CULTIVATING CLIMATE RESILIENCE IN FARMING

Ensuring California Farms and Ranches Thrive in the Face of Climate Change

Climate change is already having very real impacts on California's agricultural productivity and the livelihoods of our farmers and ranchers. A growing body of research is pointing to significantly tougher challenges ahead for farmers, our rural communities and our food security, unless we do more to mitigate climate change and improve resilience to its impacts.

Climate change is causing a combination of interrelated shifts in temperature, water availability, unpredictable and extreme weather events, and new pest and disease patterns.[1,2] It is expected that some areas of the state will no longer support the production of certain crops.[3] For example, Napa's wine grape production could be halved by 2040[4] and Central Valley acreage suitable for popular varieties of walnuts and some stone fruits is predicted to be one-half or one-quarter of its present size by 2050.[5] Threats to the viability of the state's farms and ranches also threaten our rural communities, especially in the Central Valley. As evidence, we can look to California's recent drought (2013-2016), when the state's agricultural economy lost an estimated $1.84 billion and 21,000 jobs, with the biggest financial impact on Central Valley rural communities.[6]

> *"While California farmers and ranchers have always been affected by the natural variability of weather from year to year, the increased rate and scale of climate change is beyond the realm of experience for the agricultural community."*
>
> — From "Climate Change Trends and Impacts on California Agriculture: A Detailed Review"[13]

California agriculture is the most productive and diverse agricultural economy in the nation and the leading supplier of the country's fruits, vegetables, nuts, and dairy products.[7] Climate change may increase food costs, further exacerbating issues of inequitable food access in California.[8] Additionally, the nutritional quality of food is expected to decline when grown in a climate higher in carbon dioxide.[9,10,11] Issues of food security and nutrition affect all Californians, urban and rural alike.

Here we provide a science-based review of some of the most significant impacts of climate change on California agriculture and what is predicted in the coming decades. For a more comprehensive resource, we refer interested readers to a literature review published in 2018, entitled Climate Change Trends and Impacts on California Agriculture: A Detailed Review.[12] We also provide stories of California farmers and ranchers coping with climate impacts, some strategies they are using, and recommendations for needed resources and tools to keep California producers viable and thriving in the face of the sobering challenges ahead.

CalCAN
CALIFORNIA CLIMATE & AGRICULTURE NETWORK

www.calclimateag.org
August 2019

IMPACTS

Water Scarcity and Changing Precipitation

Constrained water resources and unpredictable precipitation patterns will be among the most challenging effects of climate change for agriculture in California, the state with the most uncertain precipitation patterns in the nation.[14] Scientists predict even greater variability ahead, as well as increased intensity and frequency of extreme weather events.[15]

The Sierra Nevada snowpack—the state's primary water storage—is predicted to diminish by as much as 65 percent by the end of the century.[16] The decreased snowpack is projected to reduce runoff and—along with warming temperatures—to shift the timing and amount of available water, exacerbating tensions between competing urban, environmental, hydroelectric, and agricultural needs. This has major implications for the 90 percent of California crops that require irrigation.[17] With warmer temperatures and longer growing seasons, the demand for agricultural irrigation water is expected to increase even as water availability is reduced.[18]

Much of Californa's water infrastructure was designed to capture slow spring runoff and deliver it during summer and fall months,[19] however research suggests that future snowmelt runoff could occur up to two months earlier than it does currently.[20] In the Sacramento River system, peak monthly runoff was nearly a month earlier during the second half of the 20th century, compared to the first half.[21] Climate models project that by the end of the 21st century there will typically be only two-thirds the amount of water in some of the state's largest reservoirs at the end of the dry season,[22] compared to current levels.

