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Regional Factors Affecting the Impact of Biotechnology in U.S. Crop Production

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ABSTRACT

The regional impacts of future biotechnology in crop production would be affected by the crop mix, climate, input use, and particular pest problems which have developed in the U.S. agricultural system over the years. The future products of biotechnology are difficult to predict accurately, but researchers indicate that reducing production losses due to environmental and pest pressures is the direction being taken in the late-1980s. The use of seeds, fertilizers, and chemicals in the production of crops is a $15 billion industry and is a target for improvement through biotechnology. However, commercial products are not expected until the mid-1990's. The aggregate impact of biotechnology on U.S. crop agriculture is likely to be the greatest from innovation in four major crops: corn, soybeans, wheat, and hay. The regions of most importance for these crops are in the midwest: Corn Belt, Lake States, and Northern Plains. On a regional basis, high-input crops such as cotton, fruit, and vegetables in the coastal states could be affected by biotechnology because of their high per-acre costs of inputs.

Currently biotechnologists are developing improved methods of genetic manipulation to facilitate isolation and transfer of desirable traits to economically important crops. As yet, however, progress has occurred more rapidly with certain microbes and dicotyledonous crops than with the more important monocotyledonous cereal crops such as corn and wheat. A major hurdle in the successful development of transgenic cereal crops has been the difficulty of regenerating whole plants from manipulated cell cultures. Clearing that hurdle could increase the opportunities for a significant aggregate impact from biotechnology.

A biotechnology in corn production that eliminates the insect damage normally occurring under current control practices could increase annual production by 7 percent, a difference possibly equivalent to $978 million annually in 1995-97. Production would increase the most in the Corn Belt and Northern Plains; while increasing the least in the Delta and Pacific regions. A biotechnology that eliminates weed losses in soybean production could increase annual production 9.8 percent, a difference possibly equivalent to $760 million annually in 1995-97. In this case, the Corn Belt, Lake States, and Delta regions would increase production the most. Estimating the benefits of loss-reducing biotechnologies in other crop-pest combinations is limited by a lack of comparable regional data.

The total value of U.S. corn and soybean crops would be pressured to decline 15 percent with the projected supply increases possible from biotechnologies that eliminate insect losses in corn and weed losses in soybeans. Using elasticities of -0.408 and -0.349 for corn and soybeans, respectively, the 1995-97 combined total value of annual production with these yield increases could be $4.1 billion below what

it would be without these increases. Commodity differences with respect to elasticity of demand, yield benefits, and regional production affect the regional distribution of the producers' impact from crop biotechnologies.

The consumers' benefit from insect-resistant corn and herbicide-resistant soybeans amounts to about $2.9 billion and $3.1 billion, respectively. The combined $6 billion in consumers' benefit net of the producers' $4.1 billion lower crop value results in an annual $1.9 billion net impact from these two general biotechnologies. The distribution of the social benefit is likely to be greater in high population regions, such as the Northeast and Pacific, than in the midwest.

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Policymakers could more effectively identify the research needs and potential impacts of biotechnological innovation in U.S. agriculture by recognizing regional differences in cropping patterns, yield constraints, and production systems. Farmers in Illinois and neighboring states of the midwest are likely to benefit more from herbicide resistant corn than farmers in western and southern states where corn is less important to total crop production. Similarly, genetically engineered insect and pathogen resistance would affect production more in regions where crops and climate are conducive to pest outbreaks. A basic presumption in assessing the impacts of biotechnology in agriculture is that innovations are likely to be adopted with greater consequence in regions with greater potential benefits. Biotechnology firms also view the market potential for new products with this in mind (Smail). Therefore, it is important to know where the major crops are produced and the problems amenable to a biotechnological solution in order to anticipate where the likely significant impacts from biotechnology will occur.

In order to facilitate the policymaking process affecting crop biotechnology, more ex ante economic research is needed to build a common base of information for further analysis. An example of this type of analysis is the U.S. Congress's 1986 report from the Office of Technology Assessment (OTA). It recognized regional impacts of new agricultural technologies expected in the next century, and it gave comprehensive treatment to general policy and farm structure issues. However, the general nature of the OTA analysis permitted only limited detail about the possible regional impacts of specific crop biotechnologies. In previous research on the impact of specific biotechnologies in corn production, Tauer and Love found that losses due to weeds are likely to be variable across regions, and the benefits from eliminating weed losses with herbicide-resistant corn could vary with the year of adoption and the cost of the new technology. Similarly, Tauer found the Corn Belt, Lake States, and Northern Plains regions would be affected more than other regions under several scenarios in which biotechnology improves nitrogen fixation or use efficiency in crop production.

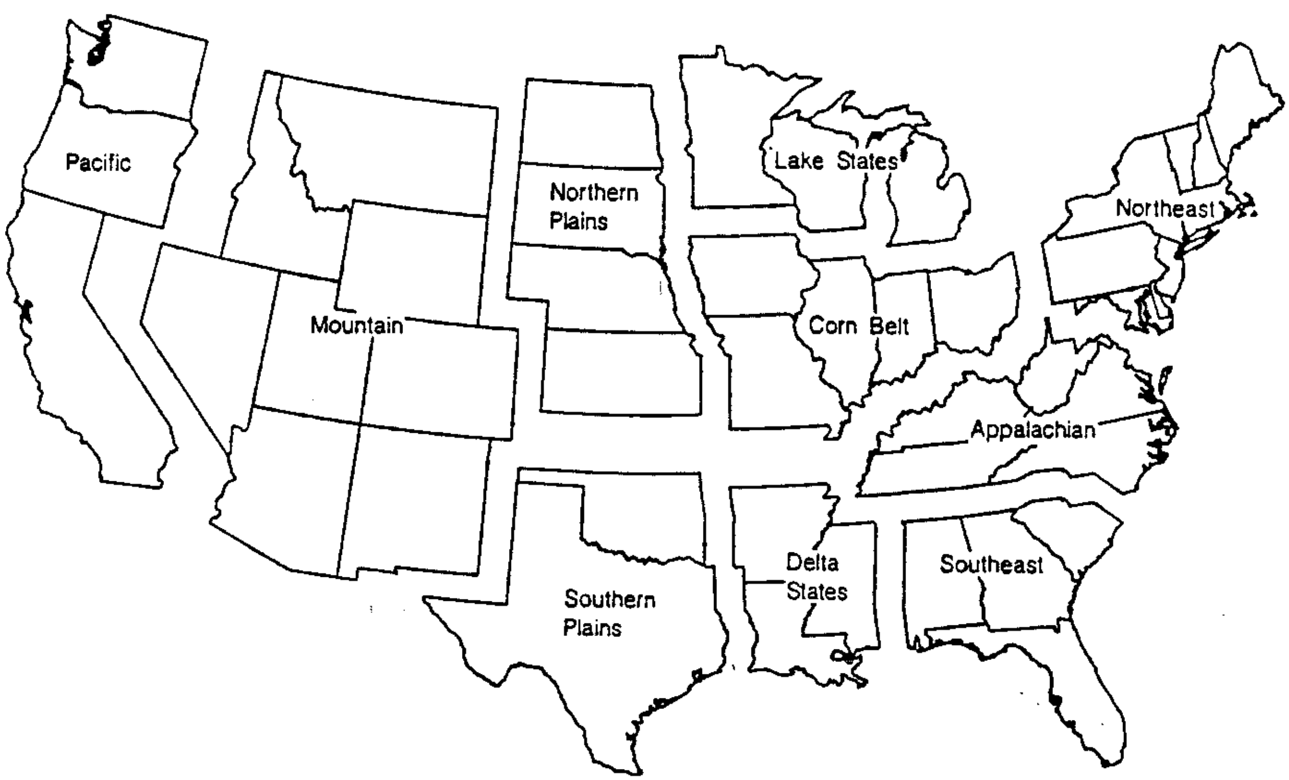
The purpose of this paper is to present a broad overview of U.S. regional differences in crop production and relate them to selected biotechnologies. The selection of future biotechnologies is based on agricultural researchers' predictions of likely near-term developments. Although these predictions may be imperfect forecasts for the particular products that actually become available to producers, they are useful guides for discussion. The paper begins with a general description of U.S. crop agriculture followed by a brief overview of the underlying concepts of biotechnology currently used in crop science. Following this, prospective biotechnologies affecting insect control in corn and weed control in soybeans and their possible regional effects on crop production are discussed. The prospects for biotechnology in controlling viral and fungal diseases on major crops are discussed in more general terms.

