today's level.

Use was stable in 1995 and 1996 but began to rise in 1997 as a result of losses incurred in 1996 in east central Illinois (see Table 5). Acres treated and pounds applied rose over 15 percent, with the biggest jump in chlorpryifos use. Illinois entomologists report substantially greater use in 1998. While some have raised concerns over the impact of the Food Quality Protection Act on the availability of OP insecticides for corn production, such fears are premature since OP residues hardly ever show up in corn-based products from field use. (Post-harvest uses of insecticides in stored corn is more likely to lead to residues than field use). If corn insecticide use rises to the point that water resources are contaminated, the FQPA will no doubt become an issue since exposures through drinking water must be taken into account in determining acceptable levels of exposure. (For a review of the FQPA and the status of implementation efforts, see the Consumers Union FQPA website, http://www.ecologic-ipm.com).

Table 4. Insecticide Use on Corn in Illinois in 1994 Ranked by Toxicity Units per Acre Treated (11.6 million Acres Planted)

Active Ingredient	Percent Acres Treated	Acres Treated	Pounds Applied	Pounds per Acre Treated	Chronic Toxicity Units	Toxicity Units per Acre Treated
terbufos	7	812,000	971,000	1.20	1,942,000,000	2,392
chlorpyrifos	11	1,276,000	1,318,000	1.03	439,328,940	344
phorate	1	116,000	177,000	1.53	35,400,000	305
fonofos	3	348,000	322,000	0.93	16,100,000	46
tefluthrin	4	464,000	56,000	0.12	1,120,000	2
permethrin	5	580,000	58,000	0.10	614,800	1
Totals		3,596,000	2,902,000		2,434,563,740	
OPs as % of Total		**71.0%**	**96.1%**		**99.9%**	

Table 5. Insecticide Use on Corn in Illinois in 1997 Ranked by Toxicity Units per Acre Treated (11.2 Million Acres Planted)

Active Ingredient	Percent Acres Treated	Acres Treated	Pounds Applied	Pounds per Acre Treated	Chronic Toxicity Load	Tox Units per Acre Treated
terbufos	4	448,000	1,117,000	2.49	2,234,000,000	4,987
chlorpyrifos	16	1,792,000	2,105,000	1.17	701,659,650	392
tebupirimfos	2	224,000	22,000	0.10	11,000,000	49
tefluthrin	4	448,000	57,000	0.13	1,140,000	2.5
permethrin	9	1,008,000	105,000	0.10	1,113,000	1.1
cyfluthrin	2	224,000	1,000	0.00	4,000	0.02
Totals		4,144,000	3,407,000		2,948,916,650	
OPs as % of Total		**59.5%**	**95.2%**		**99.9%**	

The FQPA may have a more direct impact on soybean sector. The USDA has just released the results of its 1997 Pesticide Data Program residue monitoring. For the first time, USDA carried out a special survey of residues in soybeans. Surprisingly, over 80 percent of the 159 samples tested had residues of chlorpryifos and 53 percent contained malathion. These residues almost surely are the result of post-harvest use, but will get EPA's attention because of the potential space within the OP risk cup that would need to be reserved to cover these residues. It is also likely that some buyers in Asia will monitor U.S. soybeans more closely for OP residues, especially when the beans are destined for direct human consumption.

Managing Corn Insects with Transgenics

The other big changes in corn insect pest management are occurring as a result of the introduction of *Bt*-transgenic varieties that overcome attack by second generation European corn borer. When first introduced, Monsanto and other companies marketing *Bt*-corn varieties acknowledged the possibility of resistance but argued that the high-dose expression of the *Bt* toxin, coupled with a 5 percent refugia planted to traditional varieties, would preclude the emergence of resistance.

New science and field experience have confirmed the lack of a solid science base supporting key assumptions that underlie the *Bt*-transgenic resistance management plans (RMPs) accompanying transgenic crops released to date:

- *Bt* endotoxin expression under field conditions is not uniform across fields or within plants, providing some insects with a chance to avoid plant tissues delivering a lethal dose. Plus *Bt* expression tapers off as the season progresses and any source of stress or plant injury can lead to differential toxin levels and some non-lethal foliage, which insects seem able to find (a form of "behavioral resistance" first recognized by Dr. Marvin Harris of Texas A+M University).

- Two studies published in 1997 show that resistance to *Bt* is not as rare as previously suspected. Dr. Gould and colleagues reported that the frequency of the major *Bt* resistance gene in a field population of *Heliothis virescens* was about 0.0015 (Gould et al., 1997). Dr. Tabashnik and colleagues showed that the frequency of a multiple-toxin resistance allele in susceptible populations of the diamondback moth was an astonishing 0.120, evidence that resistance gene carries very little, if any, "genetic load" (Tabashnik et al., 1997a).

- Resistance will emerge quickly to multiple strains of *Bt* endotoxin since the resistance gene appears to be a dominant trait (Tabashnik et al., 1997a,b). Tabasnik and colleagues found that diamondback moths "share a genetic locus at which a recessive mutation associated with reduced toxin binding confers extremely high resistance to four *Bt* toxins" (Tabashnik et al, 1997b). Furthermore, data from a Florida population of diamondback moth demonstrated similar results (Wang et al., 1997). At the 1997 Entomological Society meetings in Nashville, TN, Dr. Tabashnik stated that he expected that findings similar to his would emerge in ongoing work with several other lepidopteran species.

- Work by Dr. Angelika Hilbeck of the Swiss Federal Research Station for Agroecology and Agriculture has shown that *Bt*-corn can adversely impact populations of key beneficial insects. In a number of trials, Dr. Hilbeck reported 60 to 65 percent mortality among lacewing larvae that fed on lepidopteran larvae reared on *Bt* corn. (A report on this work was presented at the 1998 Joint Meeting of the

Entomological Society of American and the American Phytopathological Society in Las Vegas, Nevada).

