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American Agriculture Can Adapt to Climate Change-Induced Water Extremes

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Introduction

As climate change unfolds, agriculture will be directly affected, with ramifications for prices, domestic food supply, exports, farming communities, and employment and potential externalities associated with production adjustments. Climate change will lead to more extreme water situations affecting water availability.

Climate change is associated with more variable water supplies, reduced precipitation in some areas and greater in others, higher evaporation, and—often—less available water for consumption. However, water scarcity means scarcity not only due to lower available quantity but also due to, for example, reduced quality that restricts use, flooding that damage yields and infrastructure, or extreme drainage problems that lead to damages and alteration of management practices. Insects and diseases are stimulated by higher temperatures, reducing yields and quality (Mendelsohn and Dinar, 2009; Dinar, 2016). Adaptation by growers is key for how these effects ultimately play out. Responses depend in part on how climate change materializes and is interpreted across the planet (Libecap, 2014).

The agricultural sector has responded to climate impacts in different ways, depending on information, human capital, institutional capacity—particularly property rights, and coordinating mechanisms across irrigator groups as well as taking advantage of available capital and technology. Adaptation in agriculture takes the form of private and public actions. Private adaptation includes changes in crop and livestock mixes, alteration of planting and harvesting techniques and seasons, introduction of advanced irrigation technologies, resorting to groundwater where or when surface water is constrained, and other changes in land use patterns. Public adaptation includes breeding crops and animals to address a harsher climate, training farmers via agricultural extension, and investments in infrastructure for water storage and conveyance (Mendelsohn and Dinar, 2009; Dinar, 2016).

Because of the variation in topography and climate across the continent, U.S. agriculture has historically adjusted over time as production moved from eastern regions, where water was abundant, to western regions, where water was scarce. This experience provides an important template for following responses to water extremes—droughts and floods (Libecap and Steckel, 2011; Olmstead and Rhode, 2011). Olmstead and Rhode (2011) point out that there are more temperature and precipitation differences between the eastern and western United States than the climate change models predict. Therefore, these two regions face different climate systems and should be addressed separately.

Today, even in eastern and mid-western regions of the United States, water supply has become scarcer and less uniform across the growing season. Coping with altered access to water in U.S. agriculture has introduced a variety of innovations that will be critical in dealing with the challenges of climate change, which include more intense droughts, occasional extreme precipitation, heat, and aquifer depletion.

What Can Empirical Evidence Teach Us about Adaptive Responses?

The studies synthesized in this article examine four main areas of intersection across agriculture, water, and climate change:

(i) Adapting to climate change by addressing the movement of drainage and conveyance of irrigation water;
(ii) Addressing the potential for negative externalities that result from private adaptation responses;
(iii) Relying on groundwater extraction as a substitute for surface water substitution,

resorting new irrigation techniques and equipment, and altering cropping patterns; and

(iv) Adopting institutional reforms to solve collective action problems in water movement and groundwater extraction.

Areas (ii) and (iv) highlight the role of private adaptation to climate change as a potential response to private and social damages, which could be addressed with institutional reforms that may prevent or reduce social damages.

The four areas of intersection are also interrelated. They reflect actions undertaken by individuals and by government as climate change impacts evolve, and they reflect various adaptation options, such as technology substitution (surface irrigation-drip irrigation), water resources substitution (surface water-groundwater), and institutional substitutions (private adaptation-institutional reforms of common pool resource management). The next sections include examples and results of research dealing with each.

Responses to Altered Availability of Water in American Agriculture: A Historical Perspective

Until the late nineteenth century, agriculture in the eastern part of the United States was practiced mainly as rainfed or irrigation-supplemented agriculture. The western part of the country has always been drier, but more limited and costly water supplies did not constrain agricultural production. Leonard and Libecap (2019) reveal how prior appropriation water rights emerged in the West beyond the 98th meridian, relative to riparian rights due to the need to move water securely from streams to remote arable land and to promote coordination for irrigation infrastructure investment, water storage, and irrigation projects.

