SECTION 11

How Will Climate Change Affect Agriculture in Washington?

Washington crops and livestock will be affected by climate change via warming temperatures, rising atmospheric carbon dioxide, increasing water stress, declining availability of irrigation water, and changing pressures from pests, weeds, and pathogens. Different crops and locations will experience different impacts. Because of the high adaptability in most agricultural systems, overall vulnerability is low. However, given the combination of increasing water demands and decreasing supply in summer, water stress will continue to be a key vulnerability going forward. Since 2007, new studies have quantified impacts on specific crops and locations, and evaluated the combined effects of warming and CO2. New research has also begun to integrate impacts and economic modeling as a means of assessing market influences and the potential for adaptation.

1. **Washington State agriculture is projected to be affected by warming temperatures, rising carbon dioxide (CO_2) concentrations, and changes in water availability.**[1] Some changes may be beneficial while others may lead to losses – the consequences will be different for different crops and locations (Figure 11-1). Ultimately, impacts will reflect a combination of all of the factors listed below, the specific changes in climate that will occur, and the extent and effectiveness of adaptive actions that are taken in anticipation of the effects of climate change.

    - *Warming.* The longer growing seasons and fewer winter freezes projected for the region (Section 5) will benefit many crops and allow greater flexibility in crop selection, but in some cases may result in increased incidence and severity of pests, weeds, and diseases. Warming may decrease crop yields by accelerating the rate of development, and can have negative effects on wine grapes and some species of tree fruit due to insufficient winter chilling. Warmer summer temperatures will also result in increased heat stress and greater drought stress, affecting many Northwest crops and livestock.

    - *Increasing CO_2 concentrations.* Increasing levels of atmospheric CO_2 may result in increased productivity in some crops (referred to as "CO_2 fertilization"). In the near term, if sufficient water is available, these benefits can outweigh the negative effects of warming. Invasive species may benefit as well; some as a result may gain a competitive advantage over native species and crops.

    - *Changing precipitation.* Although year-to-year variations will continue to dominate annual and seasonal changes in precipitation (Section 3 of this report), the general tendency towards wetter winters will increase water available in spring but may also impede spring planting due to wetter soils. Projected decreases in summer precipitation would result in increased water stress in both rain-fed and irrigated agriculture.

    - *Irrigation water supply.* Water supply is a chief concern for Northwest agriculture, where the growing season coincides with the dry season. Projected reductions in summer