Managing Resistance to *Bt*

Conventional wisdom has changed rapidly in the world of *Bt* resistance management. Just a few years ago the companies introducing *Bt*-transgenic seeds downplayed the prospect of resistance and submitted to the EPA reams of documentation and modeling that supported the efficacy of the high-dose plus refugia strategy.

Most university experts had little to contribute as EPA reviewed Monsanto's *Bt*-corn resistance management plan, since they had not been granted access to any seed or detailed information on the technology until the year commercial introduction began. The few that had been granted access to seed or had helped develop the technology were constrained by secrecy agreements and/or conflicts of interest.

Development, testing, and wide scale introduction of a major new technology in near-total secrecy is a new development that undermines some of the corrective "feedback" loops that have helped make our system of technology development reasonably reliable. Hearing no science-based objections from the public, EPA assumed that no one had uncovered any problems and that hence, problems were not likely to emerge. The veil of secrecy now surrounding agricultural technology development efforts raises an important public policy issue. EPA regulations and rule-makings depend heavily on informed and disinterested public comment to assure thoroughness and balance, since EPA cannot maintain "critical mass" in all areas of commerce it is responsible for regulating. When scientists are unwilling to share data, are constrained in what they can report, and/or have no opportunity to study new technology, public institutions and regulators have to fly blind for a period of time.

Beginning in about 1993 a small number of public interest groups started to voice strong concerns about *Bt*-transgenics. In 1996 the Consumer Union (CU) book *Pest Management at the Crossroads* set forth the arguments why EPA should withdraw the conditional registrations granted to *Bt*-transgenics and called upon the agency to place a moratorium on any further approvals until proven, science-based and enforceable resistance management plans were in place. Since release of the book, CU has submitted several technical assessments on the risks associated with Bt-transgenics (copies can be reviewed in the genetic engineering section of the PMAC website, at http://www.pmac.net/ge.htm).

As new *Bt*-varieties reached farmers, a growing number of academic scientists started to assess the likelihood of resistance. Evidence mounted that the concerns were real and that decisive steps were needed, and soon, to preserve the effectiveness of *Bt* against a wide range of key Lepidopteran insects. Just in recent weeks, Monsanto and other companies have agreed to the need for at least a 25 percent refugia in the Corn Belt, and a 50 percent refugia requirement in the south, where *Bt*-corn and cotton are often grown in close proximity. While details remain sketchy on these plans, this unexpected decision by Monsanto is evidence that they feel there is, in fact, a cause for preventive action.

Other companies are being even more direct. An incentive program has just been announced by Novartis. Growers that buy the appropriate share of *Bt*- and non-*Bt* seeds will qualify for a cash incentive. More such offers are bound to follow.

E. The Role of Genetics and Breeding in Enhancing Productivity

The 1979 Pioneer Hi-Bred Annual Report explains that a hybrid must go through a 5-year staged release program to gain a commercial variety number. “Most of the 19,000 experimental hybrids will fall short of performance standards and many will be discontinued after the first year of testing. Perhaps only 5 to 8 will reach and survive the fifth year of testing, and be released for production and sale.”

On its webpage today, under “Research Highlights” in corn/maize, Pioneer now reports that:

> “Every year, Pioneer maize researchers around the world evaluate about 130,000 new experimental hybrids. These hybrids enter a four to five-generation testing cycle…The top 10 percent – 13,000 – (make it to the next round of development and testing). And finally, from about 130,000 original candidates, only about 15 to 20 hybrids ‘graduate’ to commercial status.”

The odds of a hybrid reaching the farmer have accordingly dropped from about one in 3,000 in 1979 to one in 7,500 today. As the science and art of genomics develops, it is likely the number of hybrids screened will increase and the odds of success will continue to decline, although the scope of genetic assessment will surely expand and in time the efficiency of breeding efforts will improve.

Since 1970 Pioneer Hi-Bred’s investment in corn breeding has risen steadily from less than $10 million per year supporting some 150 scientists to about $150 million in the 1990s, supporting 550 scientist years (Cassman and Duvick, 1999). Accordingly it is clear that it is taking more and more effort to sustain the 1.5-bushel average yield gain per acre that breeders have historically delivered.

How have breeders helped farmers increase yields? Dr. Don Duvick, former research director of Pioneer Hi-Bred, has participated in a study of the performance of 36 widely grown and successful hybrids released between 1934 and 1991, including some open pollinated varieties. The research team found that the genetic yield potential of maize hybrids has increased 74 kg/ha/year, a little over 1 bushel per acre, according to a large number of trials carried out in 1991-1994. According to Duvick, “Maximum yield potential per plant has neither increased nor decreased during the past 70 years, as measured on non-stressed plants grown at very low densities (1 plant/m^2).” (Duvick, 1997).

Cassman and Duvick cite other evidence to support the conclusion that the yield potential of hybrids under optimal conditions has not risen for decades. For example, the top irrigated corn yields achieved by contest winners in Nebraska plateaued at just over 300 bushels per acre decades ago and have changed little since.

Accordingly, the ability to perform well at high plant populations per acre accounts for most of the corn yield increases since the 1940s. Over time higher yielding varieties were improved in their ability to resist root lodging, premature death and stalk rot, second generation European corn borer, and other stresses associated with high density planting (Duvick, 1997). Several other traits have not changed over time – plant height, grain moisture at harvest, resistance to first generation European corn borer, and grain percent oil. Duvick also points out that breeders have pushed yields up about as much as possible through the manipulation of a number of traits including tassel size, grain protein percent, and upright leaf habit. He sees potential for future yield increases in heightening resistance to European corn borers, heat and drought tolerance, and ability to perform well in even denser plantings.