Compared to the rest of the country, the U.S. West is more drought-prone, generally drier, depends more upon water storage in surface reservoirs and aquifers (Libecap and Hansen, 2002), is more likely to utilize canal and ditch networks for water delivery, and applies more irrigation. These experiences are indicative of future conditions under climate change, suggesting that drought will become more prevalent, with alternating very wet and dry periods and more reliance on irrigation, longer distances needed to transport water from storage sites, and need to dispose of drainage.

After 1940, irrigation from snowmelt and reservoir storage and shipment was augmented with groundwater pumping. Aquifer access became feasible with greater access to electricity, more powerful combustion engines and turbine pumps, deeper wells, and improved pumping technologies. Advances in irrigation with new dam construction and groundwater delivery provided new water and led to major increases in agricultural production and higher productivity in the U.S. West, especially in the Pacific region (Edwards and Smith, 2018).

Farmers' Adaptation to Climate Change

As the climate changes, water supplies are likely to become much scarcer; altered distribution in most parts of the country will likely affect agricultural production and rural populations. Since climate change leads to greater reliance upon irrigation, especially in previously rain-fed agricultural regions in the east, the technologies, institutional responses and other innovations observed in the drier western United States could provide important laboratories for new learning (Schoengold and Zilberman, 2007; Libecap, 2011; Hornbeck and Keskin, 2014).

Overall, farmer adaptations range from replacing existing crops with new ones—especially drought and heat-tolerant varieties; intermediate fallowing during dry periods (if climate change results in times of increased water availability followed by drought); permanent withdrawal of marginal production areas; use of cover crops and tillage practices to conserve water; increases in fertilizer application and other inputs; greater reliance upon irrigation, particularly in the eastern United States, and adoption of new irrigation technologies; greater movement of water from storage sites for irrigation; higher rate of drainage removal from agricultural fields; increased reliance of marginal water sources such as recycled wastewater; and reliance upon more groundwater pumping and artificial recharge. Many of these responses will require institutional arrangements to coordinate groundwater extraction and water movement and to address other potential externalities associated with fertilizer runoff (Saleth, Dinar, and Frisbie, 2011). In addition, adjustments in crop insurance programs may assist farmers in responding to uncertainty associated with assessing climatic variability and crop yields (Garrido et al., 2011).

What Does New Research on Water, Agriculture, and Climate Change in the United States Suggest?

Adaptation in the Eastern United States

The first group of research papers refers to agricultural adaptation in the eastern United States, dealing with rainfed and/or supplemental irrigation and the need to remove excess water from fields. Edwards and Thurman (2023) assess the role of drainage under increasing likelihood of extreme precipitation events due to climate change across the entire United States. Their research identifies technical innovations introduced in drainage tile technologies required for collection and disposal of excess water. Their research highlights the role of institutional innovation, which was necessary for efficient coordination of drainage reduction, and its associated costs. Their research suggests that all U.S. regions with poorly drained soils will face excess water in the root zone of cultivated crops, leading to waterlogging and salinity, which in turn will create aeration deficits and productivity losses, leading to yield reductions. Removing excess water from irrigated fields has been supported by legislation for establishing local drainage and drainage-management districts. Edwards and Thurman estimate that drainage districts will increase land productivity and thus land value. Estimated increases in the value of, land in the worst-drained counties of the eastern United States ranged from 13.5% to 30.3% with a combined increase in land value of between $7.4 billion and $16.6 billion in 2020.

Similarly, Karwowski (2023) evaluates another measure of adaptation to climate change in humid regions in the form of the land easement program. This program provides payments to farmers who withdraw inundated cropland from production and restore it to its natural condition. The land easement program has been applied in large agricultural areas in the eastern United States that were reclaimed from wetlands and floodplains and thus are now subject to flooding risks under increased precipitation. Nearly 3 million acres of eased wetlands and 185,000 acres of eased floodplain existed in the United States in 2020. The easements program impacts agricultural production directly, by reducing planting on marginal land and thus reducing losses from flooding, and indirectly, by changing flood patterns that improve crop yields on surrounding cropland. Based on data collected from rainfed and non-irrigated counties, Karwowski finds that wetland easements reduce soybean losses from excess moisture, heat, and disease by $3.59, $6.07, and $11.23, respectively, for each dollar of precipitation liability.

