Agriculture 6

Status

- **Adaptable private sector in a very competitive and growing world market.**
- **High payoffs to public investment--but declining public interest.**
- **Increasing environmental restrictions.**

Climate Change Problem

- **Potential changes in crop and livestock productivity.**
- **Market-driven responses may alter regional distribution and intensity of farming.**

What Is Most Vulnerable?

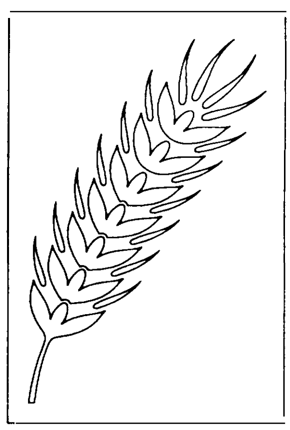
- **The long-term productivity and competitiveness of U.S. agriculture are at risk.**
- **Consumers and farm communities face high costs if the process of adaptation is slowed.**

Impediments

- **Institutional** rigidities and disincentives (e.g., commodity programs, disaster assistance, water-marketing restrictions).
- Uncertainty makes it hard for farmers to respond effectively.
- Potential environmental restrictions and water shortages.
- Technical limits-availability of suitable crops and practices for new climate.
- **Declining Federal interest in agricultural research and extension**

Types of Responses

- Remove institutional impediments to adaptation (in commodity programs, disaster assistance, water-marketing restrictions).
- Improve knowledge and responsiveness of farmers to speed adaptation (informational support, knowledge transfer, process innovation).
- Support research to enhance productivity through improved crops and farming practice (either directed at a general expansion in productivity or targeted to specific constraints and risks).



NOTE: Parts of this chapter are drawn from a paper prepared by W.E. Easterling for the Office of Technology Assessment (27).

OVERVIEW

In contrast to many natural resource systems examined elsewhere in this report, agriculture is an intensively managed, market-based system. Worldwide agricultural systems have evolved and adapt continuously to wide geographic differences in climate and to the risks associated with normal climate variability. In the past, agriculture has also been able to adjust to changes in economic conditions-such as the rapid changes in energy prices and export markets over the past two decades. There can be little doubt that the American agricultural sector will make further adaptations in response to changing climate conditions, with market forces rewarding and encouraging the rapid spread of successful adaptation. Yet, the possibility of unavoidable warming and drying in the major agricultural regions of the United States (see ch. 2,) argues for examining the potential for coping with climate change and for considering what public action might be appropriately taken in anticipation of an uncertain climate change.

For some farmers, simple adjustments in farming practices or crop selection may transform potential yield losses into gains. But for others, available responses will not compensate for the effects of harsher climates and water scarcity. The current limits to adaptation are well-illustrated by the geographic limits of where crops can be grown now. Without adequate moisture, farming becomes economically impractical. Increases in the intensity of conflicts between agriculture and the natural environment may also limit the extent to which adaptation is possible. For example, if a warmer climate leads to the expansion of intensive farming north into the Great Lakes States, land drainage could threaten ponds and wetlands, and increased use of farm chemicals could add to water pollution. In the arid West, greater demands for irrigation water could aggravate existing conflicts over the use of scarce supplies. Environmental concerns, whether aggravated by climate change or not, appear likely to constrain future expansion of agricultural production. Thus, despite adaptation, the possibility that agricultural yields will be threatened, particularly if climate becomes warmer and drier, cannot be discounted.

In a world where population growth is steadily increasing the need for food, any threat to growth in agricultural productivity must be taken seriously. For American farmers, already facing increasingly competitive world markets, any decline in productivity relative to the rest of the world could mean lost markets. For consumers, a decline in farm productivity growth could mean rising food prices. Estimates of economic effects of climate change on the United States range from damages of $10 billion to benefits of $10 billion (4). If the United States is to have a margin of security against the uncertainties of climate change, continued support is essential for research that enhances agricultural productivity and expands future options for farmers (e.g., new crops and improved farming systems).

Given the scale of the agricultural economy, a series of even small missteps and delays in the process of adaptation could, in the aggregate, prove very costly. Limited information and institutional impediments seem likely to restrict the farmer's ability to respond efficiently to a changing climate. The capability of the agricultural sector to respond to climate change can be improved through efforts to speed the movement of research results and new technologies into farm practice. In a future in which farmers must be increasingly responsive to change, the removal of unnecessary institutional impediments to adaptation is essential. For example, the framework of U.S. farm-support and disaster-assistance programs-which in many cases limit the farmer's incentives to change crops or farming practices rapidly and efficiently-should be reconsidered.

Climate change is almost certain to create both winners and losers, despite agricultural adaptation. Consumers will bear much of the cost of any decline in agricultural yields through higher prices. Some farmers might benefit from higher commodity prices, despite generally declining yields. Even so, other farmers will suffer because of relatively severe local climate changes and because of the inability--caused by a variety of factors-to respond effectively to change. Adaptation might itself result in some undesirable social and environmental impacts, particularly if climate change leads to rapid shifts in the geographical range of crops or in the intensity of farming practice. If climate warms considerably, the range over which major U.S. crops are planted could shift hundreds of miles to the north. Rapid geographical shifts in the agricultural land base could disrupt rural communities and their associated infrastructures. With agriculture and the rural economy already changing rapidly, and with the added uncertainties of climate change, it is impossible to do more than speculate about what effects climate change might have on rural communities.

This chapter provides a brief overview of U.S. agriculture and of the major trends facing it, examines the role that climate plays in agricultural production, and considers whether or not U.S. agriculture can be maintained under a changing climate. The nature of adaptation possibilities and the constraints that may limit the ability of the farm sector to respond successfully to a changing climate are considered. Finally, a potential role for the Federal Government in sustaining or improving agriculture's ability to cope with the uncertainties of a changing climate is discussed.

UNITED NATIONS, BY M. TZOVARAS

Past plant-breeding efforts have been successful in increasing productivity of crops such as wheat. Efforts to develop varieties that are better able to withstand environmental stresses, such as pests and droughts, may reduce the use of agrochemical inputs that are needed partly to compensate for unfavorable environments.

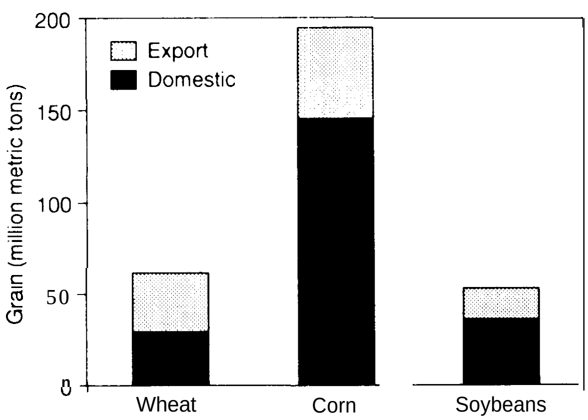
U.S. AGRICULTURE TODAY

The United States has an abundance of good agricultural land and a favorable climate for producing food, feed grains, and fiber. Cropland accounts for about 22 percent of the total U.S. land base (110). An additional 27 percent of the land base is in pasture and rangeland.[1] In 1990, the food sector[2] accounted for 17 percent of the civilian labor force, provided 15 percent of gross national product, and accounted for 11 percent of total U.S. exports (109). Although the relative importance of agriculture to the U.S. economy has declined steadily over time as the rest of the economy has grown in scale and complexity, agriculture remains of substantial economic importance.

[1] *Cropland* is land used for the production of cultivated crops (e.g., grains, hay, fruits, and vegetables) for harvest. *Pastureland is land used* for grazing, including once-forested land converted to forage cover and natural grasslands that are productive enough to support active management of forage plants. *Rangelands are natural* grasslands of low productivity.

[2] The food sector includes farm production plus the associated processing, manufacturing, transport, and marketing industries. The farm-production sector itself employs just 1.5 percent of the U.S. civilian labor force and provides 1.2 percent of the gross national product.

Figure 6-1—U.S. Production, Domestic Consumption, and Exports of Wheat, Corn, and Soybeans



NOTE: Three-year average based on 1989, 1990, and 1991 data. Exports and domestic consumption sum to U.S. production.

SOURCE: U.S. Department of Agriculture, Agricultural Statistics (Washington, DC: U.S. Government Printing Office, 1992).

The capacity of U.S. farmers to produce agricultural products far exceeds domestic needs. The United States produces more than half of the world's soybeans and 40 percent of the world's corn (maize). Much of the U.S. farm output is exported (fig. 6-l), and about 30 percent of the Nation's cropland is now producing for export (110). Even these statistics understate the current capacity to produce food. Of some 400 million acres (160 million hectares)[3] of cropland, about 65 million acres were withdrawn from production in 1991 (109) under various acreage-reduction programs, including the Conservation Reserve Program (CRP) (see box 6-A). Approximately 80 million acres now in pasture or forests could be converted to productive cropland if needed (112).4

The **U.S. Department of Agriculture (USDA) divides the country into 10 regions for the**

Box 6-A—Major Federal Programs Related to Agriculture and the Environment

Provisions of the 1985 and 1990 Farm Bills

- The Conservation Reserve Program (CRP) is designed to encourage farmers to voluntarily withdraw about 40 million acres (100 hectares)[1] of highly erodible or environmentally sensitive lands from crop production for a period of 10 to 15 years. In exchange, participating farmers receive annual rental payments ($50,000 maximum) and 50 percent cost-share assistance in establishing a soil-conserving vegetative cover on the retired land. Under the 1990 Farm Bill and new U.S. Department of Agriculture (USDA) rules for CRP operation, increased emphasis is placed on environmental benefits, including wildlife habitat and water quality improvements, as criteria for accepting land into the reserve program.
- The Wetlands Reserve Program (WRP) provides payment and cost-sharing assistance to farmers who agree to return previously farmed or converted wetlands to healthy wetland condition. WRP is intended to attract up to 1 million acres of wetlands by 1995, protecting these lands by easement for 30 years.
- Sodbuster and Conservation Compliance Provisions require that a farmer who converts highly erodible lands to crop production must have an approved conservation plan or forfeit eligibility for most USDA program benefits. The provisions apply to all highly erodible land that was not in production from 1981 to 1985. An estimated 224 million acres are subject to the Sodbuster requirements (25 percent of farmed land).
- Swampbuster provisions state that a farmer who converts wetlands, making possible the production of agricultural commodities, is ineligible for USDA program benefits (unless USDA determines that the conversion had a minimal effect).
- The Water Quality Incentives Program provides annual incentive payments of up to $3,500 per year for 3 to 5 years to farmers who implement a USDA-approved water-quality-protection plan. The voluntary program is

[1] To convert acres to hectares, multiply by 0.405.

[3] To convert acres to hectares, multiply by 0.405.

[4] This includes lands tbat have high or medium potential for conversion to agriculture (see table 7 in the appendix of ref. 112).

intended to result in the enrollment of 10 million acres. Limited appropriations have so far resulted in a smaller program than was initially authorized.

- The Environmental Easement Program provides annual payments and mst sharing for up to 10 years to farmers who agree either to have easements that provide long-term protection for environmentally sensitive lands or long-term reduction of water degradation. Participants must agree to a conservation plan to be developed in consultation with the Department of the Interior. Payment cannot exceed fair market value, No implementation has occurred to date.
- Pesticide Provisions require that producers (under threat of financial penalties) must now maintain records on the application of restricted-use pesticides for2 years. The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (P.L. 100-532) was amended to make USDA responsible for programs on the use, storage, and disposal of agricultural chemicals.
- The Sustainable Agricultural Research and Education Program (SARE), also referred to as the Low-Input Sustainable-Agriculture Program (LISA), is a competitive grants program designed to respond to the need for a more cost-effective and environmentally benign agriculture, It is unique in blending research on farming systems with strategies for ensuring that findings are made usable to farmers, Emphasis is placed on farmer participation and on-farm demonstrations. The program is currently funded at $6,7 million, although funding of up to $40 million is authorized.

Continuing USDA Assistance Programs

- The Agricultural Conservation Program, initiated in 1936, provides financial assistance of up to $3,500 annually to farmers who implement approved soil- and water-conservation and pollution-abatement programs. An increasing emphasis is being placed on water quality projects.
- Conservation Technical Assistance, also initiated in 1936, provides technical assistance through the Soil Conservation Service to farmers for planning and implementing soil and water conservation and water quality practices.
- The Great Plains Conservation Program, initiated in 1957, provides technical and financial assistance in Great Plains States for conservation treatments that cover the entire farm operation. Assistance is limited to $35,000 per farmer. The program emphasizes reducing soil erosion caused by wind through the planting of windbreaks or the conversion of croplands to grass cover,
- The Resource Conservation and Development Program, initiated in 1962, assists multicounty areas in enhancing conservation, water quality, wildlife habitat, recreation, and rural development.
- The Water Bank Program, initiated in 1970, provides annual payments for reserving wetlands in important nesting, breeding, or feeding areas of migratory waterfowl,
- The Rural Clean Water Program, initiated in 1980, is an experimental program implemented in 21 project areas. It provides cost sharing and technical assistance to farmers who voluntarily implement approved best-management practices to improve water quality.
- The Farmers Home Administration (FmHA) Soil and Water Loan Program provides loans to farmers and farm associations for soil and water conservation, pollution abatement, and improving water systems that serve farms. FmHA may also acquire 50-year conservation easements as a means to help reduce outstanding farmer loans.

Research and Extension Activities

- The Agricultural Research Service conducts research on newandalternative crops and agricultural technology to reduce agriculture's adverse impacts on soil and water resources,
- The Cooperative State Research Service coordinates conservation and water quality research conducted by State Agricultural Experiment Stations and allocates funds for competitive grants, including those related to water quality research.
- The Soil Conservation Service (SCS) monitors the condition of agricultural soil and water resources, provides information to encourage better soil management, and supervises conservation-compliance plans.
- The Extension Service provides information and recommendations on soil conservation and water quality practices to farmers, in cooperation with State extension services and SCS.

*(Continued **on next page)***

Box 6-A–Major Federal Programs Related to Agriculture and the Environment-(Continued)

Environmental Protection Agency Programs

- 1987 Water Quality Act Section 319 Programs (P.L. 95-217) require States and Territories to file assessment reports with the Environmental Protection Agency (EPA) to identify the navigable waters where water quality standards cannot be attained without reducing non-point-source pollution, including pollution from agricultural sources. States are also required to file management plans with EPA that identify steps that will be taken to reduce non-point-source pollution. All States have now filed assessment reports and management plans. The act authorizes up to $400 million for Implementing these plans, with $52 million awarded in 1992.
- The 1987 Water Quality Act National Estuary Program provides for the identification of nationally significant estuaries threatened by pollution, for the preparation of conservation and management plans, and for Federal grants to water-pollution-control agencies for the purposes of preparing plans. Under this program, USDA technical assistance to farmers has helped to reduce nitrogen and phosphorous discharges into the Chesapeake Bay by about 20,000 tons (1.8 million kilograms)[2] annually.
- The Federal Insecticide, Fungicide, and Rodenticide Act (P.L. 100-532) gives EPA responsibility for regulating pesticides, including agricultural insecticides and herbicides. EPA registers new pesticides and reviews existing pesticides to ensure that they do not present an unreasonable risk. The Agency may restrict or ban the use of pesticides determined to be a potential hazard to human health or the environment.
- The Safe Drinking Water Act (P.L. 93-523) requires EPA to publish drinking water standards for contaminants that can have adverse health effects in public water systems. These same standards are being used to assess contamination in groundwater supplies in private wells. The act also established a wellhead-protection program to protect sole-source aquifers from contamination by pesticides and agricultural chemicals.

2 To convert tons to kilograms, multiply by 907.

SOURCE: Office of Technology Assessment, 1993; U.S. Department of Agriculture (USDA), Economic Research Service (ERS), *Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook*, ERS AR-27 (Washington, DC: USDA).

presentation of farm statistics, as illustrated in **figure 6-2.** About 65 percent of U.S. cropland is found in the Corn Belt region, the Northern Plains, the Lake States, and the Southern Plains (112). Of all the States, California, Iowa, Illinois, Minnesota, Texas, Nebraska, and Florida have the highest cash revenue from farming. Irrigation, rather than extensive farm acreage, accounts for the high value of farm production in several of these States (California, Texas, and Florida). The 17 Western States, Arkansas, Florida, and Louisiana account for 91 percent of irrigated acreage. California, Nebraska, Texas, Idaho, and Colorado account for almost half of the irrigated acreage. Overall, irrigation agriculture makes up only 5 percent of the land in farms and 15 percent of the harvested cropland, but provides a striking 38 percent of crop production, by dollar value (109). Much of this value is from fruits, vegetables, and specialty crops. Figure 6-3 illustrates the regional distribution of cropland and irrigated crop acreage in the United States.

Crop and Livestock Production in the United States

Agriculture varies considerably across the Nation due to differences in climate, geography, and economic conditions. Figure 6-4 shows several distinctive farming areas that differ significantly in farm size, income, and production (57). Although not exhaustive in covering the Nation's farm lands, this characterization of farms gives a fair sense of the diversity in U.S. agriculture. Farms of the Corn Belt and Great Plains provide the largest share of the Nation's grains and livestock products. Farms there tend to be large, and farmers rely on farming for most of their income. California produces fruits and vegetables, dairy products, livestock, and grains, with most crops coming from large, irrigated farms.

Figure 6-2-The USDA Agricultural Regions of the United States

SOURCE: U.S. Department of Agriculture, Soil Conservation Service, The Second *RCA Appraisal: Soil, Water, and Related Resources* on Nonfederal *Land* in the United *States-Analysis of Conditions* and *Trends,* Miscellaneous Publication No. 1482 (Washington, DC: U.S. Department of Agriculture, June 1989, slightly revised May 1990).

The Mississippi Delta region produces cotton, soybeans, and rice. Farms of the Coastal Plains produce mostly poultry, dairy products, cattle, and soybeans. The Wisconsin-Minnesota Dairy area provides dairy products, cattle, and corn, with most production coming from small farms. Tobacco, poultry, cattle, dairy, and soybeans are typical farm outputs of the Eastern Highlands and the Southeast Piedmont. Farms in these two areas tend to be small and often provide only a part of the farmer's total income.

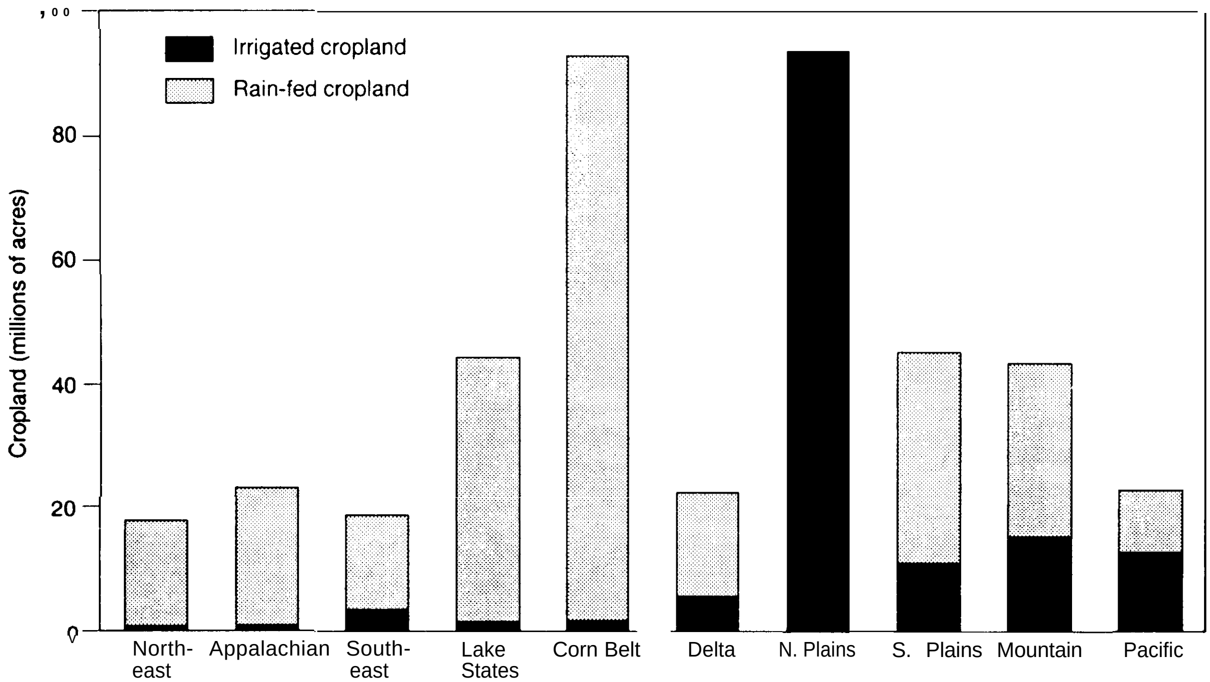
The primary annual crops grown in the United States in terms of economic value and area of land use are the grain crops-corn, soybeans, and wheat (table 6-l). Although grown across the country, most of the output of these three crops comes from the Corn Belt, the Lake States, and the Great Plains. Box 6-B outlines how climate interacts with major U.S. grain crops. The cash value of fruits and vegetables (combined) is about equal to that of grains. Fruits and vegetables are largely grown under irrigation,[5] require a relatively small amount of land, and exist in such extensive variety that it is hard to imagine climate change threatening overall supplies-as long as water is available. However, individual growers of these crops maybe at some risk of losses under rapid climate change.

Trends in U.S. Agriculture

A general overview of major U.S. agricultural trends forms a baseline against which to measure the effects of climate change. Technical, social, and economic change have greatly transformed U.S. agriculture over the past 40 years. Regardless of climate change, U.S. agriculture faces several trends in the coming decades that will almost certainly persist.

[5] About 65 percent of vegetable crops and 80 percent of orchard crops are irrigated (107),

Figure 6-3--Regional Distribution of Cropland and Irrigated Cropland in the United States



NOTE: To convert acres to hectares, multiply by 0.405.

