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Chapter 30: The Impact of Extreme Weather Events on Agriculture in the United States

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Abstract The United States has sustained over 90 weather-related disasters in the past 30 years in which overall damages exceeded $1 billion. The total normalized losses for the 90-plus events exceeded $700 billion. Droughts, floods, hurricanes, severe storms, heat waves, freezes, and wildfires pose serious challenges for farmers and the agribusiness community. Socio-economic costs of some of these natural disasters are far-reaching and long-lasting. The enduring changes in climate, water supply, and soil moisture necessitate mitigation measures and adaptation strategies to cope with these changes in order to develop effective long-term risk management plans. The preparedness strategies should include alternatives to current agricultural management schemes in certain regions.

30.1 Introduction

While agriculture in the United States continues to achieve enhanced productivity, it is also experiencing greater variability in crop yields and associated farm income in recent decades. The increased yield variability is, in part, directly related to increases in extreme weather events during critical growth phases of crop development. Pests and diseases can also cause significant crop damage, which is indirectly related to climate conditions. Pest and disease occurrences often coincide with extreme weather events and with anomalous weather conditions. Agriculture is highly sensitive to climate variability and weather extremes, such as prolonged drought, floods, severe storms, heat waves, and untimely freezes. Thus, in the U.S., while agricultural production may benefit from the projected warmer climate in

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northern crop areas, the increased weather extremes across all growing areas will likely have an adverse effect on yield potential.

30.2 Weather Disasters and Agricultural Impacts

Weather disasters cause billions of dollars of damage and considerable loss of life in the United States. Every year, droughts, floods, heat waves, severe storms, wildfires, or other weather disasters caused deaths, destruction, and significant agricultural losses in various regions across the United States. During the last several decades, there has been an increasing frequency and severity of extreme weather events (Riebau and Fox 2005). Extreme weather events can have severe detrimental effects on crop yield, and therefore, agricultural production. Most crops are sensitive to direct effects of high temperature, decreased precipitation, flooding, and untimely freezes during critical growth phases. Other effects on crops are indirect, through influences on soil processes, nutrient dynamics, and pest organisms.

30.2.1 U.S. Droughts

The economic impact of drought in the United States has been estimated at about \$6–8 billion annually (FEMA 1995). On average, over the last 110 years, 10–20% of the United States experiences moderate to extreme drought annually, based on averaging over 5-year periods using the Palmer Drought Index. The 1980 drought/heat wave in the Midwest resulted in 10,000 human deaths and an estimated \$55 billion in agricultural losses. In 1988, another prolonged summer drought/heat wave led to 7,500 deaths and over \$70 billion in agricultural losses.

The severe drought of 1988 in the U.S. Midwest, accompanied by higher than normal temperatures, began early in the spring and continued throughout most of the summer. It spread to the central and southeastern parts of the nation, affecting agriculture, water resources, transportation, tourism, and the environment. Crop yields dropped by approximately 37% and required a \$3-billion Congressional bailout for farmers (Wilhite et al. 2005).

Crop pests were also affected, with outbreaks of two-spotted spider mites damaging soybeans throughout the entire Midwest region. The damage occurred during the critical flowering, pod development, and pod filling growth stages. Approximately 3.2 million hectares were sprayed with insecticides to control the mites across the region, and estimated losses to Ohio farmers were \$15–\$20 million (Rosenzweig et al. 2001)

The drought led to decreased flows in the Ohio and lower half of the Mississippi Rivers by the end of May, restricting barge movement, and extending salt water intrusion from the Gulf of Mexico 105 miles up the Mississippi River, past New Orleans.

30.2.2 U.S. Flooding

Studies have examined trends in wet periods, finding that there is an increase in the area experiencing severe moisture surplus since about 1970 (Karl et al. 1995; Easterling et al. 2000). Population and infrastructure continues to increase in areas that are vulnerable to extremes such as flooding, and severe storm damage.

In 1993, Midwest flooding caused 48 deaths and $30 billion in damages. Flooding in the summer months of 1993 affected 41,400 square kilometers of farmland, with Nebraska, Iowa, and Michigan hardest hit. In July, the Mississippi River flood crest at St. Louis, Missouri broke the previous record. Over 4,451,000 hectares of crops were damaged, with losses of over $3 billion. Excess water presents a particularly severe problem for Iowa's low-lying soils, and increased pathogen outbreaks. Emergency measures cost over $222 million.

