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THE ECONOMIC IMPACT OF FUTURE BIOLOGICAL NITROGEN FIXATION TECHNOLOGIES

by

Loren W. Tauer

Department of Agricultural Economics
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York, 14853-7801

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Abstract

The economic impact of some future biological nitrogen fixation technologies are estimated using AGSIM, a dynamic, partial equilibrium, econometric model of the U.S. agricultural sector. Five separate scenarios were modeled: (1) legumes fix more nitrogen, (2) legumes fix more nitrogen with an increase in legume yields of 10 percent, (3) nitrogen fertilization requirements on all crops are reduced 50 percent with no yield changes, (4) total elimination of nitrogen fertilization and (5) total elimination of nitrogen fertilization and non-legume yields decrease 10 percent. Results indicate that biological nitrogen fixation technologies have a high value to society. Increasing the efficiency of legumes to fix nitrogen may have an annual benefit of $1,067 million while decreasing nitrogen fertilization by 1,706 thousand tons. Total elimination of nitrogen fertilization of the major crops has an annual benefit of $4,484 million.

I. Introduction

The availability of chemical nitrogen fertilizer has contributed substantially to feeding the world. Without it, food would be expensive and starvation would be the norm.[1] Although some argue that the new high yielding wheat and rice varieties have been responsible for feeding the world, without nitrogen fertilizer those varieties yield no more than do traditional varieties. At the same time, however, traditional varieties do not respond to nitrogen fertilization to the extent of the new varieties. Unfortunately, the increased use of nitrogen fertilizer has also led to water quality degradation as nitrates run off into surface water or leak into aquifers.

Except for periodic energy price increases, noticeably in 1973 and 1979, the cost of nitrogen fertilizer has generally decreased over the past decades in real if not always in nominal (current) prices (Vroomen). The production of nitrogen is energy intensive. Its low cost is the result of low energy prices and advances in production and transportation technology. It is

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[1]Demographers would argue that population dynamics are indeed dynamic and respond to cultural, social, and economic changes (Tierney). If the price of food increases, families respond by having fewer children. However, since actual food prices may be different than anticipated food prices, and adjustments in average family size are not instantaneous, population may more often be in disequilibrium than in equilibrium, resulting in starvation.

generally acknowledged that low energy prices will not continue indefinitely. The facts that the price and supply of nitrogen fertilizer are explicitly related to the price and supply of energy, that nitrogen fertilizer is essential in food production, and that nitrogen usage affects water quality, compel a study of the economic benefits of new nitrogen fertilizer technologies. Since nitrogen is fixed biologically by plants as well as chemically, this study will investigate the economic value of developments in biological nitrogen fixation technologies.

The perceived importance of biological nitrogen fixation is manifested by the amount of research funding on this science. The USDA competitive grants program, 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 improvements in biological nitrogen fixation could be enormous, no study has been completed to accurately estimate that economic value. An estimate would be invaluable in justifying public funding of biological nitrogen fixation research.

The primary objective of this paper is to estimate the economic value of new nitrogen technologies in the United States once those technologies are fully adopted using AGSIM, a dynamic, partial equilibrium, econometric model (Taylor). The results will provide information on cropping patterns (production), prices and income by regions as well as U.S. aggregates. Also generated will be nitrogen fertilizer purchases by region which may be utilized in formulating water quality measures. Although research is currently being completed on nitrogen fixation, the characteristics of those future technologies are not known. To overcome this information limitation sensitivity analyses will be performed. Various plant energy requirements (yield changes) will be utilized in measuring the economic value of nitrogen fixation.

The remainder of the report is comprised of six sections. The next section describes the nitrogen technologies that may be feasible. Current and potential progress will be presented. Previous economic research on nitrogen fixation technologies is reviewed in section three. The fourth section describes the model, data and assumptions used to estimate the economic impact of new nitrogen fertilizer technologies. In the fifth section model results are presented and discussed. The final section contains a summary and conclusion.

II. Current and Future Nitrogen Technologies

Current nitrogen technologies include the production of chemical nitrogen, applying animal and crop wastes to fields, and utilizing crops symbiotic with nitrogen fixation bacteria. Future technologies include improvements in these current technologies as well as extending biological nitrogen fixation to the cereal crops and increasing the efficiency of free-living nitrogen-fixing organisms. Each of these current and potential new technologies will be briefly described and then discussed. First a description of the nitrogen cycle and nitrogen pollution will be presented.

The Nitrogen Cycle

The addition, removal and alteration of nitrogen in the soil and plant is paramount in understanding nitrogen technologies. Nitrogen is added to the soil from commercial fertilizer, animal and crop wastes, biological nitrogen fixation and even from the process of lightning oxidizing nitrogen. Some of this nitrogen is in forms that can be utilized directly by plants. In other cases nitrogen is released as ammonia from the organic compounds in residuals in a process called ammonification. This is accomplished chiefly under aerobic conditions through microbial action in excess of the requirements of these organisms for their own growth.

Nitrification is the bacterial oxidation of ammonia to nitrate, the chief source of readily available nitrogen for higher plants. First ammonia is oxidized to nitrite, then nitrite is oxidized to nitrate by organisms. These bacteria obtain their energy from the oxidations and their carbon from carbon dioxide of the atmosphere. Generally the process of nitrite oxidation is faster than that of nitrite production so the level of nitrites in soil is too low to induce toxic effects. Nitrates, however, can leach or wash from the soil and pollute water.

Denitrification is the process of nitrates being reduced to molecular nitrogen which escapes to the air. This occurs mostly under anaerobic conditions (water`logged soils) as microorganisms utilize nitrate as a source of oxygen. Denitrification is not a significant problem in well drained soils.

Besides losses to the atmosphere, runoff and leaching, most nitrogen is removed from the soil when plant products are harvested. Nitrogen is the key element for amino acids from which proteins are constructed, and crops are the major source of proteins for animals and then humans directly and indirectly.

Nitrogen Pollution

The primary plant nutrient requirements met though commercial fertilization are nitrogen, phosphorus, and potassium. Potassium fertilizer does not appear to be a potential source of pollution for either surface or ground water, and only a very small amount of fertilizer phosphorus is lost from soils if erosion is controlled (OTA). However, only 20 to 50 percent of the ammonia applied to a field actually ends up in the crop plant. The remainder is lost by either nitrate runoff or leaching and denitrification (Burgess). The amount lost is quite variable, depending upon soil, weather and farming practices (OTA).