OVERVIEW OF U.S. FARMS AND CROPS

Major U.S. Crops and Farm Characteristics

The United States Department of Agriculture (USDA) delineates ten U.S. production regions (Figure 1, Appendix table 1). By applying the USDA regional definitions to the 1982 Census of Agriculture, it is possible to describe several key regional characteristics of U.S. farms. In terms of acreage harvested, the five most important regions are the Corn Belt, Lake States, Northern Plains, Southern Plains, and Mountain regions (Table 1). Based on total sales per farm, the largest farms are found in the West and Mountain regions, while the smallest are in the Appalachia. Clustered around the U.S. average sales per farm are the Northeast, Corn Belt, Lake States, and Southeast regions. The average proportion of U.S. farm sales from crops is 58 percent, ranging from 64 percent in the Pacific region to 31 percent in the Northeast.

Figure 1
Farm Production Regions



Twenty major U.S. agricultural crops are ranked by annual farm value of sales in Table 2. Sixty-eight percent of the total $58 billion in value comes from corn (25 percent), soybeans (17 percent), hay (16 percent), and wheat (10 percent). These four crops also occupy 82 percent of the 304 million total acres harvested. Therefore, in terms of total U.S. agricultural production and value, corn, soybeans, hay, and wheat are the most important crops for improvement through biotechnology. The next group comprising cotton, tobacco, potatoes, sorghum, oranges, tomatoes, grapes, barley, and peanuts accounts for 25 percent of the total value and 13 percent of the acreage. The remainder of the listed crops plus those not listed are relatively minor in comparison with these top 13 commodities.

Farm sales from grains (corn, wheat, soybeans, sorghum, oats, and other grains) are half or more of total crop sales in the Corn Belt (94 percent), Northern Plains (93 percent), Lake States (74 percent), Delta (69 percent), Southern Plains (58 percent), and Mountain (49 percent) regions. Grains are less important to total crop sales in the Appalachia (37 percent), Northeast (27 percent), and Southeast (22 percent) regions, and least important to the West, where the top sales per farm is due to the large share of high-valued fruit, vegetable, and specialty crop operations.

The midwest regions--Corn Belt, Lake States, and Northern Plains--produce most of the important grain crops in U.S. agriculture (Table 3 and Appendix table 3). Their combined shares of total U.S. value of corn are 84 percent; soybeans, 80 percent; hay, 42 percent; wheat, 53 percent; sorghum, 54 percent; and oats, 78 percent. Substantial production of hay, which is costly to transport, occurs also in the Northeast, Mountain, and Pacific regions where it is used mostly in feeding dairy animals. Wheat is produced in substantial proportions in the Southern Plains, the Mountain, and Pacific regions. Sorghum in the Northern Plains is produced mainly in Kansas and Nebraska, and in the Southern Plains mainly in Texas.

The midwest regions' 60 percent share of crop acreage also tends to produce higher grain yields than the other regions (Table 4), excepting the Pacific region. Yield trends in the major producing areas suggest that the Northern Plains region is improving its per-acre productivity in grain crops, especially in corn production (Ash and Lin). In addition to the regional effects of acreage, climate, and soil, different yields at any point in time may be affected by region-specific differences in technology adoption. The complementary infrastructure of a region's agricultural economy also affects the level of crop production. For example, even though wheat yields are above average in the Northeast, where dairy is highly important to the region's agriculture, the relatively low total production of wheat is explained by corn- and forage-based feeding practices for cows. That is, Northeast farmers have a comparative advantage in growing corn and hay rather than wheat to feed cows.

Climate and Input Use

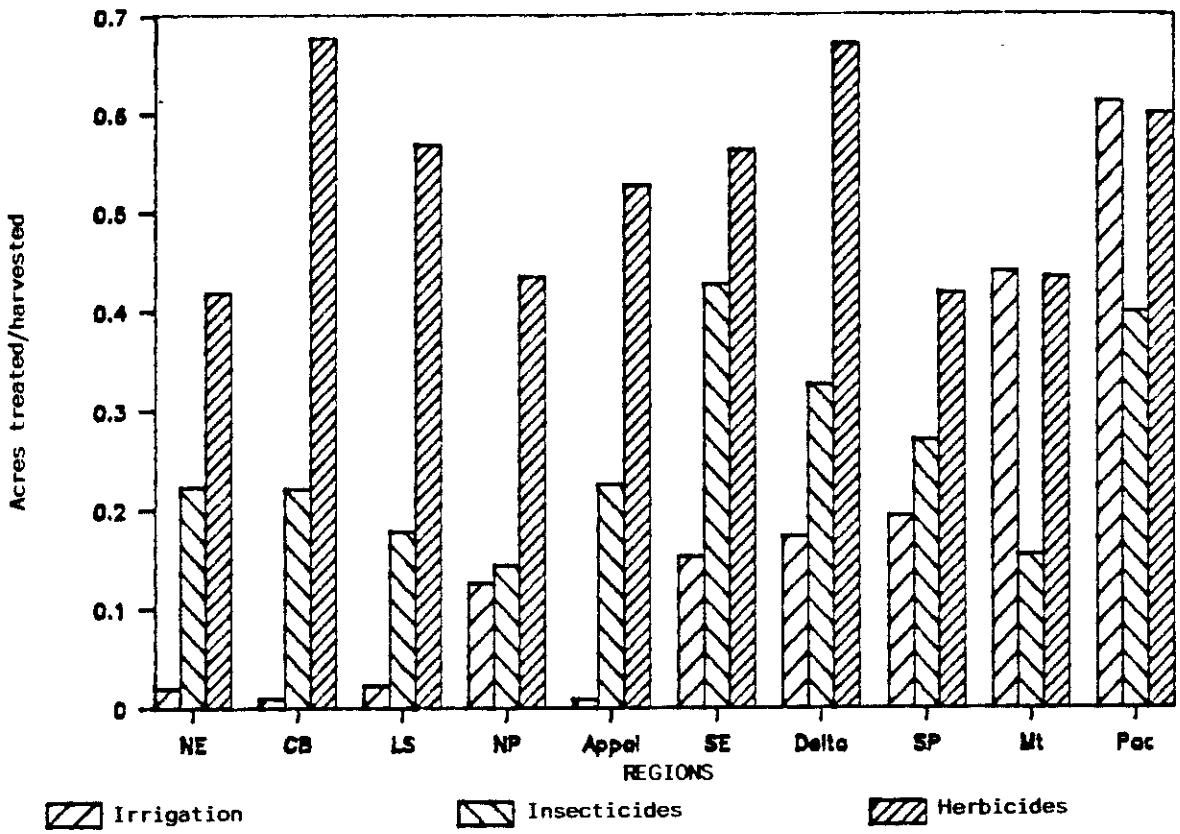
Regional differences in crop yields can be explained largely by differences in climate and input use. For example, annual variations in corn and soybean yields in the midwest are highly correlated over the last four decades. The complex climatic patterns in the continental United States result from interactions among geography, topography, moisture availability, land mass, and wind direction. Generally, the average monthly precipitation during April to September, when most U.S. crops are grown, increases from west to east (Table 5). Also, the highest average monthly temperatures are typically found in the southern states at low altitudes. However, the yield advantages of higher temperatures and longer growing seasons in the southern and western states are somewhat offset by increased costs to control insect, disease, and weed pests.

