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THE ASSESSMENT OF ECONOMIC IMPACTS OF CURRENT AND EMERGING AGRICULTURAL TECHNOLOGIES THAT AFFECT WATER QUALITY

Loren W. Tauer

Department of Agricultural Economics
New York State College of Agricultural and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York 14853

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Loren W. Tauer*

Abstract

Current and emerging technologies in agriculture are appraised to determine which technologies may have significant impacts on water quality and where the economic impact should be further investigated. Methodology from the field of futures research was also reviewed since those methods might be useful in our assessment efforts.

0. Introduction

This report discusses current and emerging technologies in agriculture that may have significant impacts on water quality, and indicates for which technologies the economic impacts should be further investigated. This endeavor falls within the realm of ex ante technology assessment. A large amount of literature exists on ex post technology assessment, but less economic research has been completed to project the impacts of technologies before they became available (Norton and Davis).

The report is divided into four sections. The first section discusses procedures that can be used for economic assessment of emerging technologies. The second section reviews some recently completed agricultural technology assessment projects. The third section reviews current and emerging technologies that may have an impact on water quality or have significant economic impacts. The final section identifies the major information gaps in the economic assessment of those agricultural technologies.

I. Economic Research on Agricultural Technology

Economic research on technology consists of technology forecasting and measuring the economic impact of technological change. Technology forecasting typically entails estimating when a product will be developed, commercialized, or adopted. Techniques include the familiar Delphi survey and estimating adoption curves, although other techniques such as cross impact analysis, morphological research, and catastrophe theory also exist. Many of these methods are ad hoc or subjective in nature and

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require the information input of experts in the specific technologies. Some, such as morphological research, were originally designed for the engineer to catalogue and sort through the technological feasibility of systems, but could also be used by those forecasting what may technologically occur.

These technology forecasting assessments fall within the endeavor of futures research, a large and growing field of study.[1] Although futures research encompasses much more than technology assessment, it is well recognized in the futures field that technology is a major driving force in determining the character of the future. Like most fields of study, futures researchers periodically assess the success of their efforts. The August 1984 issue of Futures includes a section of five articles on the status of futures research. The conclusions are succinctly summarized in the title of Linestone's paper who gives futures research an A for quantity, a C for quality and an F for impact. In other words, a large quantity of research has been completed of questionable quality which has had no impact on policy-makers and planners.

The World Future Society has published annual surveys of futures research since 1979. The material is grouped into 17 categories, including food and agriculture. The references range from newspaper articles to an occasional scholarly journal article. Technology assessment articles appearing in subject matter journals rather than the technology assessment journals are often absent. Food and agriculture has typically consisted of 3 to 4 percent of the number of studies referenced each year.

In describing the process of forward thinking, or futures research, Holroyd identifies the forecasting process as six separate activities:

1. Identifying the problem.
2. Searching for relevant factors.
3. Searching for trends.
4. Searching for impacts.
5. Searching for relationships.
6. Implications for Action. Designing the Future.

He states that it is important to obtain a clear concept of the problem and the problem situation. Once the problem and its boundaries are understood then it should be evident whether or not considerable effort spent in time and money upon a forecast is really necessary. A forecast would have little value if the problem outcome would have little impact or the problem is subject to random events. The use to which the forecast will

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[1]The principal three professional societies are The Education Section of the World Future Society, the International Association for Impact Assessment, and the World Futures Studies Federation (Markley). The World Future Society in Bethesda, MD, has approximately 30,000 members from 88 nations. The prominent journals appear to be Futures, Technological Forecasting and Social Change, Long Range Planning, and Socio-Economic Planning Sciences.

be put must also be established for this will determine the choice of techniques involved in the forecast.

He then discusses the various methods available in the search processes (Table 1). He describes each research method, states its advantages and disadvantages, and lists sources for additional information. His explicit intent was to provide the list of forecasting tools as a simple guide to anyone wishing to indulge in technological forecasting.

Having defined the problem, Holroyd states that those factors which will affect the course of events must be sought and noted. The obvious factors can often be simply written down, but by following a systematic approach involving one or more of the methods in Table 1, it is often possible to discover important factors which would otherwise have been overlooked. Having defined the problem and established the relevant factors it becomes necessary to fill out the futures forecast with some real data taken from known and measured events. Where past data are available, estimates of future trends should be made to allow the already established futures relationships to be quantified. In searching for impacts the impact of each factor or trend upon each of the other factors or trends, or upon the defined system should be assessed. Finally, he states that having defined the problem, established the relevant factors, determined the available trends and assessed their impacts, then the connections between these elements must be established so that a picture of the relationships can be built up which leads to a better understanding of the complex system. Finally, in making effective forecasts it is necessary to end with at least a statement of what should be done now as a result of the forecast; which may be 'do nothing.'

van Doorn and van Uught have summarized the popularity of the forecasting techniques in futures research. The fifteen unique approaches are grouped into four types.[2] As shown in Table 2, most researchers have had a preference for exploratative and speculative forecasting techniques. Explicative forecasting techniques are not favored, and integrative forecasting techniques have medium preference.

Agricultural economists are most familiar with time series analysis and causal methods (econometrics) with exposure to delphi, bayesian statistics, and input-output analysis. Many of the other procedures, such as historical analogy, expert opinion, brainstorming, panel consensus, and subjective probabilistic forecasting, are descriptive in their titles. Others such as cross-impact analysis are less so. An excellent discussion of the techniques is in Makridakis et al.