Using data from the U.S. Geological Survey on nitrate-nitrogen levels in ground water and an index model (DRASTIC) based upon hydrogeologic characteristics and fertilizer use, Nielsen and Lee measure potential nitrate contamination of ground water in U.S. counties. According to the data, nitrate-nitrogen contamination of ground water from agricultural activities appears to be concentrated in the central Great Plains, the Palouse and western Washington State, portions of Montana, southwest Arizona, the irrigated fruit, vegetable, and cotton-growing areas of California, portions of the upper Corn Belt, southeast Pennsylvania, Maryland, and Delaware. Many of these areas represent high fertilizer applications and irrigation. Although insufficient water quality data were available, the DRASTIC index scores indicated that many areas in the eastern Corn Belt may also be contaminated. In all, 623 counties were identified with potential ground water contamination from fertilizer use.

Chemical Nitrogen

Nitrogen fertilizers are produced by variations of the Haber-Bosch process. Atmospheric nitrogen, of which air is 79 percent, consists of 2 atoms of nitrogen linked by a very strong triple bond. In the chemical process the triple bond of N_2 is broken and 3 atoms of hydrogen are added to each of the nitrogen atoms in the presence of promoted iron catalyst to produce ammonia NH_3. To facilitate the process a temperature of 400-500 degrees centigrade is used with pressures up to 200 atmospheres. The synthesis of ammonia is very energy intensive. The synthesis of one ton of ammonia consumes about 31,000 cubic feet of natural gas, or the energy equivalent of 5.59 barrels of fuel oil, or 2 tons of coal (Dixon and Wheeler). Part of this energy is used to furnish the high temperature and pressure required to operate the system. The remaining 60 percent is used to provide the hydrogen necessary for the reaction. Natural gas is the primary feedstock.

Use of ammonia (anhydrous) directly as a fertilizer requires pressurized equipment since ammonia is a gas at atmospheric pressure and temperature. The compound is knifed into the ground using applicators and pressure tanks. Other nitrogen fertilizers are produced from ammonia by further processing. Nitrogen solutions are generally water solutions of nitrogen salts and sometimes ammonia with little or no vapor pressure. Aqua ammonia, a solution of ammonia in water, is a common liquid nitrogen fertilizer. Recently liquid nitrogen solutions have become more popular because of safety, ease of handling and ability to mix with other chemicals (pesticides) to reduce application trips. The use of anhydrous ammonia and liquid nitrogen solutions are prevalent in the U.S., but dry fertilizer is pervasive in the world because of ease of handling.

Animal and Crop Wastes

Crop wastes are generally from those crops grown on the acreage. Since much of the protein material of the plant is removed (seed), and sometimes much of the entire plant (forage), much nitrogen is removed. In fact, much of the carbohydrate material left (straw and corn cobs), when decomposed by microbial organisms, will reduce the amount of nitrogen available for plants.

Animal wastes, generally manures, are high in nitrogen. Modern manure management has reduced the volatilization of ammonia from animal manure from improper storage and spreading. As animal production has become more concentrated, the disposal of manure has often become an environmental problem rather than a benefit to soil productivity.

Technological Advances

Because agriculture in developed countries has established the practice of applying commercial nitrogen, technological advances in this area would lower nitrogen fertilizer cost and increase application rates as the real price per unit of nitrogen decreases. Burgess states that the Haber-Bosch technology is mature, and major modifications to that process are unlikely, although new sources of energy and H_2, such as coal, are being developed. She recommends the development of an entirely new system for ammonia production having the following characteristics: (1) The catalyst would be inexpensive and would operate at atmospheric temperature and pressure using protons (H^+) instead of H_2, (2) energy needs of the system would come from renewable sources, and (3) the system would operate when and where needed on a small scale. Because biological nitrogen fixation has most of these characteristics, she believes it represents the best model for creating a new system. Additional knowledge of the biological nitrogen fixation process may prove of more value in producing fertilizer chemically than in any improvements made in biological fixation itself!

The ultimate goal is nitrogen fixation in all plants. Currently the legumes and some other plants have that capability in symbiosis with bacteria. The economically important cereal crops, such as corn, rice, and wheat, do not have that ability, although recent evidence indicates low levels of associated fixation in some instances (Hardy, Bottomley and Burns). The cereals must use nitrogen that is present in the soil from mineralization of organic matter, from previous nitrogen fixers, or from commercial fertilizers. Although the perceived goal is nitrogen fixation in the cereals either through symbiosis or autosufficiency, the real goal is to eliminate the need for commercial fertilizers. The production and distribution of nitrogen fertilizer requires significant energy and resources, and its application to soils often results in polluted surface and ground water. A technology that economically eliminates the need for commercial nitrogen fertilizer could be invaluable both in developed and developing countries.

There are a number of technologies that could be utilized to eliminate or reduce the need to apply nitrogen fertilizers to crops. The successful implementation of any of the techniques hinges upon advances in scientific and technical knowledge, and the economics of the technique in crop production.

One approach currently being pursued with some elements of success is to improve the nitrogen yield of current legume-*Rhizobium* symbiosis relationships. Heichel (1978) states that protein in the roots and unharvested regrowth of alfalfa provide 150 pounds of residual nitrogen fixed by symbiosis and may reduce the N fertilization needs of the following two years of corn by 50 percent. However, contrary to common belief, he states that soybeans grown in rotation with corn do not significantly reduce the N fertilizer needs of corn and in fact may be a net nitrogen remover. That is because 70 percent of the N in soybeans is removed when the grain is harvested and less than 50 percent N needs of soybeans are typically acquired from fixation in soils of moderate to high residual N, characteristic of midwestern U.S. agriculture. As a result, more nitrogen is being removed than added to the soil.

Increasing the N fixation of legumes can be accomplished by research on the plant or on the bacterium, although one would expect most progress by working on the total system to identify limiting constraints. Increases in biological nitrogen production might increase the yield of the legume since it utilizes large quantities of nitrogen to produce protein (Burgess), as well as provide rather than deplete nitrogen in the soil for grains. A grain crop could be grown in rotation with the legume. That process would assimilate very well in much of the U.S. Corn Belt where corn and soybeans are often grown in annual rotation, and to some extent in ruminant livestock areas where alfalfa and corn are grown in rotation. Unfortunately, much of the wheat produced in the U.S. is from continuous wheat, except for the double cropping of soybeans and wheat in the Southeast. Even wheat grown in a fallow rotation program would not accommodate this technique since production of the legume may deplete the soil of the moisture the fallow program is building up.

Another possibility is the development of a leaky perennial legume that could be utilized in a no-till row crop agriculture. A major difficulty in implementing this strategy, besides the bioengineering challenges since living legumes currently do not exude much if any nitrogen, is that establishment of a perennial legume would deviate greatly from current farming practices in the U.S. where some annual tillage is still the norm. Acceptance of new nitrogen technologies could be enhanced by implementing those technologies within current farming practices.

