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How do Extreme Climate Events Affect Specialty Crops and Irrigation Management?

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Some of the highest value agricultural products in the United States are specialty crops, including fruits, vegetables, tree nuts, nursery crops, and horticulture. Many of these valuable crops thrive in the western United States under irrigation. Specialty crop farmers face difficult challenges, however, many of which are related to extreme climate events. Extreme climate events, such as frosts, heat waves, drought, and excess moisture, can ruin a crop and hurt a farmer financially.

Climate change may exacerbate these issues. Extreme climate events and water scarcity are expected to become more severe in the western United States (U.S. Environmental Protection Agency 2013). Furthermore, in comparison to the production of ordinary crops such as corn, soybeans and wheat, there is less understanding about the effects of climate change on specialty crops (U.S. Department of Agriculture 2013a). While farmers can do little on their own to prevent climate change, they may be able to change irrigation practices (e.g., irrigation technologies and water application rates) to mitigate crop losses caused by extreme climate events (Finkel and Nir 1983).

Adaptive irrigation management could affect production and consumption of fruits, nuts and vegetables, and, ultimately, human health in the United States. For example, the meal pattern and nutrition standards of the National School Lunch Program are based on the latest Dietary Guidelines for Americans. The standards increase the use of fruits, vegetables and whole grains in the school menu. The relative availability and price of agricultural commodities affects the type and amount of foods served to children under the National School Lunch Program (U.S. Department of Agriculture 2013b).

This brief addresses two research questions:

1) How vulnerable are specialty crops to extreme climate events?

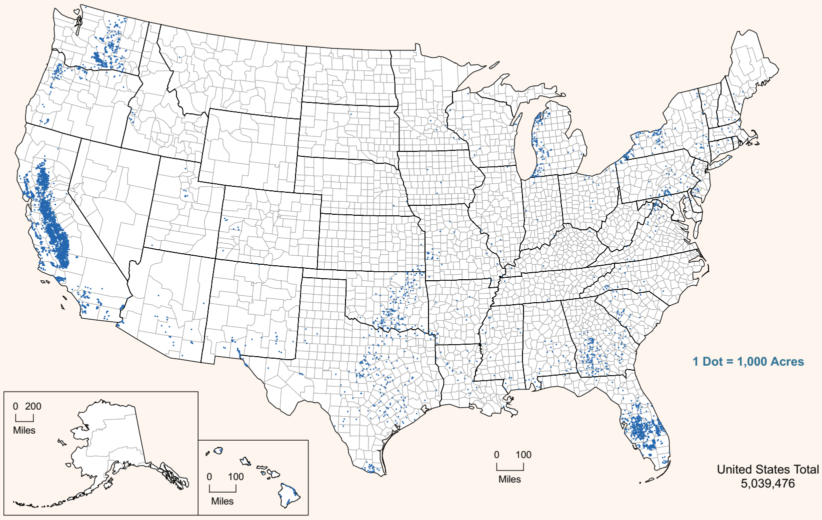
2) How do extreme climate events affect irrigation management for specialty crops?

Understanding these questions provides insights about how adaptive irrigation management and water policy affect agricultural resilience to climate change. This study focuses on the West Coast (California, Oregon and Washington), which, according to the Census of Agriculture, produced 73% and 45%, respectively, of fruit/nut and vegetable sales in the United States in 2007. Figures 1-2 show the locations and acreages of orchards (excluding grapes and berries) and vegetables in the United States in 2007, respectively.

Two data sources are used to address the research questions. The first data source is the Cause of Loss data (COL) for 1989-2012 developed by the USDA Risk Management Agency. The contract-level (field or farm) COL reports the causes of indemnified loss (i.e., damage) for specific crops under the federal crop insurance program. The federal crop insurance program is the primary agricultural risk management program in the United States, so the COL is the best available representation of production risks for specific crops. We use the COL for the West Coast for orchard/vineyard, vegetable, wheat, and forage to address the first research question.