SOURCE: U.S. Department of Agriculture, Soil *Conservation Service, The Second RCA Appraisal: Soil, Water,* and *Related Resources* on *Nonfederal/Land in the UnitedStates--Analysis of Conditions* and *Trends,* Miscellaneous Publication No. 14S2 (Washington, DO: U.S. Department of Agriculture, June 1989, slightly revised May 1990).

USDA, AGRICULTURAL RESEARCH SERVICE

A center pivot irrigation system. The sprinkler system rotates to irrigate about 130 acres.

Slow Growth in Domestic Demand

Domestic demand for agricultural products will grow slowly, probably at no more than 1 percent per year (24). Population growth in the United States, the major determinant of domestic demand for agricultural products, is now at about 1 percent per year, and is expected to drop lower (114). Per capita income growth in the United States, even if it proves to be substantial, is unlikely to add much demand for agricultural products.[6]

Increasing *World Demand*

Worldwide growth in population and per capita income are such that world agricultural demand may increase by almost 2 percent a year over the next 50 years (20). Much of this new demand will

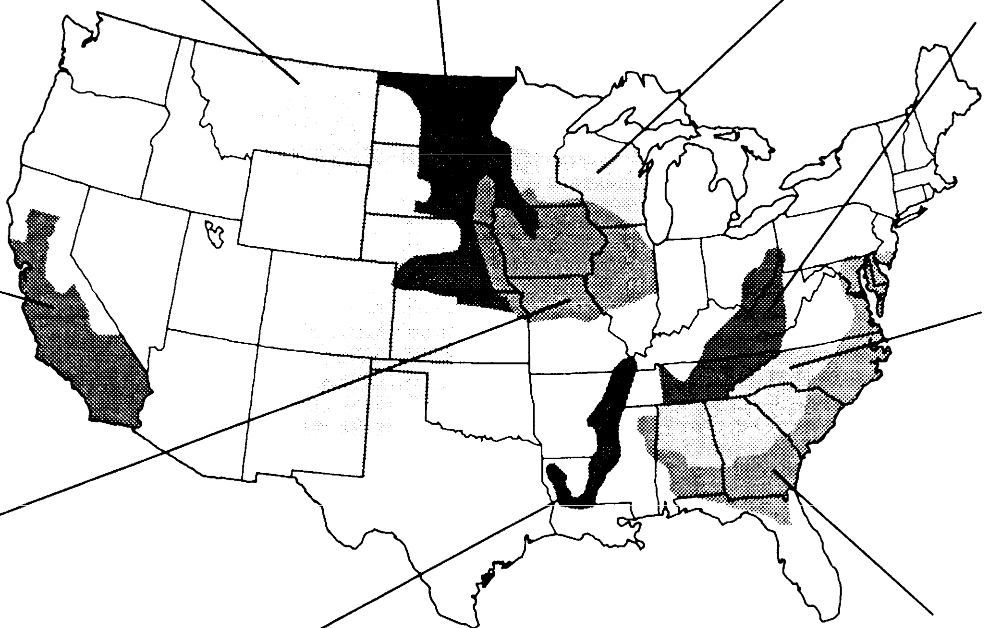
6 Between 1970 and 1992, the average consumer's food budget declined from 22 to 16 percent of total purchases (113). Only one-quarter of the consumer's food budget now pays for the cost of basic agricultural commodities, as compared with one-third in 1970 (113).

Figure 6-4-Characteristics of Nine Farming Regions

Western Great Plains. Typical farms have large acreages. The farm population relies more heavily on farming for income than in seven of the eight other regions. There are low rates of part-tlme farming and off-farm employment.

Western Corn Belt-Northern Plains. Most farmers here work full-time on their farms. The area relies on farming for income more so than any of the other region;. Farmers comprise the largest proportion of the total rural population (almost a third) in this region.

Wisconsin-Minnesota Dairy Area. This area relies heavily on dairy sales. A relatively low proportion of production comes from Iarge farms. Fewer than 30 percent of farmers hold full-time jobs off the farm. The farm population IS more dependent on farming income than in many other regions.



California Metro. Farm income IS derived mostly from sales of fruits, vegetables, and other crops not covered by major Federal commodity programs. Average farm size IS very large. The farm population IS very mobile in comparison to other regions.

Eastern Highlands. This region IS characterized by very low sales per farm, and a high percentage of sales coming from small farms. Farm operators are most Iikely here to work full-time off the farm, so farm households are not very dependent on farm Income.

Southeast Piedmont. This area relies less on farm program crops or dairy products than other areas. It has the h!ghest proportion of farmers with full-time off-farm jobs. Farming provides less than the average portion of total household income. Farmers make up only a small part of the rural population.

Core Corn Belt. Farm program crops provide most farm sales. Most farmers are full-time operators. The farm population (everyone who lives on a farm) earns more than half its income from nonfarm sources, but many rely mainly on farm income. Farm families make up much of the rural population.

Delta. This region IS the most dependent on sales of farm program crops, which provide 85 percent of gross farm Income. Although less than 30 percent of farm operators work full-time off the farm, 54 percent have some employment outside agriculture, the national average.

Coastal Plains. Farms in this region rely somewhat more heavily on program crops and less on dairy sales than the national average. The percentage of farmers working full-time off-farm IS about average, but the areas IS less dependent on farm income than are most other regions.

SOURCE: Office of Technology Assessment, 1993, adapted **from** D. **Martinez, "Wanted: Policies to Cope with Differences in Farming Regions,"** ***Farmline,*** **vol.** 8, No. 11, **1987, pp. 11-13.**

Table 6-1--Harvested Acreage and Value of Principal Crops, 1991

	Acreage (millions of acres)	Crop value ($ billion)
Corn for grain	74	18
Hay	62	11
Soybean	58	11
Wheat	77	7
Cotton	12	5
Sorghum for galn.	11	1
Vegetables	7	10
Fruits and nuts...	4	8
Rice	3	1
Peanuts	2	1
Sugar beets and cane..	2	2
Tobacco	1	3

SOURCE: U.S. Department of Agrfculture, Agricultural Statistics (Washington, DC: U.S. Government Printing Office, 1992).

come from developing countries. Meeting the growing need for food will require substantial gains in farm production throughout the world.

Increasing Productiviy and Output

U.S. agricultural productivity and yields are likely to continue to grow, but there is much disagreement over whether growth will remain as rapid as it has been in the past. Over the past four decades, U.S. farm yields increased at an annual rate of about 2 percent (24). Future gains in output are expected to be harder to achieve than they have been in the past (83), and gains averaging just 1 percent a year are predicted (1 12). For the United States, the best prospects for continuing to increase output lie in improved farm productivity. Conventional breeding strategies, more-efficient use of technical inputs, new biological technologies, and new information technologies may all contribute to improvements in farm productivity (103).

Competition for World Markets

With relatively stable domestic demands, U.S. farmers will increasingly look toward export markets. The best opportunity for growth in U.S. exports will be in the rapidly developing, populous countries of Asia and Latin America (24). However, uncertainty about future levels of agricultural production abroad leave it somewhat unclear whether foreign demand for U.S. agricultural products will increase. The advantage that U.S. farmers have long enjoyed in export markets could weaken as gains in productivity in foreign countries lower production costs relative to those in the United States.

Increasing Environmental Concerns

Strong environmental concerns could limit U.S. agricultural output and increase production costs.[7] A portion of the past gain in U.S. agricultural productivity has come at the expense of the environment. Salinization of soils, groundwater contamination, excessive erosion, and loss of wildlife habitat hav--in some areas-been the direct result of poor farm-management practices (112). Partially offsetting this has been the decline in land use for agriculture. As crop yields per acre increase, the total land area needed for U.S. agricultural production could decrease by as much as 30 percent over the next 40 years (112), thus reducing many land-use conflicts.

Society's increasing interest in protecting and preserving environmental values has led to stronger environmental policies. In the United States, this has meant taking some agricultural lands out of production (through the Conservation Reserve and Swampbuster Programs) and requiring changes in farming practices (Sodbuster Program). (Box 6-A describes Federal environmental programs related to agriculture; see also vol. 2, ch. 4, of this report.) The trend toward stronger environmental regulation will probably continue, with a likely increase in control overwater pollution from agricultural sources (e.g., fertilizers and pesticides). Stronger environmental protection policies may cause agricultural costs to rise, unless technologies that help farmers reduce environmental damage and land-use conflicts are developed.

[7] Although with other competing industrialized countries likely to be faced with similar environmental regulation it is somewhat unclear how Us. competitiveness might be affected.

Box 6-B–Primary US. Farm Products

Corn—Corn is the principal crop of the United States, grown on more farms than any other crop and with an annual production value of $18 billion in 1991 (table 6-l). Production is concentrated in the Corn Belt, which accounts for over half of U.S. corn acreage. Iowa, Illinois, Nebraska, Minnesota, Indiana, Wisconsin, Ohio, Michigan, South Dakota, and Missouri are the leading producer States, together accounting for over 80 percent of U.S. production. Corn yields are very susceptible to dry weather conditions, with drought-related losses often high. Water supply is most critical in the few weeks just before and after tasseling, which is when the tassel-like male flowers emerge. A dry spring t hat allows early planting can be important for maximum yields. Cool nights are also important for maximum corn yields; the warm night temperatures are a major reason the corn yields of the Southern Piedmont States are smaller than the Corn Belt's.[1] Reflecting the dependence on reliable moisture, farms that grow corn under irrigation have average yields almost 60 percent higher than do farms without irrigation in the same region. Irrigation is most common in the Western Great Plains States of Nebraska, Kansas, Colorado, and Texas. The United States exports over 20 percent of its corn and produces 40 percent of the world's supply. Most corn is used as livestock and poultry feed.

Soybeans—Soybeans are the second most valuable crop in the United States.[2] The primary soybean-producing region overlaps the Corn Belt. Illinois, Iowa, Minnesota, Indiana, Ohio, and Missouri are the leading producers. The soybean has a great ability to recover from climate stresses because of its indeterminate (continuous) flowering. The wide variety of genetic types available has allowed the crop to be grown in many climatic zones. Although grown in the South, soybeans do better in the cool-weather States. Yields in the South are hurt by uneven patterns of rainfall, diseases associated with dampness, and hot and dry conditions during the August pod-filling period. The United States exports 35 percent of its soybean production and provides over half of the world's supply. Soybeans are used in cooking oils, livestock feed, and several industrial applications.

Wheat—Wheat is the third-largest field crop in terms of total production value. Wheat is grown across the United States, although a large area of the Great Plains running from North Dakota and Montana down tothe Texas panhandle accounts fortwo-thirds of U.S. production. The Pacific States are also major producers. Kansas, North Dakota, Oklahoma, Washington, and Montana are generally the leading producers. Wheat infrequently grown in areas where there are few profitable alternatives. In dry areas, it is common to leave land fallow in alternate years to allow soil moisture to accumulate. Late spring freezes and inadequate moisture after flowering are the primary threats to yields. Winter wheat varieties are planted in the fall and harvested in spring or early summer-avoiding the threat of hot summer temperatures. These varieties account for about 75 percent of U.S. production. Where there is sufficient moisture and long growing seasons, winter wheat is sometimes double-cropped, with sorghum or soybeans grown during the summer. Spring wheats are planted in spring and harvested in late summer. These varieties are grown along the nort hem U.S. border, especially in Nort h Dakota, where winters are long and harsh. The United States produces about 10 percent of the world's wheat supply and exports half of its production.

Livestock and poultry—Livestock products (including poultry and dairy) account for about 53 percent of the total value of U.S. farm sales. Sales of cattle and dairy products are by far the largest component (almost 70 percent) of these livestock-related sales. The primary cattle regions are located west of the Mississippi and east of the Rocky Mountains, where t here is access to both grazing lands and feed grains. Much of t he U.S. production of earn and a large portion of soybean production goes to animal feed. Texas, Nebraska, and Kansas are leading cattle producers. Hog production is strongly linked to the corn-producing regions, with most production occurring in Iowa, Illinois, Minnesota, Nebraska, and Indiana. Poultry production is widespread, with much of it in the South.

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[1] R.S. Loomis, Department of Agronomy, University of California at Davis, personal Communication, Apr. 22, 1993.

[2] Excluding hay, which includes various grasses and legumes (such as alfalfa) grown for animal fodder.

SOURCE: Office of Technology Assessment, 1993; U.S. Department of Agriculture (USDA), Economic Research Service, *Agricultural Irrigation and Water Use,* Agricultural Information Bulletin 636 (Washington, DC: USDA).

Changing Farm Structure

The traditional small farm is gradually being replaced by the large, technologically sophisticated agribusiness.[8] Farms producing under $40,000 in annual revenues still account for almost 71 percent of the 2.2 million farms in the United States.[9] However, large farms-the 14 percent of farms with annual sales of over $100,000-now account for almost 80 percent of farm production (91). Small farming enterprises are increasingly less significant to the business of producing food.

Overall, farms are declining in number at 1 to 2 percent per year, with neighboring farm lands being consolidated into single, larger farms (91). As a result, average farm size has been increasing, rising from 213 acres in 1950 to 460 acres by 1990.[10] The trend toward consolidation of U.S. agricultural production into larger businesses will likely continue (24). Along with the increasing concentration of farm production on fewer large farms, there has been a decline in the rural population that depends on farming. on-farm populations declined from 15 percent of the U.S. population in 1950 to less than 2 percent in 1990. The declines in farm and rural populations are expected to continue (62, 101). By the time significant climate change might occur, farming will look much different from the way it looks today.

THE PROBLEM OF CLIMATE CHANGE

Climate and climate variability are already major risks to agricultural production. Agricultural losses due to climatic fluctuation are an expected part of farming. Farmers plant knowing that in some years, weather will cause poor yields. To minimize their exposure to climate risk, farmers take steps such as planting an appropriate crop, using water-conserving land-management practices, and diversifying sources of income. Such responsiveness suggests that farmers will adjust to perceived changes in climate variability, regardless of whether this is due to climate change or recognized as such by the farmer. However, future climate changes could present agriculture with unprecedented risks and circumstances.

Climate change, if it occurs, will be global, perhaps with large-scale winners and losers. There will be regional differences in the pace, direction, and extent of climate changes. Some regions are likely to be helped by climate change, while others are harmed. There is no way of knowing whether gains would offset the losses, but a changing climate would surely affect world agricultural markets and regional patterns of land use on a long-term basis. Not only will there be changes in average climatic conditions, but there may also be a change in the frequencies of rainfall and temperature-related extreme events. Although it is not clear that climate variability will increase, increases in mean temperature alone can lead to more-frequent periods of extended high temperatures (59). The changing frequency of extreme high-temperature events, rather than a gradual rise in average temperature, may present the greatest threat to farmers.

Adaptations made on the farm will be important in offsetting potential declines in yield. In some cases, simple adjustments in farming practices may transform potential yield losses into yield gains. Still, the extent to which adaptation will fully offset any negative effects of climate change might be constrained by cost and by limits to the availability of water and fertile soils. Conflicts over the environmental consequences of agriculture and the use of scarce water resources may become increasingly contentious (see ch. 5), limiting the possibilities for adapta-

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[8] It is unclear how climate change might affect farm structure. The large, specialized farming enterprises may prove to be financially and managerially better prepared to respond to climate changes than the typical smaller farm. On the other hand, it could be that smaller farms with low capitalization, high diversification in source of income, and low input requirements will prove less vulnerable to climate change.

[9] Farms producing under $40,000 in gross sales do not produce enough income to support a family by today's living standards. Many of these farms are owned by individuals who work full time in other jobs (91).

[10] Farms producing over $100,000 in revenues average over 1,500 acres.

tion. Warming could eventually shift the potential range of crops hundreds of miles to the north (7). If crop ranges shift significantly and rapidly under a changing climate, communities that depend on agriculture could be greatly affected. Although most studies have concluded that there is no immediate threat to U.S. food supplies (4, 87), the possibility of even moderate reductions in long-terrn food supplies cannot be ignored as an underlying cause for public concern.

Sensitivity of Crops and Livestock to Climate Change

Virtually every aspect of farming is affected by weather and climate. If soils are too dry or too cold, seeds will not germinate. If soils are too wet, farmers have difficulty getting equipment into muddy fields to plant or harvest. Most importantly, climate controls biological productivity. In most plants, the process of flowering and developing harvestable organs depends in a complex way on the seasonal patterns of temperature and daylength. Crop yields are sensitive to daily and seasonal levels of solar radiation, maximum and minimum temperatures, precipitation, and carbon dioxide ($C0_2$), and to the soil-drying effects of winds and high temperatures. All of these factors could be altered under climate change. Whenever climatic conditions depart from those expected, they pose some risk to agriculture.

For agricultural crops, beneficial effects from increasing concentrations of atmospheric CO_2 are expected. Crops respond to increased concentrations of atmospheric CO_2 with greater photosynthetic efficiency, improved water-use efficiency, and greater tolerance for heat, moisture, and salinity stresses (1, 49, 52). The greater photosynthetic and water-use efficiencies result in larger and more-vigorous plants and increased yields (78).[11] It is not known precisely how the direct effects of higher $C0_2$ concentrations will influence crop yields under actual field conditions. Experimental results suggest that under a doubling of atmospheric CO^2 (and otherwise ideal conditions), yields may improve by 20 to 60 percent for crops such as wheat, soybeans, and rice--the C_3 crops (5, 49).[12] Yield increases of perhaps no more than 20 percent are expected for corn, sugar cane, and sorghum--the C_4 crops. The actual extent of the beneficial impacts from elevated CO_2 will depend on there being suitable temperatures and adequate supplies of nutrients and soil moisture.

Several factors may complicate the prediction that rising $C0_2$ will be a blessing for agriculture. The relative growth advantage of C_3 plants over the C^4 crops could change regional patterns of crop production. If C_3 weeds start growing faster, C_4 crops like corn and sugarcane could face increased competition from them. (The converse is also true, of course; C_3 plants could face reduced competition from C_4 weeds.) The nutritional quality of plants and grain might decline because of the changing balance of carbon and nitrogen (a result of increased uptake of carbon). This, in turn, might lead to increased insect damage, with insects consuming more plant material to compensate for lower nutritional quality (6).

Regional warming itself can be either beneficial or harmful. In more northern regions, where cool temperatures result in short growing seasons, the beneficial effects of increased seasonal warmth may dominate. Irrigated crops, which include most of the Nation's fruits and vegetables, should also benefit, especially if longer growing seasons allow double-cropping. Water, if available, can compensate for the stress of high temperatures. But warming tends to speed up the development of plants, shortening the period in which fruit formation and grain filling occurs, and

11 Note that despite improved water-use efficiency, crop water requirements may increase because of the larger plant size.

12 The categorization of plants as C_3 or C_4 is based on the mechanism by which CO_2 is used in the cell (see ch. 2). At elevated CO_2 concentrations, the inefficiency of the C_3 process in producing sugars is overcome, and C_3 plants respond with greater growth improvement than do C_4 plants.

so reduces yields. This effect on yields is especially notable in wheat and corn (2). Warmer nighttime temperatures, even in the absence of warmer daytime temperatures, will increase transpiration and can reduce a plant's ability to recover from the rigors of high daytime temperatures. High temperatures can damage the process of pollination (corn pollen begins to lose viability at 97 OF (36 'C)) and can damage fruit and flower formation (cotton fruit aborts after 6 hours at temperatures over 104 OF (40 'C)). High temperatures can stress plants directly, reducing growth rates in most crops at temperatures above 95 OF (35 'C). Finally, higher temperatures lead to increased evaporation, reducing water availability unless drying is offset by greater precipitation. Because water is generally the limiting factor in agricultural production, any soil drying tends to reduce yields. Corn yields are especially sensitive to moisture stress in the weeks around tasseling.[13]

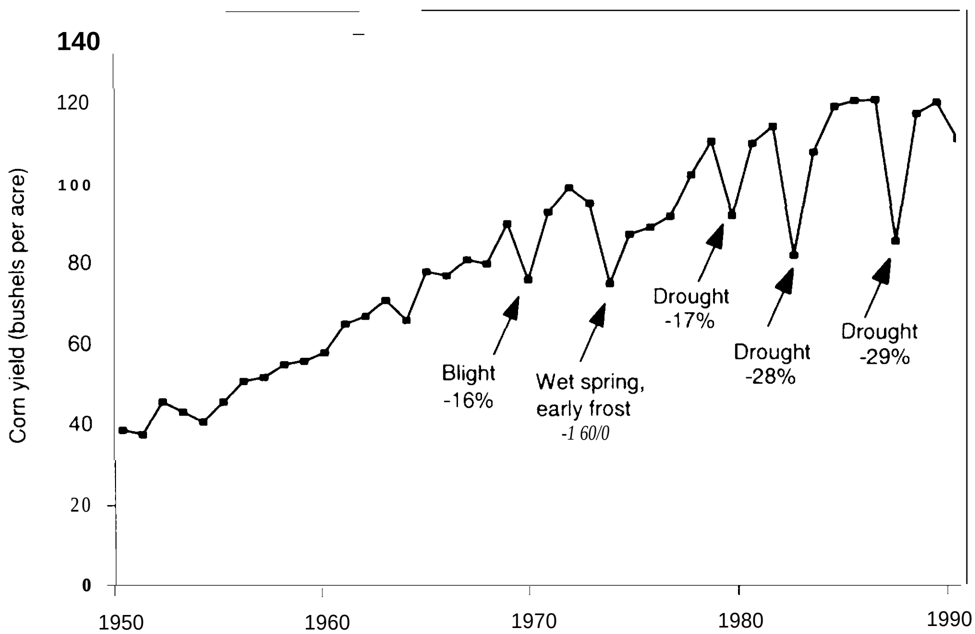
Crop yields and farm-management costs can be influenced in other, less-direct ways. Changes in the frequency or range of insects and fungal diseases seem likely to result from warmer climates, longer growing seasons, and changes in moisture levels. Pollination may be affected if the timing of plant development is out of phase with the presence of pollinating insects. Climate warming may alter the geographical distribution of existing pests now limited by winter temperatures and may allow for increased rates of successful invasion by exotic migrants. The severity of existing pest problems could be increased as longer growing seasons allow for the development of extra pest generations and as warmer temperatures raise the likelihood that pests will survive through the winter (70; see also ch. 2). Several pests, such as the southwestern corn borer and the corn earworm, could pose a greater threat to Corn Belt production. As a result, pest-management costs may rise. Farmers may also face changes in the costs of drying, storing, and transporting grain. A longer growing season might allow grains to be more fully dried in the fields, thus reducing costs. Grain-transport costs could be increased if reduced water flows limit barge traffic on the Mississippi River, as happened during the drought of 1988 (12) (see box 5-L). Livestock and poultry would also be affected by a warmer climate. Continued exposure of cattle to temperatures above 86 OF (30 'C) can slow weight gain, reduce milk production, and increase mortality (39, 50). Problems can be amplified if night temperatures rise disproportionately more than day temperatures (47) because animals need cool nights to recover from hot days. Livestock and poultry farming may also be affected indirectly, through changes in the price of feed, in water availability, in diseases, and in the availability and productivity of grazing lands. For example, any decline in acreage planted with crops in the Great Plains would lead to a corresponding increase in the land available for grazing. For the existing grazing lands, changes in soil moisture will have the greatest effect on the plant species composition and productivity (16).[14]

Climate change will threaten agriculture most in areas such as the western Great Plains, where heat stress and droughts are already problems and where increased irrigation would be costly. The extreme crop losses that occur during droughts provide a striking illustration of potential vulnerability. During the drought year of 1988, Illinois corn yields were almost 45 percent lower than previous years' (110). Figure 6-5 shows the sensitivity of U.S. corn yield to drought and other weather-related factors. Cropland now under irrigation in arid regions facing reduced water supplies and increased competition for water will

13 The male flowers that form on the top of corn plants are commonly referred to ss tassels.

14 Direct effects of elevated CO_2 may not be significant on grazing lands constrained by moisture and nitrogen. It is possible, however, that increased carbon uptake by forage plants without corresponding increases in the amount of nitrogen assimilated by those plants could reduce their nutritional value for livestock (40).