Pioneer Maize Breeding Priorities

So where is Pioneer focusing now in its efforts to deliver greater value to its customers? The goals of its corn-breeding program are outlined on the company's excellent website[5]:

- "Develop hybrids with greater than five percent yield performance advantage.
- Reduce crop losses, grower input costs and risk through genetically engineered insect, disease and herbicide resistance into maize.
- Create more value and new uses for maize…
- Use available, appropriate technologies that result in improved products for customers."

One of the best indicators of seed company research and breeding priorities is to review the featured characteristics of newly released varieties. Pioneer's website features seven new *Bt*-transgenic corn hybrids in 1998. They range in CRM values and resistance to gray leaf spot and brittle stalk. A visit to the "Products, Performance, & Info" section of Pioneer's website provides perspective how these newly released varieties augment the overall Pioneer corn seed product line. Any corn grower in northern Illinois with access to the Internet can easily find detailed performance characteristics on both existing and new varieties recommended by Pioneer for the North Illinois region.

Table 6 summarizes the 23 varieties listed under "Illinois North Corn Products." Of these varieties, 10 include the YieldGuard *Bt*-transgenic gene and three are herbicide tolerant. The table notes 20 value-added attributes across the 23 varieties, 13 of which are pest management related, or 65 percent. The focus on pest management related traits

[5] Goals and highlights of maize research can be found at http://www.pioneer.com/usa/research/corn_maize_research.htm.

is likely to persist for some time. The page announces that imidazolinone-*Bt* transgenic varieties are in final testing in 1999 and will be available in the year 2000.

The North Illinois grower using a corn-soybean rotation also will find seven new soybean varieties featured on the Pioneer website – six of them Roundup Ready. Thirteen of a total 20 soybean varieties offered are herbicide tolerant – 11 to glyphosate and two to sulfonylurea herbicides. One variety, 92B83, is resistant to both.

Table 6. Variety Characteristics of the 23 Pioneer Seed Corn Products Offered Farmers in North Illinois, 1999

		Pest Management Related			Speciality Traits		
	CRM	*Bt* Gene	Liberty Link	Imi-Resistant	High Oil	Waxy	White Food Corn
Corn Products							
35N05	105	X		X			
35A19	104						
3563	103						
34T14	110	X	X				
34R07	109	X					
34K78	108	X					
34K77	107						
34G82	107	X					
34F80	110	X					
34E 79	110						
3489	108						
33Y09	113	X					
33G27	113	X					
33G26	112						
33A14	113	X					
32J49	114		X				
Specialty Corn							
34R54	108					X	
34P93	111						X
34H98	108					X	
33A63	115					X	
32H39	114						X
High Oil							
34K82	108	X			X		
34K79	108				X		
Totals		10	2	1	2	3	2

Based on recent Pioneer varietal introductions and those from other seed companies, it is clear that introducing the *Bt* gene and herbicide tolerance has become an important breeding objective. It is also clear that *Bt* and herbicide tolerant genes have now been introduced into such a significant portion of the corn and soybean germplasm that many farmers will have little choice but to continuing planting these varieties, at least for the next few years. What is not clear, but warrants further attention, are the consequences in terms of the overall focus and direction of breeding efforts.

For a variety of reasons including high cost, emergence of resistance to *Bt*, weed shifts, and/or problems exporting to Europe, some farmers may seek out varieties not including genetically engineered traits. The capacity of the seed industry to respond to such demand is another key question. Seed companies introducing GMO varieties also maintain non-GMO breeding lines and varieties, in part to hedge their bets and to have a supply of seed to sell to Europe and other markets not wanting GMO-seed. If and as demand grows for non-GMO seed, the industry should be able to quickly respond to it.

And a key pragmatic question -- What portion of future year yield increases and productivity gains will fail to materialize because of the heavy focus in the 1990s on introducing the *Bt* gene and herbicide tolerance?

Seed and Pesticide Industry Consolidation: Impacts on Research and Grower Profit Margins

For decades the private sector has dominated breeding activity in crops like maize that benefit from crossbreeding. In the case of corn and most hybrids, achieving higher yields reliably has been the dominant goal driving private sector plant breeding.

Table 7. Grower Returns to Corn Seed Expenditures: Corn Belt States, 1975-1997

	1975-1979	1980-1984	1985-1989	1990-1994	1995-1997	1975-1997
Average Yield in Period (bushels)	99.96	104.80	114.11	121.85	127.75	114.00
Average Annual Yield Increase in Period	1.09	0.97	1.86	1.55	1.97	1.45
Average Harvest Price in Period	$2.25	$2.63	$1.94	$2.15	$2.67	2.32
Value of Average Annual Increase in Grower Income Attributed to Genetic Improvement (60 percent)	$1.47	$1.53	$2.17	$2.00	$3.15	2.01
Average Annual Increase in Seed Expenditures	$0.60	$1.20	$0.50	$0.30	$2.47	0.87
Grower Return to $1.00 Increase in Seed Expenditures	$2.46	$1.27	$4.33	$6.66	$1.28	2.30

Source: Calculations by Benbrook Consulting Services. Annual data on corn production, yield and expenditures from the costs of production data series compiled by the Economic Research Service, USDA.

Traditionally, the public sector was largely responsible for improvement of self-pollinating crops, where the focus has often been resistance to diseases and insects. With passage of plant variety protection laws in the 1970s, commercial breeding activity has increased. According to Duvick, the increase in private funding for breeding has triggered declines in public sector support "almost in inverse ratio to the increase in private activity" (Duvick, 1998).

In the 1989 report "Investing in Research," the NRC's Board on Agriculture estimated total seed industry research expenditures in 1986 at $170 million, about 7 percent of total private sector research in the food and agricultural industries. In contrast, the pesticide industry invested an estimated $695 million, or 28 percent of total private R+D.

