Oregon Climate Assessment Report

December 2010

Oregon Climate Change Research Institute

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About the Oregon Climate Change Research Institute

The Oregon Climate Change Research Insititute (OCCRI) is a network of over 100 researchers across the Oregon University System and affiliated state and federal labs. OCCRI was established in 2007 by the Oregon State Legislature to foster climate change research across the Oregon University System.

OCCRI is housed in the College of Oceanic and Atmospheric Science at Oregon State University

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4. Climate Change and Agriculture in Oregon

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Summary and Knowledge Gaps

Oregon agriculture is as diverse as the geography and climate of the state. However, while this diversity is an economic strength, it creates a wide range of sensitivity issues to climate change factors that does not produce a "one-size-fits-all" assessment protocol or universal response. Most crop systems have been maximized for optimal production and sustainability through the years, and exist in a narrow temperature niche - one that may no longer be optimal under a warmer climate. The warming of the past century has already had an effect on the growing season; Oregon's wine regions have seen the length of the frost-free period increase by 17 to 35 days.

In a changing climate:

- Availability, quality and cost of water will likely be the most limiting factor for agricultural production systems under the scenario of a warmer climate. Many Oregon irrigation systems are fed by snowmelt and stored in reservoirs. With a rise in temperature, irrigation demands are projected to increase.

- Perennial cropping systems are more vulnerable to climate change than annual systems. Research is needed to select drought resistant and robust temperature tolerant crops.

- There may be new opportunities for agriculture under a warmer climate but additional research on irrigation technologies, new crop adaptations, and associated management of new invasive plant pathogens will likely be needed.

- Crops will be vulnerable to invasion risk by pests and diseases that thrive in a warmer climate, increasing stress on plants. Warmer winter temperatures will allow insects to survive over the winter.

Agriculture is also contributing to the climate change problem. It is estimated that 8.6% of all human caused greenhouse gas emissions are from the agriculture sector (USGCRP 2001). There are opportunities for mitigation in the sector, through the use of different tillage practices, nitrogen management strategies and livestock diet management. Oregon needs to conduct studies on specific crops/commodities and how they will

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function in a changing climate. Most of the available studies on climate change effects to Oregon crops/commodities is largely speculative, drawing from studies conducted in other states (California and Washington).

4.1 Introduction

Agriculture is extremely vulnerable to climate change as most crop systems have been optimized to fit a given climate niche allowing for economically sustainable quality and production. These climatic niches range from fairly broad conditions suitable for crops such as wheat or corn, to more narrow conditions suitable for specialty crops such as berries and wine grapes. Agriculture responses to changing climates reflect the interaction between temperature, water availability and timing, and increasing carbon dioxide concentrations. As such, understanding agricultural impacts from climate change necessitates integrated studies examining the combined effects of these three factors.

As agriculture is a highly climate sensitive sector, climate change impacts are likely to have a significant impact on the growth and productivity of plants and livestock, cropping and grazing seasons, and the spread of pests and diseases (Mearns, 2009). Projected warming is expected to result in a displacement of current agricultural zones, with likely movements northward (Northern Hemisphere), toward the coast, and higher in elevation. Higher temperatures are also likely to reduce the amount of land appropriate for grazing in some regions, with implications for livestock productivity. In addition, warming may lead to greater irrigation requirements. For a rise in temperature of 1°C, irrigation demands are projected to increase by at least 10% in arid and semi-arid regions. These factors may contribute to lower agricultural yields, which may increase dependence on global grain markets and threaten food security, particularly of the urban poor, who are already heavily influenced by prices in global markets.

Furthermore, while changing climates clearly affect agriculture, the agriculture sector also affects climate through the emissions of greenhouse gases. It is estimated that agriculture in the United States contributes 8.6% of all human-produced greenhouse gas emissions (USGCRP 2001). Therefore, agriculture plays a dual role in climate change impact assessment whereby it can help mitigate impacts, but clearly needs to adapt to changes in climate so that future food supplies and regional economies can be maintained. Historically, people engaged in agricultural have adapted to a range of climate impacts over both the short and long term. Future adaptation is made more challenging by the large size of agricultural operations today, the long-term investments made in them, and the observed and anticipated rapid changes in climate. To help understand the range of impacts and increase resiliency in agriculture, scientists and governments will need to provide timely information and policies allowing for suitable adaptive responses.