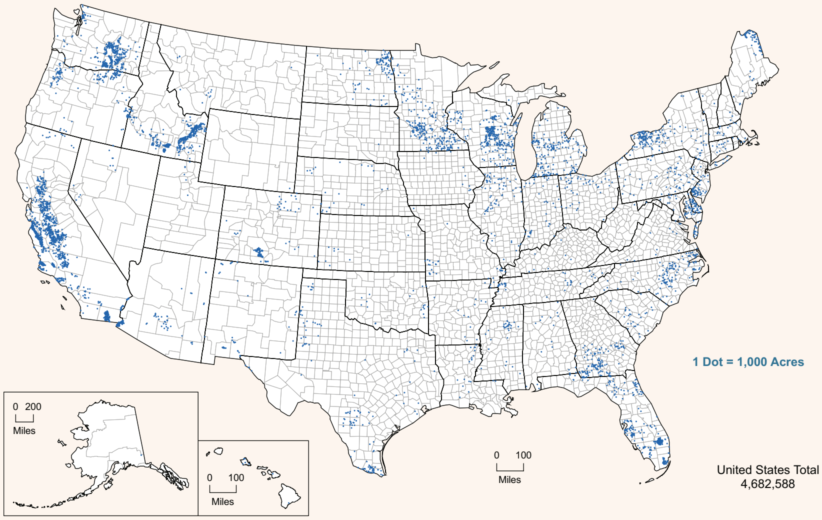
The second data source is the 2007 Farm and Ranch Irrigation Survey (FRIS) conducted by the USDA National Agricultural Statistic Service. The FRIS reports farm-level irrigation practices for specific crops, including whether irrigation is used to mitigate damage from extreme climate events such as frost or heat stress. Olen, Wu, and Langpap

Figure 1. Locations and Acreages of Orchards in the United States in 2007



Note: Map uses data from the 2007 Census of Agriculture and is available at www.agcensus.usda.gov/Publications/2007/Online_Highlights/Ag_Atlas_Maps/

Figure 2. Locations and Acreages of Vegetables in the United States in 2007



Note: Map uses data from the 2007 Census of Agriculture and is available at www.agcensus.usda.gov/Publications/2007/Online_Highlights/Ag_Atlas_Maps/

(2013) use the FRIS to assess how extreme climate events affect irrigation management for the major crops in the West Coast (orchard/vineyard, vegetable, wheat, alfalfa, hay, and pasture). They estimate three crop-specific irrigation decision models: 1) proportion of cropland irrigated; 2) irrigation technology choice (gravity, sprinkler, or drip); and 3) water application rate (acre-feet). We report results from this study to address the second research question.

Vulnerability of Specialty Crops

Extreme climate events have caused multi-billion dollar losses to specialty crops in the United States on numerous occasions over the past twenty-five years (National Oceanic and Atmospheric Administration 2013). For example, in December 1990, several days of sub-freezing temperature occurred in the San Joaquin Valley, California, causing loss to citrus, avocado trees, and other crops, with damages of $5.5 billion (adjusted to 2007 dollars). Sub-freezing temperatures occurred for an 8-day period in December 1998 in the San Joaquin Valley and caused damages of $3.2 billion to fruit and vegetable crops. A two-week freeze across most of California in January 2007 destroyed numerous crops and caused damages of $1.4 billion, with citrus, berry, and vegetable most affected. In April of the same year a freeze across much of the East Coast and Midwest caused damages of $2.2 billion to fruit crops, field crops (especially wheat) and ornamental crops. Severe drought and heat in 2012, 2009, 2008 and 2006 also caused multi-billion dollar damages to agriculture in California and other states.

Table 1 presents the shares of reported causes of loss for major insured crops in the West Coast over the past twenty-five years. The causes of loss are categorized into abiotic and biotic factors. Abiotic factors include extreme climate events, natural disasters and economic factors. Extreme climate events are the most frequent cause of damage for all crops, accounting for 96% of all the reported causes of loss for orchards and vineyards, 87% for vegetables, 89% for wheat and 73% for forage. The most frequent causes of damage shared by all crops are frost, heat, and excess moisture, which account for 36% to 64% of the causes, depending on the crop. Biotic factors cause damage most frequently to vegetable (10%), while natural disasters (12%) and economic factors (11%) cause damage most frequently to forage.

Adaptive Irrigation Management for Specialty Crops

A significant share of specialty crop farmers uses irrigation to mitigate damage to crops from extreme climate events (table 2). The share of farms using irrigation to mitigate frost damage is highest for orchard/vineyard (39%) and vegetable (16%). The share of farms using irrigation to reduce heat stress is also highest for orchard/vineyard (19%) and vegetable (12%). Specialty crops' sensitivity to irrigation and climate extremes suggests that it is prudent to better understand how extreme climate events affect irrigation management for them.

Frost and Freeze

Using irrigation to mitigate frost damage to crops increases the likelihood to adopt sprinklers by 18% for vegetables and 9% for orchard/vineyard. It decreases the likelihood to adopt gravity technologies by 13% for vegetables and 4% for orchard/vineyard.