The flood of 1993 generated a strong pulse of nitrates and other nutrients and farming chemicals into the Mississippi River and Gulf of Mexico. The runoff of nutrients may have contributed to the doubling of the Gulf's "Dead Zone" in 1993, following the flood (Rosenzweig et al. 2001). In 2009, record flooding occurred in the upper Midwest causing the Red River to overflow its banks, and setting record annual peak flow values. The Red River crested over 6.95 m above flood stage, a new record.

Precipitation is crucial for agriculture and irrigation reserves during the growing season and for replenishment of urban water supplies throughout the year in the eastern two-thirds of the United States. In the western Rocky Mountain region, winter snowfall is essential to build mountain snowpack for the western U.S. Melting snow in the spring and summer months supply over 70% of the water supply to both agriculture and urban center in the West (NRCS 2008). Excessive spring rainfall and rapid snowmelt may cause severe flash flood hazard, which can quickly endanger both life and property. Insufficient winter snowfall can cause river systems to carry insufficient water supplies to meet the demands for both agriculture and urban population reserves.

30.2.3 U.S. Hurricanes

Hurricanes are one of the most physically destructive and economically disruptive extreme events that impact the United States. In addition to the torrential downpours and destructive winds associated with hurricanes, storm surges, and salt water intrusion into freshwater river systems are serious consequences.

In 2005, Hurricane Katrina caused over $130 billion in property damage and over 1800 deaths. The nation was made painfully aware of the damages possible from extreme storm events when hurricanes Katrina and Rita struck. A total of 233,099 square kilometers was declared a federal was declared a Federal disaster area following Hurricane Katrina, covering four states and 23 coastal counties.

80% of the city of New Orleans was flooded. More than 350,000 homes were destroyed and another 46,000 seriously damaged.

Hurricane Katrina killed or severely damaged 320 million large trees across over two million hectares of forest in the southern United States. Furthermore, coastal fisheries (e.g., oyster beds, shrimp) and harvesting infrastructure (e.g. boats, processing, and storage facilities) were also severely damaged. The storm surges exceeded over 25 ft where Katrina hit the Louisiana coast. The storm hit New Orleans, causing a portion of its levee system to fail. The economic damage caused by Hurricane Katrina exceeded $133 billion, making this extreme event the most destructive natural disaster to affect the United States in its history (Lott et al. 2008).

In September 1999, Hurricane Floyd, though not an overly powerful storm when it made landfall in eastern North Carolina, dumped copious amounts of rain leading to major flooding and 77 deaths. However, storm runoff created a major pollution event due to flooding of sewage treatment facilities, farms, farm waste lagoons, and chemical and petroleum storage facilities. The flooding caused the deaths of millions of farm animals (Easterling et al. 2000).

30.2.4 El Nino/La Nina of 1997–1998

In late 1997, the tropical Pacific experienced the development of a major El Nino event, rivaling the strength of the 1982–83 El Nino. In the U.S., the El Nino was associated with several severe weather events, with heavy rain events on the West Coast from November 1997 to March 1998. In the summer of 1998, there were extremely high temperatures in Texas and Oklahoma, causing severe heat stress among the elderly population and damaging crops. These conditions spread across the South to the Carolinas. In the Southeast, there was El Nino related flooding throughout the winter and spring, while in Florida, summer dryness triggered forest fires. However, despite these regional El Nino effects, there was little impact on U.S. agriculture nationally. Wheat yields were at a record high, with the highest production since 1990; corn and soybean production was also the highest on record.