4.2 Agriculture in Oregon

Oregon agriculture is as diverse as the geography and climate of the state. As of 2008, Oregon had 38,600 farms operating on 16.4 million acres with an average farm size of 425 acres (NASS 2009a,b). The average value produced per acre in 2008 was $2260, representing a gross value of commodities and services produced in one year of nearly $5 billion for agricultural sector production. Oregon agricultural commodity production is mostly crops (72.72%) followed by livestock and poultry products (21.67%), forest-farm products (2.64%), and fishery products (2.97%) (Table 4.1). Within the crop production sector, field crops represent 27.43%, greenhouse, nursery and tree farms 19.16%, seed crops 11.11%, fruit and nut crops 9.74%, and vegetable crops 5.27% (NASS 2009a). By value, Oregon's largest single commodity is greenhouse and nursery products followed by hay, grass seed (all types), cattle and cattle products, wheat, potatoes, and Christmas trees. In terms of national rankings for agricultural production, Oregon ranks first in fifteen different commodities with many berry and seed crops producing between 70 and 100 percent of the nation's overall production (Table 4.2). Total exports of Oregon agricultural commodities were $1.6 billion in 2008 with wheat and wheat products, seeds, fruit and fruit preparations, and vegetables and vegetable preparations representing over 60% of the total (NASS 2009a).

Table 4.1. 2008 Oregon agricultural commodity sectors. (Source: NASS, 2009a)

Commodity Sector	% of all Commodities
All farm production (less fishery)	97.03
All crops	72.72
Greenhouse, nursery and tree farms	19.16
Field crops	27.43
Seed crops	11.11
Fruit and nut crops	9.74
Vegetable crops	5.27
All livestock and poultry products	21.67
Forest products, farm	2.64
Fishery products	2.97

Table 4.2. Oregon's Top 40 Agricultural Commodities for 2008. (Source: NASS, 2009b)

Rank	Commodity	Value	Rank	Commodity	Value
1	Greenhouse & nursery products*	$880,061,000	21	Sweet corn, all	$34,864,000
2	Hay	$613,311,000	22	Grass and grain straw*	$34,004,000
3	Grass seed, all*	$510,298,000	23	Crab landings	$29,175,000
4	Cattle & calves	$426,794,000	24	Snap beans, processing	$26,418,000
5	Milk	$412,482,000	25	Horses*	$25,500,000
6	Wheat	$340,178,000	26	Vegetable & flower seeds*	$25,072,000
7	Potatoes	$211,039,000	27	Mint for oil	$24,544,000
8	Christmas trees*	$122,765,000	28	Blackberries, all	$22,941,000
9	Onions, storage	$97,524,000	29	Shrimp landings	$21,384,000
10	Pears	$92,582,000	30	Hay silage*	$20,068,000
11	Winegrapes	$71,135,000	31	Mink	$20,033,000
12	Eggs	$64,974,000	32	Strawberries	$16,768,000
13	Cherries, all	$56,356,000	33	Raspberries, all	$13,082,000
14	Hazelnuts	$52,160,000	34	Tomatoes*	$12,995,000
15	Corn, grain & silage field	$52,137,000	35	Sheep & lambs	$11,369,000
16	Blueberries	$49,266,000	36	Tuna, albacore landings	$10,651,000
17	Groundfish landings	$43,587,000	37	Barley	$10,463,000
18	Hops	$37,991,000	38	Squash & pumpkins*	$9,956,000
19	Apples	$37,752,000	39	Watermelons*	$8,865,000
20	Cranberries	$36,600,000	40	Green peas, processing	$8,768,000

While some of Oregon's agricultural commodities are more broadacre crops such as hay or wheat, many of them are specialty commodities, which together represent quite different climate requirements and thresholds that need to be better understood to adequately assess climate change impacts.