Using irrigation to mitigate frost damage to orchards and vineyards increases the average water application rate by 12% (0.30 acre-feet). One explanation for this finding is that using irrigation for frost protection increases the frequency of irrigation, which increases the average water application rate in orchards and vineyards. Damaging frost events occur in the early morning, a time of day that typically does not overlap with normally scheduled irrigation events (Wallis et al. 2011).

Olen, Wu, and Langpap (2013) also find that several irrigation management decisions have a climate threshold. How farmers respond to climate change depends on whether they are located below the threshold (cooler and wetter locations) or above it (warmer and dryer locations). For example, there is a temperature threshold for the water application rate in orchards and vineyards at 67°F. In cooler locations where the average daily maximum temperature is less than 67°F, an increase in tempera-

Table 1. Shares of Reported Causes of Loss for Major Insured Crops in the West Coast

Cause of Loss	Orchard/Vineyard	Vegetable	Wheat	Forage
Abiotic Factors				
Extreme Climate Events		*share*		
Cold Wet Weather	0.12	0.09	0.07	0.04
Cold Winter	0.01	0.01	0.06	0.02
Drought	0.01	0.06	0.33	—
Excess Moisture/Precip/Rain	0.21	0.21	0.11	0.34
Frost/Freeze	0.27	0.08	0.15	0.07
Hail	0.10	0.04	0.02	—
Heat/Excess Sun/Hot Wind	0.16	0.31	0.10	0.08
Wind/Excess Wind	0.06	0.06	0.02	0.03
Other	0.02	0.01	0.02	0.15
All Extreme Climate Events	*0.96*	*0.87*	*0.89*	*0.73*
Natural Disasters				
Flood	0.00	0.00	0.01	0.12
Other	0.00	0.00	0.02	—
All Natural Disasters	*0.00*	*0.01*	*0.03*	*0.12*
Economic Factors				
Area Plan Crops Only	—	—	0.00	0.05
Decline in Price	0.01	—	0.04	—
Failure in Irrig. Supply	0.00	0.02	0.01	0.06
Other	—	—	0.00	—
All Economic Factors	*0.01*	*0.02*	*0.05*	*0.11*
All Abiotic Factors	*0.98*	*0.90*	*0.96*	*0.95*
Biotic Factors				
Insects	0.00	0.03	0.01	0.02
Plant Disease	0.00	0.07	0.03	0.00
Other	0.01	0.00	0.01	0.02
All Biotic Factors	*0.02*	*0.10*	*0.04*	*0.05*
Proportion of All Causes	1.00	1.00	1.00	1.00
Observations	19,463	3,996	9,001	265

Note: Data is from the COL for 1989-2012 for California, Oregon and Washington. For orchards and vineyards, the share of 0.27 for Frost/Freeze means that 27% of the reported causes of loss for orchards and vineyards under the federal crop insurance program are due to frost and freeze damage. Under the Extreme Climate Events category: “Frost” and “Freeze” are aggregated; “Heat,” “Excess Sun” and “Hot Wind” are aggregated; and “Other” includes “Snow-Lightning-Etc.” and “Insufficient Chilling Hours.” Under the Natural Disasters category, “Other” includes “Cyclone,” “Earthquake,” “Fire,” “Force Fire,” “Hurricane/Tropical Depression” and “Tornado.” Under the Economic Factors category, “Other” includes “Failure Irrig Equip” and “Falling Numbers.” Under the Biotic Factors category, “Other” includes “Fruit Set Failure,” “Poor Drainage” and “Wildlife.”

ture causes the water application rate to decrease. One plausible explanation for this is that frost risk is reduced as temperature rises in cooler locations, resulting in a reduction in the amount of water applied for frost protection in orchards and vineyards.

Heat Stress

Using irrigation to reduce heat stress in orchards and vineyards increases the likelihood to adopt sprinklers by 16% and decreases the likelihood to adopt drip by 18%.

For orchards and vineyards in warmer locations where the average daily maximum temperature is higher than 67°F, an increase in temperature causes the water application rate to increase. There are two plausible explanations for this. First, evaporation and dryness increase under these climate conditions, so water application rates increase to satisfy the water requirements for orchards and vineyards. Second, vulnerability to heat stress increases under these climate conditions, so additional water is applied to orchards and vineyards to reduce damage from heat stress.