As noted before, the integration of the seed and pesticide industries has been driven predominantly by the opportunity to use genetic engineering to preserve profit margins for proprietary pest management technology. Many questions have been raised about the long-term consequences of these fundamental changes in industry structure for farmers, the environment and the country as a whole.

There is some evidence already of one impact of changes in corporate structure -- seed plus pesticide technology packages appear to be eroding the traditionally high rate of return farmers have enjoyed from investments in improved hybrids.

For decades the rule of thumb has been that the seed industry has delivered $3.00 of added income for every additional dollar spent on hybrid seed. Corn cost of production, yield, and price data comes close to supporting this general rule of thumb over the period 1975 through crop season 1997. As shown in Table 7, the average grower return to an additional dollar spent on hybrid corn seed was $2.30. From 1985 through 1994 the return was well above $3.00 for each additional dollar spent.

Table 7 and Table 8, which presents the same data on soybeans, include a critical assumption. In estimating the financial return to breeding, it is necessary to determine what portion of yield increases are attributed to breeding in contrast to more intensive input use, better equipment and more timely, accurate planting, and other management factors. Based on the literature, I used 60 percent in these tables, a figure on the low-end of the range of available estimates. Those that believe breeding has been the dominant force between yield growth argue for a figure closer to 80 percent. If one were to accept 80 percent as the portion of yield enhancement attributed to breeding, the return to an additional $1.00 spent on corn seed over the last 23 years would be $3.05.

Over the last 23 years, average Corn Belt yields rose from an average of about 95 bushels in the 1970-1975 period to 128 bushels per acre, about 1.5 bushels per year. Using average market prices in each five-year period, I calculated the average annual return to increased expenditures on seed by corn farmers, based on USDA data covering the Corn Belt region. In the period 1975-1979, yields rose on average 1.09 bushels per year, earning for farmers $2.45 more in income. I assumed that genetic enhancement accounted for 60 percent of the yield growth, and hence multiplied the increase in income of $2.45 by 0.6, producing the estimated return to the grower of $1.47 per acre. During this same period, farmers spent an average of $0.60 more on seed each year. Thus, for each additional $1.00 spent farmers received $2.46 in added income.

The return to expenditures on corn seed rose sharply in the 1985-1995 period, reaching over $6.50 for every dollar spent in the period 1990-1994. But in 1995, the average annual increase in seed costs jumped some eight-fold to $2.47, reducing the return to $1.28 for each additional dollar spent on seed.

A much different picture emerges in a review of grower expenditures on soybean seed. Over the past 23 years, farmers have clearly not benefited nearly as greatly from additional money spent on soybean seed. For each additional $1.00 spent, farmers have received about $0.35 in return. Yields have risen just marginally since the mid-1970s while expenditures on seed about doubled between 1975 and 1996, rising from $8.14 per acre to $16.87. In 1997, the price of soybean seed took off, rising about 25 percent to $20.12, largely as a result of the widespread introduction of new herbicide-tolerant varieties. I am sure costs continued upward in 1998 and that average expenditures on the order of $25.00 per acre are now common (about the cost of RR soybeans).

It remains to be seen how much more farmers will be willing to pay for the perceived weed management advantages associated with planting herbicide tolerant varieties. The industry has recently announced almost across the board reductions in the price of herbicides and seed-pesticide “technology packages,” so apparently most companies are not eager to test the ceiling in farmer willingness to pay under the present market conditions.

Why the big jump in both corn and soybean seed prices beginning in the mid-1990s?

First, the integration of the seed and pesticide industries has been costly. Competition for seed company assets across the historically larger and more profitable pesticide industry has driven up the value of seed companies by at least 50 percent in a matter of a few years. Inflated stocks have inflated appetites for capital and income. Accordingly, industry integration has required a greater share of grower-income to service debt and deliver an acceptable rate of return to shareholders. In addition, in the last few years seed companies have increased the portion of income devoted to research from the historic industry average of 5 percent to 8 percent of sales to 12 percent to 15 percent (NRC, 1990; Duvick, 1998). Since the seed industry used to operate at much lower profit margins than the pesticide industry, financing this increase in R+D expenditures has placed upward pressure on prices on seed and/or technology fees.

Table 8. Grower Returns to Soybean Seed Expenditures: Illinois, 1975-1997

	1975-1979	1980-1984	1985-1989	1990-1994	1995-1997	1997	1975-1997
Average Yield in Period (bushels)	44.20	39.40	42.40	45.80	45.00	45.75	43.40
Average Annual Yield Increase in Period*	1.10	(0.96)	0.60	0.68	(0.27)	0.02	0.03
Average Illinois Harvest Price in Period	$6.21	$6.76	$5.97	$5.92	$6.97	$6.51	$6.37
Average Seed Expenditures per Year**	$8.14	$9.55	$13.18	$13.75	$16.87	$20.12	$12.30
Average Increase in Annual Seed Expenditures		$0.28	$0.73	$0.11	$0.62	$4.01	$0.38
Value of Average Annual Increase in Grower Income Attributed to Genetic Improvement (60 percent)	$4.10	($3.89)	$2.15	$2.42	($1.12)	$0.07	$0.13
Grower Return to $1.00 Increase in Seed Expenditures		($13.81)	$2.96	$21.19	($1.79)	$0.02	$0.35

* Average increase in the 1975-1979 period is based on an average yield in 1972-1974 of 38.7 bushels, i.e. (44.2-38.7)/5.