4.3 Oregon Agricultural Sensitivity to Climate Change

Oregon's agricultural diversity is an economic strength, but it creates a wide range of sensitivity issues to various climate change factors. Depending on the crop/commodity and its current climatic equilibrium, temperature or precipitation changes can either reduce or increase yields or quality. Few direct studies on climate, production and quality thresholds for Oregon's major crops have been done. Most of the direct studies done are largely speculative, indicating that if a given crop/commodity exists within today's climatic thresholds, projected climate changes would push them outside what is suitable. What is needed is much more direct and controlled studies of plant/animal growth characteristics, optimum climate requirements and variability thresholds for economic sustainability. For example, Lobell et al., (2006) and Lobell et al., (2007) have conducted studies on major crops in California revealing historical impacts and future sensitivities. These kind of studies need to be replicated for Oregon's climate and crops.

Good examples of impacts and sensitivity concerning Oregon agriculture include winegrapes and orchards. For winegrapes, research globally has shown that each variety has a relative narrow climatic optimum for both quality and economically sustainable production. For Oregon, no crop better illustrates climate sensitivity and risk associated with climate change than Pinot Noir, the state's marquee winegrape. Pinot Noir is typically grown in regions spanning from cool to lower intermediate climates with growing seasons ranging from roughly 14.0 - 16.0°C (Jones, 2006). Across this 2°C climate niche, Pinot Noir produces the broad style for which is it known with cooler zones producing lighter, elegant wines and warmer zones producing more full-bodied, fruit-driven wines. While Pinot Noir can be grown outside the 14.0 - 16.0°C growing season average temperature bounds, it is typically unripe or overripe and readily loses its typicity.

Changes in the climate of Oregon's wine growing regions since 1950 (especially the Willamette Valley) have provided longer and warmer growing seasons and less risk of frost (Jones, 2003, 2005). These changes have taken the Willamette Valley from a marginal wine climate (< 14°C) to one producing globally recognized high-quality wines (averaging 15°C or higher today). Similar changes have been seen in other wine regions worldwide (Nemani et al., 2001; Jones et al., 2005; Jones, 2006; White et al., 2006; Jones and Goodrich, 2008). However, due to the narrow niche Pinot Noir requires for optimum quality, further increases in temperature will likely move much of current acreage planted in the Willamette Valley outside of what is considered suitable for Pinot Noir (White et al., 2008). This would necessitate costly adaptation processes of replanting to different, warmer climate grape varieties (Figure 4.1), or moving to higher elevations, more toward the coast, or further north in latitude. Additional risks come from the marketing side, where changes in varieties or wine styles would require a substantial effort to inform consumers and maintain market viability.

Orchard-based crops provide another example of the potential economic impacts of climate change associated with rising temperatures. Like many crops, orchard fruits mature more quickly at higher temperatures. Earlier maturity, however, brings issues of both crop quality and its timing to market. Oregon apples and pears, for example, are sold into a global market in which crop quality and availability provide comparative advantages. Observations in Jackson County, where pears represent a large portion of the crop land, show pear bloom dates in the spring have been earlier in the year with lower frost impacts (G.V. Jones data). However, when frosts do occur, the trees are not as accustomed to the low temperatures as they used to be and minor frosts can be more problematic (Gu et al., 2008). In addition, the earlier start to the season has been followed by earlier harvests, which influence when the fruit goes to market, potentially creating disconnect with historic need. Further shifts to earlier and earlier harvests during warmer summers could both lower the quality of the fruit and shift the competitive environment in which Oregon producers must sell their crop. In addition, winter chilling requirements for orchard crops in Oregon appear to still be sufficient, unlike California. There, chilling hours during winter have declined by as much as 30% since 1950 in areas of the Central Valley to the point of not making some orchard crops viable (Lobell et al. 2006; Luedeling et al. 2009). However, as climates continue to change, similar winter dormancy issues could mean trouble for Oregon's perennial crops.