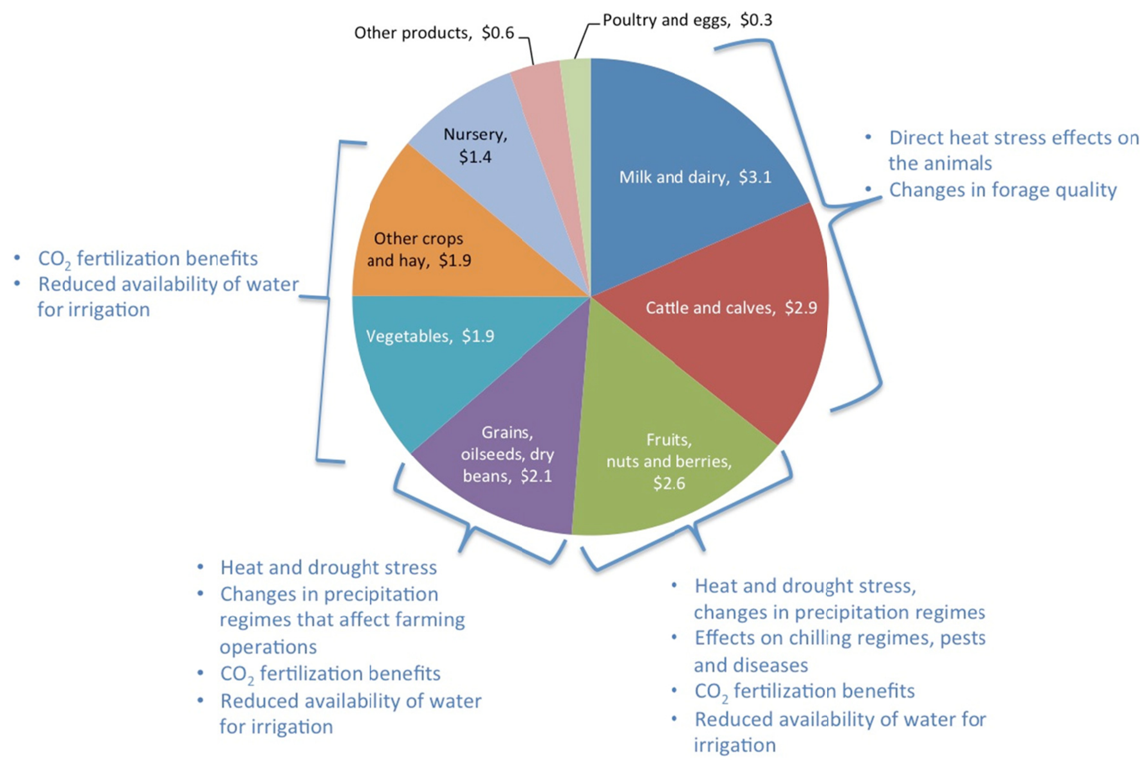

Figure 11-1. Climate change impacts on Pacific Northwest agriculture. Pacific Northwest agricultural commodities, with potential climate change impacts listed for each sector. Market values are shown in $ (billion), with a total value of $16.8 billion. *Figure source: Eigenbrode et al., 2013.*[1]

streamflow, combined with increasing evaporative demand (Section 6 of this report) will pose continued challenges to agricultural operations. In the Yakima basin, for example, water shortage years – years with curtailed water delivery to junior water rights holders – are projected to increase from 14% of years historically (1979-1999) to 43 to 68% of years by the 2080s (2070-2099) for a low and a medium greenhouse gas scenario, respectively.[A][B][2]

- *Climate extremes and fire.* Projected increases in the frequency of heat waves and heavy rainfall events (Section 5 of this report), and the area burned by wildfire (Section 7) can

[A] Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts. These are described in the text as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "medium" refers to RCP 6.0 or SRES A1B; and "high" refers to RCP 8.5, SRES A2, or SRES A1FI – descriptors are based on cumulative emissions by 2100 for each scenario. See Section 3 for more details.

[B] Average projected change for ten global climate models. Range is from two greenhouse gas scenarios: B1 (low) and A1B (medium).

all have deleterious effects on crops and livestock and potentially increase risks of damage from pests, invasives, and disease.

- *Additional research is needed to quantify the above impacts on different crops and locations.* To date, most studies have focused on one specific crop in a handful of locations, and only consider a subset of all relevant climate impacts on production. Impacts can differ substantially for different crops and locations, and little is known about the combined effects of all of the changes listed above.

2. **Annual crops in Washington State are projected to experience a mix of increases and decreases in production, primarily in response to warmer temperatures and CO_2 fertilization.** Projections are based on changes in temperature, precipitation, and evaporative demand, but do not consider other factors such as changes in water availability and pests.[C]

    - *Winter wheat yields are projected to increase.* Projected change is +23 to +35% in four eastern Washington locations by the 2080s (2070-2099, relative to 1975-2005), under a medium greenhouse gas scenario.[D][3]

    - *Spring wheat yields are projected to either remain the same or decrease.* Projected change ranges from no change to −11% in the same four eastern Washington locations by the 2080s (2070-2099, relative to 1975-2005) for a medium greenhouse gas scenario.[D][3]

    - *Potato yields are projected to decrease slightly*. Projected declines in potato yields are small: −3% for Othello, WA by the 2080s (relative to 1975-2005) under a medium greenhouse gas scenario.[E][3] Warmer temperatures can result in lower quality potatoes.[4]

3. **Perennial crops in Washington State are projected to experience a mix of increases and decreases in response to a longer growing season, reduced winter chilling, and CO_2 fertilization.**

    - *Apple yields are projected to increase*. Under a medium greenhouse gas scenario, apples in Sunnyside Washington (near Yakima) are projected to increase in yield by +16% for the 2080s (2070-2099, relative to 1975-2005).[3] However, these results assume no change in water availability – since apples are a relatively water-intensive crop, production could be negatively affected by projected decreases in water availability (Section 6).

    - *Wine grapes require winter "chilling"; new vineyards take years to establish.* Wine grapes, especially the cool climate varieties that are typically produced in Washington –

[C] Impacts on specific crops and locations described in this document represent examples rather than an exhaustive list of potential regional impacts.