Climate scientists predict that in the decades to come, California will experience increasingly severe "precipitation whiplash," in which severe droughts will alternate with shorter, rainier winters that bring more compressed, intense storms.[23] Recent experience of these extremes is exemplified in part by 2013 and 2014, the driest years on record.[24] In 2016, the final year of that drought, $603 million and 4,700 jobs were lost in California agriculture due to extreme water scarcity.[25] Livestock producers dependent on winter rains for forage production were greatly impacted.[26] Following this, the winter of 2017 was Northern California's wettest winter ever recorded, bringing its own challenges, including flooding and mudslides.[27]

Credit: Jeffrey Mitchell

SANO FARMS, FRESNO COUNTY

Alan Sano remembers helping with his first tomato harvest on his parent's farm when he was six years old. He now operates Sano Farms, growing mainly processing tomatoes and almonds on 4,100 acres near Firebaugh. In 2014-16, during the height of California's most recent drought, Sano Farms was allocated at most five percent of their typical delivery from the Westlands Water District. In 2016, Alan was forced to fallow 450 acres, almost one-tenth of their land. Some of their land has sunk (known as subsidence) because the groundwater below it is depleted. When talking about the challenges, Alan says wistfully, "I'd love to stay in farming, but it's hard."

Alan and farm manager Jesse Sanchez use a variety of strategies to adapt. They have diversified into less water-intensive crops such as garbanzo beans and garlic. When water is short, they fallow annual crops so they can water their almond and pistachio trees, where they have made long-term investments. They converted to subsurface drip irrigation long ago, and are continually looking for ways to improve water-use efficiency. They also plant cover crops and practice conservation tillage methods to improve soil health, so their land can absorb and hold more water and better retain topsoil.

"By using minimal tillage, the air is clean. The tractors run less in the field—less dust and less fumes—so it helps to create a healthier environment in the whole system. It helps everybody," said Jesse Sanchez.

Warming Temperatures and Extreme Heat

Warming temperatures affect agriculture in many ways, starting with the people who grow and harvest our food. Despite passing the nation's most stringent heat laws in 2005, after four farmworkers died from heat exposure in the field, California farmworkers continue to die from heat-related illness.[28] Extreme heat worsened by climate change has surpassed pesticide exposure to become the current primary concern facing agricultural workers in California.[29]

The state's average temperature has increased by 1.2 to 2.2 degrees Celsius in the last century, with projected increases of an additional 1.5 to 4.5 degrees C by the end of the 21st century.[30] California's high value crops are temperature-sensitive[31,32] and some are already impacted by warming trends.

"We planned for a hot summer and then had the coolest we've had in six years. We try to change crop plans and plant earlier or later, but it's tough."

— David Cooper, Oak Hill Farm, Sonoma County

Since the 1950s, the number of cool nights has been decreasing—a trend that threatens the viability of California's lucrative wine grapes and fruit and nut tree crops. To successfully set fruit, these crops depend on a certain number of "chill hours," or the number of hours at or below 7.2 degrees C (or 45 degrees Fahrenheit).[33] Because each tree variety has a specific chill hour requirement, farmers select specific varieties to maximize yields in their climate zone. Climate scientists predict that in a worst-case scenario, barring any adaptive measures, yields of almonds, walnuts, oranges, and table grapes may see a 20 percent decline and avocados a 40 percent decline by 2050.[34] Shifting to new varieties with fewer chill hours is often unaffordable, given the typical 30-year lifespan of orchards and vineyards.[35]

"We lost 70% of our chickens and experienced multiple crop failures from that 2018 July heat wave."

— Ellee Igoe, Solidarity Farm, San Diego County

Severe heat waves are predicted to increase in frequency and intensity.[36] Heat stress can cause major drops in dairy and beef production by increasing susceptibility to diseases and mortality and suppressing reproductive success. During one 2006 heat wave in California, dairy producers lost more than $1 billion in milk and cattle.[37]

FROG HOLLOW FARM, CONTRA COSTA COUNTY

Al Courchesne, or Farmer Al as he likes to be called, farms 242 acres in Brentwood. Frog Hollow Farm produces a cornucopia of apricots, cherries, plums, peaches, and more, direct marketing it around the country. In the spring of 2018, an unusually late frost hit the apricot buds just as they were beginning to form. The frost damage was so severe it deformed the buds completely and Farmer Al lost the year's harvest from 26 acres of apricot trees. "It is an investment that I won't see a return on," he said. "The impacts from climate change are subtle, but financially devastating."