In terms of input use, 58 percent of the total cost of seeds, bulbs, plants, trees, etc. is incurred in the three midwest regions: Corn Belt (31 percent), Lake States (14 percent), and Northern Plains (13 percent) (Table 6). Similarly, these three regions account for about 53 percent of the total fertilizer costs but only 46 percent of the agricultural chemical and spray costs (which are 95 percent crop pesticides). Compared to the Corn Belt and Lake States regions, the Pacific, Northeast, Southeast, and Delta regions have higher per acre costs of inputs, and the Northern Plains region has far lower. These relationships can be understood not only in the context of climate and geography, as mentioned above, but also with respect to crop mix. The higher valued items, such as tree fruits, vegetables, and horticultural specialties, are high-input crops with specialized requirements for production and marketing that lead to the high per-acre costs of production.

Figure 2 is a more detailed representation of regional patterns in irrigation and pesticide use. Regional precipitation patterns largely explain irrigation's importance on crop acreage in the Pacific (61 percent irrigated) and Mountain (44 percent irrigated) regions and its comparatively negligible use in the Corn Belt, Appalachia, and Northeast regions. In the Pacific region, the predictably dry summer climate and extensive use of irrigation support production of high-valued crops which, in turn, require extensive use of chemical insecticides to protect against losses in yield and market quality. Also, southern states which produce cotton and fresh-market fruits and vegetables use insecticides more extensively than northern states.

Herbicides are the most important single class of chemical pesticides (Table 7). The annual $2.5 billion to $3 billion U.S. value of herbicide production is about 55 percent of total pesticide value (Daberkow). The widespread adaptive nature of weeds accounts for the more uniform per-acre use of herbicides across regions. However, some crops, such as corn and soybeans, require more weed control than others. This partly explains the more extensive use of herbicides in the Corn Belt, compared to the Northern Plains, where wheat is more important. In the other regions, the distribution of herbicide use generally follows the distribution of crop acreage.

FIGURE 2. U.S. INPUT USE ON CROPS



In certain southern states continuous soybean cultivation on sandy soils partly explains the higher proportion of acreage treated with nematicides. The soybean cyst nematode, root-knot nematode, and other ectoparasitic species cause up to 8 percent losses in Southeast states and 4-5 percent in the Appalachia and Delta states (Mulrooney). This complex of disease organisms is the most important disease group in soybean production, but overall, nematicides are a relatively minor component of total U.S. agrichemical use. Crop rotation and resistant varieties are the two most important nonpesticide practices used to reduce nematode damage in the Southeast region (National Agricultural Pesticide Impact Assessment Program).

The relatively higher use of fungal disease control chemicals in the Pacific is again explained partly by the region's high-value crop mix; while in the Southeast, high rainfall and warm temperatures favor pathogen growth and development generally. By contrast, the combination of cooler, drier conditions and disease resistant varieties of grains grown in the Northern Plains region partly explains their less extensive need for chemical disease control. However, like nematicides, fungicides are relatively less important to total agrichemical use.

The annual per acre cost of using seed, fertilizer, and chemicals for production of the major crops ranges from $19 in oats to $86 in corn (Table 8). The highest seed and fertilizer costs occur in corn, while the highest chemical cost occurs in cotton. In corn production, seed, fertilizer, and chemicals account for 68 percent of the variable input costs; in soybeans, 63 percent; in hay, 32 percent; in wheat, 53 percent. On a U.S. total acreage basis, the cost of using these three inputs is highest for corn at $5.9 billion, followed by soybeans ($2.1 billion), wheat ($1.5 billion), hay ($1.2 billion), cotton ($0.79 billion), grain sorghum ($0.44 billion), barley ($0.30 billion), and oats ($0.14 billion).

In summary, several general statements can be made about the potential impact of biotechnology in crop agriculture, based on regional characteristics of production. If biotechnology is to have a significant aggregate impact on U.S. crop agriculture, it is likely to happen through effects on the major crops: corn, soybeans, hay, and wheat. At the farm level of production, these four commodities are worth $40 billion, about half of the total value of U.S. crops. They account for about three-fourths of the U.S. total crop acreage and seed, fertilizer, and chemical inputs. The overwhelming importance of these four crops to U.S. agriculture indicates where, if biotechnology is to have a significant aggregate impact, it will develop: The Corn Belt, Lake States, and Northern Plains regions. However, for biotechnologies affecting hay and wheat crops, the Northeast, Mountain, and Pacific regions are also likely to be regions of interest. Corn requires the highest per acre use of inputs, while soybeans, hay, and wheat are less input-intensive. The chief chemical inputs to corn and soybean production are fertilizers, insecticides, and herbicides, making them likely candidates for biotechnological substitution or enhancement.

On a per acre basis, biotechnology which enhances non-grain crop yields may have a proportionately greater impact in the Pacific, Northeast, Southeast, and Delta regions with high-valued crops. High-valued crops, such as fruits and certain vegetables, require higher costs of input use to maintain quality and reduce losses from cosmetic damage. Therefore, the per acre impact of biotechnology substituting for high cost-of-production items could be greater in states such as California, Texas, and Florida. For example, a biotechnology that eradicates fungal diseases could affect fresh-market produce growers in the coastal regions proportionately more than a similar technology for midwest grain producers. Another example is cotton, which requires a high cost of chemical technology against insect damage, and is grown mainly in southern states. Chemical substitution with biotechnology could result in larger per-acre benefits in the West, Southern Plains, and Delta regions.

Similar regions, with common longterm trends and variation in yields, would be expected to share a portion of the benefits of biotechnology. Dissimilar regions, with differences in climate, geography, crop mix, and land use, are expected to develop and adopt different biotechnologies and perhaps not share the benefits as much. For example, the potential for biotechnology to substitute for irrigation is expected to be greater in the Pacific and Mountain regions where precipitation during the growing season is often inadequate and to transfer less readily to other regions with adequate rainfall. Likewise, a biotechnology that substitutes for disease-control chemicals in the Pacific region is not likely to transfer readily to the midwest, where disease problems are less important.

NEAR-TERM BIOTECHNOLOGIES

Current Techniques

Biotechnologists currently use three general techniques to accomplish genetic manipulation of crops: (1) biological transfer with infectious vectors, for example, bacteria, (2) fusion or somatic hybidization, and (3) mechanical transfer with microinjection, electroporation, and high-force projectiles (U.S. Congress, 1988b). The biotechnology comprising these three methods is a potential improvement in plant breeding technology because the genes for desirable traits can be isolated and transferred without interference from other genes. In the first method, the vector is manipulated to carry the desirable gene into crop tissue, and the tissue culture is made to regenerate into a whole plant. If the vector is a plasmid from Agrobacterium tumefaciens (a gall-forming bacterium), the process is called agroinfection (Grimsley). In the second method, the walls of plant cells are removed to form protoplasts, which are amenable to genetic manipulation and can be fused together to form somatic hybrids. The fused protoplast material is made to regenerate cell walls, and the cell culture regenerates the whole plant. In the third method, genes are placed into cells by means of needle-like instruments, or allowed to diffuse across membranes with the use of electrical charges. The novel approach of bombarding cells with gene-coated pellets is known as "biolistics", and has shown the potential to alter plants that have been difficult to handle with the first and second methods (Bryant).