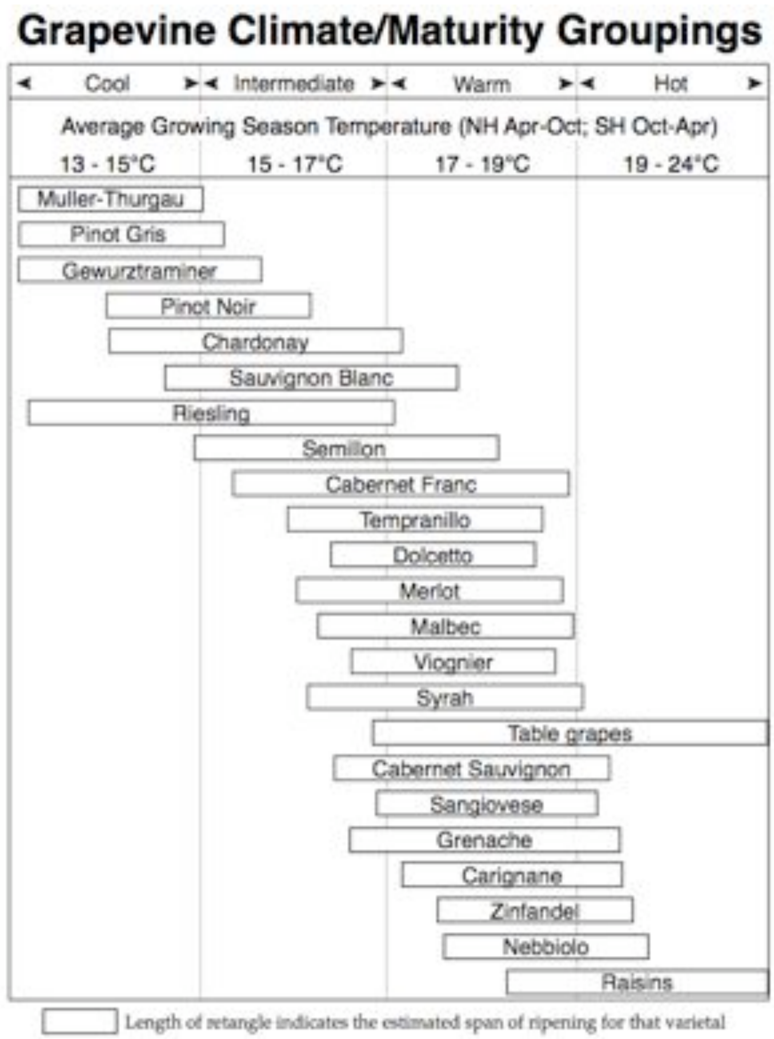

Figure 4.1. Climate maturity groupings based on average growing season temperatures and the estimated span of varietal ripening potential occurring within and across the groups. Note the climate data depicted in Table 1 is derived from grids, not station data therefore values given may deviate slightly from any one station in a given region (Jones et al., 2004).

Potatoes are also sensitive to rising temperatures because warmer temperatures accelerate plant development and leaf senescence, and because higher temperatures during tuber bulking reduce translocation of carbohydrates from the plant to the tubers (Timlin et al., 2006). Adams et al. (1999) predicts potato yield decreases at sites across the United States with rising temperatures, with yield decreases as high as 50% with a 5 °C temperature rise, due to the sensitivity of potatoes to temperatures in tuberization response. Yield increases as a result of CO_2 fertilization effect were insufficient to offset yield reductions. At the same time, the authors note there is a high degree of genetic variability in potatoes, suggesting further research may be able to help the potato industry adapt to changing climate conditions. Stöckle et al. (2008) also predicts significant potato yield decreases with modeled temperature increases, but increasing CO_2 concentrations compensated significantly for the yield reductions. Alva et al. (2002) finds high temperature during tuberization may contribute to lower tuber quality.

Increased variability in crop yields as a result of climate change is predicted to impact global cereal grain and oil seed trade (Reimer and Li, 2009).

4.3.1 Livestock Production

There will likely be both positive and negative benefits to livestock production from climate change. Milder winters may increase livestock survival and lengthen the available grazing season. A direct impact may come from increased or decreased availability of water for drinking. There are substantial costs incurred for water hauling or drilling of wells. There is an opportunity for expanded use of solar or wind powered pumping systems that might offset some water hauling or drilling costs in the long-term. A changing climate may require adaptation of water delivery systems to new areas and additional fencing to limit cattle access to creeks and riparian areas. A shift toward higher temperatures, drier conditions and less irrigation availability will influence water temperature. Increased water temperature can have a negative impact on any of a number of listed fish species (or other aquatic or riparian dependent species), and the resulting Endangered Species Act induced restrictions could have a substantial impact on production costs for livestock producers and others in agriculture.