Figure 6-5-Corn Yields in the United States, 1950-91



NOTE: To convert bushels of corn per acre to metric tons per hectare, multiply by 0.063.

SOURCE: U.S. Department of Agriculture, *Agricultural* **Statistics** (Washington, DC: U.S. Government Printing Office, annual).

be at risk and will likely require increasingly sophisticated water-conserving technologies. In Western States, for example, warming could lead to a reduction or earlier melting of the winter snowpack that now provides much of the region's irrigation water (see ch. 5). On the other hand, if moisture levels increase and allow a northwest shift of the Corn Belt into the deep, fertile soils of the Dakotas, there might be little threat to yields. An expansion of the Corn Belt into that region is already under way (84). Over the past decade, plant breeders have developed corn varieties with a shorter growing season and thus have extended the corn region several hundred miles to the north.

The various effects of climate changes on agricultural yield are only suggestive of the potential economic harm from climate change. Exactly how consumer food prices and the profitability of agriculture are affected by climate change will depend on the aggregation of farm-level responses to changes in climate. Large-scale adjustments in the location and intensity of food production have the potential to offset much of the direct effect of climate change. Box 6-C describes some studies that have looked at the market responses and economic effects of climate change.

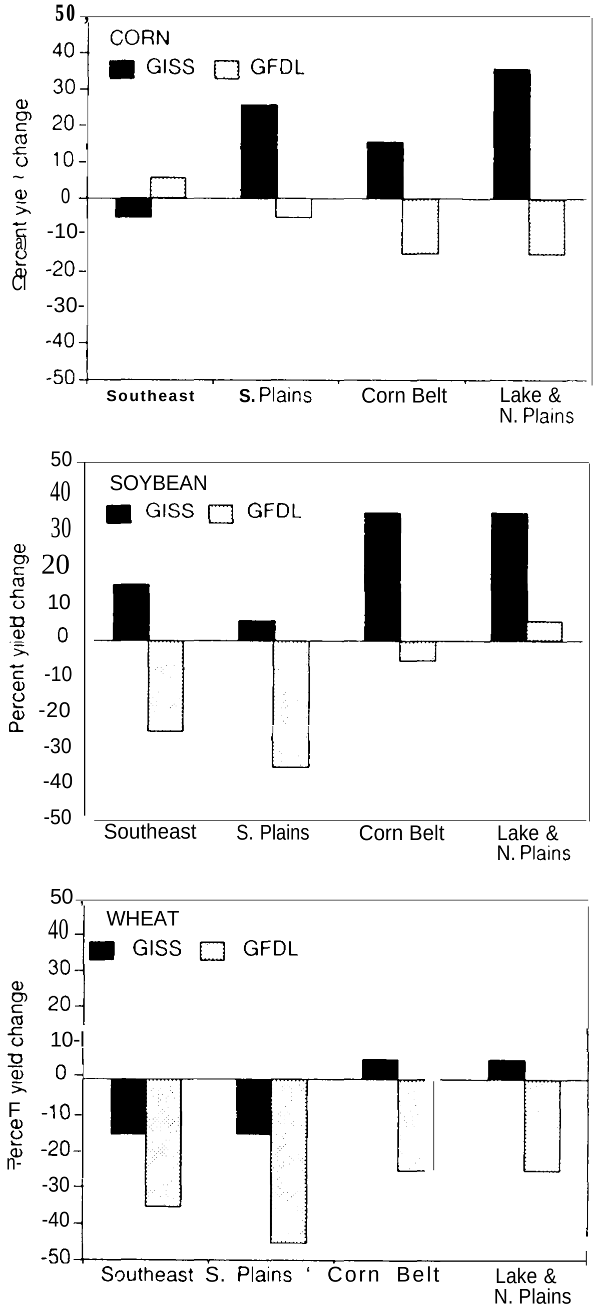
Conflicting Goals and Competing Demands for Water

Agriculture's attempts to adjust to climate change could have several potentially undesirable consequences. The U.S. Environmental Protection Agency (EPA) warns that environmental concerns and constraints on the availability of land and water could add to the difficulty of maintaining agricultural yields under a climate change (87). Any increased use of irrigation water would be in conflict with the growing demand for other uses of water. The potential for a shift in the Corn Belt into northern areas of the Lake States raises particular concern. This is an area of thin soils, with poor drainage and uneven

Box 6-C—Previous Studies of Agriculture and Climate Change

In the 1980s, the Environmental Protection Agency (EPA) commissioned many major studies of the potential effects of climate change on U.S. agriculture (87)[1]. The Agency emphasized the use of crop simulation models to predict the effects of various climate-warming scenarios on crop yields (75, 80), and gave little attention to technical changes in agricultural systems or the adaptive responses of farmers. The warm ing scenarios were generated by general circulation model (GCM) experiments under the assumption of doubled atmospheric carbon dioxide (CO_2). The GCMs used predict eventual atmospheric temperature increases of 7 to 9 ‘F (4 to 5 ‘C) for many regions of the United States, and one of the models predicts severe drying for most of the agricultural land in the United States (see ch. 2). Representative projections of yield changes from two GCMs are presented in the figure at right.

EPA found that climate change would affect crop yields and livestock productivity and would result in a northward shift in the crop production zones. Although warming alone might lead to sharply reduced agricultural yields (over 50 percent decline in some regions), the direct effects of doubled CO_2 could offset much of the potential decline in crop yields. Still, EPA predicted that yields would decline substantially under the more-severe climate scenarios, especially where droughts become more frequent. Yields across the Southern and Central States were considered particularly vulnerable, largely because of drying. A few northern locations, such as Minnesota, were expected to show yield improvements



SOURCE: C. Rosenzweig, “Potential Effects of Climate Change on Agricultural Production in the Great Plains: A Simulation Study,” in: ***The Potential Effects of Global** Climate Change on the United States,* Appendix C, **Volume 1, J. Smith and D. Tirpak (eds.) (Washington, DC: U.S. Environmental protection Agency,** 19S9).

NOTE: Yields reflect CO_2 fertilization effect. GFDL=Geophysical Fluid Dynamics Laboratory; GISS=Goddard Institute for Space Studies.

[1] The Council for Agricultural Science and T*nology(18) drew together perhaps the best overview of agriculture under climate change. Rosenberg and Crosson (79) investigated on-farm adaptation to climate change in the U.S. Midwest. A National Academy of Science study (65) reviewed the possible ways that agriculture could adapt to climate change.

(in some cases, by more than 40 percent). Including CO_2 effects and assuming no adaptive response, a reduction in the Nation's agricultural yields was projected as the most likely outcome of climate change.

Projected yield changes such as those described in the EPA studies suggest potential harmful effects of climate change but, ultimately, cost changes to consumers and agricultural producers are the concern. Exactly how consumer food prices and the profitability of farm production are affected will depend on farm-level reactions and market adjustments to climate change. Indeed, it is often not understood that farmers could benefit from the higher prices that would result from a reduction in all farm yields. Farming systems will change in response to crop productivity shifts and changes in commodity prices. Market-level adjustments in the location and intensity of food production worldwide will determine the prices faced by individual farmers and consumers.

Although the EPA studies did not explicitly consider farm-level adaptations, they suggested that farmers could act to offset some of the projected yield declines (3, 26,80). A few basic agronomic adjustments were considered (80). For dryland corn (i.e., corn that is not irrigated) in the Southern Plains, altered planting dates showed little effect in offsetting the yield reduction caused by climate warming. More dramatic effects of short-term adaptations were found for dryland and irrigated wheat. A switch in cultivars led to improved wheat yields in most of the simulations.

Others studies took a more comprehensive look at on-farm adaptation. One examined the natural resource base of the Missouri-Iowa-Nebraska-Kansas (MINK) region, investigating the effectiveness of several farm practices and innovations in offsetting effects of climate change (79), In the absence of adaptive response, they found that a permanent shift to warmer and drier climate conditions reduces net regional income by 1.3 percent. After accounting for direct CO_2 effects and short-term adaptations by farmers, regional economic losses are reduced to 0.3 percent(11). More significantly, the study considers plausible innovations in crop genetics and farm management that could further reduce the risks to the region's future economy t hat are posed by climate change.

Effects of economic adjustments through shifts in the location and intensity of production were considered in one study (3). Shifting crops to better-suited locations would be an important adaptive mechanism that would offset much of the potential economic cost of climate change. The study used a regional-market model of U.S. agriculture to examine the economic effects of changes in crop productivity due to climate change. Economic damages were significantly less than would have resulted in t he absence of shifts in the location and intensity of production. Economic effects range from damages of $10.3 billion to benefits of $10.9 billion, depending on which GCM scenario is considered (4). Depending on the climate scenario, overall crop production decreases by 20 percent or increases by 9 percent. Corresponding to these supply changes, commodity prices increase by 34 percent or decrease by 17 percent. In either case, farmers benefit while consumers bear the burden of higher prices under the harsher climate scenario.

One assessment of the world trade in agricultural products under climate change found that despite a potential for substantial effects of climate change on crops, interregional shifts in location and intensity of production and the opportunity for trade very much buffer the world from the threat of climate change (46). Price changes in international markets promote interregional adjustment in production and consumption. Essentiality no aggregate economic effect on the United States results, and economic effects on the overall world economy are estimated to be similarly small. Another assessment of world agricultural trade under a climate change found beneficial effects from world trade, with interregional adjustments offsetting 70 to 80 percent of the potential yield declines (81). Despite this finding, that assessment reached an important and less-than-optimistic conclusion: although the United States itself may not face market losses, some parts oft he developing world t hat must import food could suffer from higher food prices and an increased risk of hunger.

SOURCE: Office of Technology Assessment, 1993; W.E. Easterling, "Adapting United States Agriculture to Climate Change," contractor report prepared for the Office of Technology Assessment, January 1993.

terrain, raising the possibility of reduced **productivity** and increased environmental damage. **Intensified** farming in these northern lands would change the nature of an area now rich in forests, wetlands, and other natural habitats. Crop pests, if they expand in range or severity, might raise the Costs of maintaining farm production. Increased use of chemical pesticides to counter these threats could add to water pollution problems. In areas where farming activity declines, there could be dislocations in local and regional economies (see box 6-D).

Box 6-D-Water Transfers in the West: Winners and Losers

Colorado provides a good illustration of the complexities surrounding already scarce water supplies in the West. Many climate models predict drying in the central parts of North America. With growing urban demands for water, increasing environmental concerns related to instream flows, and less water to go around, future conflicts over water seem likely to increase in intensity. An examination of existing conflicts related to water transfers in Colorado illustrates some important social impacts that need to be considered when climate change policy is formulated.

Water transfers in Colorado are gradually moving water from irrigated agricultural to urban use. Over the past two decades, cities have purchased water rights on some 80,000 acres (24,300 hectares)[1] of agricultural land (out of some 3 million acres total irrigated land). The transfers are driven by economics. As costs for developing new municipal water supplies have increased, Colorado's cities have found it cheaper to purchase water rights from nearby agricultural areas. For farmers or ranchers, the sale of water rights has provided a desperately needed financial windfall at a time when the agricultural economy has been severely strained by high debt, poor weather, and low commodity prices. Faced with a sagging rural economy, the farmer who is offered by a city two to five times more than the value of water in agriculture sees a deal that is too good to refuse. For example, landowners in the Arkansas River Basin, who might lease a 40-acre field to a farmer for a profit of $2,500 per year, were able to sell the water rights to that land for $200,000 to the city of Aurora.

It would seem that such water transfers are a win-win situation. With farmers accounting for only 2 percent of the population and contributing 3 percent of economic output, yet consuming 92 percent of Colorado's water, small transfers of water from agriculture seem to offer the right solution to urban water shortages. The acre-foot of water that allows production of about $90 of wheat or $250 of beef will provide 4 years of water for a typical urban family of four. The farmer makes money by selling, and the city gets more than enough water to support a growing population. However, there are losers in almost every water transfer. The losers in Colorado have been the already poor counties and communities left with no future economic base after water sales to cities.

In the seven counties of the Arkansas River Basin in southeastern Colorado (see figure), large amounts of water have already been transferred to urban use. Prolonged droughts in the 1950s devastated the farm economy and triggered the first water sales to the city of Pueblo. In the 1970s and 1980s, there were major sales of water to the cities of Pueblo, Colorado Springs, and Aurora, spurred first by speculatively high water prices and later by economic troubles in the farm economy. By 1985, about 14 percent of the water rights in the seven-county basin had been sold for urban use. The dry climate of this area offers little opportunity for profitable farming unless land is irrigated. The decline in farm production has meant local suffering.

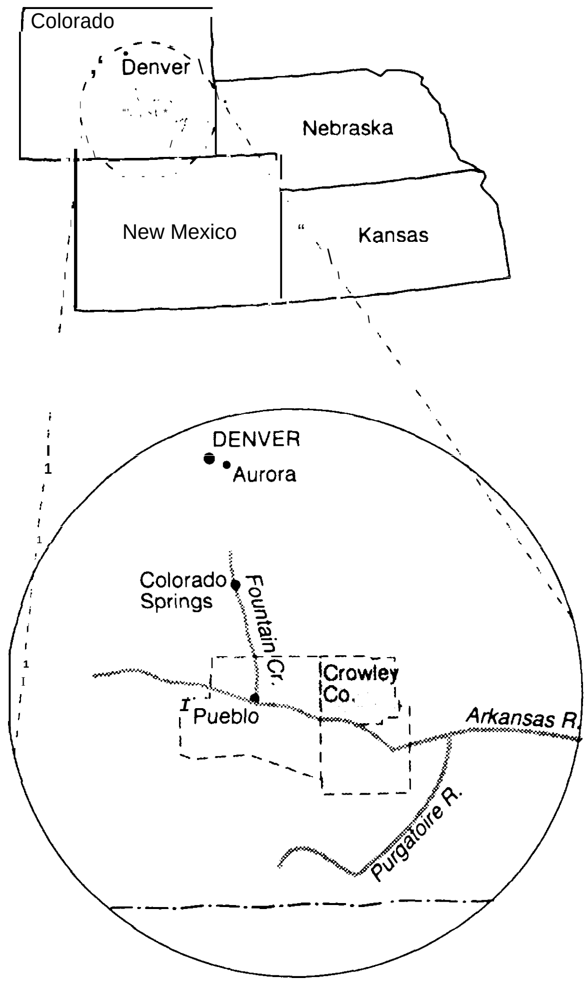
Particularity hard hit is Crowley County, which has seen 85 percent of its water rights transferred to cities. Little of the money received by farmers was reinvested in the local area. Rather, about 80 to 75 percent of the money went to pay taxes and debts of farmers who were already on the verge of bankruptcy. Crowley County already has the lowest assessed value of any Colorado county. Within the next few years, all land that has lost irrigation will be reassessed and the tax base will decline further. The burden of funding schools, local government, and other public services has shifted to the remaining few residents and farmers who chose not to sell their water. Colorado water law allows the transfer of water without regard to secondary consequences within the community. Despite attempts to jump-start the local economy with construction of a new prison, most prison employees have chosen not to live

[1] To convert acres to hectares, multiply by 0.405.

in the county, and many local businesses display "going-out-of-business" signs. Most of the farms that were once irrigated are now weed-covered and unsuitable even for grazing. The cities of Aurora and Colorado Springs have pledged to revegetate some fields with prairie grasses by providing temporary irrigation and seeding. It is not yet clear how intensively these lands can be grazed. Tens of thousands of other acres may remain weed-covered. Despite the rather bleak outlook, some residents are optimistic and look for opportunities to bring new business into the county.

Some workable solutions to conflicts over water between cities and farms are on the horizon. Ever since the Federal veto of the Two Forks Dam in 1990, Denver has been looking for new water supplies to support its growing population. Regional representatives have formed a plan outside "the traditional water development atmosphere." A combination of local utilities, cities, suburbs, farmers, environmental advocates, and the State have formulated a plan that may be appealing to all groups. Denver would purchase water from the South Platte River (currently used only by irrigators and off-limits to Denver), run the waste through an upgraded treatment plant, and then let the farmers use the cleaned-up wastewater for irrigation. This plan could make 50,000 to 100,000 acre-feet available to the City of Denver at much less than the cost of a new dam, although construction of an expensive water treatment facility would be required. Most interest groups are treating the plan as a serious alternative that minimizes losses on all sides. Other proposed solutions include the signing of "dry-year" option contracts between cities and farmers; in drought years, the city pays the farmer to forego planting crops and water is temporarily transferred to cities. These arrangements protect urban areas against drought shortages while maintaining long-term agricultural viability.

The Arkansas River Basin of Southeastern Colorado



SOURCE: Office of Technology Assessment, 1993.

Climate change could add to stresses on farmers across the western Plains. With the possibility of growing farm problems under a harsher future climate, more and more agricultural water is likely to be sold for urban use. In the past, extended droughts and poor financial returns have triggered abandonment of farming, the sale of water rights, and economic decline in rural communities. The prospect of climate change, raising the possibility that farming may have to be abandoned in large areas of the semiarid West, adds another layer of concern to these third-party effects.

SOURCES: Office of Technology Assessment, 1993; C.W. Howe, J.K. Lazo, and K.R. Weber, "The Economic Impacts of Agriculture-to-Urban Water Transfers on the Area of Origin: A Case Study of the Arkansas River Valley in Colorado," *American Journal of Agricultural Economics*, vol. 72, No. 5, December 1990, pp. 1200-1204; National Research Council, *Water Transfers in the West: Efficiency, Equity, and the Environment* (Washington, DC: National Academy Press, 1992); M. Obmascik and P. O'Driscoll, "Colorado Water: The New Harvest," *The Denver Post*, July 19-22, 1992.

So much land and water is used for agriculture that any climate-induced changes to agriculture would have profound effects on competing uses for these resources (see ch. 5 and vol. 2, chs. 4 and 6). Cropland and pasture account for 30 percent of land use, and irrigation of agricultural land accounts for 84 percent of consumed water (88). Land and water resources are particularly vulnerable to expansion of agricultural activity and to increases in the intensity of irrigation or in the use of farm chemicals. Many agricultural States have already lost much of their original wetland area (see vol. 2, box 4-E) and forest cover to agriculture.

Competition for scarce water is likely to be particularly important under climate change (3, 4). Whether increases in irrigation are possible will depend on water availability and costs. If withdrawal of water for agriculture does increase, wildlife habitat and other services that depend on freshwater flows will be increasingly threatened, particularly if climate change reduces or alters the seasonal timing of stream flows. On the other hand, without sufficient water for agriculture, farm yields will be reduced. The western regions, already facing water shortages, may see renewed pressures to construct large water-resource-development projects (see ch. 5). These projects have in the past been in conflict with the goal of protecting natural habitats.

Water quality may also be affected by a changing climate. Farm chemicals and wastes can infiltrate groundwater, and surface-water runoff and drainage can carry salts, farm chemicals, and sediments to adjacent water bodies (see box 6-E). With altered patterns of precipitation and regional agricultural activity and with altered dilution rates in streams and aquifers, the nature of the water pollution problem on a regional scale could change substantially. Concern over pollution

Box 6-E—irrigated Agriculture and Water Quality: The Kesterson Case

Climate change models suggest that many parts of the interior United States will become hotter and drier. One potential response to this is to increase the area of cultivated land under irrigation. Although increased irrigation may prove to be attractive to farmers, it is not without environmental costs-including potential damage to soils, water quality, and wildlife. The case of the Kesterson National wildlife Refuge shows how failure to anticipate potential waterquality problems can lead to severe contamination and suggests that future public efforts to support irrigation should proceed with caution and a thorough understanding of risks.