Genetic manipulation has been more successful on microbes, such as bacteria, but it is the more complex crops which are likely to hold the greatest potential for economic benefits in agriculture. A major limitation in biotechnology with the monocotyledonous cereal crops has been the difficulty in regenerating whole plants from cells which are amenable to genetic manipulation. An important reason why certain dicotyledonous crops, such as tomato and potato, are frequently included in the list of candidate crops is their capacity to regenerate and the relative ease of genetic manipulation using Agrobacterium tumefaciens as the gene vector. Improvements in the cell culture process or development of alternative methods of manipulating whole plants to avoid the necessity of cell regeneration could increase the list of candidate crops for near-term biotechnological improvement. Compared to tree crops and other perennials, annual and biannual crops are more likely to produce an impact from near-term developments in biotechnology, since the higher annual frequency of planting increases the opportunity for introducing new genes through seeds, transplants, or clonal stock.

Research Directions

Three general areas of emerging crop biotechnologies have been identified: (1) microbial inocula, (2) plant propagation, and (3) genetic modification (U.S. Congress, 1986). Biotechnology using microbial inocula essentially means putting microorganisms to work, for example, by enhancing bacterial nitrogen fixation efficiency, manufacturing pathogen and insect toxins, or deleting ice-forming bacterial genes. Plant propagation refers to bypassing the sexual phase of natural plant breeding to produce, for example, disease-free "seed" stock, increased crop uniformity, or novel types of planting material. One suggested novelty is encapsulated plant tissues that replace the need for seeds (Fraley). Genetic modification, although "the least established of the various biotechnologies used in crop improvement" (U.S. Congress, 1986, p. 6), means transferring the desirable genes of one crop to another, for example, disease resistance genes or nutrient-specific genes.

The OTA conclusion in 1986 that crop biotechnologies generally are not in the near-term stages of development agreed with other reports at the time (for example, Lu). Based on a seven- to ten-year research and development phase, Fraley estimated the mid- to late-1990's as the earliest date for commercial introduction of biotechnological innovations in crop agriculture. Florkowski and Hill surveyed scientists and concluded that crop biotechnologies probably would not be ready for commercial use until after 2000. The first biotechnologies forecasted for crops were herbicide tolerance, improved nutritional composition, and increased resistance to viruses, fungi, bacteria, and insects. Enhanced nitrogen-fixing abilities and photosynthesis were felt to be less likely to develop in the near term.

In 1988, however, the OTA cited herbicide, disease, and pest resistance along with enhanced tolerance to environmental factors (such as salt, drought, temperature, and heavy metals) and nitrogen fixation as biotechnologies "pending or anticipated in the near future". (U.S. Congress, 1988a, p. 5) In another 1988 report of scientists' assessment, biotechnologies that are expected to increase tolerance or resistance in crops affected by herbicides, pathogens, and insects were identified as near-term developments (Regulatory Considerations: Genetically-engineered Plants). By 1990, insect-resistant experimental crops may include corn, soybeans, alfalfa, tomatoes, tobacco, and rapeseed brassicas. By 1992, large-scale field testing of herbicide resistance is expected to involve corn, soybeans, rice, cotton, tomatoes, tobacco, and rapeseed brassicas. Also, early field tests of pathogen resistance will involve tomatoes, potatoes, and alfalfa.

A consensus is emerging in these reports that resistance to yield reducing factors, such as insects, diseases, or drought, is one of the approaches being tried by scientists working with crop biotechnologies. However, commercial biotechnology in the major cereal crops is expected to be available only after 1992 (U.S. Congress, 1988b). It should be cautioned that these reports are not written independently of previous assessments and the methods of forecasting dates of commercialization are not well documented, suggesting that these forecasts may contain a consistent bias toward optimism. Nevertheless, the reports are indicating particular likely areas of research where future developments will occur.

REGIONAL ECONOMIC IMPACTS OF CROP BIOTECHNOLOGIES

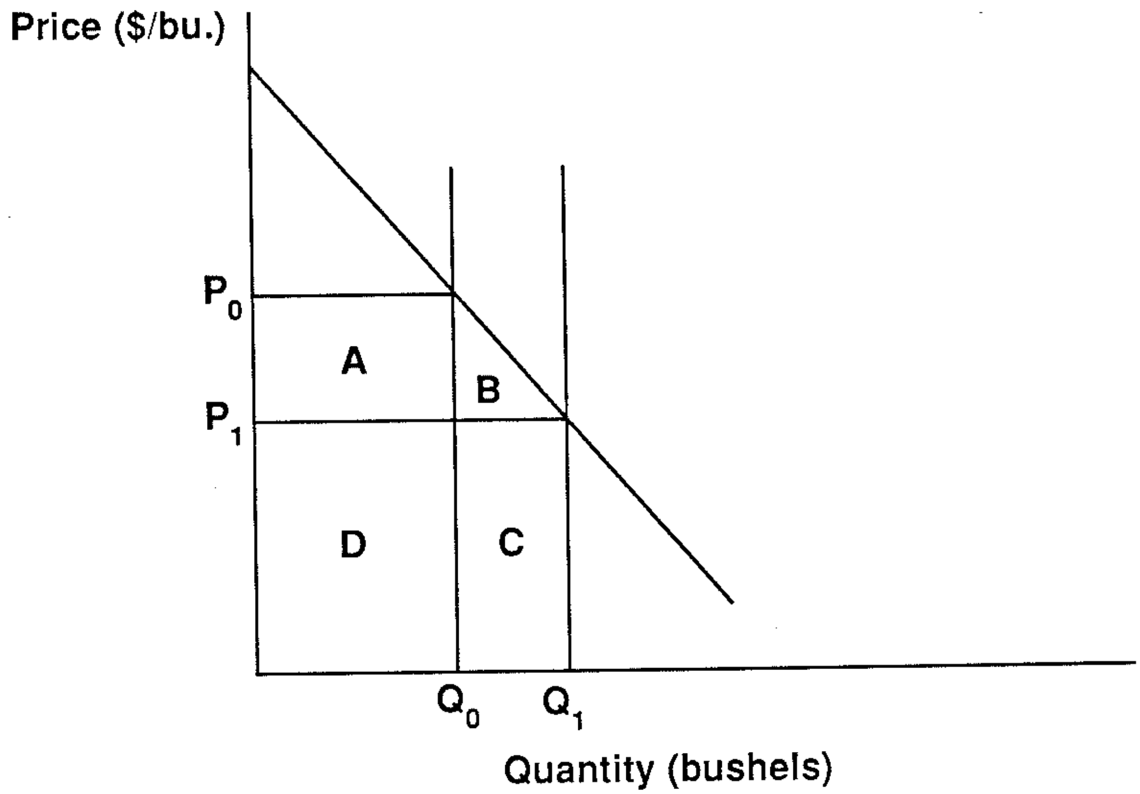
General Considerations and Assumptions

The future net impact of a biotechnological innovation in U.S. crop production is the outcome of a complex interaction of events. For example, the impact of a yield-enhancing biotechnology in corn production would depend upon the net difference between cost and benefit of adoption, the extent of adoption, the aggregate output effect on corn prices via the demand for corn, the price effect on corn supply and the consequent impact on input demand, and so on as producers and consumers adjust to the innovation. Also, whether a biotechnology substitutes, complements, or has no effect on the existing set of technologies will affect differently the use and productivity of the other inputs and subsequent impacts on output. A measure of all these changes and their meaning for U.S. agriculture is outside the focus of this analysis. Instead, the objective of the analysis is to project a regional yield response from a loss-reducing biotechnology, to place a value on the additional crop production and the total final crop, to measure the change in consumers' surplus, and to point out regional differences in the possible outcomes.