** Data on seed expenditures are from the U.S. Department of Agriculture, and reflect Corn Belt States.

Source: Data on Illinois soybean yields and seasonal prices are from the FBFM website, and are based on Illinois Agricultural Statistics Service data. To access the FBFM site, go to http://agec182.agecon.uiuc.edu/results.htm. Calculations by Benbrook Consulting Services. Annual data on soybean production, yield and expenditures from the costs of production data series compiled by the Economic Research Service, USDA.

Second, since the mid-1990s a growing portion of the focus of breeders has been devoted to the introduction of either herbicide tolerant or *Bt* genes into elite germplasm and top-selling hybrids. This has increased the costs of developing, patenting, obtaining the rights to use, and defending intellectual property.

For each seed company and across the industry as a whole, there are no publicly available data to settle the issue of whether the work required to introduce herbicide tolerance and *Bt* genes was, in effect, added on top of ongoing efforts to increase yields and productivity, or whether there were tradeoffs. To the extent the attention of breeders shifted, there will likely be lesser annual yield gains for the foreseeable future, at least compared to what they otherwise might have been.

Why? Because plant genetic enhancement is a deliberate process requiring careful empirical study of thousands of crosses in tens of thousands experimental plots and fields trials. The rush to market genetically engineered seeds may have compelled some seed companies to cut corners and market varieties before breeders had adequate time to assure all necessary traits were fully expressed, such as resistance to common pathogens. With breeders focusing on traits related to pest management and herbicide compatibility, they were not able to pursue other crosses with greater potential to increase yield.

Third, pesticide industry profit expectations and margins are different from the seed industry. In order to win and hold customers, the hybrid seed industry has tried to assure that the farmer earns, on average, $3.00 for every extra dollar spent on seed. In order to keep yields rising and grower returns high, the seed industry has had to operate on about 12 percent to 15 percent margins, and has invested about half of its profits back into research and field breeding activities (Duvick, personal communication).   For example, in 1987, Pioneer Hi-Bred spent $49.9 million on research, or 5.9 percent of gross sales and over 50 percent of operating profits (NRC, 1989). That year, DeKalb devoted a remarkable 86 percent of profits to research (NRC, 1989).

The pesticide industry, on the other hand, invests more heavily in research and incurs much higher regulatory compliance costs.   Manufacturers often earn 30 percent to 50 percent profit margins on sales of proprietary chemicals (for a general overview of the herbicide industry, see U.S. Department of Commerce, 1985).   The herbicide Roundup (glyphosate) is a notable example. This one product has accounted for over half Monsanto's total profits in some years, and has generated income on the order of $300 million plus on sales over $1 billion.

Net income from herbicides, mostly alachlor (Lasso) and glyphosate (Roundup), accounted for 59 percent to 85 percent of Monsanto's net income in 1981-1983, but represented only 18 to 21 percent of total corporate sales (Department of Commerce, 1985). Even after supporting R+D expenditures falling between 12 to 16 percent of sales, net returns of 10 to 15 percent of sales are common in the pesticide industry (Department of Commerce, 1985; current data on corporate profits from the Fortune 500 website). This data suggest operating profits on the order of 20 to 30 percent – at least double those common in the seed industry during the 1970s through the mid-1990s. Clearly, if pesticide manufacturers priced their new products the way Pioneer prices seed, the economics of row-crop agriculture would be more favorable to farmers.

Yet the profit expectations of the pesticide industry appear poised to dominate the marketing and pricing decisions covering the sale of seed and pesticides. If this trend continues, input suppliers will wind up with a greater share of the profits associated with the production of a bushel of corn or soybeans.

Plant Breeding Research Focus

Merging the seed and pesticide industries also will change the criteria used in allocating research dollars.   In most instances, companies will have the opportunity to choose between developing new genetic or chemical solutions to emerging, or old pest problems. In many instances, they will offer farmers both resistant varieties and pesticides. In some cases applications of proprietary chemicals will be required to trigger or otherwise take advantage of novel genetic traits introduced into GMO plants.

The two major goals driving industry R+D today are exploiting seed-pesticide linkages and developing value-added output traits like higher oil or protein content. Both types of technologies will make farmers more dependent on other sectors of the food system, on the one hand for inputs and pest management technology, and on the other in the marketing arena. Experience suggests that both these trends are likely to enhance the economic power and profitability of the input and processing sectors at the expense of farmers. This should, in turn, attract more capital and investment in these sectors – which historically has been a good thing. But as stated earlier, there are new concerns.

The U.S. food system is already highly integrated and becoming more so. The performance of the whole system depends on the capacity of each sector to respond to challenges and market opportunities, and to innovate. The chronically poor economic returns to the farm production sector, wide swings in prices, profits, and debt load, the backing off of public sector investment in science critical to farmers, and disinvestment in farm level natural resource management all suggest that the farm production sector is emerging as the weakest link in the system. To some the logical solution is for stronger parts of the system to simply take over production responsibilities. This is, indeed what appears to be happening in some parts of agriculture.

Farmers need the help of agricultural economists in understanding the longer-term consequences of these trends, especially any changes that limit their access to markets or the role of open competition within markets in setting prices. How will farmers retain a share of the “value added” from specialty traits in cases where only one company has the technology to do the processing and marketing of the final product? In preparing for this paper I searched several land grant university websites and found next to nothing on these key topics.

There are other reasons to worry about changes in the seed industry. Cases may emerge where companies forego the chance to breed resistance into a variety since higher profits can be earned by continued sale of a pesticide. While breeders have focused single-mindedly on increasing yields in the past, in the future their priorities are likely to be shaped at least to some degree by the need to create synergy between a company’s pesticide and seed products portfolio.

The willingness of the seed industry to change breeding objectives may also emerge as a constraint to progress in agricultural innovation and productivity. Before long, the focus of corn breeders may need to begin a steady shift from just increasing yields through more dense plantings to also preserving net per acre income by reducing costs more so than yields. Such a gradual evolution in breeding priorities will mean greater focus on using genetics to tighten the efficiency of key root system-soil-nutrient cycle-plant health linkages, and also has great potential in reducing environmental problems.