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[2]There would obviously not be unanimous agreement in the groupings. For instance, Oliver, Loveridge, and Holroyd state that there are five methods that fall into the cross impact analysis category: probabilistic cross-impact; deterministic cross-impact; game theory in all of its forms; trend-impact analysis; and systems dynamics.

Table 1. Research Methods to Complete Tasks in Futures Research (from Holroyd)

Method	Searching for Factors	Trends	Impacts	Relationships
Monitoring	*			
Analogy	*			
Brain-storming	*			
Delphi	*			
Scenario	*			
Hegelian	*			
Expert Opinion	*			
Closed System	*			
Substitution Analysis		*		
Growth Curve Analogies		*		
Envelope Curve		*		
Extrapolation		*		
Experience Curves		*		
Computer trend forecasts		*	*	
Crucial Issue Identification		*		*
Metagames			*	
Catastrophe Theory			*	
Cross Impact Analysis			*	*
Game Theory			*	*
Behavioural Studies				*
Morphological Analysis				*
Decision Trees				*
Relevance Trees				*
Dynamic Modelling				*

Table 2. Preferences for Various Forecasting Techniques (from van Doorn and van Uught, Table 5)

	1973 (USA)[a]	1980 (USA)[b]
Explorative forecasting:		
1. Time series analysis	H	H
2. Historical analogy	M	-
3. Causal methods	H	H
4. Projective scenarios	H	M
5. Morphological analysis	L	L
Speculative forecasting:		
6. Individual expert opinion	H	H
7. Brainstorming	H	H
8. Panel consensus	M	H
9. Delphi	M	M
Explicative forecasting:		
10. Subjective probabilistic forecasting	L	L
11. Bayesian statistics	L	L
12. PATTERN (relevance trees)	L	L
13. Prospective scenarios	L	L
Integrative forecasting:		
14. Input-output and dynamic systems models	M	M
15. Cross-impact analysis	M	M

H = high preference for techniques
M = medium preference for technique
L = low preference for technique
- = not ascertainable

[a]from McHale

[b]from Balachandra

Although economists have used quantitative forecasting techniques quite extensively, they have not used the technological or qualitative techniques to any extent. When technological methods are used it is often the expert who becomes the processor of facts, knowledge, and information rather than some set of mathematical rules or mathematical model (Makridakis et al.). Since that expertise typically lies outside the experience of the individual completing the forecast, the reliability of the forecast is often questioned by the researcher and others. With a mathematical procedure the bias and efficiency of a forecast can often be ascertained. That assessment is much more difficult using qualitative procedures.

A common technique used in agriculture has been the Delphi survey. The process entails surveying a group of experts concerning a future event, summarizing the results, and providing that information to the experts again to see if that alters their initial response or projection. Response outliers are often asked to provide justification to the group. A number of iterations are performed until responses stabilize to some norm. Initial information or presentations may also be provided.

Although the Delphi method has become very popular, maybe due to its ease of execution, it is plagued with problems. The major concerns deal with asking questions outside the domain of the experts and poorly formulated and worded questions. It would seem obvious not to ask biological scientists questions on the economic implications of a technological change, as it would be to not ask economists questions concerning the yield impact, but both types of questions have been asked. Even the question of a projected yield increase is ambiguous if it is not cast in terms of its setting; experiment station or average farm; other inputs held constant or optimally adjusted. Biases are often not obvious. Most scientists view their work as important and are optimistic concerning its impact. In some cases they are ignorant concerning field yields when their work has been strictly laboratory based.

A critique of a Delphi on medicine completed 10 years earlier found that many major medical achievements were missed and much of the expected scenario did not occur (Turner). Turner suggests two major reasons for the failure. The first is lack of sufficient attention to basic research since future developments occur there. The second concerns the time required to evaluate developments before they can be widely used. His conclusions suggest the need for experts familiar with basic research as well as applied research and development.

Cross impact analysis is an attempt to decouple a technological change into its components in a systematic manner. It was originally devised by Gordon and Hayward to supersede the Delphi technique. It is based upon the observance that significant developments in one area often depends upon breakthroughs in another area so uses a multivariable method of analysis that allows interaction between technical, social and economic trends and developments to be formalized. Like Delphi it requires using expert opinion in obtaining marginal and conditional probability measures on various developments. Cross impacts are also obtained. The collection of additional information allows testing and verifying the consistency in responses. Extensive efforts have gone into refining and modifying cross impact analyses during the last decade (Kirkwood and Pollock; Ducos).