Credit: USDA NRCS

Pest, Disease and Weed Challenges Intensify and Shift

Declines in crop yields can be caused by new or more abundant insect pests, diseases and weeds that accompany altered temperature and weather patterns.[38] Climate-related changes in ecosystem dynamics can cause declines in natural predator insect populations.[39] Additionally, climate change will render some major weeds in California agriculture less sensitive to herbicide treatments. Studies suggest that continued overreliance on herbicides for weed control may result in more weed management failures.[40]

Scientists expect problems with many pest insects to increase as temperatures rise and pests reproduce more rapidly.[41] Climate models project substantial proliferation in a number of notable walnut pests.[42] Milder winters can cause surges in some pest populations that previously would not have survived colder winters.[43] For example, the potato psyllid migrated into California several times during the 20th century, dying out each year. However, since 2000 the potato psyllid has established large, year-round populations in Southern California, dealing severe blows to the tomato, potato and pepper industries.[44]

In addition to all these difficulties, much of agricultural production depends on insect pollination. Crop failures or diminished yields can result from rising temperatures that inhibit pollinator activity[45,46] and from changes in the synchrony of plant and pollinator life cycles.[47,48]

Wildfire

Exacerbated by trends towards warmer temperatures and earlier snowmelt,[49] today's fire season in the western U.S. starts earlier, lasts longer, and is more intense compared to the last several decades.[50] On the heels of record-breaking heat in 2018, California communities were devastated by the largest, deadliest and most destructive wildfires on record.[51] If greenhouse gas emissions continue to rise, by 2100 the average area burned across the state is predicted to increase by 77 percent and the frequency of wildfires 25,000 acres or larger is likely to increase by 50 percent.[52]

For farms and ranches, damages from wildfires can come in the form of lost livestock, grazing land and crops, or destroyed equipment as well as infrastructure such as barns, fencing, water systems and pumps. Additionally, the risks of flooding[53] and mudslides increase significantly after wildfires, due to the destabilization of hillsides.[54] In Lake County, the 2018 Ranch Fire devastated rangelands, affecting more than 45,000 acres.[55] The 2017 Thomas Fire, California's tenth most destructive wildfire as of this writing,[56] caused over $170 million in damages to Ventura County's agricultural sector, including losses of $10 million in avocados, $5.8 million in lemons, and $3.3 million in oranges.[57] Like urban dwellers, farmers and ranchers are sometimes underinsured.

> *"We estimate that [in the 2018 fire] we lost 80 percent of our avocado crop…At this point, four months after the fire, we project that over 40 percent of our avocado trees are dead or unlikely to recover fully…Even if we could replant right away, we are looking at about six years to full recovery."*
>
> — Deborah Brokaw Jackson,
> Brokaw Ranch Company, Ventura County[58]

During the 2018 Woolsey Fire near Los Angeles—the seventh-most destructive fire in California to date[59]—many residents evacuated while 36,000 farmworkers continued to pick strawberries and other produce despite health risks from smoke inhalation and the fact that many had limited access to proper protection or medical care.[60]

MAGRUDER RANCH, MENDOCINO COUNTY

Kyle Farmer and his family are continuing a 100-year legacy of raising cattle and sheep at Magruder Ranch. In the span of less than a year from 2017-2018, two fires claimed 45 head of cattle and reduced 6,000 acres of their rangeland to char. Following the fires, Kyle began looking for new leases where the family could move their surviving cattle. Because there was not enough contiguous land to lease, the family now moves cattle over long distances between properties.