Table 2. Summary Statistics of Climate Variables

Variable (units)	Average	Variable (units)	Average
Irrigation to mitigate frost damage	*share*	Average daily maximum temperature	*°F*
Orchard/Vineyard	0.39	Orchard/Vineyard	70
Vegetable	0.16	Vegetable	68
Wheat	0.13	Wheat	67
Alfalfa	0.09	Alfalfa	66
Hay	0.06	Hay	65
Pasture	0.05	Pasture	62
Irrigation to delay early blooming or reduce heat stress	*share*	Average annual precipitation	*inches*
Orchard/Vineyard	0.19	Orchard/Vineyard	18
Vegetable	0.12	Vegetable	19
Wheat	0.09	Wheat	15
Alfalfa	0.07	Alfalfa	15
Hay	0.05	Hay	20
Pasture	0.04	Pasture	23

Note: Irrigation data is from the 2007 FRIS for California, Oregon and Washington. Climate data is from the Western Regional Climate Center for 1971-2000. For orchards and vineyards, the average share of 0.39 for "Irrigation to mitigate frost damage" means that 39% of orchard and vineyard farmers in the 2007 FRIS use irrigation to reduce damage to crops from frost. For vegetable, 19 inches is the average annual precipitation in the counties (including duplicates) where vegetables are grown in the 2007 FRIS.

The proportion of cropland irrigated is greater for crops that frequently use irrigation to mitigate damage from frost and heat stress. Relative to farms growing alfalfa, the proportion of cropland irrigated increases by 6% and 5%, respectively, when orchard/vineyard and vegetable, are also grown on the farm. In contrast, the proportion of cropland irrigated declines by 3% and 2% when hay and pasture are grown, respectively.

Excess Moisture

Moisture levels, and whether they are excessive, largely depend on precipitation patterns, irrigation practices, and plant and soil characteristics. Excess moisture directly damages crops by reducing yield and product quality. Excess moisture also causes indirect damage to crops because it is conducive to plant disease (U.S. Department of Agriculture 2013a), which is a significant cause of loss for vegetable (table 1).

Potato is a relatively shallow-rooted vegetable, with typical root depths of 2-4.7 feet. By contrast, sweet corn is a relatively deep-rooted vegetable, with typical root depths of 5-6 feet (Weaver 1926). Shallow-rooted crops are more vulnerable to variation in soil moisture than deep-rooted crops (Shock et al. 2007). In comparison to gravity technologies, sprinkler and drip can precisely control the timing and uniformity of water applications and are therefore better suited to control soil moisture. Hence, in comparison to farmers of deep-rooted crops, farmers of shallow-rooted crops often adopt sprinkler and drip technologies to prevent excess moisture from frequent, heavy and uncertain precipitation.

There are climate thresholds for the likelihood to adopt gravity, sprinkler, and drip technologies for vegetables at 25 inches of precipitation. The characteristics of different vegetables and irrigation technologies provide plausible explanations for these climate thresholds. For shallow-rooted vegetables (e.g., potato) in dryer locations with less than 25 inches of precipitation, increasing precipitation facilitates adoption of drip technologies. The drip technologies reduce the shallow-rooted vegetables' vulnerability to excess moisture from increasing precipitation. For deep-rooted vegetables that are less vulnerable to excess moisture (e.g., sweet corn), increasing precipitation in dryer locations encourage adoption of gravity technologies. In wetter locations with more than 25 inches of precipitation, increasing precipitation encourages adoption of sprinklers for deep- and shallow-rooted vegetables because there is less incentive to adopt the most water-saving technology (drip) in locations where water is abundant. Additionally, sprinklers are better equipped than gravity technologies to prevent excess moisture in locations where water is abundant.

Conclusions

Extreme climate events are the most frequent cause of damage to specialty crops in the West Coast. Many specialty crop farmers adopt sprinkler and drip irrigation technologies to mitigate crop damage from frost, heat, and excess moisture. Using irrigation for frost protection increases the water application rate in orchards and vineyards. The proportion of cropland irrigated is greater for crops that frequently use irrigation to mitigate damage from frost and heat stress. The effects of temperature and precipitation on adaptive irrigation management depends on the crop and the climate conditions (cool and wet, or warm and dry).

These findings suggest that sprinkler and drip technologies are especially useful to specialty crop farmers for managing extreme climate events. The technologies increase these farmers' resilience to climate change. The need to manage extreme climate events, however, can make agricultural water policy less effective than originally conceived. For example, orchard and vineyard farmers have a propensity to use sprinkler irrigation and to apply additional water to mitigate damage from frost and heat stress. This suggests that orchard and vineyard farmers are less likely to adopt the most water-saving technology (drip) and to reduce water application rates in response to higher water prices because drip technologies do not effectively mitigate damage from frost and heat stress. Thus, the effectiveness of water pricing to encourage farmers to adopt water-saving technologies and to reduce water application rates depends on the crops grown and prevalence of extreme climate events. ■

FOR FURTHER READING

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