The Kesterson National Wildlife Refuge was established in 1970 along the San Joaquin River in California's intensively farmed Central Valley (figure). The 5,900-acre (2,390-hectare)[1] refuge harbored a diverse array of migratory and resident waterfowl, including ducks, geese, herons, and coots, as well as an assortment of fish, mammals, and raptors. Located in a State that is estimated to have lost more than 90 percent of its wetlands over the past two centuries, Kesterson appeared to be a crucial part of efforts to conserve California's biological heritage. In the spring of 1983, some of the ducks, coots, grebes, and stilts born at Kesterson Reservoir at the southeastern edge of the refuge emerged from their eggs deformed and crippled-with oddly shaped beaks, missing wings, twisted legs, and unformed skulls. Many died shortly after hatching. The U.S. Fish and Wildlife Service, which had investigated fish die-offs at Kesterson in 1982, conducted laboratory analysis that suggested that the disappearance of fish and the deformities of birds stemmed from a common cause—unusually high concentrations of selenium in the Kesterson Reservoir water. Trace amounts of selenium occur naturally in the soils of central California, as in many parts of the arid Southwest. The contamination of Kesterson Reservoir was caused by a combination of water development projects and irrigation practices. Selenium had leached from agricultural soils, moved through drainage systems, and became concentrated in the Kesterson Reservoir. At high concentrations, the selenium proved deadly. Kesterson Reservoir lies at the drainage end of the San Luis Unit of the Westlands Water District, operated by the Bureau of Reclamation as part of the huge Central Valley Project. The saline soils of large sections of the San Luis area were not easily used for irrigated agriculture. The success of irrigated agriculture in saline soils

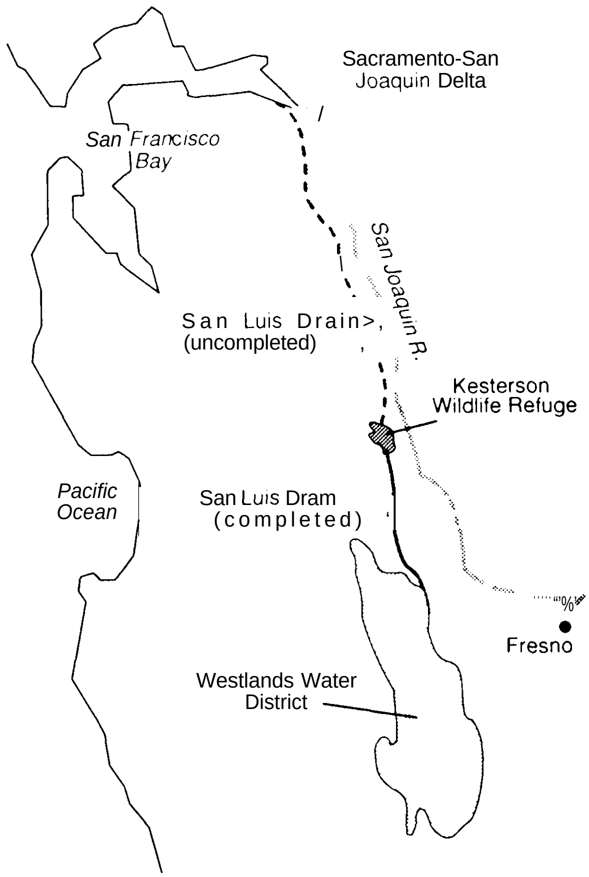
[1] To convert acres to hectares, multiply by 0.405.

depends on the application of enough water to flush salts out of the upper layers of soil. But the soils of San Luis presented an additional complication—they are underlain by an impenetrable layer of day that prevents the drainage of irrigation water. If the soils were irrigated enough to flush away salts, the poor drainage would cause the water table to rise, drowning roots of crop plants and depositing more salts in surface soils. Subsurface drainage was necessary to make the cropland productive.

As part of larger efforts to bring water to the Central Valley, the Bureau of Reclamation began planning water supply systems in the San Luis Unit starting in the 1950s, and by 1960, was authorized to begin construction of a system that came to include the San Luis Dam, Canal, and Reservoir. To achieve the proper balance of irrigation and drainage for agricultural production, the Bureau of Reclamation planned an extensive 188-mile (300 -kilometer)[2] drainage system to take drainage flows from the San Luis Unit into the Sacramento-San Joaquin Delta. Only the first 85 miles of the drain were ever completed. By 1975, the drain had reached Kesterson Reservoir—and that is where it stopped. Controversy over potential effects on water quality in the Delta and lack of Federal funds prevented completion of the full drainage system.

Since 1975, drainage water carrying selenium and other salts leached from the San Luis soils have emptied into the Kesterson Reservoir. Over the years, selenium and other potentially toxic trace elements concentrated in reservoir waters. The selenium was further concentrated in vegetation and small organisms on which waterfowl feed-a process known as *bioconcentration*—eventually producing the startling birth defects and mortality among young birds seen in 1983. Concern over possible risks to humans led the State to issue a health advisory, warning against eating duck hunted on the refuge. California's State Water Resources Control Board found concentrations of selenium up to 10 times higher than permitted by public health standards and other trace elements in amounts that exceeded Environmental Protection Agency (EPA) water-quality standards. By 1985, the Board declared the San Luis drainage water a hazardous waste that would have to be treated and cleaned up accordingly. Drainage into the reservoir was finally halted in 1986. [n less than a decade, Kesterson went from being a cornerstone of California's wildlife conservation program to a national symbol of environmental disaster. The Kesterson case is an extreme example of how irrigated agriculture may harm water quality-a particularly ill-fated confluence of Federal water projects, natural soil properties, and conflicting goals. However, the Kesterson problems are not unique. In the East, soluble salts have long ago been washed from

Kesterson Reservoir and Surrounding Areas



SOURCE: Office of Technology Assessment, 1993, adapted from R.W. Wahl, *Markets for Federal Water: Subsides, Property Rights, and the Bureau of Reclamation* (Washington, DC: Resources for the Future, 19s9).

2 To convert miles to kilometers, multiply by 1.609.

(Continued on next page)

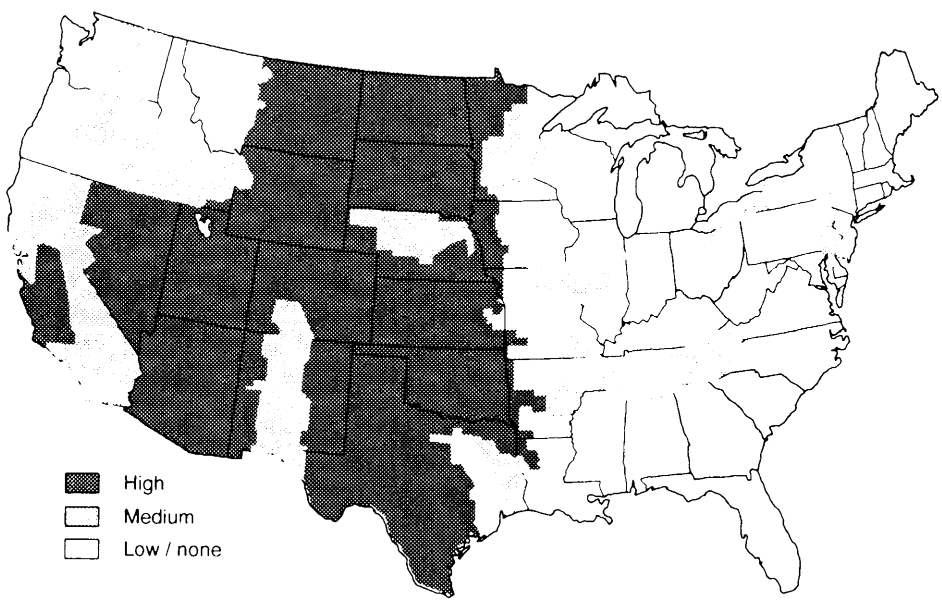
Box 6-E-irrigated Agriculture and Water Quality: The Kesterson Case-(Continued)

the soils by rainfall. But in the West, the accessibility of salt-bearing formations and iow rates of precipitation combine to make much of the region subject to salinity problems (figure below). Even on nonirrigated cropland, saline deposits can develop in areas of poor drainage. Dryland farming practices, alternating crop and fallow years (apossibleadaptation to climate change), maythemseivesaddto salinity problems. Crop-fallow rotations useless water than would natural vegetation, and the unused soil water can carry salts to low-lying areas.

Can a case like Kesterson happen again? Federal actions at water projects around the Nation will undoubtedly be more cautious in the future. However, in most Western States, irrigation and consumptive use still take priority, while protection of adequate water flows and water quality for wildlife, fish, recreation, and other natural uses receive short shrift (see ch. 5). Climate change may well increase the demand forwaterdiversions for irrigation, potentially leading to increased conflicts over water use and environmental quality.

SOURCES: Office of Technology Assessment, 1993; A. Dinar and D. Zilberman (eds.), *The Economics and Management of Water and Drainage in Agriculture* (Boston, MA: Kluwer Academic Publishers, 1991); R.W. Wahl, *Markets for Federal Water: Subsidies, Property Rights, and the Bureau of Reclamation* (Washington, DC: Resources for the Future, 19S9).

The Potential for Water-Salinit y Problems



SOURCE: U.S. Department of Agriculture, Soil ConservaticService, *The Second RCA Appraisal*, Miscellaneous publication No. 14S2, 19S9.

from agricultural sources may limit the extent to which agriculture can adjust to climate change.

Although an overall expansion in cropland seems unlikely (112), spatial shifts in the pattern of land use may still be disruptive to natural environments (4). For example, increases in farm acreage are projected in the environmentally sensitive lands of the Lake States and the erodible lands of the Northern Plains. As a result of climate change, economic forces could bring an additional 3 million acres into new production in the South, with much of this cropland created by the clearing of forests (23). Such an expansion of farming into highly erodible or environmentally sensitive lands would be inconsistent with environmental goals (see box 6-A).

TECHNOLOGIES FOR ADAPTATION TO CLIMATE CHANGE

Past experience suggests that U.S. farming is flexible and innovative enough to permit relatively quick changes in management practices and in crop choice. History is replete with examples that illustrate the responsiveness of agriculture and agricultural research to challenges (see boxes 6-F and 6-G). In responding to climate change, farmers can draw on the large array of tactics and strategies they already use to protect themselves against climate risk (see box 6-H). Many tactics, such as changing planting dates or cultivars, require little change in the nature of farm management and can be implemented rapidly. Other adjustments, such as adding irrigation or switching crops, require substantial changes in farm equipment and management, and will occur somewhat more gradually. Together, these may provide the first line of defense against climate change.

Agricultural adaptations that draw on current practices may be effective for a time in dealing with climate change. There is a reasonable chance, though, that climate change could eventually overwhelm the effectiveness of current adaptation possibilities. That is a compelling reason to consider the long-term prospects for new technologies. Long-term adaptation may require fundamental improvements in the technologies available to farmers. In the past, expansion of agricultural technology has occurred both as a market-induced response to a changing environment and through publicly supported efforts aimed at overcoming perceived resource constraints. U.S. farming has been supported in this by: 1) a sophisticated system of agribusiness; 2) a publicly supported land-grant university, research, and extension system that channels technology to farmers; 3) a transportation infrastructure organized to move food rapidly from the farm to an interlocking system of local, regional, national, and world markets; and 4) a market economy that quickly rewards successful adaptation. These institutions have provided U.S. agriculture with the ability to adapt to rapidly changing economic conditions and should, if well-maintained and directed, provide the basis for future adaptation to climate change.

USDA, AGRICULTURAL RESEARCH SERVICE

An ARS soil scientist inspects severely salt-damaged farmland in California's San Joaquin Valley.

Adaptation may be slowed by impediments to flexibility in crop choice, such as those imposed by Government farm-support programs (54). The net effect may be to discourage transition to cropping systems that are better suited to the changed climate. Uncertainty and inadequacies in the information available to farmers, both about climate change and effective responses to it, could slow the rate of adaptation. Policies that restrict or distort agricultural markets are also important constraints to effective adaptation (18, 20). The subsidies provided to farmers in some countries tend to discourage farming in regions where agriculture is more productive, and so raise overall costs of world food production.

Box 6-F—Historical Examples of Adaptability in Agriculture

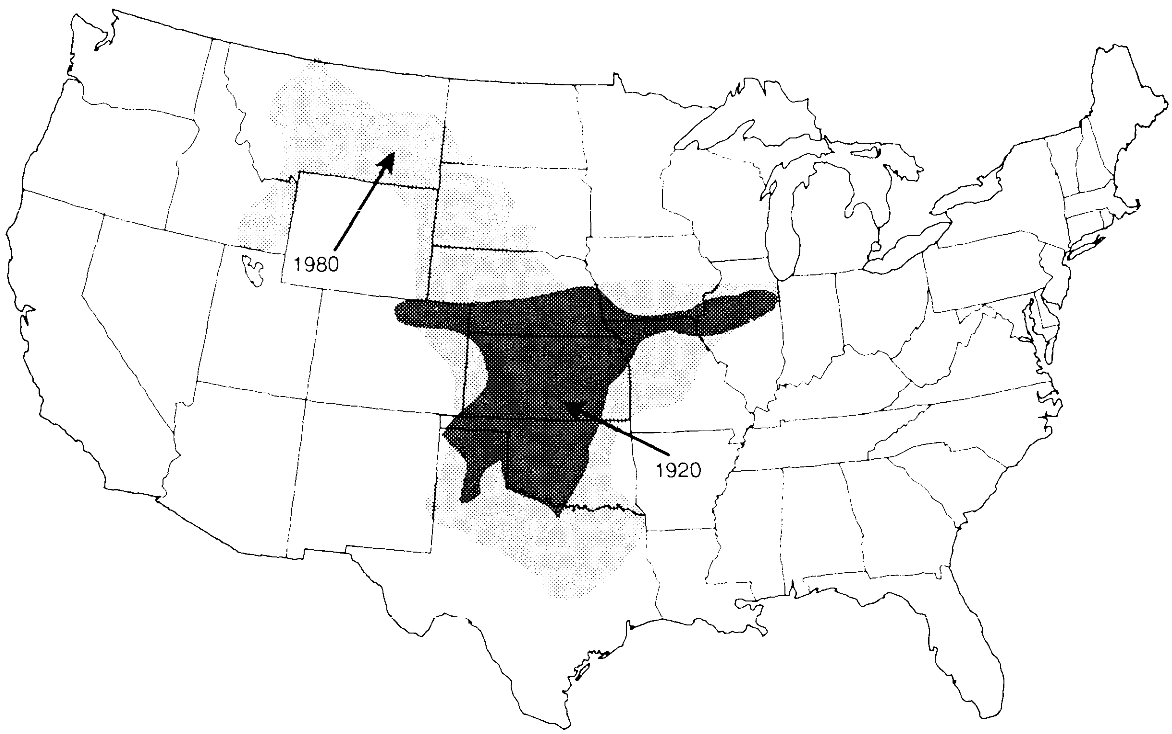
Adaptation of crops to different climatic regimes: the case of wheat and corn

Expansion of a crop into anew region often requires that the crop be adapted to a new climatic regime. Here we describe how hard red winter wheat and dryland corn have undergone such adaptation.

Hard red winter wheat—Hard red winter wheat has accounted for about half of all wheat produced in the United States. The figure below shows how much the production zone for hard red winter wheat expanded from 1920 to 1980 (76). Once limited primarily to Nebraska and Kansas, the crop is now grown as far north as the Canadian Prairie Provinces and as far south as the Rio Grande River. This process of expansion has occurred even during times of hardship in the farm economy (such as the prolonged drought and economic depression in the 1930s and the surplus production and depressed crop prices in recent years).

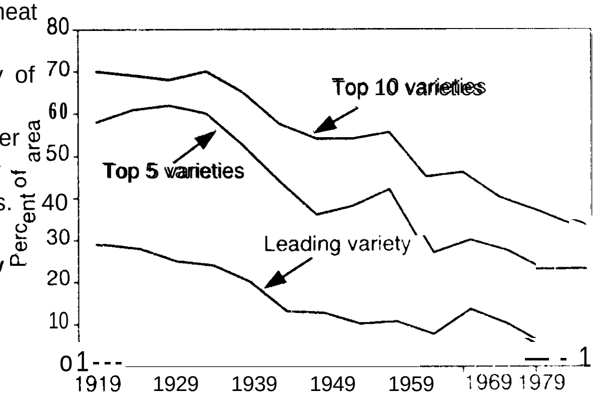
Through the efforts of crop breeders and agronomists, hard red winter wheat has been effectively adapted to colder temperatures and drier conditions. The crop is now grown in northern locations that are about 6 °F (3.5 °C) cooler and 15 percent drier than where growth was possible in 1920. The southward expansion of the crop has not been as striking as the northward spread. Still, average annual temperatures at the current southern boundary of the crop are almost 3.5 ‘F (2 ‘C) higher than they are at any location in the crop zone of 1920. The expansion in the hard red winter wheat range has come about from steady improvements in productivity made possible by the development of improved wheat varieties and farm-management practices (42).

Extent of the Hard Red Winter Wheat Zone in 1920 and 1980



SOURCE: N.J. Rosenberg, "The Increasing CO_2 Concentration in the Atmosphere and Its Implication on Agricultural Productivity, Part II: Effects Through CO_2-induced Climatic Change," *Climatic Change*, vol. 4, 1982, pp. 239-254.

Proportion of Wheat Planted to Leading Varieties in the United States



SOURCE: D.G. Dalrymple, "Changes in Wheat Varieties and Yields in the United States, 1919-1984," *Agricultural History*, vol. 62, 1988, pp. 20-36.

The development and adoption of semi-dwarf varieties in the 1940s (varieties whose stalks support heavier, grain-laden heads) boosted wheat productivity (21). Continued breeding efforts since the 1940s have resulted in the great diversity of wheat varieties now being used by US. farmers. The progression to greater varietal diversity over time (see figure) has been associated with better adaptation] of wheat to local growing conditions. Breeding for disease resistance helped the expansion to the south. Selective breeding for cold-hardy varieties of hard red winter wheat helped the expansion of wheat to the north.

Improved farming practices, especially the use of nitrogen fertilizers, better soil-moisture management practices, and large self-propelled machinery, have increased the productivity of wheat growers. The practices of stubbling-in (i.e., direct seeding of winter wheat into untilled fields immediately after harvest of the previous crop) and snow trapping (e.g., using snow fences to collect snow on fields) have reduced the risk of winterkill and permitted an expansion of the crop northeastward into Canada's western agricultural Provinces (86).

The past performance of the research community in developing new ways for wheat to overcome climatic constraints suggests the enormous capacity of the community to respond in the future. For example, as a consequence of breeding programs, the genetic diversity of hard red winter wheat is increasing; this greater genetic diversity should provide the raw material for further progress in crop development (19). This is but one example of the promise for future progress in adaptive agricultural research.

Dryland corn—Perhaps even more remarkable than the spread of hard red winter wheat into the Canadian Prairie Provinces is the recent adaptation of dryland corn to that same region. Farming systems in the semiarid northern Great Plains have historically suffered from overdependence on a narrow range of crops, especially wheat (56). This overdependence made the region vulnerable during times when wheat prices were depressed. Recognition of this problem caused farmers, working in concert with the local agricultural research establishment, to seek an alternative crop.

The Lethbridge Research Station devoted 8 years of research to adapting corn to the climate of southern Alberta (56). Relative to regions of the United States that produce significant quantities of dryland corn, southern Alberta is drier, the frost-free season is shorter, cumulative seasonal warmth is lower, and day length (period of daylight) is longer. The long day length can delay flowering, and the short growing season then provides little time for maturation.

In response to these challenges, plant breeders at Lethbridge have developed hybrids that have reduced sensitivity to day length and a short juvenile phase, so that the tassel starts to grow within a week of plant emergence. Moreover, breeders have successfully selected for varieties with a short interval between the opening of the mrn tassels and the production of silk, which appears to give corn plants increased tolerance to drought. In dryland trials, corn yields from these new varieties are competitive with those of barley and wheat (56). These results clearly illustrate how directed research (i.e., the desire to diversify cropping systems in southern Alberta) can overcome major climatic constraints on crop production.

Box 6-F—Historical Examples of Adaptability in Agriculture—(Continued)

Rapid introduction of new crops: the case of soybeans

Climate change may necessitate widespread and relatively rapid shifts in the types of crops currently grown in the United States. How easily such a shift could be accomplished will depend on the available pool of crops that will flourish under the changing climate and on their production costs and markets. The expansion of soybeans into U.S. agricultural production, especially since World War II, is a vivid example of the rapidity with which the Nation's production systems can be modified to accommodate a new crop.

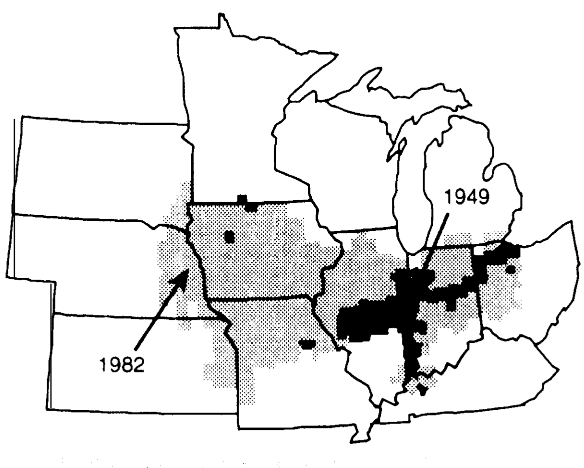
Soybeans have been cultivated in the United States since the early 1800s, although most were used for forage until the middle of this century (71). In 1920, there was no measurable acreage planted in soybeans in the Corn Belt States. Acreages planted in soybeans remained quite low until just before World War II (34). At that time, the United States imported over 40 percent of the soybeans that were used domestically.

During World War II, a growing demand for margarine created a market for soybean oil (34). Soybeans rapidly began to compete with other oil seeds, and cropland was shifted into soybeans. In the midwestern United States, increases in soybean production came at the expense of corn, wheat, and oat production. For the South, the soybean was a savior, replacing cotton as cotton prices plummeted in the wake of declining world demand. By 1949, the United States became a net exporter of soybeans. In less than 30 years, soybeans had become a major cash crop for U.S. farmers.