Thus direct nitrogen fixation by the cereal plants is attractive. That fixation could occur through a symbiotic or associative relationship or by directly conveying the genetics for nitrogen fixation into the plant (autosufficiency). It has been debated which would be the easiest to accomplish technically (Moffat). In either case it is almost universally believed that energy drains would reduce crop yields, although the energy cereals currently expend to convert nitrate into ammonia may be similar to the energy required to fix nitrogen (Postgate) so that a yield reduction may not occur. A yield reduction dismays some because they think it would eliminate the procedure as a viable technology. However, they fail to consider the economics. If the cost of the nitrogen saved is greater than the value of the yield reduction, then the technology would be profitable to adopt. In fact, since this would be a yield-reducing technological change, the adoption process could be significantly different from yield-increasing technology.[2]

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[2]Yield-increasing technology increases aggregate output as farmers adopt, leading to significant product price reductions given the inelastic nature of commodity demand. Although it may always be profitable for any single farmer to adopt, it would not be profitable for a coalition or group of farmers to adopt unless they could control supply. A monopoly would use the new technology to decrease costs but would curtail aggregate production in order to maximize revenue. In contrast, a yield-decreasing technology may not be profitable for a single farmer to adopt but could be profitable for a coalition of farmers to adopt. The aggregate yield reduction would significantly increase the commodity price, increasing the value of the reduced yield. Since farmers have difficulties forming coalitions, yield-decreasing technology may not be adopted or may be adopted more slowly than yield-increasing technology.

Another approach that has received less attention because of their current inefficiency in nitrogen yields is the engineering of free-living microbes that fix nitrogen. These might be photosynthetic or carbon-using. Given the relatively simple genetic structure of these organisms, it should be possible to genetically engineer their enhancement of fixing nitrogen. The photosynthetic organisms would only function on the top soil, and incorporating the nitrogen into the subsoil might be required. In addition, any production of nitrogen on the top soil might be subject to water or wind erosion and offsite pollution. The carbon-using organisms would drain energy from the soil system, but the grain crop could replenish that through organic material.

The limitation to implementing any of these nitrogen technologies is our knowledge base of biological nitrogen fixation. As that knowledge expands, it will become more evident which technique is technically, as well as economically, feasible.

III. Previous Economic Research on Nitrogen Fixation Technologies

In their report on the economic and social consequences of biological nitrogen fixation in corn production, Hill et al. state that their conclusions are derived from economic logic rather than mathematical models. In essence, the authors construct scenarios and do 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). The seven scenarios they construct and analyze, besides a base, are: (1) autosufficient corn under private control and (2) under public control, (3) symbiotic corn under public control and (4) under private control, (5) leaky legumes in soybean rotation, (6) leaky legumes using intercrop forages, and (7) BNF factory where nitrogen would be produced by microorganisms in vats or lagoons.

Autosufficiency in corn would be a scientific task since no higher plant (excluding free-living bacteria) currently fixes nitrogen without assistance from a microorganism. Symbiosis in corn may be most feasible because model plants (legumes, etc.) exist, although the authors claim autosufficiency as more feasible. A leaky legume would also be an accomplishment since little evidence indicates plants currently extrude nitrogen except by degradation of root and nodule tissue (Mulder et al.). The difference between public and private control is a higher seed cost under private control as firms recover research costs and earn a profit. (The public receives its return as greater supplies of output at lower prices.) After a five-year period, the impacts of private control shift to public control as increased competition develops, eroding monopoly rents.

The cost of corn production per acre decreases for each scenario except for number (7). Corn yields stay the same for scenarios (1), (2), and (7), increase for (3), (4), and (5), and decrease with (6) as wider rows are required to accommodate the forage legumes. Corn acreage increases and soybean acreage decreases for all scenarios except (7). The decrease in soybean acreage under scenario (5), leaky soybean, is surprising given the conclusions demonstrated by Beattie et al. that increasing the nitrogen fixed by soybeans would increase the acreage of soybeans. Although Beattie et al. assumed fixed prices, the results would hold, although muted, with typical supply and demand curves.

All seven technologies benefit corn producers, livestock producers, and soybean producers or are neutral. Consumers benefit from all technologies. Supply-increasing technologies that benefit both consumers and all types of farmers are rare, so these reported benefits are doubtful. The nitrogen fertilizer industry loses, but most other agribusinesses benefit except for the seed companies under scenarios (6) and (7), since the public develops those technologies and lower corn seeding rates are used. The transportation industry loses under scenario (7) because of losses in shipping nitrogen fertilizer not offset by significant increases in grain transportation.

The environmental impacts are mixed. Nitrogen pollution should be reduced even with increased livestock production except for scenario (7). Row crop acreage increases with all scenarios except (7) as more marginal land is brought into production, although the increase is never more than two percent. The acreage of soybean, a more erosive crop, is reduced except for scenario (7). The net environmental assessment is negative for scenarios (2), (3), and (5), and positive for (1), (4), and especially for (6). The impact is neutral for (7).

Unlike many scenario analyses, this study generally explains in detail how results were obtained, and the results for the most part could be replicated. Although a general equilibrium or other mathematical model was not utilized, the researchers used economic principles and previously estimated elasticities and production functions in obtaining their quantitative values. Collectively, the group brought a level of expertise into the analysis that a rigorous model with an inexperienced modeler could not duplicate. Given the tenuous nature of these future technologies, sensitivity analyses would have been a useful addition to their study.

Florkowski measured the economic impact of 22 different biotechnologies on selected crops. He first surveyed experts to obtain the expected percentage change in yield, and expected change in the use of selected impacts for each biotechnology. He then used that information in modifying the coefficients in a price-endogenous, linear programming model of the U.S. field crop sector. The biotechnologies included symbiotic nitrogen fixation in the cereal crops and increasing the efficiency of *Rhizobium*.

The respondents believed that research on symbiosis would decrease corn yields by 4 percent. Given their qualitative response on input changes, he modeled a nitrogen requirement decrease of 10 percent, and P and K requirement increases of 5 percent, after conferring with crop experts at the University of Illinois. Similar results held for wheat, rice, and sorghum. Improved symbiosis was expected to increase soybean yields by 7 percent. He decreased N needs by 5 percent but increased both P and K needs both by 5 percent for soybeans. Increases in the efficiency of *Rhizobium* were expected to increase corn yields by 4 percent and increase soybean yields by 12 percent, requiring fertilization increases similar to those required with improvements in symbiosis efficiency.