Since a large number of ex post technological impact analyses have been performed in agriculture (Norton and Davis), a useful area to pursue may be historical analogies (Ayres). In fact, the primary justification for ex post assessment is that it provides the information necessary to determine the likely impact of further technology. Although researchers review the literature in formulating their own research approach, it appears that little work has been accomplished in systematically using ex post results in developing ex ante impact models. Unfortunately, changing institutions and resources would complicate any attempt to systematically categorize the character and impact of previous technological changes.[3]

Economists often estimate economic impacts by econometrically estimating demand and supply functions or associated functions, and then shifting those curves to determine the economic impact of technological change (Osteen and Kuchler). A severe limitation of econometrically estimated functions is that they pertain to historical prices and technologies and thus are not relevant under new technology, even if the institutional structure and resources do not change. Most technological change will shift the supply curve of a commodity. The difficulty is determining the character of the shift. Not only is it difficult to ascertain the magnitude of the shift, there is often no reason to expect the shift to be parallel. The size and type of shift will affect any estimates of consumer and producer surplus (Lindner and Jarrett). In addition, the interesting questions to be answered include more than price, quantity and economic surplus changes. With the potential technological change magnitudes that are being discussed, the impact on the structure of agriculture and resource usage could be tremendous. This necessitates extending the research methods to answer those questions. It appears those requirements have stymied research on the economics of technology in agriculture. Yet, although limited in the information it generates and in its accuracy, supply curve shifting can be a useful approximation in technological assessment because of its straight forward and simple approach (Love and Tauer).

More elaborate research techniques beyond supply curve shifting are necessary to measure or estimate the detailed economic impacts of technology. It appears those requirements have stymied research on the economics of technology in agriculture since it requires building a total system of the production and economic relationships involved. The two procedures that are typically suggested are optimization and simulation. Both procedures entail modeling the production and economic relationships involved and then either optimizing a functional value or simulating based upon adjustment rules or values. Optimization procedures, such as linear programming, often start from the construction of activities based upon production data, while functional relationships in simulation models are

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[3]A book by Heinlein contains some interesting thoughts on using qualitative historical observation for predicting the future. His basic premise is that technology will change but people will not.

often estimated econometrically, but that distinction is not rigid. Programming activities can be formulated from econometrically estimated relationships and simulation models can be built from physical and biological knowledge of the relevant relationships. In fact, since empirical production or economic data on emerging technologies are not available, any model building requires modifying the production relationships based upon physical and biological knowledge. Often that knowledge base on new technologies is severely limited (Fishel and Kenney). This may suggest that agricultural economists should take a closer look at system dynamics where many of the relationships are determined in an ad hoc manner, relying on experts, but testing robustness of the results to those assumptions. Sommer discusses the differences between econometrics and system dynamics in modeling. Also, an encouraging effort in measuring the distributional affects of technological change is the recent work in modifying input-output coefficients based upon projected technological change. Rose discusses methods that have been used to project technological change in input-output models and concludes that researches no longer have a legitimate excuse for assuming away technological change or using crude modification methods. These methods may also be used effectively in modifying the coefficients for technology in mathematical programming models.

Hardaker, Anderson, and Dillon summarize the status of the agricultural economics literature on technology assessment and suggest directions for advances in a recent survey. The need for technology assessment in agriculture is necessary for directing and managing public agriculture research, but also for formulating, monitoring, and evaluating broader rural development policies and programs. For farm level assessment they encourage further extensions to farm systems research and the participation of economists. They indicate their skepticism about the utility of econometrics, but recommend mathematical programming methods, budgeting, and simulation. They also believe the use of intuition in technology assessment to be under-rated, under-used, and generally under-recognized as a useful activity. For aggregate assessment they discuss the necessity to account for general equilibrium effects rather than simply partial effects, to measure the distribution of welfare over various groups, as well as the dynamic interaction between technology and institutions.

II. Recent Agricultural Technology Assessment Studies

Symposiums are organized periodically to assess the status of current and emerging technologies and the impacts they may have in agriculture. Such a symposium was planned by the USDA and held in Chicago, September 16-17, 1981 (Lu). Fourteen clusters of technologies were identified by about 300 leading scientists and research administrators from across the United States using a Delphi process (mail). Although 50 technologies were explored, the final 14 clusters include only those agricultural production technologies which are viewed as having a 50-50 chance of being introduced for commercialization by the year 2000 and having "unprecedented" impacts on agricultural productivity, resource use, or the natural environment. At the symposium, scientists presented prepared papers discussing status and future development of those technologies. Additional efforts later established possible relationships of the impacts in agriculture (Boucher and Drobnick).

In another symposium organized by the USDA and Iowa State University, crop technologies that would specifically affect resource usage or environmental quality were addressed (English et al.). Nearly 300 of the nation's leading farmers, scientists, and agribusinessmen gathered December 5-9, 1982 in Washington, DC, to project what might be the state of America's agriculture in the years 2000 and 2030. The program included presentations by discussants and deliberations by workgroups, each composed of 15 to 23 specialists. The consensus of the workgroups was evaluated in the national linear programming model of the Center for Agriculture and Rural Development at Iowa State University.

The 1986 OTA study on Technology, Public Policy, and the Changing Structure of American Agriculture used similar methods to develop material for the report. Workshops were convened during April 1984 to obtain information about the development and adoption of emerging technologies so that the information could be used to analyze the economic, social, and environmental impacts of technology adoption. Participants of the workshops were selected to include expertise in different stages of technological innovation, and included physical and biological scientists, engineers, economists, extension specialists, agribusiness representatives, and experienced farmers. The Delphi technique was used to obtain collective judgments from the workshop participants. In additional to estimates, each expert weighed his response by the degree of confidence or expertise he had in his rating. In addition, background papers were commissioned by OTA on emerging technologies, and the economic, social, institutional and environment conditions in agriculture. The OTA report is vague as to how this information was used to assess the economic, social, and environmental impacts of these techniques except that Iowa State's CARD econometric and hybrid models were used (OTA, p. 297).