Since World War II, continuous growth in the livestock and poultry industries has further increased the demand for the high-protein soybean meal. By 1982, more than one-third of the cropland in the Corn Belt was planted in soybeans (4). The increase in midwestern soybean acreage between 1949 and 1982 is shown below. The rapidity of the spread of soybeans in the United States is significant for assessing the prospects of a successful shift to alternative crops under climate change. It demonstrates the capacity of the farming sector to convert equipment, management, and marketing to grow and process a new crop in a short period of time. It also shows the willingness of farmers to experiment with a new crop as the crop of preference (cotton, in the South) became uneconomical.

There are limits, however, to the usefulness of the U.S. soybean experience as an analogy to the shifting of crops to adapt to climate change. A major incentive to growing soybeans was the rapid growth of demand for oil and meal worldwide. The combined attributes of oil-bearing seeds and high-protein residual meal gave soybeans a clear advantage over competing crops. There do not appear to be crops waiting in the wings that could generate the kind of market that soybeans did. On a smaller scale, new crops may provide alternatives to farmers. For example, several drought-tolerant crop species, such as paloverde, jojoba, and mesquite, may be useful in dealing with increasingly scarce water in the southwestern United States (58, 102). These crops have low water requirements and produce harvestable quantities of valuable botanochemicals and other plant products.

Midwestern Soybean Acreage in 1949 and 1982



NOTE: Counties with more than 10 percent of land in soybeans.

SOURCE: Office of Technology Assessment, 1993, adapted from J.F. Hart, "Change in the Corn Belt," *The Geographical Review*, vol. 76, No. 1, 1986, pp. 51-72.

SOURCE: W.E. Easterling, "Adapting United States Agriculture to Climate Change," contractor report prepared for the Office of Technology Assessment, January 1993; Office of Technology Assessment, 1993.

Box 6-G—Adaptation to Declining Groundwater Levels in the High Plains Aquifer

The High Plains, or Ogallala, Aquifer is a large geologic formation of porous sand that underlies approximately 200,000 square miles (520,000 hectares)[1] in the U.S. Great Plains (see figure). The vast aquifer supplies water for most of this region's agricultural, domestic, and industrial uses. The response to growing water scarcity in this region may serve as a useful model for adaptation to climate change (37).

By 1980, some 150,000 agricultural irrigation wells were pumping water from the High Plains Aquifer. Use of groundwater rose steadily from 7 million acre-feet (18.6 billion cubic meters)[2] in 1950 to 21 million acre-feet by 1980 (117). In these early days of irrigation, public information about irrigation technology and the status of the aquifer was limited (118). Waste was obvious, and widespread pumping from the aquifer was causing groundwater tables to drop. Serious declines in groundwater occurred in the southern Plains, with water tables dropping more than a 100 feet (30 meters) in parts of Texas (43). in Kansas, almost 40 percent of available groundwater had been withdrawn by 1980. With declining groundwater in Kansas came increased threats to critical wetland habitats used by the whooping crane. A groundwater resource that once seemed inexhaustible appeared, by 1980, to be in danger of eventually running dry.

The Ogallala Aquifer

SOURCE: Office of Technology Assessment, 1993.

Declines in the aquifer resulted in increased irrigation-pumping costs because it takes more fuel to pump from lower depths. This increased cost has in turn prompted technical and institutional adaptations. A survey of agricultural water users across the High Plains Aquifer region found that the preferred technical adaptations to declining groundwater levels were increased irrigation efficiency and the practice of conservation tillage (51). Under conservation tillage (e.g., no-till and reduced-till management), crop stubble is left on the field after harvesting, shielding soils from sun and drying winds. A switch to low-pressure irrigation systems in the southern Plains States (53) increased irrigation efficiency by greatly reducing evaporative water losses. Overall irrigated acreage has also declined, and many farmers have switched to low-water-intensity crops such as wheat, cotton, and sorghum (66).

Institutional responses to scarcer groundwater on the High Plains have occurred at local and regional levels (48). The effectiveness of local policy has varied from State to State. Kansas, for example, passed a groundwater management law that made possible the formulation of regionally controlled groundwater management units (66). These units provide orderly development of the High Plains Aquifer with tools such as the spacing of wells, limits on numbers of wells, metering of water use, and promotion of water conservation. Areas of Nebraska have imposed similar restrictions and metering requirements. The Cheyenne Bottoms Wildlife Area of Kansas is a 13,000-acre (5,200-hectare)[3] wetland that provides critical habitat for the whooping crane and some 5 million other migra-

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1 To convert square miles to hectares, multiply by 2.590.

2 To convert acre-feet to cubic meters, multiply by 1,230.

3 To convert acres to hectares, multiply by 0.405.

(Continued on next page)

tory waterfowl that pass through each spring. The Kansas State Engineer has been able to impose restrictions on groundwater pumping in order to protect recharge rates into this wetland.

Texas, the State that could benefit most from strong groundwater governance, has rather weak groundwater management institutions (92). Unlike the other 49 States, Texas uses an absolute ownership rule in determining rights to groundwater. The rule, based on English common law, states that an owner of a parcel of land owns from the "sky above to the depths below" (92), which includes the water on, above, and below the surface. The absolute ownership rule has proved to be a formidable disincentive for landowners to agree to regulation of their water at the local level. Nevertheless, in the High Plains of northwest Texas, increasing water scarcity has resulted in innovations in the institutions for coordinating groundwater use and promoting water conservation.

The 5.5 million acres in the 15 northwest Texas counties that constitute the High Plains Groundwater Conservation District No. 1 (44) receive just 12to 16 inches (30 to 41 cm) of precipitation per year, but overlie part of the Ogallala Aquifer. Irrigation with groundwater pumped from the aquifer has allowed the region to grow large quantities of cotton, barley, sorghum, and corn for many years (74). The High Plains District was created in 1951 largely to address the needs for groundwater conservation. The District has been "dedicated to the principle that water conservation is best accomplished through public education" (44). Accordingly, the District focuses its efforts on research and demonstration projects, publishing free information about groundwater use and methods for conserving water, performing on-farm water-efficiency testing, and carefully monitoring groundwater levels and water quality.

One of the earliest District efforts was to reduce open-ditch losses. Water losses from open ditches were as high as 30 percent per 1,000 feet of ditch (44). The District performed economic analyses that showed farmers it would be cost-effective to stop losses (1 18). As of 1989, 12,097 miles (1 9,500 kilometers)[4] of underground pipeline had been laid to replace open ditches (44). Cost-effective systems for recovering irrigation tail water were also developed and demonstrated by the District (74). New technology in the form of time-controlled surge valves for furrow irrigation and low-energy precision-application (LEPA) methods for spray irrigation systems were widely demonstrated and promoted by the District. Surge valves and shortened furrows resulted in 10 to 40 percent improvements in furrow-irrigation water losses, while LEPA systems reduced center-pivot irrigation losses from around 40 percent to as low as 2 percent (W. Wyatt, ated in ref. 74; 44). In 1978, the High Plains District in conjunction with the U.S. Department of Agriculture's Soil Conservation Service initiated an on-farm water-efficiency-evaluation program. In many cases, suggested water and energy savings were sufficient to pay back farmers' costs within 1 or 2 years (74).

The High Plains District has a goal of reaching an equilibrium between groundwater withdrawals and aquifer recharge, as measured during a 5- or 10-year average. So far, net groundwater depletions in the Ogallala Aquifer underlying the District have declined from a 5-year average of 1.4 billion gallons per day (bgd) (15.3 billion liters per day)[5] in 1966-71 to an average of 0.43 bgd in 1981-86 and 0.16 bgd in 1986-91. A 25 to 40 percent cutback in groundwater use has been achieved (74); part of the cutback can be attributed to reductions in irrigated and planted area and several years of above-average rainfall (118, 44). Nevertheless, improvements in water-use efficiency and aquifer sustainability have led District officials to conclude that their voluntary, education-based approach to water conservation has been successful (44, 119).[6]

The various societal and individual responses to growing water scarcity suggest that farming regions may adapt well to a slowly changing climate. Perhaps more impressive than the ability of farmers to undertake technical adaptation has been the relative ease with which institutions have developed to promote more efficient use of scarce water resources. Still, despite the positive changes that have occurred in this region, one should not be overly optimistic. Groundwater depletion continues in much of the aquifer--even though at reduced rates-and many farmers face a reduction in future farm income as they decrease their water use.

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4 To convert miles to kilometers, multiply by 1.609.

5 To convert gallons to liters, muitiply by 3.785.

6 B. Williams, Director of Administration, High Plains Water Conservation District, Lubbock, TX, personal communication, July 1992.

SOURCE: Office of Technology Assessment, 1993.

Box 6-H--Current Technologies for Adapting to Climate Change

Changes in planting and harvesting practices

Climate warming may allow farmers to plant earlier in the spring. Earlier planting could lessen the chances of damage from heat waves at critical stages of plant growth. Shifting the period when a crop's leaf area is largest so that it matches the months of maximum sunlight would increase growth rates. Earlier planting would also allow earlier harvesting because warmer temperatures speed up plant development. Earlier harvesting reduces the risks of late-season field losses. Earlier maturation may also allow grain crops to dry more completely in the field, eliminating or reducing the need for artificial drying.

Warmer springs imply a longer growing season. Early planting in combination with a longer-season cultivar may allow farmers to increase yields by taking advantage of the longer season-provided that moisture is adequate and the risk of heat damage is not too great. For risk-averse producers, earlier planting combined with a shorter-season cultivar may give the best assurance of avoiding the large losses associated with hot summer temperatures. Planting a mix of cultivars with different maturation times could increase the probability that some portion of the crop is exposed to the most favorable climate during a growing season (93).

Planting seeds deeper in the soil and reducing planting densities (plants per acre) are two simple ways of evading drought stresses. Planting seeds deeper may give them access to more moisture, which would facilitate successful germination. Smaller pfant populations reduce competition among plants for available soil moisture.

Tactics for conserving moisture

Several moisture-conserving practices have been used to combat drought and aridit y (77, 94, 97) and may be useful in adjusting to climate change. Conservation tillage is the practice of leaving the residue of the previous season's crop on the surface of the field, rather than plowing it under the surface. Conservation tillage protects fields from water and wind erosion and can help retain moisture by reducing evaporation and increasing the infiltration of precipitation into the soil. Conservation tillage also decreases soil temperature. Furrow diking is the placing of small dikes across the furrows of the field to aid the capture of rainfall. Terracing, or contouring, can be used to more efficiently trap precipitation on sloped fields. However, the construction of terraces can be costly.

Crop substitution is potentially a way to conserve moisture. Some crops require less water and tolerate warm, dry weather conditions better than others. For example, wheat and sorghum are more tolerant of heat and dryness than is corn. Microclimate modification can be achieved through the use of shelterbelts, or windbreaks. Shelterbelt systems are linear configurations of trees or tall annuals surrounding one or more sides o? agricultural fields.[1] They greatly reduce wind speed across the protected field, benefiting plant growth by reducing evaporative-moisture losses (77). They are particularly effective in windy regions that otherwise have little natural woody vegetation, but they are costly in terms of land use.

Irrigation scheduling is the practice of supplying crops with irrigation water only when t hey need it. It adjusts the timing of the irrigation and the amount of water to match actual field conditions. Irrigation scheduling requires sources of information about soil-moisture conditions and, when using ditch irrigation, close cooperation among farmers. A study of four Nebraska counties found that irrigation scheduling on center-pivot systems reduced irrigation-water use by 9 percent and saved farmers an average of $2.10/acre in pumping costs (8). Low-energy precision application (LEPA) is an adaptation of the center-pivot irrigation system; low-pressure application of water near ground level results in less water loss to evaporation. Trickle irrigation applies water as drops or trickles through pipes on or below the soil surface. These very efficient but high-cost irrigation systems are now in common use only for fruit crops and highly valued vegetable crops.

[1] Sunflower and corn have been used In California and Arizona, respectively, as windbreaks around highly valued crops.

(Continued on next page)

Box 6-H-Current Technologies for Adapting to Climate Change-(Continued)

Increased irrigation

Increased irrigation is one obvious means of coping with drier conditions. However, inadequate water supplies and high costs will limit this option in some regions. Regions that are currently reaching the limit of existing irrigation-water supplies (e.g., the Southern Plains and California) will be unlikely to support additional irrigation-water use (35, 69). Irrigation may decline because of increased urban competition for water and because of possible reductions or seasonal changes in the timing of stream flows. Irrigated acreage may increase only in eastern regions, where water supplies are adequate. Under a climate change, irrigated acreage as a percentage of total cultivable land could increase by perhaps 3 percent in the eastern t hird of the United States (69). The trend toward increased irrigation in the eastern United States is already under way.

Equipment purchase and increased farming intensity

Climate change may cause the quantity and quality of production inputs to change. Several agricultural experts argue that climate change may encourage farmers to alter their investments in on-farm infrastructure in order to: 1) purchase equipment necessary to change cropping systems, 2) expand the size of operations in order to offset climate-induced yield reductions, and 3) enlarge storage facilities to provide a buffer against extreme events such as drought and pest and disease outbreaks (68). Others note that farmers make investments in apparently excess equipment capacity to better ensure that farm activity can be completed before a period of unfavorable weather (90). intensification of farming in areas beneficially affected by climate can be a way to maintain overall farm yields.

Reduced farming intensity

if the frequency of poor yields increases, some farmers may reduce the amounts or quality of inputs to production (89). One exam pie would be to make fewer passes over the field for cultivation in order to hold down energy costs. Allowing irrigated acreage to revert to dryland farming or grasslands may occur when water is short or when water deiivery costs rise, as has aiready happened in the southern Ogalalla Aquifer (see box 6-G). Fallowing (holding iand out of production for a year in order to accumulate sufficient soil moisture) is often a necessary practice in dryland wheat farming. in the extreme, acreage abandonment (including not harvesting planted acreage and converting to woodlands) can be the most effective cost-cutting response to an unfavorable climate (60). Successful adaptation from t his perspective means finding t he most profitable means of farming; it does not mean that past production levels are necessarily maintained.

Helping livestock adjust

Several tactics may be used to heip livestock adjust to excessive heat (38). The temperature of animals' surroundings can be reduced by providing shade or partiai shelters. Trees make the best shade because they provide protection from direct sunlight and beneficial cooling as moisture is transpired from ieaves. During a3-day heat wave in Chino Valley, California, in 1977, more t han 700 dairy cattle died (38). Deaths in lots with adequate shade were almost 70 percent lower than those in iots where cattle had inadequate shade. Evaporative coolers that lower air temperature in animal shelters can be effective in limiting productivity losses under high temperature conditions (38). Animal wetting is an effective way to lower the surface temperature of animals. This can be accomplished with a sprinkler system controlled by a timer. Maintaining large feed reserves is another tactic that livestock farmers use to lower their risk of facing feed shortages duringclimate extremes (9).

Farm structure and marketing practices

Increasing the scale of farming operation may in some cases effectively reduce the variabiiit y in income and yields. Strategic specialization can be an advantage in a small number of safe crops (55). Efficient farming in the "safest" crop is certainly a f requent—and perhaps t he best-defense against climate risk. On dryland farms in the

Western Great Plains, where crop failures from drought occur regularly, farmers grow wheat or sorghum, using conservative and low-cost methods. To the east, where rainfall is more abundant, corn and soybeans are the dominant crops. Large-scale farming enterprises can hedge against localized climate risks by diversifying geographically, spreading their farm holdings across climate zones. In the face of increasing climate uncertainty, the value of crop diversification on individual farms through the addition of less-risky crops may increase. A 1985 survey of farmers in Florida and Alabama found that they deal with variable climate risk by keeping their operations diversified (9). The large variability from decade to decade in Illinois corn yields can be seen as an example of a response to climate change, and farmers there have responded to the perception of increasing climatic risks by diversifying.

Owners of citrus groves in north-central florida adapt to the risks of winter freezes by diversifying their source of income more than do the citrus growers to the south, whc face less risk (61). Corporate ownership or partnerships allow each investor to risk relatively little income. The fruit is often sold through vertically integrated cooperatives, rather than in on-the-spot markets, as in the south. This marketing practice allows for speedy processing of freeze-damaged fruit, a benefit that compensates for lower average prices. Changes in the structure of farm ownership and vertical integration through contractual marketing arrangements can be effective institutional ways to spread the risk inherent in farming.

SOURCES: W.E. Easterling, "Adapting United States Agriculture to Climate Change," contractor report prepared for the Office of Technology Assessment, January 1993; Office of Technology Assessment, 1993.

Ultimately, the ability of agriculture to adapt to a changing climate may be most dependent on continued success in expanding the variety of crops and techniques available to farmers. Biotechnology appears to offer hope of continued improvement in agricultural productivity well into the next century. Expected improvements in overall agricultural productivity and plants with increased tolerance to pests, drought, and heat all offer the chance for increased buffering against the direct risks of future climate change. The success of these and other potential improvements in farm management and productivity will be increasingly sensitive to how well new knowledge is transmitted to the farmer. The role of agricultural research and extension in conveying information to farmers and in promoting innovation is likely to take on increased importance under conditions of changing climate. Research must be tied to the development of information and management technologies if it is to remain a source of improved productivity (85). In the absence of such a focused effort to tie research to the needs of farmers, promised gains from new technology may not materialize.

Current Technologies for Adaptation to Climate Change

Approaches that can be used now to adapt to climate change range from changing planting and harvesting times to increasing-or decreasing—the intensity of farming (see box 6-H). Some of these approaches are technical, such as irrigation scheduling or the use of evaporative coolers to help livestock adapt to the warmer temperatures. Others involve changes in farm scale and ownership as ways to reduce exposure to risk. Still others are straightforward changes in agronomic practices, such as earlier planting or reduced tillage. These may provide the first line of defense against climate change.

Prospects for Future Technologies

The impressive past productivity gains in American agriculture do not guarantee continued technological improvement, but biotechnology, computerized management, and other technologies could usher in an era of new advances. The Office of Technology Assessment (OTA) (103) reports that projected plausible increases in annual rates of yield for major agricultural commod-

Table 6-2—Projected Annual Rates of Growth in Agricultural Yields (percent)

	Less new technology	Most likely technology	More new technology
Corn	-0.2	1.0	2.0
Soybeans	0.1	0.4	1.2
Wheat	0.8	2.0	4.4
Cotton	NA	1.7	NA
Beef (meat/feed)	0.2	0,7	1.7
Swine	1.2	1,6	2.4
Dairy (milk/feed)	0.2	0,4	0.5
Poultry (meat/feed)	0.1	0.5	1.5

NA -Not available.

SOURCE: U.S. Congress, Office of Technology Assessment, *A New Technology Era for American Agriculture, OTA-F-474* (Washington, DC: U.S. Government Printing Office, August 1992).

ities range from 0.4 to 2 percent (table 6-2), but such future advances cannot be taken for granted. Some analysts are concerned that if farmers continue to use conventional technologies, yields of many important crops (e.g., rice, corn, soybeans, and cotton) may reach their maximum potential within the foreseeable future (83, 85). Yield increases from conventional breeding and increased efficiencies in farm management should continue over the next few decades. Breeders continue to be successful in finding ways to redistribute a plant's energy into grain production rather than leaf production, for example. Other gains continue from more-intensive management and from the breeding of plants that respond well to the use of fertilizer and irrigation. Further success with these approaches may be increasingly difficult to achieve (83, 85). Although average yields achieved by farmers are still less than record and potential yields, that gap has closed steadily. Biotechnology could speed up the process of cultivar development (25), and innovative farm management could reduce the environmental costs previously associated with intensive farm practices.

Biotechnology

Biotechnology involves the use of molecular genetic tools to mod@ plants, animals, or microorganisms. By using recombinant-DNA[15] and cell-fusion techniques, scientists can isolate, clone, and study individual genes. Such knowledge allows for direct modification of the genetic structure of plants and the development of microorganisms or biochemical products, such as enzymes and hormones, that will improve the growth and performance of agricultural crops and livestock. Biotechnology does not itself provide new cultivars, but rather provides the source material for more-rapid advances through conventional plant breeding. A National Research Council study suggested that Federal support of biotechnology needs to be expanded if long-term advances are to be achieved by the time they are needed (63).

New tissue-culturing and genetic-engineering tools combined with traditional agricultural breeding methods are allowing scientists to alter plants to incorporate greater disease, insect, and weed resistance, and to better withstand environmental

An insect-ravaged cotton leaf is compared with one that has been genetically engineered with a protective gene from **Bacillus thuringiensis.**

15 Deoxyribonucleic acid.

stresses such as cold, drought, and frost. These techniques are also improving the understanding of plant resistance and are allowing the development of improved pest-control agents. Crops that exhibit increased insect resistance and herbicide tolerance are expected to be commercially available by the middle to late 1990s (103). Plants with improved resistance to diseases should become commercially available over the next decade or so.

Improved insect resistance in plants has been achieved by introducing genes that produce the toxin from the bacterium *Bacillus thuringiensis* (a natural insecticide). Some success is also occurring in attempts to develop crops that are resistant to the broad-spectrum, environmentally safe herbicide glyphosate. Soil microorganisms that can control weeds and soil-borne nematodes and insects are also being developed. All of these new ways to control pests biologically offer hope for reduced use of herbicides and insecticides.[16]

Progress in improving tolerance to water and heat stress is complicated by a lack of knowledge about the physiological mechanisms of stress. Thus, genetically engineered plants tolerant to such climate stresses are unlikely to be developed in this decade (103). Development of commercial plant varieties with improved nutrient intake (i.e., they use fertilizers more efficiently) also appears unlikely within the next two decades. A better understanding of the key roles that associations between microbes and plant roots play in the use of nutrients--often supplied in the form of fertilizers-is still needed. If nutrient uptake can be improved, a secondary benefit would accrue in water-quality improvements because fertilizer losses to surface and groundwater are a significant source of pollution problems (as well as being costly to farmers),

USDA, AGRICULTURAL RESEARCH SERVICE

Precise application offertilizers is possible using the experimental global positioning unit being installed on this tractor.