In a different investigation, Cooley and Smith (2023) address the role of irrigation technologies in responding to water scarcity in the U.S. Midwest, focusing on irrigated agriculture in Illinois, which has experienced a threefold increase in irrigation-equipped cropland since 1978, mainly due to the a rise of center pivot irrigation systems (CPIS). CPIS adoption in certain locations was associated with monetary benefits in terms of annual crop yield, greater irrigated acreage, new crop selection, and reduction in drought-related insurance payments. Estimates of the value of CPIS adoption under drought conditions suggest that the use of CPIS during drought years has reduced indemnity payments for both soybeans and corn. A 1% increase in cropland equipped with a CPIS decreases insurance payments by approximately 6.34% for corn and 2.81% for soybeans. In addition, CPIS presence during a drought year has a significant effect on corn yield but no significant effect on soybean yield. Findings suggest that during a drought year, an increase in 1% of cropland equipped with CPIS yields leads to a nearly 0.46% increase in corn yield per acre across the state.

Investment in Efficient Conveyance of Irrigation Water in the Western United States

Research also addresses the roles that off-farm water conveyance and on-farm canal lining play in response to shifting precipitation. With more than one-third of the applied agricultural irrigation in the United States originating from off-farm sources, improvements in delivery and conveyance efficiency have the potential to significantly reduce water losses. Hrozencik, Potter, and Wallander (2023) estimate the value of water savings in the conveyance of water from the source to farms. The potential resource savings are large. On average, reported conveyance losses were nearly 15% of delivered water in 2019. The study indicates that at the margin, an increase of 1% in the share of conveyance piped infrastructure leads to an expected 0.16% reduction in conveyance losses. Using a simulated water-conservation supply curve, the authors suggest that nearly 2.3% of all water delivered to farms could remain in the system rather than be lost through evaporation or leakage, at an investment of less than $10,000 per acre-foot of delivered water.

That study uses costs and water savings taken from project proposals to the Bureau of Reclamation 2022 WaterSMART Water and Energy Efficiency Grants. Among the 22 funded projects (https://www.usbr.gov/watersmart/weeg/docs/2022/FY2022-WEEG-Project-Descriptions.pdf), two were in Idaho and California. The project in Idaho converted 10,458 feet of open unlined canal to a 48-inch high-density polyethylene pipeline and installed solar-powered automated headgates and measurement devices along the same section of the canal. The cost was $3,933,028 and the project is expected to result in water savings of 7,267 acre-feet annually, suggesting an investment of $541 per acre-foot saved annually. The project in California lined a half-mile section of the currently earthen upper Mohave Canal with concrete at an investment of $968,680. The project is expected to result in annual water savings of 498 acre-feet, which is currently lost to seepage, evaporation, and operational losses. This suggests an investment of $194 per acre-foot saved annually.

Adoption of Irrigation Technologies and New Crop Varieties

Climate change impacts on the water cycle may be manifested via several routes. Water availability can be altered by reduction of precipitation, by changing precipitation distribution, and by increased evaporation rates, to name a few. Adaptation to water availability through irrigation adoption is thus an adaptation to climate change.

The behavioral aspect of adoption by farmers is studied by Blumberg, Goemans, and Manning (2023). The authors show that the adoption of costly new irrigation technologies and selection of cropping patterns by farmers depend upon their perception of future drought (water availability). They examine how farmers interpret the implications of past droughts. Arguing that farmers who face possible reductions of surface water availability will be more likely to adopt more water-efficient irrigation systems, they infer their hypothesis by using data on corn production from one water region in Colorado over seven observation years during 1976–2015. Blumberg, Goemans, and Manning (2023) find that a change in beliefs about the reliability of farmers' water supply due to curtailment during past droughts led to shifts in beliefs and molded the adoption of water-saving sprinkler irrigation technology at the field level to replace older flood irrigation. An important finding also suggests that a reduction in surface water availability led to increased groundwater use to augment existing corn irrigation practices in Colorado.