Consider the multiple consequences of a change in policy that in turn triggers the need for a basic shift in breeding priorities. Suppose that the nation’s commitment to reduce carbon emissions leads to a willingness of government to support efforts to enhance terrestrial storage of carbon. Will corn farmers be able to compete with foresters? Suppose a consensus emerges that changes in breeding objectives -- for example, selecting for fuller, deeper root system architecture -- are needed for corn production to cost-effectively compete with forestry in enhancing soil carbon levels. Who will pay (and how) for bigger root systems? How will the integrated seed-pesticide industry respond if changing root architecture is seen as incompatible with other goals more directly linked to industry profitability?

Biotechnology has great potential to enhance the capacity of breeders to produce genetically improved varieties. It is legitimate and important to question whether a portion of potential societal benefits may be foregone because they are judged “not compatible” with steps seen as necessary to maximize future industry profits. This would be a classic case of market failure, where actions taken by a private company, acting in the best interest of its stockholders leave the nation less well off.

Experience also shows that the bigger and more profitable an industry becomes, and the companies within it, the more difficult time government has in changing corporate behavior if and when conflicts arise between private profits and public needs. This does not bode well for the future role of plant genetics, for years one of the public plus private sector’s most reliable tools for problem-solving and productivity improvement. New efforts and priorities, and heightened investments in the private sector is just part of the problem. The other is the retreat of the public sector from a meaningful, sustained and competitive role in the development of agricultural technology.

F. U.S. Agriculture, Inc and the Structure and Profitability of the U.S. Food System

The emergence of biotechnology has both been driven by and fueled pesticide and seed industry consolidation. Across the food chain, companies are merging and industry-lines are blurring. On both the input and food processing and marketing sides, the U.S. food system is rapidly becoming more concentrated and integrated. Despite the rate of change in production agriculture, the scope and pace of structural change in the basic production sector is clearly much less than in the input and processing/marketing sectors.

Why are most industries going through such rapid structural change? Annual reports, Wall Street experts and CEOs all emphasize the need to stay competitive, finance increasingly large R+D expenditures, and keep up with the expectations of customers here and abroad. But there are other reasons at play in the U.S. food system:

- In some industries it is cheaper to buy the competition and its proprietary technology than to fight it out in the marketplace -- and in patent court.

- The ability to increase profit margins to finance mergers, cover debt and pay for higher R+D expenditures requires a taming of competitive forces that tend to reduce profit margins.

- Mergers and vertical integration accommodate a higher order of specialization and provide greater control over pricing at all stages and levels.

- Combining seed and pesticide manufacturing within a single company offers new options to extend patent-like profit margins beyond the expiration of patents, and perhaps indefinitely.

What are the implications for farmers and rural communities? A look at the structure and performance of the basic industries that comprise the U.S. food system provides some inkling of further changes on the horizon.

An Overview of the U.S. Food System

Throughout this chapter, all data are either from USDA reports accessible on the Internet, especially the "Statistical Indicators" tables from the January-February 1999 issue of the Economic Research Service periodical *Agricultural Outlook*, or from "Company Profiles" accessible on the Fortune 500 website.

The U.S. gross national product in 1997 was $8,103 billion. Food expenditures accounted for $781 billion, or about 9.6 percent of GNP.

Consumers spent $380 billion on food consumed at home and $298 billion on food away from home, for a total of $678 billion. Government and others spent another $103 billion on food.

The U.S. food system is composed of a set of input industries, farm operations, food processing and marketing companies, the retail sector, and restaurants and food service. Each sector strives to maximize its own profitability and economic security by maximizing its share of the consumer food dollar. Some sectors also benefit by expanding export sales, but across the whole food system, international trade is a mixed blessing – exports reduce domestic supplies, keeping production and prices higher than they would otherwise be, but trade also places a ceiling above prices and is driving prices down for many commodities from oats to apple juice.

But in general within the U.S. agricultural system, one sector's gain is typically another sector's loss, and in recent years farm profits have been squeezed while other sectors have enjoyed steady growth and for some companies, exceptional profitability. In 1997 Farmland Industries earned profits equal to 21.9 percent of revenues and the company grew 18.4 percent annually between 1987 and 1997. Two major pesticide companies grew at 17.6 and 14.4 percent in the last decade, with returns to investors averaging around 30 percent.

Stock prices across the seed industry have been markedly inflated yet profits as a percent of revenues have remained well over 12 percent. Pioneer Hi-Bred, the industry leader, announced in a September 22, 1998 press release that it had meet its goal of over 20 percent total return to investors for the fifth consecutive year. Fiscal 1998 earnings were up 11 percent to $270 million on sales of $1.784 billion, for a profit to revenue ratio of 15 percent. As shown below, the agricultural production sector does not come even close to these levels of return.

U.S. Agriculture, Inc.

To place into perspective how farmers are doing, lets create a new player in the food system – U.S. Agriculture, Inc. It is composed of two major operating divisions – crops and livestock products. It operates in all states and has some 1.5 million major shareholders, each of whom operates a franchisee (a commercial farm) and has an equity stake in U.S. Agriculture, Inc.

Gross U.S. Agricultural, Inc. revenue in 1997 was $230 billion, $112.5 billion from crops, $96.2 billion from livestock products, and $22.1 billion from forestry and the sale of services.

U.S. Agricultural, Inc. controls $1,089 billion in assets. Real estate makes up the lion's share of assets, and was valued in 1997 at $850 billion. Other assets include machinery, $91 billion; $30 billion in stored crops; $50 billion in financial assets. The company owes some $165 billion in debt, and has a debt to equity ratio of 17.8 percent.