The abrupt April 1998 La Nina ushered in another year of extremes. The U.S. experiences a particularly warm winter, with January rains (rather than snow) interrupted by a cold snap, resulting in a crippling ice storm in the Northeast. The decreased winter snowpack and spring runoff exacerbated the spring and summer drought throughout the U.S. Atlantic states, severely affecting agricultural production. The second driest April-July period on record began in 1998 and intensified during 1999, inflicting the driest growing season in 105 years on the Northeast. A total of 109 million people and an estimated 918,960 farms suffered some drought in 1999. The 1998–99 drought in the U.S. resulted in reduced commodity receipts (from 1998) by an estimated $1.29 billion. Estimated net farm income losses, including yield losses, increased expenses and insurance indemnities, totaled $1.35 billion, approximately 3% of 1999 U.S. net farm income.

Then, Hurricane Floyd (September 1999) flooded coastal regions in North Carolina and New Jersey. North Carolina was also hit by Hurricane Dennis and Hurricane Irene, causing prolonged flooding and increasing the risk of fungal infections to agriculture and human health.

30.3 Food Production Vulnerability to Weather Events

30.3.1 Crop Responses

Precipitation, the primary source of soil moisture, is probably the most important factor determining the productivity of crops. Interannual precipitation variability is a major cause of variation in crop yields and yield quality.

Drought stress and heat stress frequently occur simultaneously, exacerbating one another. They are often accompanied by high solar irradiance and high winds. Under drought stress, the crop's stomata close, reducing transpiration and, consequently, raising plant temperatures. Flowering, pollination, and grain-filling of most grain crops are especially sensitive to water stress. By reducing vegetative cover, droughts exacerbate wind and water erosion, thus affecting future crop productivity.

Excessively wet years may cause yield declines due to waterlogging and increased pest infestations. High soil moisture in humid areas can also hinder field operations. Intense bursts of rainfall may damage younger plants, promote ripening-grain lodging in standing crops, and cause soil erosion. Episodes of high relative humidity, frost, and hail can affect yield and quality of fruits and vegetables. And, the costs of drying corn are higher under wetter climate regimes.

Greater precipitation (if not excessive) during the growing season tends to increase yields. Corn yields decline with warmer temperatures due to acceleration of the crop's development, especially during the grain-filling period.

The extent of any crop damage depends on the duration of stress and the developmental stage of a particular crop. Crop yields are most vulnerable to adverse weather conditions, especially extreme temperatures and excess or deficit precipitation, during critical developmental stages such as seedling and reproductive development stages.

A general outline of stress indicators by growth stage is summarized below.

30.3.2 Juvenile Stages

Soil temperature higher than 35°C (95°F) causes seedling death in soybeans. Air temperature above 30°C (86°F) for more than 8 h can reverse vernalization in wheat. Saturation of soil increases the risk of seedling diseases, especially at air temperatures above 32°C (89.6°F). Flooding causes seedling death in corn and soybean; the combination of flooding with high temperature accelerates death.

30.3.3 Reproductive Stages

Air temperatures higher than 36°C (96.8°F) cause pollen to lose viability in corn and reduce grain yield in post-blooming soybeans. Soil temperature higher than 20°C (68°F) depresses potato bulking. Soil moisture deficits are very detrimental to corn – 4 days of soil moisture stress reduces yields up to 50% – and other grain crops. Grain crops are also highly vulnerable to flooding. A spring freeze in April 2007 in the eastern U.S. affected 11 states and caused $2 billion in agricultural losses to field and horticultural crops.

30.3.4 Mature Stages

Soil saturation causes long-term problems related to rot and fungal development and increased damage by diseases (e.g., crazy top and common smut in corn). Water deficits increase aflatoxin concentration in corn.

30.3.5 All Stages

Extremely high air temperatures (>45°C; 113°F) persisting for at least 30 min directly damage crop leaves in most environments; even lower temperatures (35–40°C; 95–104°F) can be damaging if maintained for longer periods.

The United States is responsible for about 40% of the world's corn supply and nearly 70% of the total global exports (USDA/WAOB). U.S. corn yields have steadily increased since the 1950's. However, the annual growth rate in yields (i.e., relative percentage gain in annual yields) has steadily declined since the 1960's (Kucharik and Ramankutty 2005). Moreover, corn yield variability has escalated since 1950 in the United States (Naylor et al. 1997; Reilly et al. 2003).