Kyle has since partnered with two nearby ranching operations—spanning more than 10,000 acres in total—to spearhead a collaborative grazing project along Highway 101, where several vehicle-related fires have ignited, threatening suburban developments. The ranchers use cattle grazing to reduce the load of combustible grasses.

"Catastrophic wildfire like the ones my community experienced aren't inevitable," said Kyle. "Ranchers can use management techniques like prescribed grazing and controlled burning to influence the intensity, timing and frequency of fire, and safeguard our communities and climate at the same time."

Credit: Kyle Farmer

Credit: Saxon Holt/PhotoBotanic

Credit: Saxon Holt/PhotoBotanic at Gabilan Cattle Company

Credit: Creatives by Chelsey

Credit: Sam Earnshaw

CULTIVATING RESILIENCE: ADAPTATION STRATEGIES ON FARMS AND RANCHES

Farmers and ranchers are employing a number of on-farm strategies to improve resilience to greater weather extremes. These techniques provide mitigation benefits along with other agronomic and environmental health advantages. The strategies include the following:

Investing in Soil — Building soil health improves soil structure and allows water to better penetrate and be retained for plant access, thereby turning soil into a reservoir.[61] Organic matter holds 18 to 20 times its weight in water. One percent of soil organic matter in the top six inches of a field can hold approximately 27,000 gallons of water per acre.[62] Organic matter also increases fertility and can reduce reliance on chemical inputs and improve plant vigor to better resist pests and diseases.[63]

Diversification — Diversifying income streams and increasing the varieties and types of crops with different requirements and vulnerabilities will hedge against unexpected changes in temperature, precipitation, pests and diseases, and markets. Restoring and enhancing on-farm diversity and habitat can foster beneficial insects including pollinators and predators, as well as other wildlife.

Planting and Planning for the Future — With adequate resources and appropriate information, growers can sometimes anticipate which crops are more likely to thrive in the coming changes. Growers can also adjust sowing and harvesting schedules. Replanting aging blocks of orchards and vineyards will require good research and reliable information about which varieties will thrive in anticipated conditions several decades in the future. Given the high degree of volatility and extreme events predicted for the future—which are outside the agricultural community's historical experience—agricultural professionals advise farmers to base future management decisions on both average trends and extreme trends.[64]

Water Stewardship — Improving irrigation efficiency decreases on-farm dependence on scarce and unreliable water availability. The practice also lowers energy use and costs associated with pumping. Increasing water recycling and building on-farm water catchment systems will strengthen on-farm self-reliance. Groundwater recharge during rainy seasons, when possible, will create a water bank account.

Credit: Saxon Holt/PhotoBotanic at Gabilan Cattle Company

THINKING BIGGER, ACTING BOLDER: FORTIFYING ON-FARM ADAPTATION WITH POLICY

Farmers and ranchers can do only so much at the farm level in the face of unpredictable and unprecedented weather events, droughts and pest patterns. To support the industry through the erratic variability, extremity, scale, and pace of future change, the state must re-invest in research, technical assistance and financial assistance for farmers and ranchers to maintain our agricultural industry in the face of coming challenges.

To assess relevant climate risks and adaptation strategies and integrate them into their business planning and decision-making, farmers and ranchers need science-based, farm-level planning tools and trained technical assistance providers to work with them. This is especially true for small, moderate-sized and socially disadvantaged farmers and ranchers who do not have equal access to technical assistance and who often have fewer resources to adapt to climate change.

Technical assistance providers and agricultural organizations also need training in climate risk management. According to a 2017 survey of 144 UC Agriculture and Natural Resources staff, 88% of respondents believe it is important to incorporate climate-change information into farm extension programs, but only 43% actually do so. Respondents expressed interest in education on technical tools and information resources, as well as training in climate science communication.