In addition to on-farm adoption of new irrigation technologies, farmers can consider using new seed varieties that are more tolerant to drought and other related climate-induced effects, or introducing new management practices, such as planting cover crops to conserve water. McFadden, Smith, and Wallander (2023) report on what motivates farmers to adopt drought-tolerant corn varieties in response to an increased frequency of drought in the United States. The authors use 2016 data from a survey of U.S. corn operations and a sample covering over 73.3 million acres, representing nearly 78% of 2016 U.S. corn acreage where drought-tolerant corn was grown on non-irrigated land in 2016. Their results suggest that the duration and severity of recent droughts do not appear to motivate adoption of drought-tolerant seeds but that higher average temperatures and variability of rainfall, instead, lead to higher adoption rates. In addition, higher adoption rates occur on lower quality, more highly erodible land. As expected, increased rainfall results in lower adoption rates.

In similar research, Dong (2023) investigates adoption of cover cropping to improve resilience to drought. Cover crops include grasses, annual cereals, such as rye, wheat, barley, oats; annual or perennial forage grasses, such as ryegrass; and warm-season grasses, such as sorghum. Cover crops can protect and improve soil between periods of regular crop production through control of erosion, infestation from weeds, and pests; recycling of nutrients; provision of habitat for beneficial organisms; and greater water efficiency by reducing evaporation form bared soil. Trade-offs associated with cover cropping include incremental costs of soil preparation, seeds, and labor as well as difficulties in implementation and management of rotating cover crops with major cash crops. With such background and data available for soybean production in the United States, Dong (2023) explores factors influencing farmers' adoption of cover crops and examines the impact of cover crops on soybean yield and production risk. She finds regional differences in adoption, likely the result of hedonic effects, such as soil types and quality, landscape, and climate. She also finds that cover crops were affected by farmers' concerns regarding production outcomes. Farmers who had concerns over wind-driven erosion, soil compaction, and water quality were more likely to adopt cover crops. Still, she finds that the voluntary adoption rate of cover crops is relatively low. Government financial support, however, increased cover crop acres enrolled in the government programs from 312,600 acres in 2009 to 2,443,000 acres in 2020.

Despite the attractive possibility of saving water and increasing yields using new irrigation technologies, management practices, and new seed varieties, these strategies can present negative externalities in the form of groundwater depletion, interruption of surface stream flows, and downstream pollution. Crop mix decisions, especially continued reliance upon water-intensive corn, reflects the effect of past crop subsidies.

The Unintended Consequences of Successful Adaptation to Climate Change

While facing climate-change-induced water extremes, farmers introduce adaptation practices. For example, farmers compensate for yield loss from having less access to water by adding more fertilizers, which are washed to waterways (rivers or groundwater) after rain and negatively affect downstream farmers and ecosystems. Policy interventions to regulate such negative externalities include incentivizing individual farmers to internalize the negative externalities in what we coin private responses. In addition, as will be discussed in the next subsection, negative externalities from overuse of open access resources, such as aquifers, are handled via institutional adaptation reforms affecting all users of the resource.

Elbakidze et al. (2023) analyze the consequences of nitrate concentrations in runoff from farmland upstream on water quality downstream in the Mississippi River Basin. Using a combination of physical and economic models, they estimate that nitrate delivery to the Gulf of Mexico increases by 0.5%–1.6 % (1,690–5,980 metric tons). The effects vary because changes in production and nitrate use are spatially heterogeneous. That is, in some counties, nitrate use intensifies, while in others it decreases. While these impacts may not look substantial in terms of magnitude relative to baseline runoff, the corresponding marginal damages/opportunity cost to aquatic ecosystems might be significant. The results suggest that without climate change adjustments, the opportunity cost of ecosystems is $7.8 billion, while alternatively, the estimate rises somewhat to between $6.4 and $8.1 billion.