The Economic Research Service completed a technology assessment workshop in 1976. The purpose of the workshop was not to present and discuss emerging technologies, but rather to improve the technology assessment procedures being utilized by ERS. In many of the published papers, however, an assessed technology was presented in discussing the assessment methodology. As the publication overview states, technology assessment in ERS stresses feasibility of new technologies for adoption within agriculture instead of addressing the broad social impacts of that technologies. Yet in his paper, the administrator stated that no other factor has done more to shape the structure of agriculture or influence the outcome or performance of the system than technology has.

The Food and Agriculture Committee of the National Planning Association organized a forum November 8, 1984 on new technology as the driving force in the food system. The program was not planned to be a comprehensive discussion of emerging technologies but rather a general discussion of developments in biotechnology and the economic and policy implications of new technology. An encouraging component of that meeting was the inclusion of a paper discussing developments in using agricultural commodities as building blocks for chemical processes, a demand increasing technology.

Johnson and Wittwer address the research funding necessary to increase agricultural output to meet future demands. The emphasis in their report is the research process, but they do list and discuss future technologies. They do not analyze the economic or social impacts of new technology, except for their section criticizing the critics of the agricultural research establishment.

An excellent commodity specific technology assessment is the work by Sundquist, et al., on corn production in the U.S. They discuss technology groups in terms of past, current and future potential changes using pertinent scientific literature. They also incorporate individual technologies into an aggregative assessment of the corn production system and evaluate past R&D and research for the future.

The Joint Economic Committee of the Congress of The United States held hearings on October 2, 1984 titled "New Directions for Agriculture: The Science and Technology of the Future." The hearings included reports on new crops, biotechnology, and information systems. Much of the presentations provided information on technologies in these three areas but policy subscriptions were also presented.

These major projects, meetings, and hearings indicate that substantial efforts have gone into technology assessment and evaluation. In reviewing these efforts it becomes apparent that two major gaps exists. The first is incomplete assessment of the social and economic impacts, the second is the non-existence of a procedure for continuous technology assessment in agriculture.

Although many of the assessment projects included economists on the panel of experts, the ad hoc assessments of the economic impact by the economists may be as limited as the projections by the scientists. Generally, it would be expected that the economists' knowledge of the science and technological feasibility would be as incomplete as the economic knowledge of the scientists. Although synergism between the experts may have occurred to overcome these limitations, a more formal approach using the scientists to project the technology and economists to project the economic impact would be warranted. This type of approach must be cognizant of the fact that much technology is demand driven, and thus prices and institutional arrangements are important in explaining the pace of technological development.

A panel of experts is still limited in their ability to assess the impact of future technologies because of the complexities and relationships involved in the agricultural system. Although aggregate projections may be reasonable, disaggregate impacts on regions, sectors, institutions, and resources cannot be estimated with any degree of confidence. Assessing these impacts requires detailed economic research on the technology or commodity using the research techniques discussed earlier. One purpose of this study is to suggest some technologies that should be studied based upon their potential economic, social, and water quality impacts. Yet, to screen and select those technology candidates requires initial assessment of the impacts using speculative forecasting (van Doorn and van Ught).

This prompts the recommendation that a standing committee of technology experts be formed to monitor developments in the pace of technological advances in agriculture. Unexpected developments within a few years can drastically alter commercialization dates expected.[4] In addition, unexpected scientific advances may produce new unexpected technologies. Turner has shown this to be true in medicine over a 10 year period. Convening a symposium every decade, or symposiums more often with differing missions, would not provide sufficient information on the pace of development. Holroyd finds this to be a limitation of the Delphi procedure since it only provides a static view of a future situation. His remedy is recurrent Delphis covering the same subject area. Thus it is necessary to standardize and routinize the technology assessment process by annually surveying a panel of experts. The panel could initially meet in a symposium to formulate benchmark projections. Those projections could be modified annually and new technologies identified by an annual survey approach. The procedure could use panel consensus or some other speculative forecasting technique (Table 2).

The panel would be reconvened periodically to formulate new benchmark projections. Since technology is a major driving force explaining the structure of agriculture, continuous technological forecasting and assessment would be as useful as collecting and forecasting commodity prices for decision making at all levels. Policy makers could use the information for agricultural programs; farmers could use the information in formulating investment and production plans for the future (strategic decisions).

III. Current and Emerging Agricultural Technologies

The two most recent comprehensive agricultural technology assessment efforts have been the 1983 CSRS report and the 1986 OTA report. Both projects ranked current and emerging technologies according to impact and availability, based upon a Delphi survey of experts. Those rankings will be used to delineate and rank technologies that will have an impact on water quality and the economics of production.

In the CSRS study, three rounds of mailed Delphi surveys were utilized. During the process technology clusters were added, merged, and deleted until 14 technology clusters were identified and ranked (Table 3). With all 14 technologies, the upper quartile of responders believed that the probability was 50 percent or greater that production processes derived from the technology will be on the market for adoption by the year 2000, if not earlier. The impact of each technology on productivity,

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[4]As an example, the Agriculture 2000 report by the Baltelle Memorial Institute published in 1983 stated that bGH may be commercially available in 1983. Currently in 1988 it is not yet commercially available.

resource use, and the environment was ranked by each respondent on a scale of one to five, where the value of five has the greatest impact. The respondents were also asked to evaluate on a scale of one to five their own expertise in each of the technologies. One hundred fifty-three scientists responded to the final (third) round. A summary of the rankings is shown in Table 3. The numbers shown in the table are the sums of the rankings weighed by the levels of expertise, with larger numbers denoting greater potential benefit of the technology.