Based on input from dozens of farmers, ranchers and agriculture professionals around the state, **CalCAN developed the following set of recommendations to guide the development of policies and tools needed by the state's producers in order for them to adapt and thrive in the face of climate change:**

- Re-invest in technical assistance for farmers and ranchers through the University of California Cooperative Extension and the Resource Conservation Districts.
- Streamline the permitting process for practices such as composting, building on-farm ponds, and doing controlled burns on grasslands.
- Foster farmer-to-farmer learning opportunities through demonstration projects and producer collaboratives.
- Develop science-based, farm-level decision-support and adaptation planning tools.
- Provide financial assistance for multi-benefit projects like groundwater recharge and carbon sequestration.
- Conduct research to inform farmer decision-making and long-range agricultural and land-use planning.
- Use public plant-breeding programs to develop new crop varieties that are heat-tolerant, salt-tolerant, low-chill, and drought-resilient.
- Invest in marketing support for new crops and varieties.
- Reform crop insurance to be accessible to all producers and incentivize resilient practices.
- Fund disaster recovery that is robust, organized, and accessible.

CLIMATE ADAPTATION RESOURCES FOR CALIFORNIA FARMERS AND RANCHERS

California Climate Change Assessments
(California Natural Resources Agency) — These reports provide the scientific foundation for understanding climate-related vulnerability at the local scale and inform state adaptation policies, plans and programs. The most recent assessment was published in August 2018.

Climate Change Consortium for Specialty Crops: Impacts and Strategies for Resilience
(California Department of Food and Agriculture) — A 2013 report on the findings of a diverse group of California specialty crop agriculture experts that identified climate change adaptation strategies for growers.

Safeguarding California
(California Natural Resources Agency) — Updated every two years, most recently in January 2018, the report guides the work of various state agencies to protect communities in California from climate change.

Climate Adaptation Program
(California Wildlife Conservation Board) — Makes grants for natural and working lands conservation easements and adaptation planning, implementation, and technical assistance projects for farmers, ranchers and other landowners.

California 2030 Natural and Working Lands Climate Change Implementation Plan Draft
A multi-agency draft report released in January 2019 that identifies the scope and scale of activities that California can undertake to help meet the state's climate change goals through natural and working land climate change strategies.

Climate Change Research Program
(California Strategic Growth Council) — Funded by cap-and-trade auction proceeds, the program supports cross-cutting research investments for community resilience, to integrate land use and development considerations, and to facilitate the transformation of California communities.

Climate Smart Agriculture Programs
(California Department of Food and Agriculture, Department of Conservation) — Financial incentive and technical assistance programs for farmers and ranchers to adopt management practices and protect farmland resources that will reduce greenhouse gas emissions and improve resilience.

CalCAN
CALIFORNIA CLIMATE & AGRICULTURE NETWORK

The California Climate and Agriculture Network (CalCAN) is a statewide coalition that advances policy reforms to realize the powerful climate solutions offered by sustainable and organic agriculture. Since 2009, we have cultivated farmer leadership to face the challenges of climate change and to serve as the sustainable agriculture voice on climate change policy in California.

916.441.4042 or 707.329.6374

info@calclimateag.org | www.calclimateag.org | Twitter: @calclimateag

Special thanks to reviewers: Amélie Gaudin, University of California, Davis
Katherine Jarvis-Shean, University of California Cooperative Extension
Tapan Pathak, University of California, Merced
Valerie Eviner, University of California, Davis

ENDNOTES

1 Bedsworth, L., et al. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUMCCCA4-2018-013.

2 Hoegh-Guldberg, O., et al. 2018. Impacts of 1.5°C Global Warming on Natural and Human Systems. In: Global Warming of 1.5°C. An IPCC (Intergovernmental Panel on Climate Change) Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., et al. (eds.)].

3 Luedeling, E., et al. 2009. Climatic Changes Lead to Declining Winter Chill for Fruit and Nut Trees in California during 1950–2099. PLoS ONE 4(7): e6166.