The procedure is outlined in Figure 3. The pre-biotechnology estimate of annual production for 1995-97, corresponding to Q_0, was obtained from trend yields and 1985-87 average annual acreage (Appendix tables 2-5). The post-biotechnology yield improvement is represented by the change in supply from Q_0 to Q_1. Before the introduction of a biotechnology, the commodity markets are assumed to be in equilibrium at 1985-87 regional prices, corresponding to P_0. The impact on price is measured through Conway's elasticity estimates, which indicate that for U.S. corn and soybeans, a 1 percent increase in supply is accompanied by a 0.408 and 0.349 percent decrease in price, respectively. The price response is represented by the change from P_0 to P_1. The consumers' benefit is represented by area A plus area B. The impact on producers is represented by the change in total crop value $(Q_1*P_1)-(Q_0*P_0)$, corresponding to area C minus area A. The impact on producers does not account for any increased cost that may occurr from adopting the biotechnology. The net impact on consumers and producers corresponds to area B plus area C.

To obtain estimates of the possible additional benefits of pest-control biotechnologies, percentage losses due to insects, weeds, and diseases in crop production are obtained from pest control experts in the National Agricultural Pesticide Impact Assessment Program (NAPIAP). Relying upon research and demonstration plots, field experience, and pest control surveys, NAPIAP estimated percentage yield losses assuming the 1983 pattern of pest control practices in the major production states. Not all states were surveyed by NAPIAP, so estimates from the surveyed states in a region are used to represent the nonsurveyed

Figure 3. Demand Analysis



states. If all the states in a region were not surveyed, then the average of all surveyed states is used to represent the region. Because the NAPIAP estimates are limited to corn and soybean production, the discussion is primarily focused on the impact of biotechnologies for these two commodities.

Insect-resistant Corn and Herbicide-resistant Soybeans

A considerable amount of scientific attention has been focused on genetically engineered biological control of insects (Miller). Leading the list of potential commercial biological control agents (BCAs) is a bacterium, Bacillus thuringiensis (Bt). The Bt gene that produces a potent insect toxin has been isolated and field trials of transgenic corn plants with the Bt gene have been reported (Joyce). Other possible, less developed BCA products include viral and fungal entomopathogens (Carter). The potential advantages of BCAs generally include target-pest specificity and low environmental persistence. Pointing to several past shortcomings which have hindered BCA competition in the chemical pesticide market, Jutsum suggests that future BCAs will not substitute but rather complement chemical pesticides. The competitive advantages of chemical pesticide use include convenience in application, reliability or consistency, and profitability. The complementary aspect of BCAs with chemical pesticides may be a slowing of development of pest resistance to chemicals. Unfortunately, this complementary aspect involves the characteristic of a common property and there may be little profit incentive for an individual farm to use BCAs.

The use of insecticides in corn production is second only to herbicides. About half of the corn acreage in the Corn Belt, Lake States, and Northern Plains regions is treated 1 to 2 times per season with chemical insecticides (Suguiyama and Carlson). The average per-acre cost of insect control on U.S. corn acreage is about $4.25, 22 percent of the $19 per acre in total chemicals costs (Tauer and Love). On the basis of total variable costs to produce corn, $4.25 per acre amounts to about 3 percent (U.S. Department of Agriculture, 1988d). Applying this average cost of corn insecticides to 68 million acres of corn planted results in a U.S. total annual cost of about $289 million to control insect damage.

The average loss in U.S. corn production from all insect pests is estimated to be about 7 percent (Table 9). To forecast the future value of a biotechnology that eliminates insect damage, the NAPIAP estimates were applied to the projected 1995-97 annual production. A 7 percent loss from insect-pest damage in U.S. corn production would represent about 9.8 bushels per acre in 1995-97, or about 643 million bushels additional annual production. An aggregate increase of 7 percent in the supply of U.S. corn would put pressure on corn prices to decrease by about 17 percent, resulting in a value of additional production worth about $977 million. This corresponds to the area in C of Figure 3.

Herbicide use in soybean production amounts to over $1 billion annually, nearly half of the herbicide market value (Netzer), and 95 percent of all U.S. soybean acreage is treated with herbicides one to two times per season (U.S. Department of Agriculture, 1987). Weeds cause about 9.8 percent loss in annual U.S. soybean production (Table 9). A biotechnology in soybean production which eliminates weed losses by 1995-97 could increase annual production by 207 million bushels. As with the additional corn supply, an annual value of $760 million for the additional soybean production is represented by area C in Figure 3.

The impact of these two general biotechnologies on the producers of corn and soybeans is to lower the value of total production (Table 10). Total crop values with biotechnology are lower than without the biotechnology by 11 and 21 percent for U.S. corn and soybeans, respectively. The decrease in value amounts to about $1.9 billion in corn and $2.2 billion in soybeans. Each estimate corresponds to area C minus area A in Figure 3. Combined, the impacts at the producers' level amount to about $4.1 billion lower value of production. These are annual estimates.

Among the midwest regions, the Northern Plains fairs best in the case of insect-resistant corn with only a 9 percent reduction in total crop value, while the Lake States fairs best in the case of herbicide-resistant soybeans with only a 17 percent reduction in total crop value.

The reason for the difference is that the highest yield benefit exists in these regions. That also applies in the Mountain States, where the insect damage in corn production is highest among all regions and the relative decrease in crop value is lowest. The impact in the midwest regions, though, is more important due to the volume of production, where a decrease of about $3.5 billion is 85 percent of the total $4.1 billion producers' impact.

Table 10 shows what could happen to annual total crop value of U.S. corn and soybeans under the assumption of immediate and complete adoption of the insect resistance in corn and herbicide resistance in soybeans. However, the downward pressure on total crop value would put pressure on producers to reduce costs or substitute other, higher valued production with available inputs. Cost reduction could be accomplished by scale economies--enlarging operations--or adopting other technologies. Substituting other, higher valued production could be accomplished by switching enterprises; but conditions, such as proximity to markets and managerial expertise, must be appropriate to realize the profitability of switching.

The consumers' benefit (A+B in Figure 3) from insect-resistant corn amounts to about $2.9 billion, and from herbicide-resistant soybeans amounts to about $3.1 billion. The net difference of the combined consumers' benefit ($6 billion) and the combined producers' impact ($4.1 billion) is about $1.9 billion. There may be important regional differences in the distribution of this net impact. Regions with high populations, such as the Northeast and Pacific, would benefit more than low population regions in the midwest. The high population regions thus have an incentive to increase funding of biotechnology research and development in U.S. crop agriculture as long as the cost of R&D are lower than the benefits.

