The Consequences of Drought on Plant Pathology

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Executive Summary: Climate change is expected to increase the frequency and intensity of severe weather events such as drought. This extreme weather will affect crops and all animals and humans that depend on them. Plants under drought conditions become stressed, which leads to increased susceptibility to pathogens and pests, as well as decreases in overall yield and productivity. As the world's population continues to grow, there will be increased dependency on states like California to produce the necessary quantity and quality of food. However, as a leader in crop production and a recent victim of severe drought, California is particularly threatened by the changing climate. With a decline in crop production, water availability, and job opportunities, the recent drought has affected California agriculture in more ways than one. We invite the California State Legislature committees on Natural Resources and Water, in partnership with the committees on Agriculture, to examine crop management in the context of climate change. Additionally, we task these committees with recognizing the need for novel methods, technologies, and products and taking action on supporting the research and development of these ideas that will help alleviate major crop production issues. Collectively, these efforts will lead the agricultural industry one step closer to meeting the needs of consumers, in light of changing climates, especially during drought.

I. Introduction

California leads the nation in the production of 75 different commodities and is the sole producer of 14 of those commodities. In 2017, the California agriculture industry was valued at $50.13 billion, with exports accounting for nearly half of that (California Department of Food and Agr...). California is a leader in crop production (Figure 1), and with a strong history of drought the agricultural industry has been forced to develop novel approaches to produce crops with limited water available. Though the definition of drought is not standardized, it is generally characterized by "abnormally low levels of precipitation that has adverse impacts on vegetation, animals, and people" (Drought Background 2014). Over the last 100 years, there has been a drought recorded approximately every 20 years in California. Most recently, California experienced a drought from 2012 to 2016 (Drought Background 2014).

Among agricultural issues, drought is particularly difficult to predict and manage. Drought drastically depletes both surface and groundwater that is essential for sustaining our agroecosystems. Altered water availability and elevated temperatures distort soil chemistry, increase salinity, deplete soil carbon, and disrupt natural beneficial microbial communities. This damaged environment amplifies plant stress responses to other living and non-living factors, such as pathogens and pests. Furthermore, these stresses have been shown to lead to a reduction or total loss of crop yield (Farooq et al. 2009). As a result, the livelihood of farmers is directly impacted, while industries and consumers dependent on agricultural products are left with uncertainty.

Climate change will create warmer temperatures and warmer air. Warm air holds more water and leads to rapid evaporation of surface water. This causes soils to dry out faster, thus increasing the demand for water (Arndt and Enloe). Climate change will also prompt alternating extreme wet and dry seasons with increased flooding and drought (Colgan 2018). These conditions will have a major impact on the agricultural industry, especially crops. From a plant pathology perspective, these extreme conditions may prove more favorable to certain pathogens and pests, render common control practices less effective, and negatively affect overall plant health and productivity.

The California State Legislature has taken steps to protect and equip Californians for natural disasters, but research and development to prevent these disasters has not been thoroughly supported. Related laws such as California State Senate Bill 45, the Wildfire, Drought, and Flood Protection Bond Act of 2020, allocate funds towards restoring areas affected by these types of natural disasters. However, it is imperative to support research that will improve our understanding of factors that prompt disasters and exploration of preventative measures. Examples of agricultural issues exacerbated or caused by drought and current or promising future solutions to abate drought stress are provided below. Additional resources and contact info for relevant experts are also provided. Although this report is California focused, the suggestions outlined below can be applied to any region that is undergoing a drought.

II. Main agricultural issues

i. Plant defenses

Without an ample water supply, plants cannot reduce internal temperatures using evaporative cooling. Numerous plant systems experience temperature dependent resistance, but signaling mechanisms used to detect and defend against pathogens can stop functioning at elevated temperatures (Zhu et al., 2010). For example, certain tobacco plants produce a protein that provides protection against Tobacco Mosaic Virus. However, if the plant reaches a temperature over 82°F, that protein loses its function, and the once immune plant is rendered susceptible (Marathe et al., 2002). Heat and water stress alter the plant immune system and make them more susceptible to diseases, leading to reduced crop yields.

ii. Poor water quality

Drought decreases the amount of water available, often leading to the use of poor quality water. Though the water is properly sanitized, there are many concerns about the chemical composition of the recycled water. The recycled water can be higher in salts, which are detrimental to plant growth, quality, and yield (Grattan and Grieve 1998). Water high in salts can simultaneously stress plants and encourage the growth of certain pathogens, increasing the severity of plant diseases (You et al. 2011). In addition, recycled water can contain trace amounts of chemicals, such as those found in painkillers, antidepressants, and antimicrobials. These chemicals have been shown to be taken up by plants and have unknown effects on both plant and human health (Wu et al. 2015).