Many of the results reported by Florkowski are unusual and may be the result of the modeling assumptions and procedures used. Technical change typically increases the supply and reduces the price of commodities rather than decreases supply and increases the price as he reports. With symbiosis in corn he models a 4 percent decrease in corn yields, but only a 10 percent savings in nitrogen requirements. Ignoring price changes, a 4 percent yield reduction on 125 bushels an acre of corn is 5 bushels, which at $2 a bushel is worth $10. A 10 percent savings of nitrogen might be 20 pounds of nitrogen, which at 25 cents a pound would be only $5. Additional P and K are also necessary. Thus symbiotic corn, as he modeled, would appear not to be profitable, not adoptable, and would not enter solution in a mathematical programming model. Yet it enters the solution because it appears to be the only corn technology defined in the model. If corn is produced, it has to be produced using symbiosis.

Besides not modeling alternative technologies in the linear programming model, a limitation of his research was only qualitatively asking the experts whether various inputs would increase or decrease, or significantly increase or decrease, and then routinely using 5 and 10 percent for the two levels of changes for all the inputs. None of the qualitative input change responses are surprising; insect resistance should significantly decrease the use of pesticides. Speculating on the percentage change in input usage is probably no more difficult for experts than speculating on yield changes for technologies that have not yet been developed.

Halbrendt assessed the impact of biological nitrogen fixation (BNF) in corn on nitrogen fertilizer demand and corn acreage in the nine major corn-producing states using an annual, simultaneous equations model of the fertilizer industry. Her approach was to model the nitrogen supply industry as well as the corn production sector. Corn supply was estimated as a function of profitability. That profitability depended upon the use and cost of nitrogen fertilizer. To assess BNF in corn she reduced nitrogen fertilizer requirements by 25, 33, and then 50 percent holding corn yields constant. For simplification she assumed these changes occurred in 1985 and simulated out to 1990.

When nitrogen fertilizer application rates were reduced by 25 percent, the total quantity of nitrogen fertilizer consumed in the 9 states for all crops dropped 18 percent consistently through the years. When reduction rates were reduced by 33 and 50 percent, the quantity consumed dropped 25 and 36 percent respectively. Reductions in the costs of corn production slightly increased its planted acreage; as the application rates of nitrogen fertilizer decrease, the acreage planted increases. However, since the price of corn is determined by both supply and demand, corn prices fall and the increase in aggregate acreage was minimal, less than one percent in most states.

IV. The Model and Data

The purpose of this research is to estimate the economic value of future nitrogen technologies once those technologies have become fully adopted. Given the uncertainties concerning the characteristics and availabilities of these future technologies, no estimate of the benefits and costs during the adoption process was made, although the cost of resource reallocation could be significant. Because these technologies may have intricate impacts on the agricultural sector, a dynamic, partial equilibrium, econometric simulation model was used (Taylor). The economic impacts were measured by solving the model with and without the new technologies. The reduction in nitrogen fertilizer applied by region with the new technologies was calculated. No attempt was made to incorporate fertilizer utilization into nitrogen pollution estimates. Canter has concluded that currently there is no complete agreement among researchers on the nature of the relationship between nitrogen application and nitrate concentration in water supplies. Most researchers, however, agree that reduced nitrate concentrations in the nation's water systems would be possible if farmers applied less nitrogen fertilizer per acre.

AGSIM is an econometric-simulation model of regional crop and national livestock production in the United States developed by C. Robert Taylor and colleagues. The model was constructed to analyze the regional and aggregate economic impacts of a wide variety of issues facing agriculture, including technological change. The model consists of econometrically estimated supply and demand functions. The crop supply equations are rather unique in that supply response was estimated as a function of profitability rather than prices. Thus the supply equations are strictly behavior relationships. Technology is altered in the model by adjusting costs or yields, which in turn affect profitability. This is in contrast to the normal estimation procedure of estimating supply as a function of prices such that technology is embedded in the estimated coefficients along with behavior relationships.

The eleven regions used in AGSIM are listed in Table 1. These are the standard 10 USDA regional definitions with Illinois separated from the other Corn Belt states. Crop supply equations are estimated for each of the eleven regions. Livestock production, however, is estimated at the national level. There are also consumer and export demand functions for the various commodities. The AGSIM model allows the user to change yields per acre by crop by region by year, variable or fixed costs per acre by crop by region by year, support price and diversion payments by crop by year, and conservation reserve acreage by region by year. Changes in yields and variable costs with various nitrogen fixation technologies will be discussed later. No changes were made in support price or diversion payments. The conservation reserve acreage used in all applications, including the base run, is listed in Table 2 and was taken from Taylor.

The economic value of any new technology depends upon whether resources are fully utilized or excess production capacity exists. Also important is the level of technical efficiency in production at the time the new technology becomes available. The new nitrogen technologies will not be available for a number of years and uncertainty exists concerning the agricultural situation at that time, making it difficult to assess their economic impact from other changes that will occur. To overcome these limitations, the technologies will be evaluated as if they were available in the year 1987, the first year of the simulation, with complete adoption. They will thus be evaluated based upon the current technology and commodity demand situation. Results for the last year of the simulation, 1996 will only be reported.

Table 1. AGSIM Regional Definitions.

Region	States
Illinois	Illinois
Other Corn Belt	Indiana, Iowa, Missouri, Ohio
Lake States	Michigan, Minnesota, Wisconsin
Northern Plains	Kansas, Nebraska, North Dakota, South Dakota
Southern Plains	Oklahoma, Texas
Delta	Arkansas, Louisiana, Mississippi
Mountain	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
Pacific	California, Oregon, Washington
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Appalachia	Kentucky, North Carolina, Tennessee, Virginia, West Virginia
Southeast	Alabama, Florida, Georgia, South Carolina

Table 2. AGSIM benchmark: Conservation reserve acreage, 1986 to 1990-96.

State or region	Year			
	1986	1987	1988	1990-96
	Thousand acres			
	--actual--	---projected---		
Illinois	272	481	785	1,127
Other Corn Belt	1,090	1,926	3,144	4,514
Lake	1,169	1,834	2,499	2,853
Northern Plains	2,469	4,323	6,177	7,163
Southern Plains	3,239	4,714	5,714	6,188
Delta	545	812	970	1,112
Mountain	4,845	6,975	8,425	9,113
Pacific	1,116	1,734	2,352	2,679
Northeast	262	634	1,006	1,205
Appalachia	675	1,285	1,895	2,220
Southeast	918	1,345	1,599	1,826
U.S. Total	16,600	26,063	34,566	40,000

The economic value of specific nitrogen technologies will be assessed by solving the model with and without the technologies and comparing the differences for 1996. These differences will be assumed to continue annually indefinitely. The explicit assumption is that any continuous increase in commodity demand will be met by increases in productivity, and those productivity increases will not bias the productivity of the nitrogen technologies. Thus, for instance, if nitrogen autosufficiency decreases corn yields by 10 percent, that 10 percent applies to 120 bushels an acre corn as well as to 200 bushels an acre corn.