30.4 Regional Impacts of Climate Extremes in the Future

30.4.1 Western United States

Major climate change models predict winter snowpack in the western U.S. will decline in the twenty-first Century and snowmelt will occur earlier, resulting in greater runoff. The demand for water is rising in the region. Ground-water withdrawals have increased significantly in recent years in many Western states both for irrigation agriculture and for increasing urban demand for water throughout the region.

Consequently, water shortages will force farmers in the region to fallow their lands. The estimated economy-wide loss for the Central Valley region of California is expected to reach up to $6 billion annually during the driest years. Decreased supplies of water are expected to significantly diminish the value of farmland in California. The value of wine production in California is $3.2 billion, which may be compromised, as grape quality will likely diminish with higher temperatures. The decline in dairy cow productivity is directly correlated with higher temperatures, as well. A loss is expected in this industry in California as well.

Forestry in the Pacific Northwest is expected to be greatly impacted as increased incidence of fire is expected. Increases in spring and summer temperatures and earlier melting of snowpacks have contributed to the six-fold spike in the area of forest burned since 1986, compared with the 1970–1986 period. Moreover, the average duration of fires increased from 7.5 to 37.1 days since 1986. In 1987, 486,000 ha of forest burned throughout the U.S., the first time since 1919 that more than 400,000 ha burned in 1 year. As a result of similar fires in 1988, 1994, and 1996, and a record 866,000 h fire in 2000, fire suppression costs increased significantly. A 50 percent increase in the number of hectares burned is expected by 2020, and a 100% increase by 2040.

Agriculture in the Pacific Northwest may benefit from a longer growing season, but these benefits may be offset by higher maximum temperatures and water shortages. Expected annual crop losses from water shortages are projected to rise from $13 million at present to $79 million by mid-Century.

30.4.2 Great Plains

The agricultural sector in the region contributes $22.5 billion annually in market value of products – 35% of which is attributed to crops and the rest to livestock. The consumptive demand for water for crops (especially grass and alfalfa) may increase by 50% by 2090, straining water resources in the region. Farmers who plant corn in the Great Plains will likely experience declines in yields, while wheat yields may increase. Adaptation, especially at the farm level, will be essential for limiting losses due to changing climatic conditions (Scheraga and Grambsch 1998).

The Southern and Plains regions may experience a decline in productivity totaling as much as 70% for soybeans and 10–50% for wheat; although crops in other areas may temporarily increase their yields.

An additional burden on the agricultural sector may be an increased resilience of insects to pesticides. Pesticide use and the associated costs are estimated to increase by 10–20 % for corn; 5–5% for potatoes; 2–5% for cotton and soybeans; and 15% for wheat.

Higher incidences of severe weather events are likely to cause major damage to the region's infrastructure. For example, a 1999 outbreak of tornadoes in the Great Plains caused $1.16 billion in damages and 54 deaths; and an extreme flooding event in 1998 in southeast Texas inflicted $1.16 billion in damages and caused 31 deaths.

30.4.3 Midwest

A big concern in the region is drought-like conditions resulting from rising temperatures, which increase evaporation and contribute to decreases in soil moisture and reductions in lake and river levels. Forestry is an integral part of the economic structure in the Midwest. Over 90% of forestland is used for commercial forestry, resulting in economic activity valued at $4.6 billion. The sector employs 200,000 people and produces $27 billion in forest products. Potentially negative impacts are expected to the $5.7 billion dairy industry, since milk production is temperature-sensitive and is reduced once temperatures advance beyond a certain threshold. The agriculture sector also may experience losses similar to the 1988 drought, which cut production of grain by 31% and production of corn by 45%.

30.4.4 Southeast

With warmer weather and warmer water in the Atlantic and the Gulf of Mexico, the region may experience an increased frequency and intensity of storms, seal level rise, and the loss of important agricultural areas, crops, and timber species. In addition to coastal infrastructure, forests, agriculture and fisheries, water quality and energy may be subject to notable change and damages as well.

Forestry is a major economic sector in the Southeast. The state of South Carolina boasts 60% forest cover and forestry is, after tourism, the second largest economic sector. Given the diversity of species and environmental conditions, short- to medium-term impacts on forests are uncertain. Sea level rise resulting in salt water intrusion may damage forests, particularly in southern Florida and Louisiana. Higher temperatures, decreased soil moisture, and more frequent fires may stress forest ecosystems and ultimately lead to a conversion from forest to savannah and grassland. However, some species may see, at least temporarily, increases in productivity and forested acreage due to a longer growing season, CO_2 fertilization, and a switch from stressed to more acclimated species.