[D] Changes in crop yield were simulated for 4 eastern Washington locations: Pullman, St. John, Lind, and Odessa, using the average projection from four global climate models (PCM1, CCSM3, ECHAM5, and CGCM3) and a medium greenhouse gas scenario (A1B; see Section 3). The range in projections is a result of differences in growing season and precipitation at these four locations.

[E] Based on the average projection from four global climate models (PCM1, CCSM3, ECHAM5, and CGCM3) and a medium greenhouse gas scenario (A1B; see Section 3).

e.g., Pinot Gris, Pinot Noir – require winter "chilling" conditions in order to produce fruit of sufficient quality. Annual frost-free days are projected to decrease by −35 days on average by the 2050s (2041-2070, relative to 1970-1999) under a high greenhouse gas scenario.[F][5] There are significant costs associated with shifting to warmer grape varieties: grapes are a multi-decade investment for farmers, taking 4 to 6 years to mature and remaining productive for several decades.

4. **Pests are affected by warming, which can increase growth and reproductive success, and alter their vulnerability to predators.** Projections are limited to a small selection of species and locations, and do not include the combined effects of changing crops, predators, and other factors.

   - *Codling moth (Cydia pomonella) populations are expected to increase, affecting apples.* The codling moth, which is the main pest attacking apples in Washington, is projected to reproduce more rapidly with warming. For Sunnyside, Washington (near Yakima), warming under a medium greenhouse gas scenario is projected to cause adult moths to hatch about 2 weeks earlier and increase the fraction of the third generation hatch by +81% by the 2080s (2070-2099, relative to 1975-2005) for a medium greenhouse gas scenario.[E][3]

   - *Populations of the cereal leaf beetle (Oulema melanopus) are expected to increase*. Temperatures in the Northwest are projected to become more favorable for the invasive cereal leaf beetle. Preliminary work also indicates that the parasitoid wasp (*Tetrastichus julis*), which attacks cereal leaf beetles, may become less effective as a population control as a consequence of warmer springs.[6]

   - *Parasitic wasp (Cotesia marginiventris) populations are projected to decrease*. Reproduction by this wasp, which attacks caterpillars, including those species affecting Northwest crops, is projected to decline substantially in response to warming, potentially allowing caterpillar populations to increase.[7]

5. **Livestock are affected by climate via impacts on food sources as well as the direct effects of heat stress.** Research has generally focused on the isolated effect of warming or CO_2 fertilization in specific locations, and does not include factors such as changing water availability, fire risk, and invasive species.

   - *Rangeland grasses are expected to have increased growth but decreased digestibility.* Experiments have shown increased forage growth in grazing lands in response to both elevated CO_2 concentrations[8] and warming[9]. However, these studies also found a decrease in digestibility of grasses grown under these conditions and a changing balance of grass species, as some benefit more from the changes than others. Invasive species may also benefit from warming and rising CO_2 concentrations[10]. Warming is likely to decrease soil water availability, especially in late summer, resulting in decreased forage growth and an increased risk of fire.[11][12]

[F] Projection based on regional climate model simulations under a high greenhouse gas scenario (A2; see Section 5 of this report).[5]

- *Increases in forage and pasture crop production, decreases in digestibility.* Experiments indicate that CO_2 fertilization will result in reduced nutritional value in these crops, for instance finding up to a −14% reduction in digestibility for livestock in response to a doubling of CO_2.[13] In spite of decreases in nutritional value, alfalfa production is projected to increase by +27 to +45% in response to a doubling of CO_2 and a warming of 4.5°F.[G][14] Projected decreases in irrigation water supply (Section 6 of this report) may limit forage production.

- *Impacts on livestock are minor.* Livestock eat less in response to heat stress, are less efficient at converting feed into protein (either dairy or meat), and have reduced reproductive rates. Dairy cows in Washington are projected to produce slightly less milk in response to heat stress – about −1% less by the 2080s (2070-2099, relative to 1970-1999) for a medium greenhouse gas scenario.[15] Preliminary results project that beef cattle will mature more slowly, taking +2.2 to +2.5% longer to achieve finishing weights in response to a doubling of CO_2, which is projected to occur by about mid-century under a high greenhouse gas scenario.[16]

6. **Agriculture is expected to be very adaptable to changing circumstances, although some crops and locations are more vulnerable than others.**

- *Farming and ranching are inherently flexible.* Agricultural production already involves adapting to changing weather and climate conditions. This flexibility will facilitate adaptation to climate change.