On a similar note, hotter, drier climatic conditions, coupled with less irrigation could affect the timing and amount of forb production on rangelands, playas, meadows, etc. which could impact an important food source for sage grouse chicks during part of their life cycle. If bird populations decline, especially enough to trigger an ESA listing, restrictions will likely impact production costs for livestock producers. At certain times, insects are also an important component of sage grouse diets. If insects are negatively impacted by climatic change, sage grouse could suffer population declines and additional management restrictions could be imposed. In drier areas, grazing may need to be limited or foregone. There is a need to do research on developing new forages, livestock breeds resilient to temperature changes, and the development of new grazing or feeding strategies.

Climate change has the potential to influence the rate of increase and distribution of invasive plants species and to alter plant community distribution. Depending on the nature and magnitude of these changes, if they occur, both cost and capacity of production could be affected. Increases in atmospheric CO_2 has have impacted the retention of cheatgrass biomass and it seems likely that it this could have implications for fire disturbance (Ziska et al., 2005). This type of disruption can impact livestock grazing opportunities (see Chapters 6 and 7).

4.3.2 Changes/Shifts in Growing Seasons

There is much evidence pointing to a lengthening of the growing season globally of between 10 and 20 days in the last few decades (Linderholm 2006). The change is asymmetric and largely due to an earlier onset of spring instead of later ending of fall (Christidis et al., 2007). Growing season lengths are often defined by the period of time that is frost-free and Easterling (2002) finds that warming in the United States has resulted in a decrease in the number of frost days, an earlier date of the last spring frost, a later date of the first fall frost, which has resulted in a lengthening of the frost-free period during the last half the 20th century. Examining wine region climates across the western US, Jones (2005) finds longer growing seasons (38 days longer on average) and less risk of frost. Oregon's wine regions have seen the length of the frost-free period increase by 17 to 35 days.

Growing season shifts, or increases in growing season duration, can have mixed effects to regional agricultural production, benefiting some crops while harming others. Adams et al. (2006) models changes of yields and irrigation water demand for a variety of crops in California and finds warming during the growing season is generally beneficial to yields in cooler regions of the state, but is harmful to yields in the San Joaquin region. Models also predict crops in cooler regions benefit from additional degree-days of warming. However, longer and warmer growing seasons translate into generally higher irrigation water demands, although this is mitigated somewhat by the CO2 fertilization effect.

Adams et al. (1999) also model the impacts of two climate change scenarios on cattle and forage production in Texas. Increased temperatures combined with the CO2 fertilization effect have mixed results on forage production in different regions of Texas: production increases in some regions but decreases in others. Cattle production is affected by increased summer temperatures and associated stress to livestock, along with lower energy requirements for maintaining body heat in the winter. The authors predicted the net effect to cattle production in Texas to be negative.

4.3.3 Extreme Events and Agriculture

Possible increases in the frequency and intensity of extreme daily precipitation events are likely to affect agriculture and aquaculture adversely and to threaten food security. Impacts can include damage to crops and infrastructure, delayed effects due to pests and diseases, as well as waiting periods of several years for uprooted trees and plants to be replaced and become productive. In turn, these can result in loss of crop and fishery productivity, food shortages, and elevated food prices in the absence of adaptation.

The costs of weather-related disasters in the U.S. have been increasing since 1960, and globally trending upward faster than population, inflation, insurance penetration, and non-weather related event costs (Mills, 2005). It is difficult to estimate the impacts of natural disasters in Oregon to agriculture. Costs are not broken out by sector by the U.S. Federal Emergency Management Agency (FEMA) for specific disasters. While U.S. Department of Agriculture disaster payments to agricultural producers may provide some relative measure of disaster impacts, they are unlikely to provide a comprehensive cost of a disaster's impact to agriculture. This is because only certain crops are eligible for disaster payments or insurance programs, and cost-share payments may vary by program, not reflecting agricultural producers' matching investments for disaster response.