As increased storm frequency and intensity impacts coastal infrastructure, they may also reduce water quality and harm fish populations. Fish and shellfish are at risk in warmer waters and when exposed to increased pollution following major storm events. Much of this pollution will come from stronger storms stressing water management systems and causing sewer systems to overflow, as well as increased nutrient runoff from agricultural lands.

30.5 Expected Changes in Extreme Climate Events in the Twenty-First Century

The following observed changes in U.S. extreme events can be summarized, as well as the likelihood that the changes ill continue through the twenty-first Century. First, over most land areas, the last 10 years had lower frequency of severe cold outbreaks than any other 10-year period with this trend very likely to continue. Second, more frequent hot days and nights are observed over most of the country. Third, more frequent heat waves are most pronounced over the northwestern two-thirds of the nation, and this trend is very likely to continue. Fourth, more frequent and intense heavy downpours, with a higher proportion of heavy precipitation events, are expected over many areas of the U.S. 50 increases in area affected by regional drought are likely to expand.

Finally, likely increases in intense hurricanes are expected in the Atlantic Ocean linked directly to increasing sea surface temperatures.

30.6 Measures to Improve Our Understanding of Climate Extremes and Preparedness Strategies for Long-Term Planning

Drawing on the material presented in this report, there are opportunities to define highest priority areas for rapid and substantial progress in improving understanding of weather and climate extremes and developing adaptation strategies for agriculture to cope with both short-term climate variability and extreme events to longer-term changing climate. These include:

1. The continued development and maintenance of high quality climate observing systems to improve our ability to monitor and detect future changes in weather and climate extremes;
2. Efforts to digitize, homogenize, and analyze long-term data observations analyses to improve our confidence in detecting past changes in climate extremes;
3. Weather observing systems adhering to standards of observation consistent with the needs of both the climate and the weather research communities to improve our ability to detect observed changes in climate extremes;
4. Extended reconstructions of past climate using weather models initialized with homogenous surface observations to help improve our understanding of strong extratropical cyclones and other aspects of climate variability;
5. The creation of annually-resolved, regional-scale reconstructions of the climate for long-term historical records to help improve our understanding of very long-term regional climate variability;
6. Improvements in our understanding of the mechanisms that govern hurricane intensity would lead to better short and long-term predictive capabilities;

7. More extensive access to high temporal resolution data (daily, hourly) from climate model simulations both of the past and for the future to allow for improved understanding of potential changes in weather and climate extremes;
8. Enhanced communication between the climate science community and those who make climate-sensitive decisions to strengthen our understanding of climate extremes and their impacts;
9. A reliable database that links weather and climate extremes with their impacts, including damages and costs under changing socioeconomic conditions, to help our understanding of these events;
10. Preparedness is the key to proactive agricultural risk management planning measures;
11. Preparedness plans for weather and climate extreme events need to develop and incorporate comprehensive insurance and financial strategies into their overall long-term plans;
12. Crop insurance is an important risk management option;
13. A safety net of emergency relief should be maintained to emphasize sound stewardship of natural resources;
14. The combination of preparedness programs and emergency response measures needs to be coordinated in an effective, efficient, and customer-oriented manner;
15. The long-term strategy is threefold: (i) preparedness to improve the effectiveness of response and recovery, such as through establishment of early-warning systems; (ii) mitigation measures to reduce the impact of extreme events or natural disasters prior to their occurrence; and, (iii) adaptation strategies to prepare for and cope with the potential impacts of extreme events or natural disasters.
16. Weather and climate knowledge should be incorporated into planning and management decisions for agricultural production.
17. Sustainable, optimized production levels can be achieved through the effective use of weather and climate information, while maintaining environmental integrity and minimizing the degradation of soil, nutrients, and water resource bases.
18. Finally, technology (fertilizers, new seed varieties, farming practices) should aid production, but not harm there resource bases in the long run.

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