These assumptions, which are reasonable given no prior information on availability and thus supply and demand, dramatically simplify benefit/cost analysis. If the technical change is forecast for the year 2000 and beyond, then the net present value of that change can easily be computed given a constant annual economic value beyond the year 1999. The net present value provides an upper limit on net present cost that can be expended on research and development and still experience a net economic gain.

Nitrogen Technology Scenarios

Five separate scenarios were modeled. They are: (1) legumes (alfalfa and soybeans) fix more nitrogen, (2) legumes fix more nitrogen with an increase in legume yields of 10 percent, (3) nitrogen fertilization requirements on all crops are reduced 50 percent with no yield changes, (4) total elimination of nitrogen fertilization, and (5) total elimination of nitrogen fertilization and non-legume yields decrease 10 percent. Although not exhaustive, these five scenarios are comprehensive and represent a variety and range of technical possibilities. For instance, a 50-percent reduction in nitrogen fertilization requirements could represent any combination of nitrogen fixation, utilization or application technologies.

In scenario (1) a nitrogen fixation efficiency in legumes (soybeans and alfalfa) of 90 percent was modeled (compared to the current norm of 40 to 60 percent) with no yield increase. Since nodules are not formed instantaneously, some nitrogen might still be extracted from the soil and seed (Dixon and Wheeler). Data to compute the additional residual nitrogen fixed are from Heichel (1987), Tables 3.4 (nitrogen budget for soybean) and 3.5 (nitrogen budget for seeding-year alfalfa).

At 35 bushels an acre yield the symbiotic nitrogen return in the residue of soybeans is 16 pounds an acre under 40 percent fixation of nitrogen requirements. At the same time 151 pounds of nitrogen are removed in the grain (protein) of which 90 pounds was not fixed by the plant, leading to a net nitrogen removal of 74 pounds. If fixation efficiency can be increased to 90 percent, then 37 pounds of nitrogen can be residually fixed. Of more importance, however, is the fact that of the 151 pounds of nitrogen removed through the grain, only 15 pounds (10 percent) were not fixed by the soybean plant, leading to a net nitrogen addition of 22 pounds. The difference between this amount and the previous net removal of 74 pounds means that increasing fixation efficiency from 40 percent to 90 percent reduces nitrogen requirements from soil organic matter or from carryover fertilizer by 96 pounds or 2.74 pounds per bushel of soybeans produced. It is assumed that this ratio applies to all regional yield levels.

It is known that current nitrogen fixation efficiencies vary by location depending upon environmental conditions and soil fertility. Although the factors responsible for these variations are known, the multivariable quantitative impact is not known sufficiently nor do sufficient empirical observations exist to determine the current fixation efficiency of soybeans grown in various regions. However, lower efficiencies are reflected in the fact that more nitrogen is currently applied on soybeans in some regions than in others.

From Heichel (Table 3.5) the symbiotic nitrogen return in the roots and crown of alfalfa that yields 3.47 ton D.M. per acre is 40 pounds. At the same time 78 pounds of soil nitrogen is removed in the herbage for a net nitrogen removal of 38 pounds. This assumes all herbage is harvested and none is plowed down. This occurs at a nitrogen fixation efficiency of 63.5 percent. If nitrogen fixation efficiency is increased to 90 percent, then 57 pounds of nitrogen would be residually fixed. The pounds of soil nitrogen removed in the herbage would decrease to 21 for a net nitrogen increase of 36 pounds per acre. Thus, increasing nitrogen efficiency from 63.5 to 90 percent would reduce nitrogen requirements from soil organic matter or other sources by 74 pounds or 21.3 pounds of nitrogen per ton of hay produced. Heichel's data were for seeding-year alfalfa. Hesterman et al. state that it is possible that a greater proportion of incorporated legume N could be recovered by corn following an older alfalfa stand. To reflect this, the 21.3 pounds was increased 15 percent to 24.5 pounds of nitrogen per ton of hay produced.

Although all biologically fixed N may not be made available to a cereal crop in a succeeding year, it is also true that all N fertilizer applied is not made available. Much of those losses are attributed to over-fertilization; if correct amounts were applied, utilization efficiency would increase. Some nitrogen may also be lost because of application during the fall or spring when rainfall can leach or wash much of the nitrogen from the soil before it is needed for plant growth. In contrast, much of the release (mineralization) of biologically fixed nitrogen occurs when plants are actively growing.

Heichel (1987), after reviewing the literature on legume N availability to a succeeding crop, has stated that maybe only 25 percent of the symbiotically fixed N contained in a legume would be recovered by the first subsequent nonlegume crop, and another 4 percent by the second crop. The remainder of the legume nitrogen is apparently incorporated into a soil organic matter pool that turns over very slowly. A work group report on crop nutrition technology at the RCA symposium on future agricultural technology and resource conservation (English et al.) also concluded that nitrogen fertilizer use efficiency is currently 50 percent.[3] If only 25 percent of

[3]Nitrogen use efficiency was defined as the nitrogen contained in the above-ground portions of the fertilized crop minus the nitrogen content of a nonfertilized check divided by the amount of fertilizer nitrogen applied, all times 100.

biologically fixed nitrogen is utilized and only 50 percent of chemically applied nitrogen is utilized, then two pounds of biologically fixed nitrogen would be necessary to replace one pound of applied fertilizer nitrogen.

The amount of nitrogen fertilizer reduction for a cereal crop following soybeans with 90 percent N from symbiosis is then one-half of 2.74 or 1.37 pounds per bushel of soybeans produced. Table 3 shows the value of that nitrogen reduction for the 11 regions of the model. To include these values in the AGSIM model the variable cost of growing soybeans in each region was reduced by the value of the nitrogen, reflecting the added value of soybeans due to the nitrogen carryover. For Illinois, which has an average soybean yield of 35.79 bushels, 49.03 pounds less nitrogen would be necessary for corn that follows the next year with no reduction in corn yield. At a price of $150 a ton for 30 percent nitrogen solution fertilizer, the marginal value of that nitrogen is $12.26. For cereal crops following alfalfa the nitrogen fertilizer reduction is 12.25 pounds per ton of hay produced. For an Illinois average all hay yield of 3.17 tons of hay per year, nitrogen fertilizer would be reduced by 38.83 pounds for a succeeding year grain crop. However, since only 58 percent of the hay acreage in Illinois is alfalfa, the value of the nitrogen saved per acre of all hay is only $5.63 (Table 4). Since the AGSIM model is defined in terms of all hay, this adjustment in nitrogen from the alfalfa acreage was necessary. The adjustment is not completely accurate since the yield used for alfalfa is the all hay yield. At the same time, unlike the other modeled crops, AGSIM does not use a regionally differentiated hay budget, but rather the national cost average so that the costs of producing hay do not vary regionally.