Droughts are one of the most costly natural disasters. Many counties in eastern and southeastern Oregon have experienced season-long or prolonged drought in recent years, with the Klamath Basin drought in 2001 being one of the most well-known as far as its impacts to agriculture. Droughts are likely to be exacerbated by earlier and lower spring snowmelt and runoff, which is occurring 7 - 10 days earlier than the historical average (Cayan et al., 2001). Estimates of economic impacts for natural disasters such as drought are difficult to reproduce because of the unique nature of drought, including its slow onset and significant secondary impacts (Kunkel et al., 2008). U.S. agricultural losses have been estimated at $4 billion per year over the past 10 years, but it is unclear if they are directly related to crop production or other factors. Little to no official estimates exist for the livestock sector, as well as several other nonagricultural sectors (Kunkel et al., 2008).

Heat waves can also cause significant economic damage to crops and livestock. Even short-lived events can damage crop quality and reduce yields (Reilly, 2002). Reilly (2002) suggests breeding for cold tolerance during germination and heat tolerance during grain filling will probably mitigate some impacts of increases in temperature variability and some extremes, but this conclusion is mostly based upon research conducted on grain crops. Livestock are especially vulnerable to higher temperatures in the summer, but these losses will very likely be mitigated by warmer winter temperatures in the state (Hauser et al., 2009).

Some types of natural disasters may decrease in frequency under changing climatic conditions. Over the last ten years, most land areas in the United States had lower numbers of severe cold snaps than any other ten-year period. In addition, a decrease of frost-free days has been observed in the U.S., with a more pronounced decrease in the West (Kunkel et al., 2008). Depending on the timing of cold snaps, this trend may decrease damage to Oregon's crops, but it may also increase the likelihood of survival of insects and other pests. In addition, if a crop experiences a rapid swing between high and low minimum temperatures, winterkill can result (Reilly, 2002).

Nationally, the frequency and intensity of heavy precipitation events is on the rise. The most pronounced changes have taken place in other parts of the U.S. outside the Pacific Northwest. There is some indication these events may increase in the Pacific Northwest. The Northwest is located in a transitional area where some models show increasing precipitation and the others show the opposite. However, the projected upward winter temperature trend suggests more precipitation will likely fall as rain rather than snow (Chapter 1 - Climate). This pattern, combined with earlier snowmelt, could mean less summer water availability for irrigation and other natural resource needs.

Interannual variability will continue to dominate precipitation (particularly winter) in the Pacific Northwest. Historically, the El Niño Southern Oscillation and La Niña phenomena have resulted in periods of drought and heavy precipitation in the Pacific Northwest. Changing precipitation patterns are predicted to cause significant increase in crop losses, but better forecasting could partially offset these losses (Reilly et al., 2002).

4.3.4 Adaptability of Oregon Agricultural Producers to Changes in Climate

Agriculture is considered one of the sectors most adaptable to changes in climate. Typically, agriculture producers are an adaptable group, however, increased heat and water stress, changes in pest and disease pressures, and weather extremes will pose adaptation challenges for many crop and livestock production systems.

Probably the biggest advantage Oregon agricultural producers have relative to changes in climate are that those in agribusiness continually adapt to variations in climate, otherwise they would not be successful. As a result adaptation by farmers should allow them to maintain quality and production levels in the face of short-term and modest warming. However, if warming is very rapid and compounded by less and less availability of water, then the ability to adapt is much lower. This has been seen in Australia where a multi-year drought episode, and government policies that failed to manage water appropriately and inform stakeholders, has brought near collapse to the wine industry in many regions. Surveys out of California and Australia, reveal growers deem site factors are essential to quality and these include climate and access to irrigation. They also believe heir ability to adapt to changes in climate becomes increasingly difficult with greater warming unless there are better understanding of their system and government policies that are proactive.