California law (CA Title 22 Division 4.5 Chapter 16 Article 8.5) states that there are three levels of recycled or reclaimed water which vary in the level of sanitation: primary, secondary, and tertiary (Barclays Official California Code of Regulations). If recycled water is being used for edible crops, the tertiary process must be applied. This process removes suspended and dissolved solid waste and microorganisms, then it undergoes further chemical disinfection and filtration (Schulte). The acreage in California utilizing recycled water has increased significantly since the 90s. Currently, over 250 systems create and provide growers with recycled water (Use of Municipal Recycled Water – Cal...).

iii. Soil nutrient cycling

Water is vital for maintaining microbial metabolic activities that process carbon and nitrogen by physically moving nutrients through soils, which increases their accessibility to microbes. When drought results in complete drying of soils, microbial activity and nutrient cycling decrease and enter a dormant "storage" mode. However, when soils are re-wetted after drought, a flush of newly-available nutrients combined with quick recovery of microbial activity can result in immediate and massive pulses of C and N cycling (Jenerette and Chatterjee 2012). In systems where inputs of C and N into soils are excessive, re-wetting may cause nutrients to "leak" from soils as greenhouse and other gases or as leachates into groundwater (Liang et al. 2016). These changes in nutrient cycling can affect a plant's overall health and ability to fight off pathogens and pests (Zhou et al. 2016).

III. Recommendations

i. Accurate data collection systems

Soil moisture sensors, weather stations, and tools such as CropManage aid in the adoption of precision agriculture. CropManage is an online tool that incorporates weather data, plant size, and plant water uptake so growers can more efficiently irrigate their crops. However, it has only been developed for some vegetable and berry crops and is not calibrated to all growing regions. Tools such as soil moisture sensors are often very costly for growers to use. The continued support for research and development of more cost-effective solutions is necessary to improve precision agriculture practices.

ii. Water subsidies

While drought is limited, it is important to utilize and maintain current resources. For example, the California Food and Agriculture Department runs the SWEEP Program to implement irrigation systems that reduce greenhouse gases and save water on California agricultural operations. Additionally, state bonds may be used to fund water efficiency projects. Finally, bills that incentivize water conservation can be brought to each state (e.g., California Senate Bill 253, Environmental Farming Incentive Program).

iii. Recycled water

During a drought, it is important to use recycled water, but further research must be conducted to ensure that the processing of recycled water results in water that is clean and safe for plants, animals, and the environment. For example, California State Senate Bill 332 addresses treatment of wastewater and establishes guidelines about the use of recycled water but doesn't address the need for further research into its safety and environmental impacts.

iv. Microbial applications

Plants house millions of beneficial microbes that have been shown to enhance plant growth, improve crop yield, provide tolerance to environmental stress, and help control pathogens and pests (Haney et al. 2015; Mendes et al. 2011; Ritpitakphong et al. 2016; Rosenberg and Zilber-Rosenberg 2016; Schlaeppi and Bulgarelli 2015; van der Heijden et al. 2016). Drought dramatically impacts the effectiveness of the microbiome as a result of compositional and functional changes due to environmental alterations (Naylor and Coleman-Derr 2017). It was shown in grapevines that members of the microbiome can promote plant growth and increase biomass under drought conditions (Rolli et al. 2015). Future solutions could result from microbial applications or by maintaining an optimal habitat for these beneficial microbes.

v. Genetic engineering

Some plants have characteristics that confer drought tolerance. Extraordinary examples of this are resurrection plants. After prolonged periods of drought, these plants dry out, curl up, and appear dead to the untrained eye. They can survive in this state for months or even years. Once the plant regains access to water it rapidly rehydrates and resumes growing within a day or two. Further research could lead to identification of genetic targets that orchestrate this rare form of drought tolerance. These traits could be engineered in cropping systems using gene editing tools such as CRISPR-Cas9 to enable crops to survive long periods of drought.

IV. Conclusions

In the face of climate change, extreme weather events such as drought are predicted to occur more frequently. The most recent drought in California took place from 2012 to 2016 and led to a decrease in water availability, reduction of crop production, and decline in agricultural job opportunities (Cooley et al. 2015). Drought has and will continue to have a major impact on crop production. It directly affects plant health and leads to changes in soil chemistry, microbial activity, nutrient availability, and water quality.

Drought thus compounds factors detrimental to both plant growth and to their ability to defend against pathogens and pests. The use of recycled water can make the industry more sustainable, but the chemical composition and safety of this water must be explored further, as well as its impacts on natural water flows. Incorporating new technologies can help alleviate these issues. From moisture sensors and

CropManage to help use water more efficiently, to using tools such as CRISPR-Cas9 to create drought resistant plants, and applying beneficial microbes to crops, technology will play a crucial role in climate resilience.

Solutions to the agricultural consequences of drought will not come from one source, but they must be backed by science and accessible to growers. It is encouraging that new laws such as California State Assembly Bills 839 and 409, which establish grant programs to fund research related to climate change and agriculture, and California State Senate Bill 166, which establishes a study group to advise the legislature on the reuse of process water, are being considered. It is our hope that this momentum continues and support from legislators in the form of incentive programs, state bonds, or grant programs for research and development move forward with urgency.

V. Expert contacts

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Top 5 Agricultural States in Crop Cash Receipts, 2017

Rank	State	Crop Cash Receipts[1] $1,000
	United States	374,341,092
1	California	50,132,029
2	Iowa	26,979,830
3	Texas	22,901,476
4	Nebraska	21,456,823
5	Minnesota	17,286,890

[1]Based on August 20, 2018 USDA Economic Research Service cash receipts.

Figure 1 - The value of the California Agricultural Industry is ranked number one in the nation. Obtained from the California Agricultural Statistics Review 2017-2018 written by the CDFA.

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