I summed the rankings on productivity, resource use, and the environment to arrive at a combined score and then used the value of the combined score to prioritize the 14 technologies. The impact of productivity and resource use will affect the economics in agriculture, and inherent in the environmental impact is water quality. The top five priorities are water and irrigation management, plant and animal pest control strategies, minimum tillage, genetic engineering in plants and animals, and biological nitrogen fixation.

In the OTA study, animal and plant technologies were reported separately. The results summarized here will only be for the plant technologies since the scientists participating found the crop technologies to have greater impacts on water quality than did the animal technologies.

Nineteen plant technology clusters comprised of various technologies were identified. The participants were asked to further place the clusters into packages of technologies for the separate crops of wheat, corn, soybeans, rice, and cotton. The technology groupings differed slightly by crop. Among the estimations that were elicited included the most likely percentage change in crop yield for each technology package for each crop, and the year that each technology was likely to be introduced for commercial adoption. Two Delphi rounds were done ad situs. The yield increases are shown in Table 4. Since the 19 technologies were grouped, many of the technologies have the same estimated yield increase. All new technologies were expected to be available for commercial introduction by the year 2000.

A separate group of eleven experts was assembled to assess the environmental and natural resource impacts of the technologies. The evaluation was performed on a 10-point scale. A technology with a strongly favorable impact on the environment would receive a rating of 10.0. A technology with a strongly adverse impact would receive a rating of 0. If the impact was judged to be neutral, the rating would be 5.0. Two Delphi rounds were used ad situs. The water quality ratings were by technology group and are also summarized in Table 4.

I prioritized the importance of the 19 technology clusters by lexicographic ordering based first upon impact on water quality, and then the most significant yield impact on the most number of crops. Thus biological nitrogen fixation with the highest water quality index of 7.1 received the top ranking. Plant disease and nematode control, management of insects and mites, and weed control all received water quality indexes of 6.9. However, disease and nematode, and insects and mites both had most

Table 3. The Impact of Current and Emerging Agricultural Production Technologies as Identified and Measured by a CSRS Study*

	Impact on				
	Productivity (Score)	Resource Use (Score)	Environment (Score)	Combined (Score)	Priority Ranking for Economic Research
Genetic engineering in plants and animals	1290	920	863	3073	4
Enhancement of photo-synthetic efficiency	791	685	735	2211	9
Plant growth regulators	467	435	420	1322	13
Plant and animal pest control strategies	1086	1566	1261	3913	2
Biological nitrogen fixation	953	909	843	2705	5
Water and irrigation management	1210	1562	1307	4079	1
Soil, water, and plant relationships	707	712	636	2055	10
Minimum tillage	1020	1218	1302	3540	3
Land treatments for soil erosion	798	929	970	2697	6
Multiple cropping	713	836	796	2345	7
Increased animal reproductive capacity	505	432	443	1380	12
Crop residue and animal waste utilization	804	731	755	2290	8
Information systems	272	254	247	773	14
High efficiency pesticide application	483	528	502	1513	11

*from Lu

Table 4. The Impact of Current and Emerging Agricultural Technologies as Identified and Measured by OTA*

	Impact on Water Quality[a]	Most Likely Estimated Percentage Change in Crop Yield					Priority Ranking for Economic Research
		Wheat	Corn	Soybeans	Rice	Cotton	
Genetic engineering	6.4	NR	21.5	22.1	12.4	12.0	6
Enhancement of photo-synthetic efficiency	6.2	NR	NR	22.1	12.4	12.0	10
Plant growth regulators	6.2	24.0	NR	22.1	12.4	12.0	9
Plant disease and nematode control	6.9	24.0	21.5	22.1	12.4	12.0	2
Management of insects and mites	6.9	24.0	21.5	7.2	14.4	12.0	2
Weed control	6.9	24.0	14.4	7.2	14.4	12.0	4
Biological nitrogen fixation	7.1	NR	NR	7.2	NR	0.0	1
Chemical fertilizers	NR	24.0	14.4	7.2	14.4	12.0	12
Water and soil-water-plant relations	6.2	24.0	21.5	7.2	14.4	12.0	8
Soil erosion, pro-ductivity and tillage	6.3	24.0	14.4	7.2	NR	12.0	7
Multiple cropping	6.4	24.0	14.4	22.1	14.4	12.0	5
Organic farming	5.7	24.0	-28.8	7.2	NR	0.0	11
Labor-saving technologies	NR	1.5	NR	7.2	NR	12.0	17
Crop separation, clean-ing, and processing	NR	1.5	NR	7.2	14.4	0.0	17
Engines and fuels	NR	1.5	MR	NR	NR	12.0	17
Land Management	NR	24.0	14.4	NR	NR	12.0	13
Communication and in-formation management	NR	5.0	21.5	4.6	14.4	3.1	13
Monitoring and control	NR	5.0	21.5	4.6	14.4	3.1	13
Telecommunications	NR	5.0	21.5	4.6	14.4	3.1	13

[a]Based on a 10 point scale with 10 representing the most favorable impact.