Using a different analytical framework to address the same research question, Metaxoglou and Smith (2023) estimate the extent of nutrient pollution in U.S. agriculture in another study area. They use an econometric approach applied to a long-term dataset and introduce a framework for nutrients, corn production, and precipitation in estimating and interpreting their results. Even if corn yield is not affected by over applying nitrate fertilizer, farmers in the basin may still apply more fertilizer as an insurance measure against possible yield reduction arising from reduced precipitation. Any residual nitrogen from overdoses remains in the soil and is leached into lakes, rivers, and streams as nutrient pollution. Given yield increases due to nitrogen applications, corn acreage and nitrogen concentration in drainage water are expected to increase. The authors use data on changes in corn acres planted for eastern counties (excluding Florida), precipitation patterns, Mississippi stream flow for 1970–2017, and secondary estimates of the median potential damage costs of nitrogen increases in the Gulf of Mexico. They estimate that an additional 50,800 metric tons of nitrogen in the Gulf of Mexico yield an estimated damage of nearly $805 million per year.

Risk to Groundwater as an Adaptation Buffer

Increased surface water scarcity as a result of climate change leads to increased groundwater pumping to support irrigation. Doing so can deplete groundwater stocks, increase pumping costs, cause land subsidence, and lower groundwater quality. Bruno, Hagerty, and Wardle (2023) show the importance of several new institutional arrangements to regulate groundwater withdrawal that have been introduced in California. The Sustainable Groundwater Management Act (SGMA) enacted in California in 2014 is used as an example of the benefits and costs of legislative policy intervention. The law identified local groundwater sustainability agencies (GSAs) as key for negotiation and implementation of pumping controls among members to achieve sustainable withdrawals. Pumpers bear direct costs due to cutting back on water withdrawal. These costs vary. The impact of reductions is immediate and generally predictable, while the benefits are longer term and more uncertain. Using data for all 343 GSAs formed following the enactment of SGMA, the authors estimate the gross cost of agricultural groundwater regulation through the changes in land values across GSA boundaries before and after the SGMA enactment. Findings suggest that although SGMA encouraged a move from the previous status quo of open access to a joint management regime of groundwater, the high costs of reduced pumping are significant. The estimates suggest that, on average, a reduction of 1 acre-foot per acre of expected future water pumping from an aquifer reduces land values of farms within the borders of the GSA by 55% in the post-SGMA period. The study identified a significant gap between the likely public good benefits and the localized private net costs. This finding explains why the policy may not benefit everyone's situation, and suggests that groundwater extraction controls may be resisted, slow to implement, and incomplete.

In a final study addressing groundwater impacts in eastern Arkansas, a region with precipitation variability overlaying the Mississippi River Alluvial Aquifer, Kovacs and Rider (2023) develop an approach to quantify how the demand for in situ groundwater can help identify the value of groundwater to farmers who experience climatic change effects. Using detailed field-level data and data from land markets in the region, the authors provide empirical evidence of decreases in the value of agricultural land due to increased overdraft of groundwater. Land values fall as farmers use more water from the aquifer. The authors estimate that farmers are willing to pay $4.70 and $24.80 for a foot increase in saturated water aquifer thickness for all farms and rice farms, respectively, when current aquifer thickness is 100–120 feet. In all regional land markets analyzed, a 20-foot decrease in saturated thickness from 120 feet to 100 feet would decrease the per acre property values by $148 for all farms and $296 for rice farms.

Conclusion

Recent new empirical research provides insights into the responses of American agriculture to changes in access to water as climate change unfolds. Farmers' responses include greater use of more efficient irrigation and related technologies, investment in infrastructure for water transport and drainage removal from fields, adoption introduction of new drought-tolerant crop varieties and cover crops, intensified application of nutrient fertilizers to maintain yields, and shifts to greater reliance upon groundwater. At the same time, new institutional arrangements, consistent with local farmer incentives, mitigate the losses due to open access in groundwater, promote use of easements, and reduce downstream negative externalities from upstream fertilizer runoffs.

All of the studies indicate that U.S. agriculture and the food stocks, fibers, other outputs, and exports as well as related employment and viability of rural communities are likely to be resilient. There is a wide margin for adaptation, including moving from less appropriate to more appropriate growing locations, technological and managerial options, genetic improvements, institutional developments, and many more. Farmers have incentives to exploit these adaptation options and initiate them actually.

For More Information

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