<u>Other Biotechnologies in Pest Control</u>

The number of crop-pest combinations in U.S. agriculture is large enough to prohibit usefully listing them all and estimating their regional importance. However, average losses in U.S. crop production due to broad categories of pests were estimated by the U.S. Department of Agriculture for the 1940s and 1950s, and a sample of the major crops is given in Table 11. Along with weeds and insects, there are viruses, fungi, bacteria, nematodes, and rodents and other mammals which cause diseases or losses in a wide variety of crops. (See Love and Tauer, Chapter 1, for an overview of crop losses.) A comprehensive, up-to-date literature on the production losses from many crop-pest combinations by region or state does not exist and is not likely to be forthcoming (Teng and Shane, Padula). In fact, NAPIAP estimates for corn and soybean losses are the only recently available compilation of expert opinion that assigns losses to crops by U.S. regions. Therefore, regional analyses for wheat, hay, sorghum, barley, oats, potatoes, tomatoes, etc. are beyond the limitations of available data.

To gauge the complexity of the broad pest categories in Table 11, disease pests--which can cause from a half to a third of the losses due to pests--will be examined more closely. The disease-causing organisms are mainly fungi, bacteria, and viruses. In wheat production, the principal fungal pathogens are Puccina spp., Fusarium spp.. and Septorium spp. In Barley, the fungal pathogens are mainly rootrots, Helminthosporia spp., and Fusarium spp.; the viral diseases are mainly stripe mosaic and yellow dwarf. In oats production, the fungal pathogens are crown rust, blast, root necrosis, and stem rust, while the important viral disease is yellow dwarf. Bacterial diseases in citrus and in pome fruit can cause severe disease losses, and in some cases relocation of production to other regions. In vegetable production, the principal viral pathogens are Potato Leaf Roll Virus, Cauliflower Mosaic Virus, Aster Yellows, Broad Bean Wilt Virus, and Bean Yellow Mosaic Virus. In potato production, a major fungal pest is late blight, Phytophthera infestans, but other fungi are also important. Each organism has evolved a specialized relationship with its host crop, and offers particular problems to biotechnological solution. Regional differences in environmental conditions are highly important to the pressures exerted by different pests on crop production, and generalizations from particular crop-pest combinations in one region are difficult to apply to other crop-pests or other regions.

Several general statements can be made, however, about the relative importance of some pests and regional factors affecting the potential for biotechnology in U.S. crop production. For instance, biotechnology which affects wheat, oats, or barley will impact northern states. In contrast, biotechnology which affects cotton or citrus fruits will impact southern states. The impact on producers of pome and stone fruits, for example apple, pear, and cherry, would occur mainly in northern states: Washington, Michigan, and New York. The impact on fresh-market vegetables would occur mainly in coastal states: California, Texas, and Florida and the eastern seaboard. The impact on processing vegetables would occur in several western and midwestern states: California, Oregon, Washington, Minnesota, Wisconsin, and Idaho.

SUMMARY AND DISCUSSION

Because of regional differences in resources, climate, and crop mix across the United States, the potential impact of biotechnology in agriculture may be unevenly distributed, depending at least on which technologies are developed and adopted. The near-term promise of biotechnology in U.S. crop production appears to lie in reducing the losses due to pests which are not currently controlled with traditional methods. An emerging consensus among scientists indicates that progress may be forthcoming in genetically engineered crops that resist herbicides, insects, fungi, bacteria, and other loss-causing factors. In our analysis, regional differences in the impacts of specific biotechnologies were measured using experts' estimates of crop loss, trend yields, and information about the likely price response from an increase in the supply of corn and soybeans. For other crops, the general lack of crop loss assessment limits the discussion to general terms.

Assuming that adoption is rapid and complete, our analysis shows that the midwest regions stand to be affected more from reducing insect losses in corn production and weed losses in soybeans, compared to the rest of the United States. The Delta region also is affected relatively more from reductions in weed losses in soybeans. The regional differences are due to differences in pest pressures, acreage harvested, and trends in yields.

The consumer is the major beneficiary of lower cost agricultural production, as intermediate producers tend to pass along the cost savings through competitive pricing. Therefore, regional differences in the final benefits of biotechnology may be important at the level of population and household consumption patterns. For this reason, regional benefits of biotechnology could be unevenly distributed among regions. Another consideration would be the benefit of off-season production to the nonproducing regions. For example, a biotechnology that reduced shipping losses in fresh-market tomato production would benefit northern consumers in the winter months.

Several limitations of the analysis should be discussed. Indirect impacts on the crop sector of agriculture through biotechnological innovation in the livestock and poultry sector are not treated, but previous research in the area of growth hormones has been done (see Kalter, et al.) Also, the assumption that adoption is immediate and complete is convenient for the purposes of analysis, since the actual pattern of regional and temporal diffusion of future biotechnology is unknown. However, the impact of adjustment during the diffusion phase is perhaps the most important part of a comprehensive analysis. The specific relationships with biotechnology await further research.

A biotechnology is almost certain to require some trial and error, and we have indicated that certain biotechnologies could be more attractive in some regions than in others. However, the cost of waiting to adopt could diminish, or even exceed, the very economic benefits promised by higher yields. The magnitude of price response in an inelastic market such as corn or soybeans is a major incentive for producers to be early adopters of a new technology. Early adopters have the opportunity to realize the increase in yield while receiving a higher market price than late adopters, who may realize the increase in yield, but only after the market has devalued it. Therefore, differential rates of adoption would affect the distribution of the technology's impact.

The impacts of past technologies in agriculture are difficult to unravel from the effects of other factors. For instance, attributing past changes in farm population, income, employment, trade, or other indicators of U.S. agriculture to fertilizers, herbicides, insecticides, cultivation techniques, improved genetic resources, weather, farm policy, and other factors is difficult. With this in mind, the speculative component in predictions about future impacts of biotechnology should be weighed considerably. However, agricultural policy decisions are certainly affected by changes in technology, and biotechnology could contribute to major changes in future innovation. Therefore, further <u>ex ante</u> research on the impacts of agricultural biotechnology could help to anticipate future policy questions.

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Table 1. U.S. agriculture: Harvested acreage, farm size, and proportion of farm sales from crops and grains, by region, 1982.

Region	Acreage harvested	Farms	Farm size acreage	Farm size sales	Farm sales share from crops	Farm sales share from grains
	Million	1,000	Acres/ farm	$1,000/ farm	Percent	
Northeast	12.9	151	85.2	56.6	31	8
Corn Belt	82.4	491	168.0	57.8	53	50
Lake States	37.0	235	157.5	56.9	37	27
Northern Plains	72.0	207	347.6	84.9	41	38
Appalachia	17.4	336	51.9	28.0	51	19
Southeast	13.1	159	82.5	56.2	55	12
Delta	18.0	125	144.4	49.4	56	39
Southern Plains	29.7	258	115.4	44.5	34	19
Mountain	26.2	122	214.9	85.9	40	19
Pacific	17.5	158	110.1	111.1	64	10
Total 1/	326.3	2,241	145.6	58.9	58	28

1/ Subject to rounding error.

SOURCE: Data compiled from U.S. Department of Commerce.

Table 2. Twenty major U.S. crops: Annual acreage, yield, production, and value, 1985-87 average.