NR = Not Rated

*U.S. Congress, Office of Technology Assessment.

significant yield impacts on 4 crops and tied for second ranking, while weed control only had the most significant impacts on 3 crops and received the fourth ranking.[5]

The top five priority rankings from each of the two tables were merged into the list in Table 5. Water and irrigation management received the number one ranking from the CSRS table. Biological nitrogen fixation received the number one billing from the OTA table. Plant pest control strategies is the combination from the OTA table of plant disease and nematode control (second ranking), management of insects and mites (second ranking), and weed control (fourth ranking), as well as plant and animal pest control strategies (second ranking) from the CSRS table. Minimum tillage (third ranking) is from the CSRS table and multiple cropping (fifth ranking) is from the OTA table. Finally, I have added the animal growth hormones. The OTA report identified bovine growth hormone as having a very significant impact on diary production. Since that date developments have occurred in other animal growth hormones and it appears that significant impact on cropping patterns and thus water quality may occur (Kalter and Milligan). I did not include genetic engineering on the list. It appears to me that this is a procedure to develop new biotechnology products rather than a technology per se in production agriculture. Animal growth hormones are a product from genetic engineering and so may be many plant pest control strategies. Also listed in Table 5 is my subjective assessment of the quantity of economic research that has been performed in these six areas which will be discussed in the next section of this report.

Canter also used information from the CSRS study to rank emerging agricultural technologies using lexicographic ordering techniques.[6] His rankings based upon water quality considerations and yield increases are given in Table 6. His rankings agree for the most part with mine, which is expected given much the same data were used, except for the omission of plant growth regulators and enhancement of photosynthetic activity from my list of the six most important technologies. He ranks plant growth regulators as 3 and 4 while my overall ranking would probably have been only 13. He ranks enhancement of photosynthetic activity as 5 and 3 while my overall ranking would have been a 9. The difference between these rankings was primarily due to the added information of the OTA report in formulating my ranking, which ranked the water quality impact of these two technologies quite low. In addition, he assessed the CSRS data differently, using information from a final study report (Boucher and Drobnick) while I used the Delphi survey results.

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[5]Disease and nematode most significantly impacted wheat, corn, soybeans and cotton while insects impacted wheat, corn, rice and cotton. Since soybeans are more economically important than rice some might place disease and nematode ahead of insects and mites.

[6]I discovered Canter's study after I performed my rankings.

Table 5. Status of Economic Research on Agricultural Technologies with Significant Economic and Water Quality Impacts

	Ranking	Completed Economic Research on	
		Farm Management	Farm Structure
Water and irrigation management	1	much*	much
Biological nitrogen fixation	2	none	little
Plant pest control strategies	3	much	some
Minimum tillage	4	much	some
Multiple cropping	5	some	little
Animal growth hormones	6	little	little

* Ordinal ranking consisting of much, some, little, none.

Table 6. Canter's Ranking of the CSRS Identified Emerging Agricultural Technologies (from Table 76)

	Ranking based upon		
	Surface and Ground Water Quality[b]	Yield Increases[c]	My Ranking
Water and irrigation management	1	2	1
Biological nitrogen fixation[a]	2	1	2
Plant growth regulators	3	4	NR
Erosion control (tillage)	4	5	4
Enhancement of photosynthetic activity	5	3	NR
Plant pest control strategies	6	6	3
Multiple cropping	7	7	5
Commercial nitrogen (small scale production)	8	8	NRS

NR = Not ranked in top 6 technologies; NRS = Not ranked separately

[a]Referred to as Genetic Engineering by Canter.
[b]Equal weightings given to surface and ground.
[c]Equal importance given to corn, soybeans, and wheat.

IV. Economic Assessment of Agricultural Technologies

The economic literature was reviewed to determine the extent that economic research has been completed on the six identified technology groups that will have significant impacts on water quality. Completed economic research can be separated broadly into one of two types; farm management or farm structure, which Hardaker et al., refer to as farm-level and aggregate-level respectively. Farm management research entails making economic recommendations to farmers concerning new technologies available to them. Farm structure research entails adoption profiles, impact on prices and quantities, sector and regional impacts and total benefits and costs to society. Farm management research is important in guiding farmers in the best use of their resources and thus benefiting society. Farm structure research is important in planning and accommodating any changes that may occur from new technology and in guiding future public research funding. The availability of completed farm management research is not normally critical until the technology becomes available for adoption, except that management or adoption of future technology may influence decisions concerning current technology. However, alleviating any undesirable impact on farm structure of future or emerging technology may require economic evaluation and policy adjustment well before availability of the technology.

Water and irrigation management research in the U.S. has centered on irrigation rather than drainage of non-irrigated areas. Much research has been completed on both farm management and structural issues of irrigation (Frederick and Hanson; Young), although Rogers (English et al.) states that in most of the discussion of irrigation, there has been a surplus of engineering and biological efficiencies research and a shortage of economic efficiency studies. This perceived neglect has been rational because of the low marginal cost of water to farmers, either because of low energy costs, or water prices not based upon full marginal costs. The response by farmers have been to maintain the institutions that support or permit those pricing strategies. Given a low marginal cost of water, farmers' research demands would be to remove those engineering or biological constraints that do not allow yield maximization.