For scenario (2) the same nitrogen fixation improvements were used as in scenario (1) but legume yields were also increased 10 percent. Since legumes are high in protein, increasing their ability to fix nitrogen may also increase their yields. To implement this scenario soybean yields were increased 10 percent in each region. The all hay yield was also increased 10 percent weighted by the ratio of alfalfa to all hay (Table 4). For the Corn Belt this amounts to an all hay yield increase of .108 tons per acre. No additional costs were imputed in producing 10 percent additional yields. Few farmers would change input usage, and the marginal cost of harvesting approximately 3 more bushels of soybeans or 200 lbs. of alfalfa is trivial.

If cereals fix all of their own nitrogen in scenarios (4) and (5), then the nitrogen fixed by legumes has no carryover value. To reflect this, no legume carryover value was used and the nitrogen applied to soybeans was eliminated since preceding any nitrogen fixation in the cereals should be improvements in legume symbiosis. Burgess states that with nitrogen fixing cereals the need for fertilizer would be eliminated, but no increase in yields would be expected.[4] Thus in scenario (4) cereal yields were not altered. However, since it may not be possible to engineer cereals to fix their own

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[4]Because cereals obtain their N from nitrate which must be converted into ammonia before it can be used, and the energy required for this process is just about equivalent to that used for N^2 fixation, Burgess believes the total amount of energy required by the plant may be similar.

nitrogen without a yield reduction, scenario (5) also included a 10 percent reduction in non-legume yields. For simplicity, when these cereals were modeled to fix only half their nitrogen needs in scenario (3), no carryover nitrogen value was imputed for the legumes and legume nitrogen fertilizer needs were also halved. Englestad speculates on the impact of a corn crop that supplies half its own nitrogen requirements.

Table 3. Regional per Acre Values of Increasing Nitrogen Fixation Efficiency in Soybeans.

Region	Soybean Yield (bu/acre)	Increased Nitrogen from Soybeans (lbs/acre)	Value of Nitrogen (a)
Illinois	35.79	49.03	$12.26
Other Corn Belt	32.96	45.16	11.29
Lake States	33.35	45.69	11.42
Northern Plains	27.06	37.07	9.27
Southern Plains	21.89	29.99	7.50
Delta	22.71	31.11	7.78
Mountain	NG		
Pacific	NG		
Northeast	27.65	37.88	9.47
Appalachia	23.50	32.20	8.05
Southeast	20.38	27.92	6.98

(a) Valued at $0.25 a lb. of N.
NG = Not Grown.

The scenario of 50-percent reduction in nitrogen fertilizer with no yield reduction can represent nitrogen technologies other than biological nitrogen fixation by the cereals. Examples include reduction in nitrogen losses from denitrification, better nitrogen placement and utilization, and the enhancement of nitrogen fixation by free living microorganisms.

The USDA crop production budgets, on which the AGSIM model was estimated, list expenditure on total fertilizer per crop by region. To implement the nitrogen fixation scenarios it was necessary to estimate the proportion of the fertilizer expenditure that was nitrogen.[5] Fertilizer quantities for corn, cotton, soybeans, and wheat came from the Inputs: Outlook and Situation Report, which provides estimates of the quantity of fertilizer used by nutrient (nitrogen, phosphate, and potash) in major producing states. Since fertilization data were not available for all crops for all regions, contiguous or similar regions were used. These quantities

[5]This estimation was done by John Love, Research Support Specialist, Cornell University.

were then multiplied by regional fertilizer prices obtained from Agricultural Prices. The estimated fertilizer expenditures were then compared to the fertilizer cost in the USDA cost of production budgets, and expenditures on the three nutrients were proportionally adjusted so that fertilizer expenditures were identical. In most cases little adjustment was necessary because the procedure used is apparently very similar to the procedure used by the USDA to develop regional budgets. Data on the minor crops were not available, so the proportion of their fertilizer budget that was nitrogen was based upon the nitrogen proportion of a similar crop. For milo, corn was used. Wheat was used for the other small grains (barley and oats). The amount of nitrogen applied on hay was not computed. Only one hay budget for all regions is available and the fertilizer expenditure was $12.50. Nitrogen is applied on the grass hays, but given their lower value it is doubtful whether these will be engineered to fix nitrogen until a much later date than the crops.

Table 4. Regional per Acre Values of Increasing Nitrogen Fixation Efficiency in Alfalfa.

Region	All Hay Yield (ton/acre)	Increased Nitrogen from Alfalfa (lbs/acre)	Ratio of Alfalfa to All Hay (a)	Value of Nitrogen (b)
Illinois	3.17	38.83	.58	$5.63
Other Corn Belt	2.56	31.36	.42	3.33
Lake States	3.13	38.34	.63	6.06
Northern Plains	1.88	23.03	.47	2.73
Southern Plains	2.30	28.18	.12	.83
Delta	1.96	24.01	.04	.26
Mountain	2.63	32.22	.62	4.96
Pacific	3.93	48.14	.60	6.22
Northeast	2.40	29.40	.43	2.59
Appalachia	1.80	22.05	.13	.72
Southeast	2.17	26.58	.04	.29

(a) Derived from the 1982 U.S. Agricultural Census by taking the ratio of alfalfa acreage to all hay acreage.
(b) Valued at $0.25 a lb. of N.

Table 5 shows the nitrogen fertilizer cost per acre by region for each crop. That cost was subtracted from the variable cost of production in the AGSIM model to simulate total elimination of nitrogen fertilizer, and one-half the cost was subtracted to simulate 50 percent reduction in nitrogen fertilization. No allowance was made for application costs. Many farmers now apply nitrogen with P and K, which still would be applied, or apply nitrogen solutions as carries for pesticides. Application costs would be eliminated with anhydrous ammonia, commonly used in the Corn Belt and Plains. Table 6 shows non-legume crop yields by region. These were reduced by 10 percent in scenario (5) with complete nitrogen fertilizer elimination.

Table 5. Estimated Nitrogen Fertilizer Expenditure by Crop by Region.