Crop and unit	Acres harvested	Yield	Production	Value
	1,000	Per Acre	1,000	$1,000
Corn, for grain (Bu.)	67,850	119.0	8,063,604	14,731,030
Soybeans, for beans (Bu.)	58,771	33.7	1,981,115	10,069,435
Hay, all (Tons) 1/	61,197	2.5	151,091	9,050,541
Wheat, all (Bu.)	60,462	36.5	2,207,313	5,929,887
Cotton, all (Lb.) 2/	9,582	632.6	12,629	3,564,778
Tobacco (Cwt.)	624	20.9	13,006	2,062,230
Potatoes (Cwt.)	1,288	299.0	384,798	1,693,554
Sorghum, for grain (Bu.)	13,748	67.9	933,088	1,574,028
Oranges (Tons)	582	12.6	7,319	1,271,729
Tomatoes, all (Cwt)	385	464.0	178,712	1,238,418
Grapes (Tons)	772	6.9	5,361	1,164,402
Barley (Bu.)	11,212	51.4	576,305	1,020,535
Peanuts, for nuts (Cwt.)	1,512	25.2	38,032	1,018,050
Apples (Tons)	450	9.7	4351	948,155
Sugarbeets (Tons) 3/	1,183	21.3	25,230	831,718
Rice (Cwt.)	2,394	55.1	131,998	769,501
Oats (Bu.)	7,321	58.3	426,974	565,591
Dry Edible Beans (Cwt.)	1,562	15.2	23,790	410,753
Sunflower (Cwt.)	2,191	12.8	28,123	207,889
Rye (Bu.)	693	28.8	19,959	33,317
Total 4/	303,778			58,155,541

1/ Value as baled. 2/ Production in 480-lb. bale units. 3/ Sugarbeet value does not include 1987. 4/ Subject to rounding error.

SOURCE: Data compiled from U.S. Department of Agriculture (1988a, 1988b).

Table 3. Major U.S. grain crops: Value of annual production, by region, 1985-87

Region	Corn 1/	Soybeans 2/	Hay 3/	Wheat 4/	Sorghum 5/	Oats
			Million dollars			
Northeast	558	130	1,057	70	--	47
Corn Belt	7,773	6,005	1,312	439	179	116
Lake States	2,227	1,088	1,409	414	--	160
Northern Plains	2,398	974	1,039	2,314	670	166
Appalachia	687	623	685	134	45	6
Southeast	252	309	244	106	19	6
Delta	102	892	198	123	157	2
Southern Plains	327	49	768	738	427	26
Mountain	261	--	1,271	916	43	18
Pacific	147	--	1,069	676	5	18
Total 6/	14,731	10,069	9,051	5,930	1,574	566

1/ Corn for grain. 2/ Soybeans for beans. 3/ Alfalfa and other hays. 4/ All wheat. 5/Sorghum for grain. 6/ Subject to rounding error.

SOURCE: Data compiled from U.S. Department of Agriculture (1988b).

Table 4. Major U.S. grain crops: Annual per-acre yields, by region, 1985-87

Region	Corn 1/	Soybeans 2/	Hay 3/	Wheat 4/	Sorghum 5/	Oats
	---Bushels---		Tons	-------Bushels-------		
Northeast	98	28	2.4	48	--	66
Corn Belt	129	39	2.7	49	83	67
Lake States	115	35	3.0	45	--	61
Northern Plains	115	34	2.0	34	74	52
Appalachia	84	26	1.8	36	72	48
Southeast	72	21	2.1	30	46	43
Delta	100	22	2.1	37	67	67
Southern Plains	108	25	2.3	29	58	45
Mountain	140	--	2.6	35	44	53
Pacific	155	--	4.0	57	85	79
Total 6/	119	34	2.5	37	68	58

1/ Corn for grain. 2/ Soybeans for beans. 3/ Alfalfa and other hays. 4/ All wheat. 5/Sorghum for grain. 6/ Subject to rounding error.

SOURCE: Data compiled from U.S. Department of Agriculture (1988a).

Table 5. U.S. climate: Monthly average precipitation and temperature in October-March and April-September, by region, 1950-1986

Region	Precipitation		Temperature	
	April-Sept.	Oct.-March	April-Sept.	Oct.-March
	Inches per month		Degrees Fahrenheit	
Northeast	3.67	3.17	62.6	35.1
Corn Belt	3.84	2.29	66.4	35.6
Lake States	3.36	1.50	61.1	26.8
Northern Plains	2.83	0.93	64.4	30.7
Appalachia	4.21	3.84	70.3	45.4
Southeast	4.73	3.85	75.3	55.3
Delta	4.33	4.52	74.9	51.2
Southern Plains	2.96	1.63	75.0	50.2
Mountain	1.52	0.88	59.9	32.7
Pacific	0.83	2.98	64.1	44.2

SOURCE: Teigen and Singer

Table 6. U.S. agriculture: Annual total farm expenditures, by region, 1985-1987

Region	Selected cost Items				
	Seeds & plants	Fertilizers	Agri-chemicals	Other 1/	Total
	Million dollars				
Northeast	231	420	167	7,577	8,395
Corn Belt	1,118	2,278	1,055	21,320	25,771
Lake States	499	789	423	10,915	12,626
Northern Plains	467	803	385	13,238	14,893
Appalachia	207	585	240	6,608	7,640
Southeast	263	554	316	6,145	7,278
Delta	175	333	301	4,268	5,077
Southern Plains	217	500	190	9,606	10,513
Mountain	205	415	208	7,938	8,766
Pacific	282	619	462	11,697	13,060
Total 2/	3,664	7,294	3,747	99,313	114,018

1/ Other includes livestock, poultry and related, feed, farm services, interest, taxes, labor, fuels and labricants, supplies, building and fencing, machinery, trucks and autos, and other unallocated expenses.
2/ Subject to rounding error.

SOURCE: Data compiled from U.S. Department of Agriculture, (1988c).

Table 7. U.S. agriculture: Acreage irrigated and treated with chemicals for insects, nematodes, diseases, and weeds, by region, 1982

Region	Irrigated Crop acreage harvested	Acreage treated with chemicals for 1/			
		Insects	Nematodes	Diseases	Weeds
	Thousand acres				
Northeast	266	2,886	364	672	5,416
Corn Belt	814	18,322	1,392	922	55,846
Lake States	854	6,622	813	1,024	21,101
Northern Plains	9,113	10,426	670	1,182	31,395
Appalachia	161	3,938	967	697	9,196
Southeast	2,015	5,629	1,444	1,897	7,418
Delta	3,135	5,880	414	1,001	12,079
Southern Plains	5,788	8,054	566	900	12,473
Mountain	11,546	4,075	320	1,038	11,406
Pacific	10,740	7,016	583	2,352	10,542
Total 2/	44,433	72,848	7,533	11,685	176,871

1/ Chemicals formulated as sprays, dusts, granules, fumigants, etc.
2/ Subject to rounding error.

SOURCE: Data compiled from U.S. Department of Commerce.

Table 8. Major U.S. grain crops: Annual variable costs of production, selected items, 1984-86

Crop	Variable cash expenses				
	Seed	Fertilizer	Chemicals	Other 1/	Total
	Dollars per acre				
Corn, for grain	17.78	49.14	19.41	40.35	126.68
Soybeans, for beans	9.66	6.97	19.30	20.42	56.35
Hay	5.00	1.50	12.50	39.98	58.98
Wheat	6.13	16.01	3.24	23.54	48.92
Cotton	8.62	22.67	51.39	132.88	215.56
Grain sorghum	3.93	18.99	9.39	30.16	62.47
Barley	5.66	15.11	5.96	24.47	51.20
Oats	7.72	10.13	1.22	19.77	38.84

1/ Other includes lime and gypsum, custom operations, fuel, lubrication, electricity, repairs, hired labor, purchased irrigation water (except in oats and soybeans), miscellaneous (in wheat, grain sorghum, and barley), technical services, and (in corn and sorghum) drying, ginning (in cotton).