4.3.5 Changes in Crop Diseases and Pests

While agricultural crops are responding to changes in climate, so are plant diseases, pests, weeds, and vertebrates. Climate change is expected to enhance invasion risk from many crop diseases, pests, and weeds (Bradley et al., 2009; Sutherst et al., 2007) ultimately increasing the stress on crop plants and requiring more attention to pest and weed control. In addition to the direct impact on plants growing in both managed and natural ecosystems, a changing climate will affect pathogens causing diseases, reduction in productivity, and often death of their hosts. It is expected that changes in temperature, precipitation and other environmental factors will have both direct and indirect impacts on host-pathogen interactions. These will be host and pathogen specific and it is not possible to make accurate general predictions. There are, however, numerous examples of how plant disease occurrence and spread appear to be closely tied to prevailing climatic factors and evidence that global climate change is already impacting the occurrence of some diseases (Anderson et al., 2004; Bergot et al., 2004; Harvell et al., 2002; Woods et al., 2005). In the long-term, one expects the increases in some diseases to be balanced out by decreases in others (Coakley et al., 1999; Scherm and Coakley, 2003). Unfortunately, in managed ecosystems, the speed of climate change and the often long growing cycle (e.g., fruit trees, grape vineyards, and forests) are likely to result in significant and difficult to manage economic losses for some crops before adjustments can be made (Garrett et al., 2006). If an annual crop such as wheat is hit severely by disease one season and it looks like disease pressure will be high again the next, one may be able to choose another cultivar resistant to the pathogen or another crop. If a perennial grass or mint field develops a soil borne root disease, the only option may be to remove and replant with another crop. In the case of perennial cropping systems, e.g.,vineyard or hop yard, the use of predictive models and chemical control can help manage the response. There are several examples of agricultural diseases important in the Pacific Northwest that may be impacted significantly by a change in temperature or precipitation patterns. Downy mildew on grapes has not been found in Oregon since the late 1930s. Downy mildew is thought to be related to a generally unfavorable climate. However, a very similar pathogen occurs on Boston Ivy, a closely related species, and the potential exists for this pathogen to re-emerge in Oregon. Research out of Italy suggests additional sprays (currently 7 - 10 are used) might be needed to control this disease with the most likely climate change scenarios expected (Salinari et al., 2006). In contrast, powdery mildew does occur on grapes in Oregon, but is fortunately an easier disease to manage. Spider mites are an example of a plant pest that may increase in severity under warmer and drier conditions. Following a particularly mild winter in 2005, voles reached epidemic numbers in the Willamette Valley and wreaked havoc on grass fields and vineyards. The following winter was unusually wet and cold and the vole populations rapidly returned to normal. This example serves as a reminder of how vulnerable perennial cropping systems may be to pests favored by unusual climatic conditions.

Rising temperatures allow both insects and pathogens to expand their ranges to regions where they were once not found (Kamata et al., 2002). In addition, warmer winter temperatures allow more insects to survive over the winter, whereas colder winters once controlled their populations. The absence of normal low winter temperatures across Canada may be directly related to the increase of pine bark beetles across Canada. Furthermore, changes in climate have the potential to disrupt the natural enemies of some crop pests (beneficial insects), ultimately producing greater overall crop vulnerability (Campanella et al., 2009; McEvoy and Dauer, 2009; Hatfield et al., 2008; Thomson et al., 2010).

Warmer temperatures may also allow for additional generations of insect pests within a single growing season. Stöckle et al., (2008) models codling moth populations under baseline conditions and four Global Climate Model (GCM) projections and finds earlier emergence of adults in spring coupled with warmer temperatures in summer would result in most apple-growing locations in Washington state experiencing a complete third generation hatch. These results suggest additional costs to apple growers from additional pheromone and sprays per season. Altermatt (2010) reviews European datasets documenting the number of generations of 263 European butterflies and moths per growing season and finds higher frequencies of second and subsequent generations in many species, suggesting a higher risk of outbreaks for some agricultural and forest pests. Furthermore, changes in climate have the potential to disrupt the natural enemies of some crop pests (beneficial insects), ultimately producing greater overall crop vulnerability (Thomson et al., 2010).

The warmer, wetter fall and winter seasons projected for the Pacific Northwest may have similar impacts on plant pests. Stöckle et al. (2008) predict warmer and wetter falls and winters will result in greater numbers and growth of winter and annual weeds, such as volunteer potato.