Information and Management Technologies

Future improvements in productivity may increasingly rely on the development of information and management technologies and the effective transfer of knowledge to farmers (85). Improvements in information technologies and the technology of farm management offer alternatives to the intensified use of traditional farm inputs as the basis for expanded agricultural production. Improved efficiency in the use of farm inputs and practices can increase productivity and has the potential to reduce the environmental costs associated with farming. Central to this is improved understanding of plants, animals, and farming systems, which may rely on the increased use of computers, better computer software, the use of smart machines and control systems, in-field and remote sensing, geographical information and imaging systems, and electronic networks or other communication technologies.

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16 Some fear that the development of herbicide-tolerant plants will lead to an increased use of herbicides. So far, however, efforts have&n focused on developing plants that tolerate one of the more benign herbicides, allowing less use of persistent and toxic herbicides (30). See reference 103 for a discussion of the risks related to the uses of biotechnology,

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Farmer and engineer check automated weather station that feeds data into the COMAX software system to update its prediction of cotton yield and to suggest a harvest date.

Although computers have already had an impact on farm management, they could contribute a lot more. Systems for livestock management and for access to weather and marketing information are the best-developed applications to date. The earliest new applications of computer-software technology to attain broad use may be simple "expert systems' that help the farmer diagnose and respond to very specific production problems, such as disease (103). More complete decision-support packages for farm management might begin to be available within a decade (103). Much effort is still needed in the development of crop-simulation models to support integrated-decision-management software.

The potential for the use of advanced technologies is already being demonstrated on farms that grow highly valued crops. The means exist for sensing temporal and spatial variations in field conditions and delivering irrigation water, fertilizer, and pesticides to each area of the field precisely as needed. Irrigation of highly valued crops is now automated on some farms; it relies on computer programs, soil-moisture sensors, and weather-data networks (17). Farm machinery that can selectively till, weed, or fertilize only those areas in need of attention is also being produced commercially. Widespread use of advanced agricultural technologies and computerized information services is not likely to occur until costs decline significantly and the technologies have been adapted for a wider range of production systems.

Information-retrieval systems, allowing farmers access to electronic networks and collections of farm-management information based on compact-disk read-only memory (CD-ROM), are likely to be available by the mid-1990s. The packaging of information and decision-support technology in a manner that makes it useful to farmers will be critical to enhanced farm productivity. The extension services and the private sector will need to be prepared to take advantage of the new communications techniques to deliver effective and integrated decision-support services. The USDA Agricultural Research Service has recognized the importance of research into integrated management systems and information technologies. However, research on and teaching of computer software and computer-assisted-management tools are not yet well-established in agricultural schools (103).

New *Crops and* Cropping Systems

The idea that new crops could help stabilize and diversify the farm economy is hardly new. Only a handful of crops is being readied for possible commercialization in the near future (72, 102). *Cuphea* is an oilseed that can replace imported coconut oil in soaps and detergents, but commercialization will depend on the development of varieties that retain their seeds better. *Crambe* and winter rapeseed provide erucic acid, used to produce plastics and lubricants. *Crambe* tolerates climate conditions similar to wheat. Winter rapeseed can be double-cropped, grown over the winter in the Southeast and southern Midwest.[17] Both could be commercialized quite rapidly under current conditions. Guayule produces a high-molecular-weight rubber that is well-suited for use in tires. The guayule plant tolerates the arid conditions of the Southwest, but problems with low yields must still be overcome.

Jojoba is a desert evergreen with seeds that provide a substitute for sperm oil and for some petroleum-based oils. Jojoba oil is already used in the cosmetics industry and may be useful in commercial waxes, lubricants, and polishes. Bladderpod tolerates low annual rainfall, and its seeds contain oils that substitute for castor oil in plastics production. Continued efforts in plant breeding are necessary to increase the oil content and yields. Kenaf is a warm-weather plant that produces a fiber with a cellulose content similar to that of wood. The fiber can be used in high-quality newsprint, cardboard, and high-quality paper. Late-season dryness and some salinity are tolerated, but there must be adequate water during the initial period of germination and growth. Kenaf appears to have considerable promise for commercialization.

New crops have their own drawbacks, however. It is difficult to develop new markets when existing crops or synthetic chemicals are competing for them. A limited genetic base can slow crop-breeding advances and may leave crops vulnerable to unanticipated pests and disease. By and large, new crops succeed only when they are safer and cheaper than the old or fit a unique market niche.

Several Federal programs fund research and development of new crops or new uses for existing crops. The Food, Agriculture, Conservation, and Trade Act of 1990[18] (P.L. 101-624), for example, established the Alternative Agricultural Research and Commercialization Center within USDA to provide research and financial assistance in commercializing new nonfood products from agricultural commodities. Less attention is given to new food crops because these tend to compete with existing farm products. There are, however, various food crops grown elsewhere in the world or with limited production in the United States (e.g., sorghum and various minor grains and grain legumes) that may offer opportunities under climate change. New specialty crops, multi-cropping approaches, and integrated agro-forestry

USDA, AGRICULTURAL RESEARCH SERVICE

A stand of Kenaf, a fibrous plant with potential to supplement wood-based paper pulp, is inspected at Rio Farms in Texas' Rio Grande Valley.

17 Production of canola, a spring rapeseed low in erucic acid, developed in Canada, and suitable for human and animal foods, is now expanding rapidly in the Northern Plains States.

18 Referred to subsequently as the 1990 Farm Bill.

and livestock operations may become viable future options for smaller farmers who do not have the capital to rely on high-technology farming.

THE INSTITUTIONAL SETTING

Reducing risks associated with variability in farm yields has become a central part of U.S. agricultural policy. Various institutional and structural measures are designed to support the farm sector and buffer the consumer from fluctuation in supplies and prices of farm commodities. These include commodity support programs, disaster-assistance programs, and subsidized irrigation. (See box 6-I for discussions of these programs.) In addition, the agricultural sector is supported by an extensive research and extension network.

Commodity programs are of three types: price support, income support, and supply management. Although not viewed as buffers against climate risk, the commodity programs do provide participating farmers with protection against the low prices that result from bumper-crop yields. The costs of these commodity programs are shown in figure 6-6.

The disaster-assistance programs, including disaster payments, crop insurance, and emergency loans, provide direct relief to farmers suffering weather-related losses. In recent years, Congress has provided disaster payments for losses beyond some specified percentage of normal yields (35 to 40 percent in 1992), providing partial compensation to any farmer suffering losses in excess of that amount. low-interest emergency disaster loans are available to family farmers experiencing crop losses of at least 30 percent. Individual farmers become eligible for emergency loans once their county has been declared a disaster area by the President or the Department of Agriculture. Federally subsidized crop insurance is also available to almost all farmers. Farmers may insure up to 75 percent of their average crop yield, receiving payment on additional losses if weather causes yields to fall below the insured level. Up to 30 percent of the cost of insurance is paid for by USDA. Federal expenditures on disaster-assistance programs are shown in figure 6-7.

U.S. public-sector agricultural research and extension is a dual Federal-State system that is credited for much of the remarkable growth in America's agricultural productivity. Public research expenditures in agriculture have produced high returns (32). Much of this success can be attributed to the effective transfer of knowledge to farmers and to a decentralized structure that has maintained a focus on practical research problems (82). The public agricultural research system includes the State Agricultural Experiment Stations (SAESs) and USDA's Agricultural Research Service (ARS) and Economic Research Service (ERS). The Cooperative Extension Service (CES) is the network of Federal, State, and local experts that delivers research results to farmers and feeds problems back to researchers. USDA's Soil Conservation Service (SCS) also serves a technology-transfer role, encouraging soil and water conservation in farm management. (Box 6-J discusses the USDA departments and their activities in more detail.)

Private research by food and agricultural industries and innovation by farmers have also played a significant role in sustaining agricultural productivity. Increasingly, agricultural industries are conducting their own research whenever there is the possibility for developing proprietary products. However, industry has relied on the public sector to provide funds for much of the basic research and evaluation.

Despite the strength of the overall agricultural-research establishment, there has been some debate about how well it is prepared to deal with the future (10, 73, 99). Federal funding for agricultural research has seen little or no increase (in deflated dollars) over the past two decades (see fig. 6-8). Hope for future improvements in agricultural productivity has increasingly come to rely on advances in basic science achieved outside the traditional agricultural-research struc-

Box 6-I-The Institutional Setting for Agricultural Adaptation to Climate Change

Commodity support programs

A major goal of current agricultural policy is the achievement of stability in farm incomes and commodity prices. The 1990 Farm Bill authorizes through 1995 continuation of the various commodity programs that support farm incomes and crop prices. The commodity programs are administered by the U.S. Department of Agriculture's (USDA's) Commodity Credit Corporation.[1] It provides support to producers of about a dozen commodities. The so-called ***program crops*—wheat,** corn, sorghum, barley, oats, rice, and cotton-are covered by **deficiency-payment, nonrecourse-loan** programs and by acreage-reduction programs. Other commodities, such as soybeans and other **oilseeds** (e.g., sunflower and **canola),** are covered only by the **nonrecourse-loan** programs. **Meat,** poultry, fruits, and vegetables receive no direct support. Total support expenditures of the Commodity Credit Corporation are shown in figure 6-6. The commodity programs have at times been very costly, **with** outlays reaching a high of almost $26 billion in 1989. By 1990, commodity-program payments and related expenses had declined to just over **$6 billion.** Annual **program** payments were **projected** to remain **below** $12 billion under the provisions of the 1990 Farm Bill (95). However, **FY** 1993 **payments** are now estimated at $17 billion because of bumper corn yields and high outputs of other program crops.

Price support-Price support is provided through ***nonrecourse loans.*** In essence, the Government sets a floor price (the ***loan** rate)* for covered crops-guaranteeing farmers this **price** for their crop. In practice, farmers borrow at the loan rate, with their crop **as** collateral against the loan. The loan is intended to be a marketing tool that **allows** farmers to temporarily store some of their crop and to sell it over a period of a few months, thus avoiding any glut on the market and the resulting steep drops in **market** prices. If market priis remain below the loan rate, a farmer can choose to forfeit the crop instead of repaying the loan.

Income support—income support is provided to farmers through direct payments called ***deficiency payments.*** Payment is provided whenever market prices fall below a ***target price,* which** is typically set above recent **market** prices. Deficiency payments make up the difference between the target price and the market prii (or the loan rate if that is higher). Farmers are guaranteed at least the target price for the portion of their crop that is eligible. To qualify for **a deficiency** payment a farmer **must** have planted that crop on some portion of the farm for the past 5 consecutive years. A farmer's ***crop acreage base*** for a commodity is the 5-year average of acreage planted in that crop. Only the crop acreage base is eligible for deficiency payments, with payment made on average yields from the 1981-85 period.

Supply management-Participation in the price-and income-support programs is voluntary (for most crops), although participating farmers can be required to reduce the acreage they **plant.**[2] Acreage *reduction programs,* under which some land is removed from production or is otherwise restricted in use (i.e., planted to soil-conserving crops), are set for each commodity by USDA. Acreage reduction is intended to restrict supplies, thus holding up farm prices and limiting Federal expenditures under the support programs.

A growing criticism of the deficiency-payment programs has been the inflexibility they impose on the farmer. A farmer loses base acreage and eligibility for deficiency payments when program acreage is planted in a crop other than the crop for which the farmer is enrolled. Establishing eligibility in a new crop takes 5 years of continued production. **Thus,** a farmer could sacrifice considerable income in order to **switch** crops. Previous OTA reports have noted how this has inhibited the introduction of new industrial crops (102), discouraged conservation rotations (100), and favored the production of quantity rather than **qualit** y in crops (98).

Partly in response to these concerns, the 1990 Farm Bill (as amended by the Omnibus Budget Reconciliation Act, or **OBRA,** of 1990; P.L. 101-508) introduced some degree of flexibility into the **deficiency-payment** programs.

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1 **USDA's** Agricultural **Stabilization** and Conservation **Service** (ASCS) administers and finanoes **commodlty** programs through the Commodity Credit Corporation.

2 **Certain other crops, such** as **sugar and peanuts, have** mandatory supply-control programs that operate **at little** or no cost to the Federal Government but do **impose higher crests on consumers by restricting supply in order** to maintain high prices.

(Continued on next page)

Box 6-I—The Institutional Setting for Agricultural Adaptation to Climate Change-(Continued)

Farmers may now shift up to 25 percent of their crop-acreage base to the production of other crops,[3] without having that acreage removed from their program base. Under the 1990 Farm Bill, the deficiency payments are now made for only 85 percent of base acreage. On the 15 percent of the base acreage (*normal flex acres)* on which payment is not received and, optionally, on an additional 10 percent (*optional flex acres*) of the base acreage, farmers can plant most other crops without loss of their program base.[4] An increase in the normal flex acres to 20 or 25 percent is being considered in the FY 1994-98 budget reconciliation.

Disaster-assistance programs

Disaster payments-Disaster-payment programs provide farmers with partial compensation for crop losses suffered due to natural disasters or adverse weather. Since 1990, partial compensation (up to 65 percent) has been provided to all farmers for crop losses greater than 40 percent (35 percent for holders of crop insurance). Certain other permanently authorized programs, such as the livestock programs, provide assistance onty to farmers in counties that have been dedared eligible by the President or the Secretary of Agriculture.

Before 1985, various omnibus farm bills authorized continuing disaster-payment programs. Since 1985, disaster payments have been provided annually through ad hoc congressional legislation. The Federal Crop Insurance Act of 1980 (P.L. 96-365), which broadened the availability of crop insurance, was intended as the first step away from the disaster-payment programs. The Food Security Act of 1985 (P.L. 99-198) sought to further discourage the use of disaster payments as the primary means of farm risk management However, political pressures led to passage of supplemental disaster-assistance acts and appropriations for disaster payments in each year from 1986 to 1992(15). After the drought year of 1988, the Federal Government paid out nearly $4 billion in disaster payments to farmers and livestock producers (fig. 6-7). The Food, Agriculture, Conservation, and Trade Act of 1990 (the 1990 Farm Bill, P.L. 101-624) offered no new policy for disaster-assistance programs.

Critics of disaster-payment programs have argued that much of the risk inherent in farm production is unfairly transferred to the general public (e.g., see ref. 36). Past programs were also considered unfair because they were not equally available to all who suffered crop losses; only farmers growing program crops or farmers within counties declared to be disaster areas were eligible for payment. Some argue that disaster payments reduce the farmer's incentive to limit exposure to risk, encouraging production of high-risk crops in marginal areas. Such programs are thought to perpetuate marginal and inefficient farming practices.

Crop insurance-Federally subsidized crop insurance is available to almost all farmers. It provides a means for the farmer to spread the cost of occasional crop losses overtime, reducing annual fluctuations in farm income. Under the crop insurance program, farmers may insure up to 75 percent of their average crop yield, receiving payment on additional losses if natural disasters or adverse weather causes yields to fall below the insured level. Up to 30 percent of the cost of insurance is paid for by the USDA for coverage up to 65 percent. No additional subsidy is provided on extra coverage.

Federal crop insurance has been available to farmers since 1939, although restrictions on coverage limited its use until 1980. The Federal Crop Insurance Act of 1980 represented an attempt to expand the crop insurance program. Under this legislation, crop insurance was subsidized for the first time, and the eligibility for insurance

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3 There are some restrictions on the crops that can be planted. Fruits and vegetables are not allowed. Certain other crops are excluded at the discretion of the Secretary of Agriculture. These exclusions have included peanuts, tobacco, trees, and tree crops.

4 In 1991, 8 out of 41 million potential flex acres were converted from the original program crops. No deficiency payment is provided for aops grown on flex acres, although loan support is provided. The loss of deficiency payments on optional flex acreage reduces the incentive for their use.

5 Disaster payments were authorized only Acre crop insurance was unavailable. Because crop insurance was available in all counties, this essentially meant that disaster payment could be authorized only through supplemental legislation.

was greatly expanded. Despite the stated goal that crop insurance would replace disaster payments as the primary tool of farm risk management, participation in the program was disappointing.[6] The intent of the 1980 Act and the Food Security Act of 1985 to encourage the purchase of crop insurance was undercut by subsequent disaster payment programs.

Incentives to participate in the crop insurance program have been diminished by high premium rates, inadequate coverage, perceived administrative problems, and expectations of continued disaster payments (13,14). Many farmers choose instead toself-insure through savings or by otherwise acting to reduce the variability of farm income through pooled ownership or conservative management practices. The farmers who do purchase crop insurance tend to be those facing the highest risks, keeping program costs and premiums high.[7]

Even with what many farmers find to be high premium rates, crop insurance in the United States has been heavily subsidized. From 1980 to 1990, the Federal Government paid farmers $3.3 billion more than it received in premiums (96). In addition, the Government spent more than $2 billion on administrative expenses over this period. Since 1980, premiums have covered little more than 40 percent of total program costs. In 1988, the Federal crop insurance payout to farmers exceeded premium receiptsbyarecord$616 million. As with disaster payments, the unintended consequence of crop insurance has been the encouragement and subsidy of farmers most at risk.

The 1990 Farm Bill called for a move toward an actuarially sound insurance program (i.e., one with premiums sufficient to cover expected losses) but postponed the decision on a major overhaul of crop insurance and disaster assistance programs. Despite Administration and House proposals to eliminate funding, the 1991 Agricultural Appropriations Act (P.L. 101-506) maintained funding for the crop insurance program.

Low-interest loans-Emergency loans are provided through USDA's Farmers Home Administration (FmHA) to eligible producers who have sustained losses due to natural disasters. The emergency loans are offered at a subsidized interest rate to farmers experiencing crop losses in counties that have been declared disaster areas by the President, the Secretary of Agriculture, or the Administrator of FmHA. In the 1970s and early 1980s, some $2 billion of new loans were made annually under this program. In recent years, the importance of the program as a source of new loans has been greatly decreased. Eligibility is now restricted to family farms experiencing crop losses of more than 30 percent, having crop insurance, and otherwise unable to find credit. Despite the reduction in new loans, program expenses have increased significantly throughout the decade. Costs have risen (peaking at $2.2 billion in FY 1989; seefig. 6-7) because of the interest subsidy on existing loans and because of rapidly increasing default rates on earlier loans.

Subsidized irrigation water

The application of irrigation water to crops to supplement precipitation has been a powerful tool for stabilizing crop yields in the face of climatic variability in both humid and semiarid regions. The Reclamation Act of 1902 mandated several federally sponsored irrigation projects, mainly in the form of large reservoirs (36). Prices for Federal irrigation water have been subsidized at less than the full costs of storage and conveyance and well below the market value of water in alternative uses. According to the Bureau of Reclamation, almost 10 million acres of land in 17 Western States received project irrigation water in 1985 (17 percent of the total irrigated acres in the United States). The Congressional Research Service (119) estimates that the subsidy ranges from $60 to $1,800 per acre, depending on the irrigation district. Such water-pricing policies, coupled with the institutional constraints farmers face in marketing the water they do conserve, have discouraged the efficient use of irrigation water. With the increasing demand for water for nonagricultural uses, the opportunity costs of restricting Federal-project water to irrigation are increasing. (See ch. 5 for more details on water issues.)

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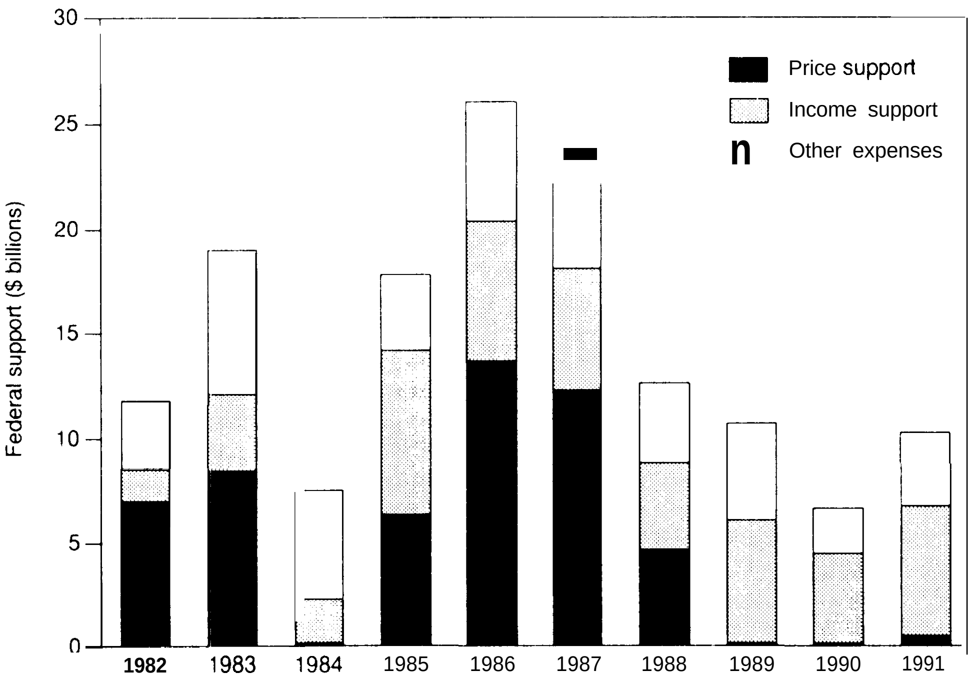
6 By FY 1988, participation in crop insurance was 23 percent of eligible acres, well below the target rate of 50 percent. In 1989, participation In the insurance program rose to 40 percent of the eligible acres. The increase occurred because many producers who participated In disaster assistance programs in 1988 were required to buy crop Insurance.