SOURCE: U.S. Department of Agriculture (1988d), except for hay (Taylor).

Table 9. U.S. corn and soybeans: Average annual losses due to selected pests, by region, 1995-97

Region	Insect losses in corn			Weed losses in soybeans		
	Quantity 1/		Value 2/	Quantity 1/		Value 2/
	%	1,000 bu.	$1,000	%	1,000 bu.	$1,000
Northeast	6.8	20,533	36,132	7.4	2,160	7,806
Corn Belt	7.3	348,202	516,594	7.3	90,340	330,502
Lake States	2.9	41,434	59,495	15.1	36,957	135,833
Northern Plains	9.5	148,199	221,400	5.4	11,370	39,811
Appalachia	6.2	25,722	43,426	17.6	21,649	80,483
Southeast	5.1	7,226	12,573	17.0	11,904	40,618
Delta	7.0	3,437	5,808	17.7	32,263	121,690
Southern Plains	7.0	15,209	27,050	9.8	1,045	3,585
Mountain	17.4	27,867	45,831	--		
Pacific	7.0	4,797	9,518	--		
Total 3/	7.0	642,627	977,827	9.8	206,878	760,329

1/ Average percentage losses are weighted by 1985-87 state production. Quantity is percentage loss times 1985-87 annual average acreage times 1995-97 projected yield. 2/ Corresponds to area C in Figure 3. Corn values are based on regional average price (P) adjusted (P*(1+(.07/-.408))) for 7 percent aggregate supply increase and elasticity of aggregate demand. Soybean values are based on regional average price (P) adjusted (P*(1+(.098/-.349))) for 9.8 percent aggregate supply increase and elasticity of aggregate demand. 3/ Totals subject to rounding error.

SOURCES: Losses from National Agricultural Pesticide Assessment Program, quantities and prices from USDA, elasticities from Conway.

Table 10. U.S. corn and soybeans: Change in annual total crop value, comparing with and without biotechnology, 1995-97 1/

Region	Corn, for grain			Soybeans, for beans		
	with	w/out	difference	with	w/out	difference
	$1,000,000		Percent	$1,000,000		Percent
Northeast	571	646	-12	113	146	-23
Corn Belt	7,580	8,533	-11	4,834	6,261	-23
Lake States	2,109	2,476	-15	1,035	1,249	-17
Northern Plains	2,558	2,822	-9	777	1,025	-24
Appalachia	741	843	-12	537	635	-15
Southeast	258	296	-13	280	333	-16
Delta	89	101	-12	811	958	-15
Southern Plains	416	469	-12	40	51	-21
Mountain	309	318	-3			
Pacific	146	165	-12			
Total 4/	14,777	16,669	-11	8,427	10,658	-21

1/ Biotechnology in corn means no losses from insect damage. Biotechnology in soybeans means no losses from weed damage.

Table 11. Major U.S. crops: Average annual losses due to pests in production, 1951-1960

Crop	Pest category				
	Weeds	Insects	Diseases	Nematodes	Total
			Percent		
Corn	8	9	9	2	28
Wheat	9	5	12		36
Barley	10	4	12		26
Oats	11	3	17		31
Potatoes	2	10	14	3	29
Tomatoes	5	10	14		29
Onions	4	13	14		31
Apples	2	10	6		18
Oranges	4	5	9	3	21

SOURCE: Cramer

Appendix table 1. U.S. agriculture: Regional definitions

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

SOURCE: Teigen and Singer

Appendix table 2. Major U.S. grain crops: Annual average acreage harvested, by region, 1985-87

Region	Corn 1/	Soybeans 2/	Hay 3/	Wheat 4/	Sorghum 5/	Oats
	Thousand acres					
Northeast	2,672	917	5,571	552	--	542
Corn Belt	33,623	30,247	8,965	3,381	1,353	1,300
Lake States	11,160	6,113	7,950	3,413	--	2,047
Northern Plains	11,508	5,932	12,800	25,419	5,970	2,514
Appalachia	3,986	4,598	5,622	1,398	359	85
Southeast	1,657	2,841	1,712	1,307	248	101
Delta	500	7,707	1,904	1,222	1,307	23
Southern Plains	1,410	417	5,430	9,917	3,967	315
Mountain	938	--	7,713	9,835	516	235
Pacific	396	--	3,540	4,019	27	159
Total 6/	67,850	58,771	61,197	60,462	13,748	7,321

1/ Corn for grain. 2/ Soybeans for beans. 3/ Alfalfa and other hays. 4/ All wheat. 5/Sorghum for grain. 6/ Subject to rounding error.

SOURCE: U.S. Department of Agriculture (1988a)

Appendix table 3. Major U.S. grain crops: Annual average production, by region, 1985-87

Region	Corn 1/	Soybeans 2/	Hay 3/	Wheat 4/	Sorghum 5/	Oats
	Million bushels		Tons	---Million bushels---		
Northeast	262	26	14	26	--	36
Corn Belt	4,337	1,181	24	166	112	88
Lake States	1,284	213	24	155	--	125
Northern Plains	1,329	200	25	866	441	130
Appalachia	337	121	10	51	26	4
Southeast	120	61	4	40	11	4
Delta	50	170	4	45	88	2
Southern Plains	152	10	12	284	229	14
Mountain	131	--	20	345	23	12
Pacific	61	--	14	230	2	13
Total 6/	8,064	1,981	151	2,207	933	427

1/ Corn for grain. 2/ Soybeans for beans. 3/ Alfalfa and other hays. 4/ All wheat. 5/Sorghum for grain. 6/ Subject to rounding error.

SOURCE: U.S. Department of Agriculture (1988a)

Appendix table 4. U.S. corn and soybeans: Yield trend equations, by region, 1956-87 1/

Region	Corn, for grain				Soybeans, for beans			
	Constant	Slope	R^2	D-W	Constant	Slope	R^2	D-W
	Bu./ac./yr.		Percent		Bu./ac./yr.		Percent	
Northeast	-2834	1.48	73	2.6	-531	0.28	34	2.2
Corn Belt	-3834	1.99	77	2.1	-783	0.41	73	1.9
Lake States	-3616	1.88	78	1.4	-1085	0.56	79	1.9
Northern Plains	-4925	2.54	89	1.9	-925	0.48	61	2.1
Appalachia	-2915	1.51	66	2.6	-221	0.12	20	2.7
Southeast	-2938	1.52	69	2.2	-176	0.10	11	2.1
Delta	-3972	2.04	71	0.6	-110	0.07	7	2.2
Southern Plains	-6837	3.50	86	0.6	-220	0.12	21	1.5
Mountain	-6406	3.30	98	2.0				
West	-5446	2.82	96	0.6				
U.S.	-4130	2.14	86	2.0	-573	0.30	71	2.1

1/ Regression of regional yield on constant (1) and year (1956, 1957, ..., 1987). Regional yields are averages of state yields weighted by production. D-W denotes Durbin-Watson statistic.

Appendix table 5. U.S. corn and soybeans: Annual yields, projected, 1995-1997

Region	Corn 1/	Soybeans 2/
	Bushels per acre	
Northeast	113.7	31.8
Corn Belt	141.6	40.7
Lake States	127.9	40.0
Northern Plains	135.9	35.5
Appalachia	103.7	26.7
Southeast	85.1	23.0
Delta	98.7	23.7
Southern Plains	155.0	25.6
Mountain	170.8	--
Pacific	173.9	--
U.S.	135.5	34.5

1/ Corn for grain. 2/ Soybeans for beans.

SOURCE: Appendix table 4