In producing $230 billion worth of food, U.S. Agricultural, Inc. spends $118.5 billion on production inputs and feed. Of these expenditures, $46 billion go for feed, seed and livestock purchases; $29 billion for fertilizer and lime, pesticides, fuel, and electricity. Other expenses – repairs, storage, marketing, labor – account for another $44 billion in expenditures. After factoring in government payments, capital consumption, employee compensation, and interest, the USDA estimates that U.S. Agriculture, Inc. earned $50 billion in operating profits in 1997. These profits were the source of the $30,000.00 franchise fee (farm family living expenses) paid to the 1.5 million farms that make up the company. These payments shrink the $50 billion operating profits of U.S.

Agricultural, Inc. to just $4.8 billion. The size of the payments -- $30,000.00 – is well below the median farm operator household income of $52,300 reported by USDA for 1997 (84 percent comes from off-farm sources of income).

Table 9. U.S. Agriculture, Inc. Income and Expenditures, 1997		
	1997	
Gross Sales	($Billion)	
Crops	112.5	
Livestock	96.2	
Other	22.1	
Total Income	**$ 230.8**	
Plus Net Government Transactions	0.1	
Expenditures		**Percent of Total Expenditures**
Seeds	6.7	5.7%
Pesticides	8.8	7.4%
Fertilizer	10.9	9.2%
Feed	25.2	21.3%
Livestock	13.8	11.6%
Fuel and Oil	6.2	5.2%
Electricity	3	2.5%
Other intermediate expenses	43.9	37.0%
Total Production Expenses	**$ 118.5**	100.0%
Gross Value Added	**$ 112.3**	
Minus Capital Consumption	19.5	
Net Value Added	**92.8**	
Minus -- Rent to nonoperators	13.2	
Debt Service	13.7	
Labor	16	
Net Income	**$ 49.8**	
Minus Franchise Fee (Family Living Expenses -- 1.5 million commercial farms, $30k per)	45	
Net Return to Shareholders	**$ 4.8**	

An overview of U.S. Agricultural, Inc.'s performance is presented in Table 9. Table 10 presents a sector-by-sector overview of basic financial data on food system-related companies listed among the Fortune 500 and the Global Fortune 500. U.S. Agricultural, Inc. is included in this table as the production sector.

The data on assets, market value, revenues and profits are rough since the Fortune 500 clearly does not include all companies in each sector. I estimated sector-wide assets, revenue and profits by calculating averages from the companies for which performance data was available.   The estimates correspond reasonably well with USDA data on the size of various sectors, and on financial performance data reported in the business and financial press. I hope to be able to carry this analysis forward in the next few years, and challenge some of the students in the agricultural economics department to consider doing a thesis on the size, performance, and profit of Illinois Agriculture, Inc. in light of the structural changes occurring in the input and food processing industries.

Table 10. Rough Estimates of the Size and Performance of the Basic Sectors in the U.S. Food System, Late 1990's

					Profits as a Percent of --		
Sector	Assets	Market Value	Revenue	Profits	Assets	Market Value	Revenues
	($Billion)	($Billion)	($Billion)	($Billion)			
Seeds	22	33	6.7	0.804	3.7%	2.4%	12.0%
Pesticides and Drugs	36	71	24.1	1.43	3.9%	2.0%	5.9%
U.S. Agriculture, Inc.	1,088	1,632	230.8	4.8	0.4%	0.3%	2.1%
Food Processing	329.5	638.9	429.9	30.1	9.1%	4.7%	7.0%
Retail	140	239.6	319.9	14.8	10.6%	6.2%	4.6%
Food Service, Restaurants	62.3	123.6	297	10	16.1%	8.1%	3.4%

Table 10 leads to a number of conclusions about the relative economic strength of U.S. Agriculture, Inc. relative to other food system sectors –

- The production sector's profits to assets ratio is about one-tenth that of the seed and pesticide industries, and less than one-twentieth of the other more profitable sectors.

- Profit as a percent of revenue is much lower than the two sectors dealing directly with production agriculture.

- The assets of the food processing industry are enormous -- about one-third of the production sector -- but the economic return to processing sector assets and revenues is much higher than U.S. Agriculture, Inc.'s.

Implications

The lack of profitability in the production sector is and could continue undermining the ability of farmers to invest in changes in farming systems, soil and water resource enhancement, buildings and machinery, and will continue to fuel trends toward specialization and growth in average farm size. These trends further increase grower dependence on other sectors and may set the stage for ecological and biological production setbacks on a scale never experienced before.

Growth, debt service, merger activity and return to investors in the seed plus pesticide and the food processing industries will require annual revenue increases on the order of 5 to 15 percent per year. A significant portion of these additional revenues will have to come from capturing a larger share of the "value added" in the production sector.

The relative economic size and performance of the sectors within the U.S. food system affect the comparative ability of each sector to influence media coverage, public attitudes and public policy. It also influences relative access and control over information, expertise, markets and capital, as well as ability to shape and make investments in new technology, information and services. For these and other reasons, the slipping influence of the production sector is likely to continue relative to other, more profitable sectors.

G. Some Conclusions and Future Challenges

In a perfect world public sector science should focus on diagnosing problems and creating the knowledge base needed to solve problems with minimal drain on scarce "system" resources – especially the time and management focus of farmers, soil and water quality, expenditures on inputs, and the attention of plant breeders.

As the private sector has exerted more and more dominance in advancing new technologies, the public sector has had to invest a growing share of its resources in evaluating and responding to the challenges posed by integrating private sector technologies into ongoing farming systems.

Exclusive reliance on any single pest management technology tends to trigger shifts in pest species composition or the evolution of resistance through one or more mechanisms. In general, the greater the selection pressure across time and space, the quicker and more profound the evolutionary response.