4 Diffenbaugh, N.S., et al. 2011. Climate Adaptation Wedges: A case study of premium wine in the Western United States. Environmental Research Letters, 6: 024024.

5 Luedeling, E., et al. 2009.

6 Howitt, R., et al. 2015. Economic Analysis of the 2015 Drought for California Agriculture. Center for Watershed Sciences, University of California, Davis.16 pp. Available at: https://watershed.ucdavis.edu/files/biblio/Economic_Analysis_2015_California_Drought__Main_Report.pdf

7 California Department of Food and Agriculture. California Agricultural Statistics Review 2017–2018. Available at: https://www.cdfa.ca.gov/statistics/PDFs/2017-18AgReport.pdf.

8 California Natural Resources Agency. 2014. Safeguarding California: Reducing Climate Risk. Available at: http://www.resources.ca.gov/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf.

9 Zhu, C., et al. 2018. Carbon dioxide (CO2) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries. Science Advances, 4(5).

10 Myers, S.S., et al. 2014. Increasing CO2 threatens human nutrition. Nature, 510: 139–142.

11 Dong, J., et al. 2018. Effects of Elevated CO2 on Nutritional Quality of Vegetables: A Review. Frontiers in Plant Science, 9 (924).

12 Pathak, T., et al. 2018. Climate Change Trends and Impacts on California Agriculture: A Detailed Review. Agronomy, 8(3): 25.

13 Pathak et al. 2018.

14 Dettinger, M.D., et al. 2011. Atmospheric rivers, floods and the water resources of California. Water, 3: 445–478.

15 Pathak et al. 2018.

16 Ibid.

17 Ibid.

18 Bedsworth et al. 2018.

19 Maurer, E.P. and P.B. Duffy. 2005. Uncertainty in projections of streamflow changes due to climate change in California. Geophysical Research Letters, 32 (3): L03704.

20 Rauscher, S., et al. 2008. Future changes in snowmelt-driven runoff timing over the Western US. Geophysical Research Letters. 35: L16703.

21 California Department of Water Resources. 2015. California Climate Science and Data for Water Resources Management. Available at: https://water.ca.gov/LegacyFiles/climatechange/docs/CA_Climate_Science_and_Data_Final_Release_June_2015.pdf.

22 Bedsworth et al. 2018.

23 Swain, D., et al. 2018. Increasing precipitation volatility in twenty-first-century California. Nature Climate Change, 8 : 427-433.

24 Swain et al. 2018.

25 Medellín-Azuara, J., et al. 2016. Economic Analysis of the 2016 Drought for California Agriculture: A report for the California Department of Food and Agriculture. Center for Watershed Sciences, University of California, Davis. Available at: https://watershed.ucdavis.edu/files/DroughtReport_20160812.pdf.

26 Macon, D., et al. 2016. Coping with Drought on California Rangelands, 38 (4): 222-228.

27 Swain et al. 2018.

28 As reported in UC Davis' Science & Climate News on August 31, 2017: https://climatechange.ucdavis.edu/news/protecting-californias-farmworkers-as-temperatures-climb/.

29 Ibid.

30 Pathak et al. 2018.

31 Cook, C., M. Levy, and A. Gunasekara. 2013. Climate Change Consortium for Specialty Crops: Impacts and Strategies for Resilience. California Department of Food and Agriculture. Available at: https://www.cdfa.ca.gov/environmentalstewardship/pdfs/ccc-report.pdf.

32 Kerr, A., et al. 2018. Vulnerability of California specialty crops to projected mid-century temperature changes. Climatic Change, 148:419.

33 Ibid.

34 Lobell, D.B., et al. 2006. Impacts of Future Climate Change on California Perennial Crop Yields: Model Projections with Climate and Crop Uncertainties. Agricultural and Forest Meteorology 141 (2–4): 208–218.