	Corn	Milo	Wheat	Barley	Oats	Soybeans	Cotton
Region			- - - - - - - - - $ Per Acre - - - - - - - -				
Illinois	24.85	NG	23.83	NG	7.17	6.12	NG
Other Corn Belt	24.85	NG	23.83	NG	7.17	6.12	NG
Lake States	24.85	NG	23.83	NG	7.17	6.12	NG
Northern Plains	9.71	6.25	6.83	6.91	3.64	2.00	NG
Southern Plains	19.31	5.81	6.69	7.22	3.25	2.00	4.25
Delta	29.97	9.01	20.32	NG	7.17	5.13	17.86
Mountain	15.19	9.36	5.64	14.58	4.10	NG	21.48
Pacific	15.19	9.36	16.92	14.58	3.01	NG	21.48
Northeast	24.76	NG	18.45	14.13	17.33	15.76	NG
Appalachia	29.97	9.01	20.30	14.13	7.17	15.76	28.27
Southeast	29.97	9.70	20.32	14.13	7.17	15.57	28.27

NG = Not Grown.

Table 6. Crop Yields per Acre by Region.

	Corn	Milo	Wheat	Barley	Oats	Cotton
Region	Bu.	Bu.	Bu.	Bu.	Bu.	Lbs.
Illinois	116.34	NG	41.78	NG	40.63	NG
Other Corn Belt	110.08	71.71	39.52	NG	43.86	411.18
Lake States	102.55	NG	38.97	52.84	50.64	NG
Northern Plains	101.98	60.00	30.16	43.26	39.46	NG
Southern Plains	120.04	52.37	22.53	30.01	10.64	290.45
Delta	67.61	56.99	32.67	NG	44.68	561.17
Mountain	130.63	40.69	31.83	52.11	24.86	1029.25
Pacific	138.51	76.62	54.20	56.21	19.99	961.48
Northeast	97.67	NG	36.93	43.74	53.50	NG
Appalachia	85.25	58.47	31.32	44.56	22.21	414.09
Southeast	65.00	39.22	27.99	41.48	26.15	518.15

NG = Not Grown.

V. Results

Consumers benefit under all five nitrogen fixation technologies except when non-legume yields decrease by 10 percent. Then consumers experience an annual consumer crop surplus reduction of $12,788 million (Table 7). Likewise, crop producers also gain under all five nitrogen fixation technologies except when legume yields increase by 10 percent where they suffer a reduction in income of $4,125 million (Table 7). The results clearly show the transfer of benefits between producers and consumers under technology that changes yields. Consumers benefit the most when yields increase 10 percent, but producers then suffer the most, and vice versa when yields decrease 10 percent.

Technological change does not necessitate a transfer of wealth from producers to consumers or vice versa, however. If total nitrogen fertilization can be eliminated, crop consumers' welfare increases by $866 million while producers' income increases by $3,034 million a year. Engineering legumes to fix more nitrogen also benefits both consumers and producers, although the gain to consumers is almost as large as nitrogen fertilization elimination, while the gain to crop producers is considerably less than they would gain by the total elimination of nitrogen fertilization.

The changes in consumer livestock surplus is similar to the changes in consumer crop surplus but at some magnitude less. Increases or decreases in crop production or prices are indirectly felt by livestock consumers through changes in livestock prices or production as a result of changes in crop production and prices.

The changes in livestock producers' income are often opposite that of crop producers' income, reflecting the transfer of benefits resulting from changes in feed costs. The elimination of nitrogen fertilization requirements benefits both crop producers and livestock producers. Crop producers benefit from lower production cost; they increase crop production so that livestock producers also benefit. However, when that technology is coupled with a 10 percent per acre yield decrease, crop producers gain immensely due to high crop prices, but livestock producers are negatively affected by the higher crop prices. Engineering an improvement in legume nitrogen fixation benefits crop producers but costs livestock producers because of the shift from grains to more legume production.

The various technologies do have some regional variations in distributions of costs and benefits. The share of the total U.S. benefits or costs that accrue to the Corn Belt is either 39 percent, 41 percent or 42 percent depending upon the technology. Likewise, the Lake States share is also fairly constant at 15 percent, 16 percent or 17 percent. Of course, a one percent change can range from a positive $83 million to a negative $35 million a year. The percentage distribution variation is more significant in some of the other regions. Specifically, the Northern Plains capture only 5 percent of the U.S. benefit if crop nitrogen requirement is reduced, but capture 11 percent of the U.S. benefit if legumes fix more nitrogen. The Northern Plains produces significant amounts of alfalfa. The same distribution pattern exists for the Mountain states. In contrast, the opposite is true for the Appalachian and Southeast regions. Their distribution of benefits (and actual benefits) is greater with reducing nitrogen fertilization rather than increasing legume fixation efficiency, since these regions produce soybeans but little alfalfa.

The impact of the five technologies by commodity is shown in Table 9. If legume nitrogen fixation efficiency is increased, more legumes are grown and less grains, but all commodity incomes increase. If there is simultaneously a 10 percent increase in legume yield per acre, then legume product prices decrease causing legume acreage to decrease and grain acreage to increase. The effect is to decrease all commodity incomes.

Reducing fertilization requirements causes grain acreage to increase with a product price decrease, and legume acreage to decrease with an increase in product price. In all cases producers' incomes increase, grain producers save on fertilizers, and legume producers receive a higher price. If grain yields also decrease by 10 percent, grain prices increase and the income impact is even more significant for the grains.

These results are all applicable for the last year of a 10-year simulation with the technologies introduced in the first year of the simulation. Since these future technologies are ambiguous, it is uncertain when they will become available and how quickly they will be adopted. Yet, these figures can still be used to roughly estimate the net present value if an introduction year is selected. For instance, the total net consumer and producer surplus of increasing legume nitrogen fixation is estimated to be $1,067 million a year. If that technology would be available in 10 years, the net present value of a perpetual benefit flow at a discount rate of 10 percent is $4,113 million. At a 10 percent interest rate it would be possible to expend up to $669 million a year for 10 years on research and development and still generate a positive net benefit to society. However, if the benefits are only available 30 years in the future, the annual amount that can be spent for 30 years is only $64 million.[6] These benefit/cost comparisons do not include any reduction in ground water contamination which could be a significant benefit (Nielsen and Lee).

All five nitrogen technologies reduce the quantity of nitrogen fertilizer applied (Table 9). Over half of the nitrogen fertilizer reduction occurs in the Corn Belt and Lake States but that is where over half of the fertilizer is currently used on the crops modeled. Increasing the efficiency of legumes in fixing nitrogen reduces nitrogen proportionately more in the Corn Belt, Lake States, and Northern Plains because more alfalfa is grown there and the yields of alfalfa and soybeans are higher, creating more residual biomass. Reducing the nitrogen fertilization requirements of all crops (but hay) tends to benefit the southern regions proportionately more.