7 A recent survey in Virginia and Montana found that insured farmers were In a riskier situation than uninsured farmers. Insured farmers were less likely to have irrigation and had less income and savings and greater debt (36),

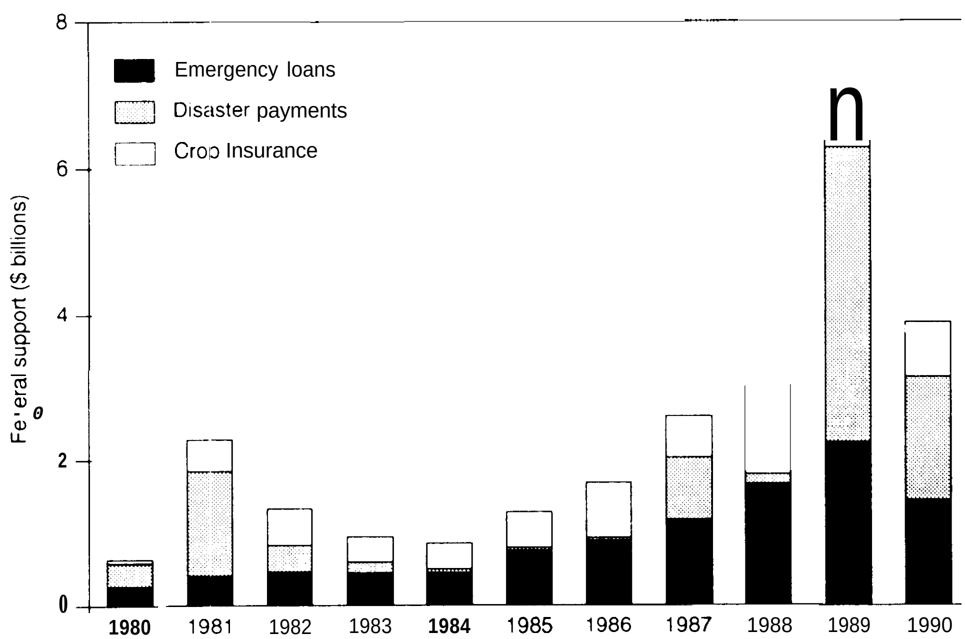
SOURCE: Office of Technology Assessment, 1993.

Figure 6-6—Net Outlays of the Commodity Credit Corporation, 1982-91



SOURCE: U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, *Commodity Credit Corporation Report of Financial Conditions and Operations*, 1992.

Figure 6-7—Costs of Federal Disaster-Assistance Payments Over the Period 1980-90



SOURCE: U.S. Congress, General Accounting Office, "Crop Insurance Program Has Not Fostered Significant Risk Sharing by Insurance Companies," GAO/RCED-92-25 (Gaithersburg, MD: U.S. General Accounting Office, 1992).

Box 6-J-Structure of the Agricultural Research and Extension System

The Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) conducts basic and applied research in agricultural sciences and technology and also maintains extensive collections of seeds, clonal materials, and genetic stocks of farm animals. ARS research is in such areas as environmental quality, agricultural sustainability, rural development, food safety, nutrition, marketing, soil and water conservation, and the biology and production of crops and livestock. Research is conducted at five major regional centers in Maryland, Pennsylvania, Illinois, Louisiana, and California, and at about 130 other locations, many of which are associated with universities. The regional centers are concerned primarily with the development of new products that will result in alternative markets for agricultural commodities. A national program staff is responsible for planning and coordinating the research program and for allocating funds to the agreed-upon national research priorities. Research is generally directed toward basic science that is national in significance, long term in nature, and unlikely to be adequately addressed by private or State research efforts. For example, ARS has de-emphasized the breeding of most crop varieties on the assumption that private and State efforts are adequate. Instead, emphasis has turned to genetics and the development of germ plasm that can be used by industry to develop new varieties. ARS employs approximately 2,700 scientists and research engineers and had an FY 1993 budget of $695 million. In FY 1991, ARSexpenditures on biotechnology were about $81 million, and expenditures on sustainable-agriculture research were estimated to be about $120 million.[1]

The Land-Grant Colleges of Agriculture were established with the passage of the Merrill Act in 1862. The Merrill Act provided Federal grants to States to fund creation of colleges that would offer practical programs of higher education focused on agriculture and the mechanical arts. In many States, the original land-grant college grew to become the foundation for the State University system. In 1890, Congress passed the second Merrill Act, which provided additional yearty Federal funds to the land-grant institutions and required that States provide college-level agricultural education to black as well white students. Seventeen Southern and border States created separate black agricultural schools.

The State Agricultural Experiment Stations (SAESs) were established with the passage of the Hatch Act of 1887. The act created the agricultural experiment stations as departments within the college of agriculture at land-grant institutions and provided annual Federal funding to support agricultural research and experimentation. Today, there are 57 SAESs, one in each State and Territory. These institutions include laboratories, field sites, and research farms. Roughly 12,000 State-employed agricultural researchers work in the network of land-grant schools and the associated Agricultural Experiment Stations. Overall, the SAES system spends about $1.6 billion (FY 1990) on research, most coming from State funds. In 1990, USDA provided $224 million to State Agricultural Experiment Stations. Other Federal agencies provided an additional $144 million in agricultural research money.[2]

The Cooperative State Research Service (CSRS) is a coordinating agency within USDA charged with dispersing Federal funds to SAES and to the State land-grant institutions. CSRS also administers grants programs that fund agricultural research. Each SAES receives Federal funds through CSRS according to a formula first specified in the Hatch Act of 1887.[3] The formula funds have been valuable as a stable funding base for long-term and applied research. Additional Federal funding is provided through competitive grants to individual researchers. Competitive grants have been used to strengthen the scientific foundations of agricultural research and to direct basic scientific research to areas of national interest. These grants are based on scientific merit, as determined by

1 J. van Schilfgaarde, Associate Deputy Administrator, Agricultural Research Service, personal communication, May 27, 1993.

2 The National Science Foundation, the National Institutes for Health, and the Department of Energy are among the largest of the many other sources of Federal funds for the agricultural research stations.

3 Hatch Act funds are allocated by a formula: 20 percent of the money is allocated equally among SAESs, at least 52 percent is allocated in proportion to the State's share of overall farm and rural population, and the remainder-if not needed for administration costs—can be allocated to cooperative research between States.

(Continued on next page)

Box 6-J—Structure of the Agricultural Research and Extension System—(Continued)

a peer-review process. A third category of support is special grants, usually awarded by Congress to specific institutions for research on particular agricultural problems. CSRS employs about 155 people and had a FY 1993 budget of $482 million. Research money provided through competitive and special grants programs totaled almost $160 million in FY 1992, up considerably from the $80 million provided in 1989. The increase in funding of competitive grants reflects a shift in funding priorities toward basic sciences and away from more applied research.

The Cooperative Extension System was created by the Smith-Lever Act of 1914 to carry the results of research to farmers and rural communities. The act provides Federal funding to the land-grant colleges for extension work, a term that describes the process of taking research findings and extending them to the public through on-farm demonstrations, distribution of publications, or courses. The system includes State extension offices, now found in nearly every county of the United States; specialists located at the land-grant institutions; administrative staff on the land-grant campuses; and a USDA support program, the Extension Service. The State systems employ about 21,000 people, including almost 10,000 county agents and some 4,600 technical specialists.

The Extension Service (ES) within USDA distributes funds to the Cooperative Extension System and works cooperatively with State extension services to transfer practical results of agricultural research to landowners, farm operators, and rural communities. The Federal Government provided 31 percent of the annual $1.2 billion extension budget in FY 1990. Federal support for the extension services has been declining relative to inflation and funding is increasingly directed toward community services and rural-development programs rather than toward direct assistance for farm operators. The ES employs about 175 people and had an FY 1993 budget of $425 million.

The Soil Conservation Service of USDA serves to transfer soil and water conservation technologies to farmers. In this, they complement the transfer of production and farming-systems technology by the extension services.

The Economic Research Service (ERS) was established in 1961 to provide economic and social-science information for improving and understanding the performance of agriculture and the rural economy. ERS performs statistical and analytical research on farm-production costs and returns, commodity markets, agricultural trade, farm technologies, and the rural economy. ERS conducts policy analyses and assessments of the economic impacts of alternative agricultural policies, programs, and technologies. The research program is small, with limited funds to contract for outside research. The FY 1993 budget was $58.7 million.

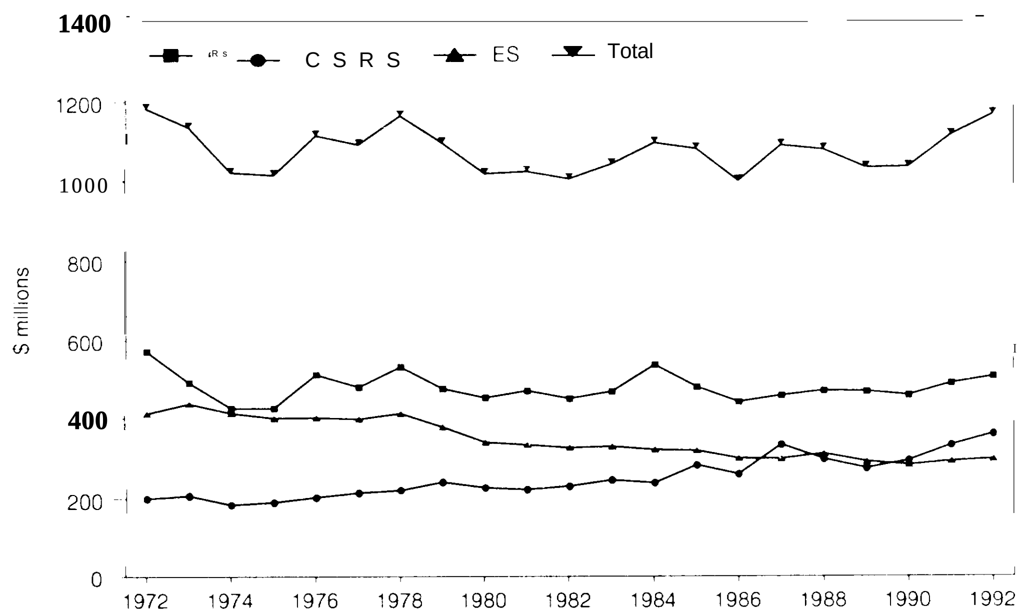
SOURCES: Office of Technology Assessment, 1993; J.M. Rawson, Library of Congress, Congressional Research Service, "Agricultural Research and Extension: Current Issues," 93-83 ENR, January 1993.

ture. **As funding goes increasingly to new and specialized areas of scientific research, traditional research addressing the day-to-day problems that plague agricultural production may be neglected (100). Federal funding for the extension services has also declined (in deflated dollars), while their mission has broadened beyond providing for the traditional family-farm constituency (73). Observers question whether the State or county extension service agents still have the expertise to assist farmers in undertaking new technologies. Encouraging basic science while maintaining an effective link between scientific research and real farm problems is a challenge that will require a broadening of the capabilities and reach of the existing research and extension system.**

POLICY OPTIONS

The resiliency of the farm sector will be enhanced by broadening and improving the choice of crops and technologies on which farmers can draw. In particular, advances that improve farm yields and efficiency in input use-that is, use of water, energy, fertilizers, pesticides-offer hope for meeting the growing demands for food and for resolving conflicts between agriculture and the natural environment. In a future that will be increasingly competitive

Figure 6-8—Appropriations for **USDA Agricultural Research and Extension Programs** for FY 1972-93



NOTE: ARS=Agricultural Research Service; CSRS=Cooperative State Research Service; ES=Extension Service.

SOURCE: J.M. Rawson, Library of Congress, Congressional Research Service, "Agricultural Research and Extension: Current Issues," 93-83 ENR, January 1993.

and uncertain, the roles of the educated farmer and of the agricultural research and extension services in speeding the transfer of knowledge to farmers become more important. The potentially high costs of climate change can be reduced by improving the capability of farmers to successfully adapt.

The ability of farmers to adapt to climate change may be constrained by several factors: 1) inflexibilities imposed by commodity support programs, 2) inflexibilities in disaster-assistance programs, 3) increasing competition for scarce water, 4) technical limits to increased productivity, and 5) an inadequate framework for planning the long-term needs of the agricultural sector. Each of these factors and related policy options are discussed below.

Commodity Support Programs

Commodity support programs are designed to stabilize farm supply and maintain farm incomes (see **box** 6-I). The means by which they currently do this may discourage the changeover from one cropping system to another that is better suited to a changed climate. For example, if climate change creates a situation in which crops are shifted to the north, the financial penalties imposed under current programs on farmers who change crops will slow the rate of adjustment and so add to the cost of climate change (54). On the other hand, if elevated $C0_2$ results in enhanced crop yield but no shift in range, there may be more-frequent bumper crops and low commodity prices, but substantially higher costs in farm-income support.

The deficiency-payment programs result in the greatest disincentive for farmers to switch crops (see box 6-I). First, crop choice is often driven by the level of support payments rather than by market prices. Relatively high target prices, such as those seen in the past decade for corn, discourage a switch to crops that might otherwise be more profitable at market prices. Second, because support is linked to establishing and maintaining a record of continued production in a particular commodity, farmers are penalized when they do switch crops. With the distortion of underlying market-price signals and penalties for crop switching, farmers may persist in growing crops that are not well suited to changed climate conditions. The public will bear the costs of this misallocation of productive effort through higher commodity prices or program costs.

The deficiency-payment programs have also been criticized for discouraging sound management and leading to an expansion of farming into marginal lands, many of which are highly erodible or otherwise environmentally sensitive.[19] Because traditional rotation. crops such as leguminous forages, are not covered by any support programs and detract from the acreage in program crops, farmers are discouraged from engaging in sound rotation practices (100). This exacerbates erosion and encourages the use of chemical fertilizers.

Equally serious are the problems that result from coupling deficiency payment to farm yields. Because deficiency payments are directly related to output, farmers have a strong incentive to maintain high yields through the intensive use of farm chemicals. The price subsidy also encourages an expansion of agriculture into marginal lands. At the same time, under the Conservation Reserve Program, the Wetlands Reserve Progam, and various water-quality incentive programs, farmers are paid to remove erodible lands from production and to reduce environmental damages. This is why the farm programs have been compared with 'driving a car with one foot on the gas and the other on the brake."[20] The expansion of farming into marginal lands and the discouragement of conservative farming practices expose the public to risks of higher program costs and greater disaster-assistance needs under climate change, along with the likelihood of increased environmental damage.

Partly in response to these concerns, the 1990 Farm Bill as amended by the Omnibus Budget Reconciliation Act of 1990 (P.L. 101-508) introduced some degree of flexibility into the deficiency-payment programs. Farmers may now shift up to 25 percent of their program acreage base to the production of other crops, without having that acreage removed from the program base-that is, from the total acreage used to calculate their benefits. On 15 percent of the base acreage *(normal flex acres),* there are no deficiency payments but the farmer is free to switch to other crops.[21] An additional 10 percent of the base acreage *(optional flex acreage) may also be* switched to other crops, but deficiency payments are lost if the land is planted in other crops (see box 6-I). As a budget-reducing measure, an increase in the normal flex acres to 20 or 25 percent is being considered in the FY 1994 budget reconciliation.

Policy Options: Commodity Support Programs

Option 6-1: *Allow fiull flexibility (normal crop acreage). The* Bush administration and others have suggested that farmers be allowed to grow any program crop they choose on all acreage normally planted in program crops and be eligible for deficiency payments on whichever crop is grown. This approach, known as normal crop acreage (NCA), eliminates most of the inflexibili-

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19 Previous OTA reports have noted how this inflexibility in farm programs has inhibited the introduction of new industrial crops (102), discouraged conservation rotations (100), and favored the production of greater amounts of-rather than higher-quality—crops (98).

20 Senator Rudy Boschwitz, R-MN. Address presented at a conference held by the Center for the Study of Foreign Affairs, Arlington, VA, Nov. 25, 1986.

21 There are some restrictions on tine crops that can be planted. Fruits and vegetables are not allowed, and certain other crops are excluded at the discretion of the Secretary of Agriculture. These exclusions have included peanuts, tobacco, trees, and tree crops.

ties in crop selection.[22] However, fully **reducing the inflexibilities also requires an adjustment in the methods by which target prices or farm-income-support payments are set, perhaps by making farm-income support independent of crop production. Without this, crop choice will still be largely driven by target prices, and not responsive to climate change. Congress could incorporate the NCA approach into the definition of the farmer's base acreage in the 1995 or subsequent farm bills.**

A concern with the NCA approach is that it reduces USDA's control over the supply of individual crops because acreage set-aside requirements can no longer easily target specific crops. This lack of control raises concerns about increased instability in farm prices. Farmers now growing crops without program support have expressed concern that they will be unfairly exposed to new competition from supported farmers who switch crops (participation in most commodity programs is voluntary). Another concern is that farmers' crop choices may still be driven largely by the target prices set for individual crops, thus limiting responses to climate change and market prices. To deal with this, some uniform method for setting target prices is needed. Alternatively, the current deficiency-payment programs could be replaced with an income-support program that is not coupled to crop production.[23]

Option 6-2: *Increase flex acreage. The flex-***acreage** approach appears to have been successful in introducing some flexibility in crop choice[24] and in reducing the potential costs of commodity programs (through the elimination of deficiency payments on normal flex acres). Congress could gradually increase normal or optional flex acreage in successive farm bills, further adding to farmers' flexibility in crop choice.

Normal flex acreage could **be** increased to at least 25 percent in the next farm bill. Because deficiency payments are withdrawn on normal flex acres, the costs to the Government of commodity programs would also be reduced.[25] Subsequent farm bills could further increase normal flex acreage. Gradually phasing out farm support in this manner appears to follow the direction set by the 1990 Farm Bill, avoiding the substantial difficulties associated with any full restructuring of commodity programs. However, linking increased flexibility to reduced farm support may prove hard for farmers **to accept.**

An alternative would be to increase optional flex acreage. So far, however, farmers have shown little interest in using the optional-flex-acreage allowance because program support is lost when the acreage is planted to new crops (an indication of how much the support programs do influence the behavior of farmers). Still, an increase in the optional flex acres may offer somewhat more flexibility than now exists, allowing farmers to respond to significant changes in market prices and growing conditions. A farmer who uses optional flex acres maintains eligibility for program support, regaining support if the land is replanted to the program crop. This protection somewhat reduces the risks involved in changing cropS.

Disaster-Assistance Programs

Periodic losses caused by climate variability are inherent to farming. Farm prices, land values, and farming practices adjust so that farmers, on

22 The NCA approach was briefly used by USDA in 1978 and 1979. Although there is little indication that there were any fundamental problems, it was later abandoned by the agency and the Senate Agricultural Committee. See reference 29 for details on NCA programs.

23 See reference 28 for discussion of proposals to decouple farm-income-support payments from yields. Even with payments that are unrelated to farm yields, any subsidy will tend to encourage a higher level of farming activity than would otherwise be profitable (28). Farmers have been reluctant to accept income support that is independent of farm yields, perhaps fearing that such an approach seems more like welfare.

24 In 1991, 8.3 of 41.3 million potential flex acres were converted from the original program crops.

25 It appears likely that as a budget-cutti.rlg measure, normal flex acreage will be increased to 20 percent under the 1994 Budget Reconciliation Bill.

average, are adequately compensated for climate risk under competitive market conditions. Subsidies and disaster assistance have distorted the market, encouraging expansion of farming into marginal lands and reducing incentives to undertake safe farming and sound financial practices (54). Much of the burden of increased risk-both the monetary costs and any environmental costs associated with conversion of marginal lands to farming-is placed more broadly on society. The Australian Government, faced with similar concerns, is moving to eliminate all agricultural disaster payments and to replace them with programs that encourage self-sufficiency and information on sound farming practice (116).

The costs of disaster-assistance programs (crop insurance, disaster payment, and emergency loans; see box 6-I) can be expected to rise if climate change leads to more-frequent episodes of drought and related crop losses. The subsidies provided by these programs reduce farmers' incentives to recognize and adapt to increasing climate risks, which imposes further costs on the general public. Reducing these subsidies will better prepare the farm sector to respond to changing climatic risks and should also prove beneficial in reducing conflicts between agriculture and the natural environment.

Society does benefit from stable food prices, and well-designed risk-spreading programs contribute to this stability. Disaster-assistance programs should be restructured-not eliminated— to encourage farmers to limit their exposure to climate risk and thus to lower the costs of the programs to society.

Policy Options: Disaster-Assistance Programs

Option 6-3: *Define disasters formally, with assistance provided only for unusual losses.* Congress could formalize the criteria for receipt of disaster payments and eliminate the crop insurance program. Currently, disaster-payment programs are provided each year in ad hoc legislation passed in somewhat pressured situations and driven by immediate needs. It is unlikely that disaster payments will be eliminated. Farmers have come to rely on this protection, and Congress faces considerable pressure to provide it. If requirements for disaster-payment programs were form W, some of the more undesirable features might be controlled. For example, all farmers could be provided with free coverage against truly catastrophic climate events, but otherwise would receive no disaster payments. With this change, farmers' incentives to undertake precautionary farm-management and financial practices could be greatly increased, and buffering against climate change risks would be improved.

Currently, disaster-assistance programs compensate farmers who have experienced crop losses of at least 35 to 40 percent. Partial compensation is received for losses greater than that amount.

- Congress could set the trigger for compensation to a level that is less frequently exceeded (say, a loss of 55 or 60 percent).
- Alternatively, coverage could be eliminated for farmers who have repeated losses. For example, farmers might be limited to receiving payments two times within any 10-year period.

A permanent disaster-payment program could be authorized, providing payment to any farmer who experiences significant weather-related losses. With universal coverage, potential inequities that result if eligibility is limited to farmers in declared disaster areas are removed. One of the strongest objections to eliminating crop insurance (that to do so strips farmers of individual protection against climate risks) would thus be removed. However, with a permanent and universal program of disaster payments, expenses might become less controllable.

- To reduce budget expenses, farmers or farm counties could be required to contribute to a disaster-assistance fired in order to be eligible for disaster payments.