35 Lobell et al. 2006.

36 Pathak et al. 2018.

37 Nardone, A., et al. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science, 130: 57-69.

38 Trumble J. and C. Butler. 2009. Climate change will exacerbate California's insect pest problems. California Agriculture, 63(2): 73-78.

39 USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., et al. (eds.)]. U.S. Global Change Research Program, Washington, DC.

40 Matzrafi, M., et al. 2019. Increased temperatures and elevated CO2 levels reduce the sensitivity of Conyza canadensis and Chenopodium album to glyphosate. Scientific Report, 9(2228).

41 Trumble and Butler. 2009.

42 Luedeling, E., et al. 2011. Climate change effects on walnut pests in California. Global Change Biology, 17(1).

43 Trumble and Butler, 2009.

44 Liu D. and J.T. Trumble. 2007. Comparative fitness of invasive and native populations of the potato psyllid (Bactericera cockerelli). Entomol Exp Appl., 123(35-42).

45 Scaven, V.L. and N.E. Rafferty. 2013. Physiological effects of climate warming on flowering plants and insect pollinators and potential consequences for their interactions. Current Zoology, 59(3): 418–426.

46 Corbet, S.A., et al. 1993. Temperature and the pollinating activity of social bees. Ecological Entomology, 18(1): 17-30.

47 Polce, C., et al. 2014. Climate-driven spatial mismatches between British orchards and their pollinators: increased risks of pollination deficits. Global Change Biology. 20: 2815–2828.

48 Memmott, J., et al. 2007. Global warming and the disruption of plant-pollinator interactions. Ecology Letters. 10: 710– 717.

49 Westerling, A.L.R. 2016. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. Phil. Trans. R. Soc. B, 371(1696).

50 Westerling, A.L., et al. 2006. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. Science, 313(5789): 940-943.

51 NOAA National Centers for Environmental Information, State of the Climate: National Climate Report for July 2018. Available at: https://www.ncdc.noaa.gov/sotc/national/201807.

52 Bedsworth et al. 2018.

53 Cannon S. and J. DeGraff. 2009. The Increasing Wildfire and Post-Fire Debris-Flow Threat in Western USA, and Implications for Consequences of Climate Change. In: Sassa K. and P. Canuti (eds.) Landslides – Disaster Risk Reduction. Springer, Berlin, Heidelberg.

54 Cannon, S.H., et al. 2008. Storm rainfall conditions for floods and debris flows from recently burned areas in southwestern Colorado and southern California. Geomorphology, 96(3–4): 250-269.

55 As reported in the Woodland, CA Daily Democrat on August 14, 2018: https://www.dailydemocrat.com/2018/08/14/officials-assess-wildfires-toll-on-agriculture/.

56 Top 20 Most Destructive California Wildfires, as reported by CalFIRE on March 14, 2019: https://calfire.ca.gov/media/5511/top20_destruction.pdf

57 Ventura County 2017 Crop & Livestock Report. Available at: https://cdn.ventura.org/wp-content/uploads/2018/07/Ag-Comm-2017-Annual-Crop-Report-final-lr-07-30-18.pdf.

58 Ibid.

59 Top 20 Most Destructive California Wildfires, as reported by CalFIRE on March 14, 2019: https://calfire.ca.gov/media/5511/top20_destruction.pdf

60 As reported by National Public Radio's The Salt on November 24, 2018: https://www.npr.org/sections/thesalt/2018/11/24/670513650/many-california-farmworkers-forced-to-stay-behind-during-the-wildfires.

61 Hudson, B.H. 1994. Soil organic matter and available water capacity. Journal of Soil and Water Conservation 49(2): 189-194.

62 United States Department of Agriculture, Natural Resources Conservation Service. 2013. Soil Health Key Points. Accessed online June 2019: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1082147.pdf.

63 Muller, A., et al. 2017. Strategies for feeding the world more sustainably with organic agriculture. Nature Communications, 8: 1290.

64 Walthall, C.K., et al. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935. Washington, DC. 186 pages.