Since irrigation is very important regionally, and has ramifications on water use, control, and quality, it will continue to receive research attention as new developments surface (English et al.). The economic information gap here is not significant, although it will be important to continue economic research on water and irrigation management.[7] Recent articles range in coverage from improved scheduling procedures (McGuckin et al.) to adoption (Caswell and Zilberman) to institutional alternatives (Young et al.) to economic welfare (Huffaker and Gardner).

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[7]Some would argue that water is not efficiently being allocated in some water basins. If that is known to be true, then there may be political or legal research yet unaccomplished, but there is no economic information gap.

A recent USDA publication comprehensively reviews farm drainage in the United States, including an historical perspective on drainage, a review of its practical purposes, assessment of technological progress, economic evaluations, discussion of institutional mechanisms, and consideration of environmental issues (Pavelis). The role of drainage was paramount in developing the midwest, coastal and irrigated areas, and approximately 110 million acres of land within farms are artificially drained. Government programs and tax policy now discourage further drainage of land, which at current commodity and land prices is economically marginal anyway. At the same time, drainage technology is still undergoing important changes and the maintenance and renovation costs of current drained areas will be significant and important for future U.S. production competitiveness. Most replacement decisions will be firm specific, although the type of technology utilized may have implications for water discharge quality and flow. Institutional structure and decisions will also be important in determining the performance and productivity of water drainage districts.

The perceived importance of biological nitrogen fixation is manifested by the amount of biological research funding on this science. The USDA competitive grants, for instance, has biological nitrogen fixation as a program area. Additional funding occurs in the public and private sectors. Although conceivably the economic value of biological nitrogen fixation could be enormous, no study has been completed to correctly estimate that economic value.

A recent study by Hill et al., discusses in an exploratory manner future nitrogen technologies, using theoretical connections drawn from previous research and experience of the authors. They essentially constructed scenarios and did a behavioral study on each scenario. A behavioral study is an historical approach to the future taking into account the known behavior patterns of groups, systems and societies (Holroyd). All seven scenarios they analyzed benefit corn producers, livestock producers, soybean producers and consumers. Supply-increasing technologies that benefit both consumers and all types of farmers are rare. Most agribusinesses benefit except for the nitrogen fertilizer industry. The environmental impacts are mixed. Nitrogen pollution should be reduced but row crop acreage increases. Halbrendt modeled the nitrogen fertilizer market in the nine major corn producing states using econometrically estimated supply and demand curves and shifted those functions to analyze the impact of biological nitrogen fixation in corn. She assumed corn yields would not be altered but costs of production per acre would fall as less nitrogen fertilizer was applied. Her results indicated very little increases in corn acreage (less than 1 percent in most states) but reductions in nitrogen fertilization. Sundquist et al., also included biological nitrogen fixation in the set of future technologies they assessed in corn production. An economic model developed by Beattie et al., to address product complementary production used as an example enhancing the nitrogen fixation properties of a legume. Rosegrant et al., also analyzed the economic use of Azolla in rice production.

These studies indicate that some research has been completed on the impact of biological nitrogen fixation on farm structure but less has been completed on farm management issues, at least in domestic agriculture. Farm management research, however, would be meaningless until a specific technology becomes available for commercialization, except to the extent that farm level response is necessary to estimate sector impacts. Noticeably missing is any estimate of the economic value of these technologies and aggregate impact on water quality. These estimates would be invaluable in justifying public funding of biological nitrogen fixation research.

The economic research on plant pest control has emphasized the farm management component of integrated pest management of insects, since control chemicals are toxic, and insects have become resistent. The element of a common property (insects) has also made the research more interesting (McCarl). Less effort has been expended on weeds (Zacharias and Grabe) or other pests. All of these efforts have utilized currently available technologies. None have included emerging or future technologies except to the extent of banning current pesticides (Osteen and Kuchler). Yet, herbicide resistance may easily be the first commercially available plant biotechnology product (Benbrook and Moses). Microbiology or plant production of insecticides or weed suppressants are also possible. When these products become commercially available they will be incorporated into the economics of farm management integrated pest management.

Yet, because these are novel biological control products, the potential impacts on farm structure and the agricultural supply industry should be investigated before the products become available. Industrial organization research concepts, coupled with technological assessment, may be relevant in analyzing the potential impacts. Since groundwater contamination has resulted from the use of chemical pesticides, the potential impact on water quality of alternative pest control systems should be measured and evaluated. This may influence the direction of public research in pest control.

An enormous amount of economic research has been completed on minimum tillage, although much of it has concentrated on farm management (Crosson) or adoption by various groups (Lee and Stewart). The structural impact has been less adequately addressed, although adoption of minimum tillage reduces labor requirements per acre and allows a farmer to operate additional acres.

Since minimum tillage systems have to be designed for specific geographical areas, it is critical that farm management research be continued as new systems are developed. It has become obvious that general statements such as minimum tillage "reduces yields" or "requires additional pesticides" are not always applicable. Once a management system is well established, yields may increase exclusive of soil loss reductions. The type of pests may change with minimum tillage (i.e., shift from annual to perennial weeds) and require alterations in pest control strategies rather than simply an increased use of pesticides. Specialized equipment has also assisted in the exact placement of seed, fertilizer, and pesticides. The impact on farm structure should be further investigated as minimum tillage adoption continues.