- *Agriculture in the Pacific Northwest is very diverse.* The diverse climates of the Pacific Northwest host a wide range of agricultural production. This will likely facilitate adaptation, as some crops fare better than others.

- *Selective breeding and improved management practices could outpace climate impacts.* For instance, the pace of recent changes in livestock production – in response to changes in management and breeding – is much larger than existing projections of climate change impacts.[15]

- *Western Washington agriculture is likely less vulnerable than the interior.* Greater water availability, access to urban markets, and the milder climate of coastal Washington will likely make it easier for agriculture to adapt in this region. Areas in the interior, especially semi-arid regions with limited access to irrigation water, have much less capacity for adaptation.

- *Transitioning to new crops can require substantial investments in time and money.* Wine grapes and apples, for instance, require years to establish and begin generating revenue.

- *Some subsidies and conservation programs could inhibit adaptation.* Some policies and regulations – including crop subsidies, disaster assistance, conservation programs,

[G] 4.5°F is near the middle of the range projected for mid-century (2041-2070), relative to 1950-1999, under a low greenhouse gas scenario (RCP 4.5).

environmental regulations, and certain tax policies – may reduce the incentive for adaptation.

7. **Since 2007, new studies have quantified impacts on specific crops and locations, evaluated the combined effects of warming and CO_2, and begun to integrate climate impacts with economic modeling of market influences and adaptation.**

- *New advancements include the following:*
  - Improved understanding of climate impacts on specific crops and locations, and studies of impacts on new species not previously assessed.
  - More information on the combined effects of warming, CO_2 fertilization, predator-prey interactions, and other factors impacting the response of crops to climate change.
  - New efforts to integrate climate impacts modeling with economic models that consider market influences and potential for adaptation.
- *Available studies are still limited to a subset of Washington crops and locations.* Research is needed to quantify impacts on additional crop, weed, and pest species; assess the synergistic effects of multiple stressors on yields; and identify vulnerabilities in the food system and barriers to adaptation.[17]

Specific Information and Resources to Support Adaptation to Changes in Agriculture
The following resources are suggested for additional information beyond the summaries provided in this document.

- **Integrated modeling of climate change, agriculture, and economics.** The *Regional Approaches to Climate Change for Pacific Northwest Agriculture* integrates climate modeling with research and modeling of economics, crop systems, and agriculture. Driven by stakeholder needs, this research will evaluate the combined effects of climate change and adaptation on Pacific Northwest agriculture. www.reacchpna.org
- **Water supply and demand forecast.** The *Columbia River Basin long-term water supply and demand forecast*[18] provides historical data and projected changes in water supply and agricultural demand as a result of climate change. Other demand forecasts (municipal, hydropower, and instream flows) do not incorporate climate change. Results are available for each individual Water Resource Inventory Area (WRIA) in eastern Washington and the Columbia River basin as a whole. http://www.ecy.wa.gov/programs/wr/cwp/forecast/forecast.html
- **Climate and hydrologic scenarios.** The Climate Impacts Group provides downscaled daily historical data and future projections of temperature, precipitation, snowpack, streamflow, flooding, minimum flows, and other important hydrologic variables for all watersheds and 112 specific streamflow locations in Washington State, as well as for locations throughout the Columbia River basin and the western US. These are based on projections in IPCC 2007.[19] http://warm.atmos.washington.edu/2860,[19] http://cses.washington.edu/cig/
- **Modeling the interactions between climate, water, carbon, and nitrogen.** The *Regional Earth System Modeling Project (BioEarth)* links global climate model projections with a regional model that simulates complex interactions between the land, water, and atmosphere, including vegetation changes, water and nutrient cycling, and agriculture. www.cereo.wsu.edu/bioearth/
- **Modeling the interactions between water resources, water quality, climate change, and human decisions.** The *Watershed Integrated Systems Dynamics Modeling (WISDM)* project is focused on agricultural and urban environments. A primary goal is to engage stakeholders in the development of scientifically sound and economically feasible water policy. www.cereo.wsu.edu/wisdm/

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