Pest management systems should spread the control burden across at least two and preferably three distinct control tactics. Any technology that lessens the ability of farmers to diversify pest management is likely to trigger adaptive responses that raise costs and yield instability.

Unique Role of Crop Genetics and Breeding

The selection and breeding of improved varieties has and will continue to contribute to technological innovation by relaxing one or more yield constraints, by making it possible to grow more plants per acre, and by enhancing desirable features or traits of harvested commodities.

Genetic capital is limited – both the time and effort of breeders and the germplasm they draw upon in plant improvement. Like any scarce resource, the efforts of breeders should be strategically allocated where it, and only it, can raise yields and profit potential most significantly.

To maximize gains in agricultural productivity, breeders and plant geneticists need to focus their efforts on overcoming those problems and constraints that can not be cost-effectively overcome though other means.

Roots of Technological Change

Positive technological change tends to occur reliably when farmers are able to –

- Solve problems, raise attainable yield levels, improve environmental quality, and/or lower costs by changing the mix of farming activities – enterprise type, rotations, conservation systems.
- Reduce over time the frequency and severity of pest problems and/or increase the cost-effectiveness of control measures utilized.
- Manage evolutionary processes to enhance productivity, rather than being reactive when adaptive forces shift problems, undermine once effective practices, or pose new constraints on yields.
- Increase realistically attainable yields by improving soil quality or adoption of improved genetics.

Technological innovation can often be achieved most cost-effectively through management changes that alter biological processes and interactions. As a source of innovation, American agriculture is under-utilizing farm system design change. Indeed, in some regions, farm system changes have become a negative force, undermining yields and natural resource productivity because of over-reliance on chemical solutions to biological problems stemming from management choices.

Innovation can come from incorporation of new genetics and inputs that allow farmers to more effectively manage biological processes and ecological interactions. But inputs and genetics must be utilized in ways that limit the capacity of soil organisms and pests to adapt to whatever new selection pressures arise within a farming system.

The most valuable technological innovations make it possible to alter farming systems in ways that eliminate or relax, at least in most years and circumstances, otherwise common yield constraints or threats to production.

Technological change that solves one problem but in the process creates another, or causes long-run costs to rise, is not innovation. The impacts of technologies are often determined by the broader systems within which they are used. Technologies that promise to short-circuit the need to carefully manage systems often contain the seeds of their own demise.

Over time the tools of biotechnology will unlock the incredible complexity of the linkages between genes, organisms, plant growth, and the environment. The impacts of biotechnology will be determined by how it is used to exploit this knowledge.

Diversity in rotations, tillage and planting systems, soil fertility and quality enhancement efforts, pest management systems, and income generating activities is inherently good for a host of reasons. It is disadvantageous for a few reasons that can be overcome by community-level innovations in the sharing of machinery, labor, and transportation/processing infrastructure.

Technologies that expand grower-choice will, in general, help farmers capture a bigger share of per acre gross income. Technologies that narrow choice will help others capture and hold a larger share of gross income from farming activities. Hence the impact of new technology on the diversity of farm operations should be a key evaluation criterion.

Farmers wishing to contain costs and preserve degrees of freedom should follow a hierarchy of interventions beginning with management system changes, progressing through the purchase and use of inputs, and finally to changes in crop and/or animal genetics, if available. When these responses fail to solve problems, farmers either have to accept slippage in system performance and financial returns or make more fundamental changes in farming system design and enterprise mix.

The agricultural research community should assume responsibility for perfecting and applying a set of "Leading Indicators" of the health of Illinois agriculture. It should apply the indicators retrospectively and identify threshold values for indicators beyond which farming system stability and sustainability might be jeopardized.

When the value of a given indicator is moving in the wrong direction, especially when it approaches a critical threshold value, the research community should engage farmers, policy-makers, scientists and the private sector in understanding why and identifying ways to reverse slippage.

Impacts of Biotechnology on the Farm Sector and Society

Technology fees and contracts will remain a key part of the process for farmers wishing to plant genetically modified seed.

Companies developing herbicide tolerant plants will try to shift as much per acre cost as possible from the herbicide onto the seed via seed costs and/or technology charges. With increasing frequency, price reductions for herbicides will be limited to growers purchasing technology packages.

The scope of the technology contracts will likely expand. Whenever possible, they will continue to require farmers to buy the company's brand of inputs and will forbid farmers from keeping or selling the seed. Contracts in the future may well specify other agronomic and pest management requirements.

Contracts governing the planting of "value added" varieties are likely to address additional issues, especially in cases where one or a few companies have the technology to process the crop and take advantage of the value-added trait. Such contracts may set target harvest dates and delivery schedules, impose new quality specifications, possibly linked to price, and stipulate other conditions governing the sale and handling of the harvested crop. These provisions could change the distribution of production and marketing risks, and might limit technological choice on the farm.

The integration of the seed and chemical industries appears destined to accelerate increases in per acre expenditures for seeds plus chemicals, delivering significantly lower average returns to growers.

A new set of criteria may come to govern the identification of priorities within seed plus pesticide companies. In cases where a company projects a higher profit margin for a chemical versus genetic solution, or vice versa, the range of options offered to farmers may narrow, at least from that company. This could have long-run consequences for costs, innovation and sustainability, depending on how other companies are able and willing to respond.

Public willingness to invest in the agricultural sciences, education and technology development is a function of what the public believes it is getting from its investments. Recent trends in biotechnology and changes in the structure and financial performance of agricultural input and processing industries may transform attitudes among both consumers and farmers regarding whom is benefiting from publicly funded science and education activities. Such a shift in attitudes will trigger the need for new partnerships to provide leadership and political support for public research and extension programs.

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