Multiple cropping in the U.S. primarily means double cropping wheat and soybeans in the Southeast. More farm management than farm structure research has been completed, although it is obvious that the technology has lead to increased production of wheat and soybeans (Marra and Carlson). Additional research on wheat/soybeans and other crop combinations is warranted because they have significant impacts on soil usage and water quality, and can dramatically impact aggregate production of specific crops.

The most significant potential in this area lies in the development of a leguminous cover crop grown with a row crop that can prevent soil erosion, provide nitrogen fertilizer, and produce a second crop of economic value. The morphological research concept could be used to determine what may be technologically feasible from the large number of possible systems. An ideal system with corn might be a permanent legume that grows in the fall and spring but becomes dormant during the summer in order to release critical moisture and nutrients to the corn. The development of such a system might be extremely difficult to engineer and implement but would have a radical evolutionary impact on agriculture, and could be invaluable in preserving soil resources and water quality.

Initial economic research on the animal growth hormones has been completed. A 1985 report (Kalter et al.) discusses the commercial production cost, the adoption rate potential, farm management implications, as well as the potential impact on the New York dairy sector of bovine growth hormone (somatotropin). Additional research on the sector impact of bGH (bST) has been completed (Magrath and Tauer), as well as the farm level impacts of porcine growth hormone (Meltzer). Since these hormones and other reapportioning agents will be available for all major livestock groups and poultry, and may become commercially available almost simultaneously, the impact on total crop acreage and by crop type may be significant (Kalter and Milligan).

Additional research includes the farm management impact of bGH (Yonkers et al.) as well as regional impacts (Boelhje and Cole). Concurrent research on the economic impacts of bGH and other animal growth hormones is now being completed at many locations. Given the significant impact that the hormones have on production and feed usage, continued research interest will probably surface well past adoption and ex post assessment. These various independent research efforts using different research techniques should be encouraged and financed in order to determine if consistent economic impact results are obtained.

The enhancement of photosynthetic efficiency and plant growth regulators are not ranked in my top 6 emerging technologies, but are significantly ranked in Canter's. Photosynthetic enhancement in corn production as concluded by Sundquist et al., would have no direct or indirect environmental consequence. Enhancement of photosynthesis in specific plants and not others could alter cropping patterns and impact conservation and water quality. Yet, enhancement of photosynthesis may not increase cereal grain yields significantly because other factors appear more limiting. Furthermore, noticeable breakthroughs are believed by many to be far down the road.

Growth regulators may not have a direct environmental impact but may have indirect impacts if cropping patterns are altered. The direct impact on yields may not be significant since growth regulars may primarily be used to assist in performing crop operations (ripening and defoliation). A potentially high purchase price may limit widespread adoption especially with low commodity prices and land extensive cultivation. Yet, there appears to be active research by chemical companies on growth regulators because the end sales product is similar to what they have historically marketed to farmers.

V. Conclusions

This report appraised current and emerging technologies in agriculture to determine which technologies may have significant impacts on water quality, and where the economic impact should be further investigated. The six most important agricultural technologies identified are (1) water and irrigation management, (2) biological nitrogen fixation, (3) plant pest control strategies, (4) minimum tillage, (5) multiple cropping, and (6) animal growth hormones.

Additional economic research on all six of these technologies is important. However, a number of significant economic research gaps were identified. The economic value of biological nitrogen fixation should be estimated in order to guide public research expenditures on that technology. The water quality impact of emerging biotechnology pest control mechanisms should be investigated, as well as the market structure implications on the farm input industry. The farm structure impact of minimum tillage has not been investigated to any great extent. The impacts of the animal growth hormones need to be thoroughly investigated because of the potential changes on regional crop acreage and animal production. Lastly, the feasibility of developing a permanent legume to multicrop with row crops should be explored. The impact on water quality and nitrogen fixation could be enormous.

In reviewing technology assessment studies it became apparent that ex post technology evaluation studies were not being fully utilized to assess emerging or future technologies. Methodology needs to be developed to systematically organize the information from ex post assessments to forecast the impacts of new technologies. Methodology from the field of futures research should be studied and utilized if appropriate in our assessment efforts. A review of that literature was done here.

The assessment of technology development and progress in agriculture has entailed convening or surveying a group of experts using a Delphi or other survey process. Performing these assessments by different agencies with differing missions and experts does not provide efficient information on the pace of development. Since it has been stated that no factor has done more to shape the structure of agriculture or influence its outcome or performance than technology has, it is recommended that technology forecasting and assessment be considered as important as commodity forecasting in providing critical information to decision-makers.

Although this paper discussed the interaction of technology and water quality, the potential role of technology in ensuring environmental quality is succinctly summarized by Crosson and Phipps. "Environmental problems arise because of a divergence between the private interest and the public interest in resource management. Research on new technology can be used as an instrument for reducing if not eliminating the divergence. The trick is to develop technologies which simultaneously serve the private economic interest and the public social interest in resource management. The great advantage of this is that it avoids the costly and socially divisive fights likely to erupt when a regulatory approach is the only option for protecting the social interest in the environment."

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