Recent disaster-payment programs have set payments based on losses relative to “normal” production. This is usually based on average yields over a period of years, with extreme yields (either high or low) excluded from the average. It would seem unwise to exclude ‘‘abnormal’ years from the average if climate change is in fact altering normal climate.

- Congress could require that a moving average of crop yields over the past 5 years be used to determine normal output.

Option 6-4: *Combine disaster-payment and crop insurance programs.* Congress could combine disaster payments and crop insurance, giving all farmers free catastrophic-loss coverage (partially compensating for losses beyond some high limit) and offering additional coverage to those who are willing to pay. The Federal Crop Insurance Reform Act of 1990 considered by the 101st Congress would have provided such a combined disaster-assistance program. All farmers would have received disaster protection for losses exceeding 50 to 70 percent (depending on participation in other farm programs), The crop insurance program would have remained essentially unchanged, with subsidized coverage available for crop losses greater than those covered by the catastrophic policy.

Proponents of the plan argued that it would eliminate the pressure for supplemental disaster legislation and would encourage farmers to protect themselves against ordinary climate risks. Opponents were fearful of the potential costs. Although administrative expenses and the insurance subsidy would be largely unchanged, expenditures on disaster payments could increase with universal coverage. Opponents also expressed concern that the proposed plan would eliminate any chance of making the crop insurance program sound.

Option 6-5: *Improve the crop insurance program. In* principle, crop insurance provides an attractive mechanism by which farmers can reduce the inherent variability in farm income. However, few would argue that the goals of the Federal crop insurance program have been met. Participation is limited, program costs are high, and disaster payments remain a primary cushion against climate risks. Because of the high cost of insurance and the expectation of continued disaster payments, participation in the crop insurance program is primarily limited to farmers in high-risk areas.

Several potential reforms of the crop insurance program were suggested to Congress during debate of the **1990 Farm Bill (13, 14).[26] Some analysts and researchers have sought to reduce subsidies on crop insurance, hoping to make the program actuarially sound (i.e., self-supporting). Many have sought to encourage greater program participation through increasing subsidies, reducing deductibles,[27] improving administrative procedures, modifying in the means by which losses are calculated, or requiring crop insurance for eligibility in other farm programs. A more radical reform would combine crop insurance and income-support programs into a revenue insurance scheme that would guarantee a minimum farm revenue.**

Congress could choose to revisit the many reforms that have been suggested in the past. The success of any reforms in the crop insurance program would be contingent on expanded participation, which would allow crop insurance to replace disaster payments. The resulting restructured program might then offer both improved risk management and reduced costs over the current combination of crop insurance and disas-

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X The Federal Crop Insurance Commission Act of 1988 (P.L. 100-546) authorized the formation of a 25-member commission to identify problems with the crop insurance program and to make recommendations for increasing farmer participation.

27 The highest level of coverage that can be purchased requires farmers to absorb the first 25 percent of losses. Many farmers consider such losses sufficiently rare that insurance is an unneeded expense.

ter assistance programs. However, if **greater participation is achieved through higher subsidies and lower deductibles, these benefits might well be lost.**

Option 6-6: *Provide a self-insurance program for income stabilization.* **Congress could consider a program modeled roughly on individual retirement accounts (IRAs), under which farmers would be encouraged to self-insure against climatic risks. The program could be supplemented with catastrophic coverage either through crop insurance or disaster payments, and it would allow farmers to smooth the fluctuation in their income over time.[28] Farmers would be allowed to set aside income, tax-free, into a self-insurance account. Annual deposits up to a maximum amount (say, $15,000) would be allowed, with no further deposits allowed once the account reaches some maximum cap (say, $150,000). The cap would encourage active use of the account for income smoothing, and the tax-free status would encourage participation. Withdrawals could be made at any time, subject to income tax payment at that time (with no penalty for early withdrawal, in contrast to the IRA model). Existing disaster programs might be gradually phased down, until they provide only protection against truly catastrophic events.**

Water-Use Efficiency

Many climate-change forecasts suggest that agricultural regions of the United States could become hotter and drier, so efficient use of irrigation water might be required to maintain farm production (see box 6-I). Farmers who can manage water efficiently would be better prepared to respond to harsher climate conditions. Unfortunately, many farmers have little incentive to conserve water **because** of subsidized prices, inadequate institutional arrangements for regulating access to groundwater, and limited marketability of conserved water. Farmers who receive water from Federal irrigation projects generally pay less than the water costs (see box 5-F). The subsidized price encourages high levels of agricultural water use. Farmers who do conserve water may be inadequately rewarded for doing so or may actually be penalized under some State laws. Water saved may even be forfeited.

Policy Options: Water-Use Efficiency

Chapter 5 provides a thorough discussion of water issues. Agricultural water use is one component of several broader options discussed in that chapter. Among them are the options involving: 1) reform in pricing in Federal water projects (option 6-7, or 5-5), 2) clarification of reclamation law on trades and transfers of water (option 6-8, or 5-7), and 3) reform of tax provisions to promote conservation investments (option 6-9, or 5-4). Incentives for installing efficient **irrigation equipment** and for undertaking water-conserving farm-management practices could be implemented through direct subsidy or in exchange for eligibility in existing commodity-program **or water** subsidies.[29] Soil Conservation Service standards for soil suitability and irrigation efficiency could be used to determine eligibility for incentive programs (see ch. 5 for details).

Agricultural Productivity

Broad-based research directed at enhancing the long-term basis for increased agricultural yields is an essential element of a public research strategy. Public efforts should be directed at those areas not adequately handled by the private sector. In other words, the Federal effort may be best directed at basic science, long-term or high-risk technology

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28 Before the Tax Reform Act of 1986 (P.L. 99-514) was passed, taxes could be computed on the basis of "income averaging." Farmers, who regularly experience fluctuating incomes, have felt they were unfairly treated by the elimination of this provision (31). The approach offered here provides the benefits of income averaging, plus a strong incentive to actually smooth fluctuations in income.

29 Subsidies that lower the capital cost of installing new irrigation equipment may encourage conservation by farmers already using irrigation; they could also lead to the undesirable outcome of more overall irrigation. This should not be an insurmountable problem.

development, and other areas where private profit is limited but public value is high. Biotechnology and related genetics research may offer at least a partial solution to the problem of sustaining the ability to produce food over the long term. Continued public research is needed to build an understanding of the genetic and biological bases of nitrogen fixation, drought and heat tolerance, and pest and weed resistance. Efforts are needed in the development of new germ plasm that could be the basis for subsequent commercial development of plant varieties. Protection of existing **germ** plasm in traditional and nontraditional crops is also important because it ensures the ability to develop new crops and strains in the future.

Conventional breeding efforts should not be ignored as a source of productivity gains in the near term. The ability to manipulate complex genetic characteristics through biotechnology remains limited.[30] For example, conventional breeding may offer the best immediate hope for improving drought and heat tolerance in crops. Efforts to expand the diversity of available cultivars through crop breeding may provide insurance against an uncertain future climate. Attention to the development and commercialization of new crops may become more important in a future under which climate change might threaten the competitiveness of traditional crops. Public efforts will be needed for those crops and market or climate niches that receive little attention from commercial breeders. It may be important to develop crops and cultivars that are adapted to warmer or drier climate conditions. Efforts toward developing cultivars that require small amounts of farm chemicals would help relax the environmental constraints that might otherwise limit expansion of farm output.

Equally important are efforts to enhance the knowledge and skills of farmers and the technology of farming. Farmers face a future in which they must be increasingly responsive to world competition, environmental concerns, and the uncertainties of climate change. The competitiveness of the U.S. farm sector will increasingly come to rely on its ability to farm with greater skills than the rest of the world. One of the most important attributes of future technologies will be the ability they give farmers to deal with unanticipated changes. Information and management technologies in the form of computer software, sensors, robotic and control equipment, and other packaged-knowledge products can provide this flexibility. These *intelligent* farm technologies offer the potential for substantial gains in efficiency of farm management and for reductions in agriculture's undesirable environmental consequences. The role of technology transfer also takes on increased value under a changing climate. If farmers are to adapt to any sort of change in a timely manner, efforts must be made to provide them with accurate, convincing information on the effectiveness of new farming systems, crops, and technologies. The private market may respond to meet some of these needs, but a public role seems imperative.

Policy Options: Agricultural Productivity

Option 6-10: *Enhance research on and development of computerized farm-management systems.* Congress could act to enhance the role of the Agricultural Research Service (ARS) as the center of excellence in design and integration of new information and management technologies into farm-management systems. Increased competitive-grant funds could be provided to universities and private researchers to carry out the research needed to fill critical knowledge gaps that are barriers to delivery of new agricultural technologies to the farmer.

The potential to develop and expand the use of intelligent information and management (i.e., using land-based or remote sensors, robotics and controls, image analysis, geographical informa-

[30] At the least, it should be recognized that the benefits of biotechnology will ultimately be put in place through the efforts of plant breeders.

tion systems, and telecommunications linkages-packaged into decision-support systems or embodied in intelligent farm equipment) to improve crop and livestock production and farm-resource management is considerable. Tractors are now produced commercially that can plant, till, or apply chemicals as needed to specific areas of a field. There are also commercial packages (including computer hardware and software, sensors, and telecommunications linkages) that can control irrigation and provide decision support for fertilization and pest-control application. Only farmers growing the highest-valued crops (such as fruits and vegetables) can afford these systems now.

Long-terrn public funding has been essential to the development of the few existing commercial packages. Enhancing these systems and reducing equipment costs to allow broader application will require considerable research and development effort. ARS proposed a program of research on intelligent farm-management systems under the Federal Coordinating Council for Science, Engineering, and Technology's (FCCSET'S) 1994 Budget Initiative on Advanced Manufacturing. ARS expects that $1 million will go to integrated, or intelligent, farm-management-systems research. ARS had initially hoped for a larger role in the FCCSET initiative, sufficient to provide $6 million for intelligent farm-management-systems research. The strategic plan for the State Agricultural Experiment Stations also considers this a high-priority area for new research, suggesting a need for $47 million in new funding (33). No other single area was considered to need this large a funding increase.

Option 6-11: *Improve the research and extension process by expanding farmer input.* Congress could support an expanded role for farmers in assessing the effectiveness of farming practices and in disseminating results of research on innovative farm practices. A broad-based program of grant support for systematic on-farm experimentation and a database on farmers' financial successes and failures under different farming systems could help farmers adapt to climate change.

Farmers are most convinced by the success of other farmers-rather than by information from experiments conducted on university lands under ideal management conditions. State experiment stations have already found that demonstration plots on farms are excellent teaching aids and succeed in getting farmers to more quickly adopt certain practices. The willingness of farmers to take up new techniques (including techniques designed to reduce the environmental costs of farming) could be further enhanced if farmers were more extensively included in the research, experimentation, and inforrnation dissemination process.

- Support on-farm experimentation. Abroad-based program of support for on-farm experimentation in new cropping practices would be useful in providing the information that would help farmers adapt to climate change. A model that could be built on for this purpose can be found in the Sustainable Agricultural Research and Experiment (SARE) program funded under the 1990 Farm Bill (see box 6-A). Under this program, Federal funding is provided to experiment stations to support farmer participation in research and on-farm demonstration projects. One possibility is to pay farmers for conducting field tests to demonstrate the success or failure of new farming systems in real-world situations, working with experimentstation, Soil Conservation Service (SCS), or extension-service personnel.[31] Farmers could be compensated if they bear the risks of trying unproven technologies.
- Develop a database on successful practices. In conjunction with a program of

31 Usually, only nominal rents must be paid for setting up experimental plots on farmers' fields. The State of Illinois has found it cheaper to use farmers' fields than to own cropland and has been able to sell some research facilities as a result.

on-farm experimentation, there could be support for a wider program of recordkeeping to establish a database on the financial successes and failures of farming systems. An easily accessed database, giving farmers access to records and information on successful farm-management practices, could help speed adoption of successful practices. Such databases could be developed and maintained at State experiment stations (or distributed on compact disk) and be made accessible by phone line to personal computer users, Software that could provide easy access to the database and efforts to organize the database into a useful format would be required. Cooperative support for farmer-initiated networks and information exchanges might be another way to increase the efficiency with which farmers accept innovations in farming practices,

Option *6-12: Support agricultural biotechnology and genetics.* Congress could maintain or increase funding for regional centers of excellence in agricultural genetics and biotechnology research. Increases in competitive grants in areas of particular interest could be used to direct the research effort. Areas of obvious long-term national interest include programs addressing the understanding of photosynthetic efficiency, nitrogen fixation, tolerance to heat and drought, and the development of crops that require reduced herbicides or pesticides. Although climate change does raise the importance of research about drought and heat tolerance, this area should be promoted in tandem with pursuing broader gains in productivity, where the probability of success and the ultimate payoff may be higher.

Option 6-13: *Support conventional crop-breeding programs.* Congress could encourage USDA to sustain or increase public, conventional crop-breeding efforts. Crop breeding offers the most immediate hope for providing improved cultivars that are adapted to particular climatic niches. This may be especially so given the number of ‘‘wild” varieties that have yet to be studied and that could improve the existing domestic crops. Efforts at expanding diversity in cultivars are not adequately supported by the private sector unless investors anticipate profitable markets. Conventional breeding is also considered necessary for the maintenance of desirable cultivar attributes. One consequence of ignoring this maintenance effort can be an increased need for pesticides to compensate for declining resistance to pests. This unglamorous side to breeding has been underfunded. Further, breeding of minor but potentially valuable crops, such as forages, small grains, and oats, may be getting too little attention from either the Government or the private sector.

Option *6-14: Increase support for the development of new commercial crops.* Development and introduction of new commercial crops can be a slow process. Successful commercialization relies on a combination of farmer and market readiness that may be difficult to achieve. Availability of new crops might provide U.S. farmers with opportunities to diversify to counter the threat of climate change or a chance for profitable specialization. Congress could expand ongoing USDA research aimed at improving the commercial characteristics of several promising alternative crops. Priorities should be given to crops for which there are potentially profitable markets and perhaps to crops suited to hot or dry conditions. Congress could authorize assistance to businesses to establish crops and product markets, once the development of commercially stable varieties has been demonstrated.

Planning Needs

By improving the process of agricultural resource assessment and program evaluation, USDA could improve its ability to develop responses to major issues like climate change. A model might be the program and assessment process that is undertaken by the USDA Forest Service under the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 (P.L. 93-378). (See vol.

2, ch. 6, for a more complete discussion of OTA'S RPA assessment.)

USDA currently provides periodic assessments of agricultural soil and water conditions and trends under the appraisal process, authorized by the Soil and Water Resources Conservation Act (RCA) of 1977 (P.L. 95-192). Despite the considerable background effort that goes into these analyses, the assessments are narrowly focused on the specific concerns of USDA's Soil Conservation Service. With little extra effort, USDA could provide a full assessment of trends in the agricultural resource, farm ownership, rural economic conditions, agricultural technologies, supply and demand, and the impact of farm programs and subsidies. Included in this evaluation could be an assessment of climate change as one of many possible significant future disturbances to supply and demand, as the Forest Service has been doing. On the basis of this assessment, USDA could develop a program document that clarifies the agency's direction and justifies its programs as a whole.

■ Policy Option: Planning Needs

Option *6-15: Broaden the focus of the current Resources Conservation Act appraisal.* Congress could **amend the current authorization for the RCA appraisal process, creating a new agricultural program and assessment process modeled** on the RPA program and assessment of the USDA Forest Service. As in the Forest Service, the assessment should be made by staff members who are not tied to a specific: action agency within USDA (currently, the RCA is tied to the Soil Conservation Service).

FIRST STEPS

If public policy aims to ensure that U.S. agriculture can adapt to climate change and maintain its competitiveness in world markets, there is a wealth of policy options, as outlined above. However, the most pressing targets for policy appear to be:

—removing the impediments to adaptation that are created by commodity support programs, disaster assistance, and irrigation subsidies;

—improving technology and information transfer to farmers in order to speed the process of adaptation and innovation in farm practice; and

—supporting research and technology that will ensure that the food-production sector can deal successfully with the various challenges of the next century.

The agricultural sector of the U.S. economy is already unusual in the great amount of public money spent in support of research, development, and technology transfer. The steady stream of technological improvements that have resulted has allowed the United States to feed a growing world population at increasingly low cost. In recent yearn, the focus has shifted away from how effective the effort has been, pointing instead to the expense of farm programs and the environmental consequences of intensive farming. However, if the United States wants to remain competitive in the world market even though rapid population growth is increasing the demand for food while biological limits to productivity growth seem ever closer, public efforts to support the continued growth in agricultural yields remain necessary. With its technological and institutional strengths, the Nation should be in a position to enhance its role in a growing world agricultural market. But in the competitive world market, success will rely on continued improvements in productivity and on the skills of U.S. farmers as they innovate and adapt to changing market conditions.

Climate change adds to the importance of efforts to increase agricultural productivity, to improve the knowledge and skills of farmers, and to remove impediments to farmer adaptability and innovation. Efforts to expand the diversity of crops and the array of farm technologies ensure against a future in which crops or farming systems fail. Efforts to enhance the adaptability of farmers—to speed the rate at which successful farming

systems are adopted--can lower the potentially high costs of adjusting to climate change.

All of the options described in the previous section are of some value if implemented today, even if no climate change occurs. Many options, particularly those related to research and extension, are being pursued to some degree. Others, such as the options to modify commodity support programs, disaster assistance, and irrigation subsidies, have been much discussed. In general, climate change strengthens the case for actions already being considered or underway rather than suggesting new directions of effort.

Several of the options we have suggested should be addressed promptly. Research on information and management technologies is important now because of the time needed to develop and implement new technologies and because of the lack of effort now being made (33). Modifications to the farm commodity program are included as first steps because there appears to be a window of opportunity to implement changes. Disaster programs fit in much the same category; frustration with current programs makes some political action likely. The difficulty experienced in redesigning the agricultural programs suggests all the more that these reforms be placed on the agenda early so the process of change can begin. Although conventional crop breeding has not been included in the list of first steps, it is an area that merits more attention. Efforts to improve or maintain the desirable cultivars appear to be underfunded for many crops-as more glamorous research areas have attracted public funds and private efforts have focused on larger markets.

Some areas of obvious concern, such as biotechnology research and new-crop development, have not been included as first steps. This is not because they are unimportant or not urgent, but rather because there is considerable effort under way already. Improvement in the effectiveness of the extension process, through more deliberate inclusion of farmers and better dissemination of data, may ultimately be of great importance. However, there seems to be little cost to waiting before implementing such actions. Perhaps most important here is that existing technology-transfer services should not be allowed to decline to the point that they cannot be rebuilt. Institutional changes that will encourage the conservation and efficient use of irrigation water will also be important in buffering agriculture against the threat of climate change. (See ch. 5 for a discussion of water issues.)

- **Revise the commodity support programs to encourage responsiveness to changing climate and market conditions Congress addresses farm issues every 5 years in omnibus farm bills, with the next one likely to be debated for passage in 1995. The annual budget-reconciliation process and agricultural appropriations bills offer intermediate opportunities for revisions in commodity support programs. The high expenditures on commodity support programs and the previously successful implementation of the flex-acreage program have made it very likely that flex acreage will be increased in the current budget-reconciliation process. This revision provides the opportunity for reducing expenditures on commodity support and increasing the adaptability of farmers to climate change. A further increase in flex acreage or other more substantial revisions in commodity programs (e.g., introduce normal crop acreage) would probably have to be considered in the 1995 Farm Bill.**
- **Use the 1995 Farm Bill to modify disaster-assistance programs. Since the late 1970s, Congress has been considering how to best structure the crop insurance and disaster-payment programs. After a flurry of proposals and studies before the passage of the 1990 Farm Bill, the programs were left essentially unchanged. There is, however, an ongoing sense of frustration with the current system that suggests that major revisions are likely to be considered in the 1995 Farm Bill. It remains unclear what the best option is for**

revising these programs. However, any program that provides a. greater incentive for farmers to reduce their exposure to risk should help in preparing for the risks of a climate change. Features of a restructured system might include:

-defining disasters formally, with assistance provided only for unusual losses;

-eliminating either crop insurance or disaster payments (i.e., do not have one program undercut the incentives to participate in the other);

—limiting the number of times a farmer could collect disaster payments; and

—requiring farmers to contribute to a disaster-payment fund (payment could be related to past claims), thus providing an incentive to reduce exposure to risks.

■ Enhance the agricultural technology base. Congress could act to enhance research in computerized farm-management systems. The competitiveness of the farm sector will increasingly depend on technological advances that improve the efficiency of U.S. farmers-rather than on further increases in mechanization and intensity of input use. Computerized farm-management systems will be increasingly important to the farmer's ability to increase yields, control costs, and respond to environmental concerns. Limiting the runoff and leaching of farm chemicals depends most on careful timing of application and on applying only what is needed.

ARS has suggested that about $6 million annually would allow considerable improvement in its current program.[32] Funding this full $6 million program or similar support by Congress would provide for the development and broader use of technologies that have the potential to greatly enhance the efficiency of farming and increase the flexibility with which farmers can respond to climate conditions. ARS already provides leadership in this area.

AGRICULTURE—FIRST STEPS

- **Revise the commodity support programs**
  —Increase flex acreage or introduce normal crop acreage in the 1995 Farm Bill to allow farmers to switch crops without penalty.
- **Modify disaster-assistance programs**
  —Formalize requirements for disaster payments in order to encourage farmers to reduce exposure to climate risks (e.g., tighten threshold for coverage, require farmer contributions to disaster fund, limit payments for repeated losses).
  —Consider eliminating either disaster payments or crop insurance so the programs do not undercut each other.
- **Enhance the agricultural technology base**
  —Encourage the development and wider use of information technologies and computer-supported farm-management tools.

32 J. van Schilfgaarde, Associate: Deputy Administrator, Agricultural Research Service, U.S. Department of Agriculture, personal communication, July 1993.