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[6]These large benefits and potential rates of return are not unusual in agricultural research (Evenson and Kislev).

Table 7. Impact of Various Nitrogen Technologies on U.S. Agriculture.

	Legumes Fix More Nitrogen	Legumes Fix More Nitrogen with 10% Legume Yield Increase	Reducing Crop Nitrogen Fertilization by 50%	Total Elimination of Nitrogen Fertilization Requirements	Elimination of Nitrogen Fertilization and Non-Legumes Yields Decrease 10%
	--- Millions of Annual Dollars ---				
Change in Consumer Crop Surplus	577	8,623	438	866	-12,788
Change in Producers' Crop Income Above Variable Costs	462	-4,125	1,503	3,034	8,828
Change in Consumer Livestock Surplus	152	3,774	32	67	-1,346
Change in Livestock Producers' Surplus	-124	-741	261	517	-4,004
Change in Crop Income by Region					
Corn Belt	154 (39%)*	-1,444 (41%)*	545 (42%)*	1,096 (42%)*	3,190 (41%)*
Lake States	69 (17%)	-591 (17%)	208 (16%)	421 (16%)	1,184 (15%)
Northern Plains	43 (11%)	-518 (15%)	71 (5%)	145 (6%)	1,015 (13%)
Southern Plains	10 (3%)	-155 (4%)	41 (3%)	83 (3%)	328 (4%)
Delta States	31 (8%)	-214 (6%)	89 (7%)	182 (7%)	388 (5%)
Mountain	31 (8%)	-194 (5%)	36 (3%)	74 (3%)	374 (5%)
Pacific	14 (4%)	-199 (6%)	37 (3%)	74 (3%)	263 (3%)
Northeast	17 (4%)	-86 (2%)	50 (4%)	100 (4%)	214 (3%)
Appalachia	16 (4%)	-76 (2%)	105 (8%)	211 (8%)	407 (5%)
Southeast	12 (3%)	-77 (2%)	116 (9%)	234 (9%)	377 (5%)
U.S.	397	-3,554	1,297	2,620	7,739

*Percents of U.S.

Table 8. Impact of Various Nitrogen Technologies on Specific Crops.

	Corn	Wheat	Soybeans	Cotton	Hay	Other	Total
Legumes Fix More Nitrogen							
Change in Price ($1.00/unit)	.01	.01	-.26	.01	-.90	NA	NA
Change in Acreage (1,000 acres)	-161	-76	476	-52	55	-5	237
Change in Producers' Income (mil. $)	66	14	246	18	106	12	462
Legumes Fix More Nitrogen with 10% Legume Yield Increase							
Change in Price ($1.00/unit)	-.11	-.10	-1.80	-.01	-15.87	NA	NA
Change in Acreage (1,000 acres)	999	891	-3,028	51	-1,087	200	-1,974
Change in Producers' Income (mil. $)	-646	-165	-1,926	-14	-1,219	-2,593	-4,125
Reducing Nitrogen Fertilization Requirements by 50%							
Change in Price ($1.00/unit)	-.04	-.06	.12	-.01	-.01	NA	NA
Change in Acreage (1,000 acres)	471	498	-286	74	-46	208	919
Change in Producers' Income (mil. $)	644	339	421	37	5	57	1,503
Total Elimination of Nitrogen Fertilization Requirements							
Change in Price ($1.00/unit)	-.08	-.12	.24	-.02	-.04	NA	NA
Change in Acreage (1,000 acres)	949	1,003	-578	152	-89	414	1,851
Change in Producers' Income (mil. $)	1,300	691	843	75	9	116	3,034
Elimination of Nitrogen Fertilization and Non-Legume Yields Decrease by 10%							
Change in Price ($1.00/unit)	.71	.92	.94	.11	.93	NA	NA
Change in Acreage (1,000 acres)	2,580	1,144	-1,367	-9	-84	1,240	3,504
Change in Producers' Income (mil. $)	4,107	1,629	2,002	255	106	729	8,828

NA = Not Applicable.

Table 9. Change in Nitrogen Fertilizer Used by Technology by Region.*

	Legumes Fix More Nitrogen	Legumes Fix More Nitrogen with 10% Legume Yield Increase	Reducing Crop Nitrogen Fertilization by 50%	Total Elimination of Nitrogen Fertilization Requirements	Elimination of Nitrogen Fertilization and Non-Legumes Yields Decrease 10%
	--- Nitrogen Reduction in Tons Per Year ---				
Corn Belt	758,283	781,496	1,259,065	2,527,806	2,527,806
Lake States	253,031	267,001	523,777	1,056,621	1,056,621
Northern Plains	170,729	179,475	368,507	736,687	736,687
Southern Plains	19,923	16,720	167,493	335,858	335,858
Delta States	181,483	190,713	170,612	347,429	347,429
Mountain	78,226	88,832	156,241	314,409	314,409
Pacific	37,178	39,726	139,589	279,940	279,940
Northeast	46,003	50,688	87,003	176,156	176,156
Appalachia	95,510	88,037	296,278	598,170	598,170
Southeast	65,173	49,738	236,389	481,118	481,118
U.S.	1,705,539	1,752,427	3,404,955	6,854,196	6,854,196

*Total nitrogen use on corn, cotton, wheat, and soybeans was 6,962,000 tons in 1985 (Vrooman).

VI. Conclusions

It is clear that biological nitrogen fixation technologies have a high value to society. Increasing the efficiency of legumes to fix nitrogen may have an annual benefit of $1,067 million while decreasing nitrogen fertilization by 1,706 thousand tons. Total elimination of nitrogen fertilization of the major crops has an annual benefit of $4,484 million.

These results and others were obtained by using the AGSIM model (Taylor) to econometrically determine the impact of five separate nitrogen technologies. Yet, the results must only be viewed as approximates because of limitations in using the AGSIM model to assess nitrogen fixation technologies. Crop rotations are not explicit in AGSIM and many of the BNF technologies would alter crop rotation plans. Some of the BNF technologies also shocked the AGSIM variables outside the historical values used to estimate the equations, questioning the validity of some results. The hay sector of the AGSIM model is also its weakest section (one budget was used on all regions), and improvements in nitrogen fixation may occur in alfalfa initially. AGSIM does model net exports, but no production is modeled outside the U.S. Any BNF technologies may be available worldwide, affecting trade of commodities.

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