Higher temperatures and atmospheric CO_2 concentrations may affect the effectiveness of existing pesticides on diseases, plant pests, and insect pests. Ziska et al. (1999) and Ziska and Goins (2006) find glyphosate looses its effectiveness on weeds grown at CO2 levels likely occur in the future.

4.4 Indirect Effects of Increasing CO_2 on Agriculture

Carbon dioxide is essential to plant growth and evidence suggests total crop yields may rise when averaged across the globe due to effects of CO_2 fertilization (Drake et al., 1997). Even with the advent of more realistic field experiments (e.g., Free-air concentration enrichment - FACE) few impact studies have been done outside of broadacre crops such as wheat, corn, and soybeans.

Kimball (1983) reviews 430 prior studies evaluating crop response to higher CO_2 concentrations. C3 crops (most crops, including wheat and soybeans) respond with yield increases up to 30% under doubled CO_2 concentrations. C4 crops (corn, sorghum, sugar cane) having much lower yield increases, around 7%. Kimball et al. (2002) summarizes crop yield impacts under free-air CO_2-enriched environments.

In addition to increasing plant growth and biomass production, higher carbon dioxide concentrations can mitigate drought stress to certain crops by causing partial stomatal closure. Hatfield et al. (2008) review a variety of studies demonstrating reduced crop stomatal conductance under CO_2-enriched environments. Fleisher et al. (2008) find that in potato plants under drought stress, plants grown in elevated CO_2 conditions produce higher yields, suggesting that CO_2 enrichment will mitigate drought-induced yield reductions. Curtis and Wang (1998) review studies of woody plants and find elevated CO2 decreases stomatal conductance less in woody plants than in herbaceous plants. Kimball et al. (2002) reviews FACE experiments and notes elevated CO_2 levels stimulate growth in plants under water stress as much as plants in well-watered conditions.

Models evaluating climate change impacts to agriculture have generally shown reduced crop yields from changing climate conditions, but significant mitigation of yield losses because of the CO_2 fertilization effect. Stöckle et al. (2008) models yields for several types of crops under increasing temperatures and higher CO_2 levels. Temperature increases are generally detrimental to crop yields, but CO_2 fertilization greatly reduces these effects. In some cases, the net effect of a temperature increase and CO_2 fertilization on crop yields is positive.

Rising atmospheric CO_2 levels can have both positive and negative impacts on crop quality depending on other factors such as temperature, water, and nutrient availability. Wolfe (1994) notes that fertility and growing conditions need to be good in order to maximize potential benefits from higher CO_2 concentrations. Research on the effects of increased CO_2 levels has been carried out since the early 1980s, often in controlled situations, to assess the effects to crop quality and yield (Mearns, 2009). When nutrient supplies are limited, the quality of the crop, especially grain protein content, may decline (Bazzazz and Fajer, 1992). Ziska and Goins (2006) observe a significant vegetative response of soybeans to higher CO_2 concentrations, but no consistent effect on seed yield. Bindi et al. (2001) evaluates the response of winegrapes to enriched CO_2 and documentes higher biomass and fruit production, with little change in fruit and wine composition. Studies in rangelands find lower nitrogen concentrations in shortgrass steppe, tallgrass prairie, and mesic grassland at elevated CO_2 levels (Owensby et al., 1993; Hungate et al., 1997; King et al., 2004; Wan et al., 2005; Gill et al., 2006), which presents significant implications for forage quality.

Even under conditions with good nitrogen availability, plant and grain nitrogen quality may decline under higher CO2 concentrations. In their review of FACE experiments, Kimball et al. (2002) find an average decrease in grass leaf nitrogen concentration of 9% under elevated CO2 levels and ample water and nitrogen, and under low soil nitrogen conditions, an average leaf nitrogen concentration of 16%. Kimball et al. (2001) finds a 3% decrease in wheat grain nitrogen concentration under good conditions, and a 9% decrease under low soil nitrogen conditions. The authors report that low soil nitrogen by itself cause serious reductions in nutritional and baking quality and elevated CO2 makes the situation worse.

Some experiments predict greater plant nitrogen uptake to maintain carbon to nitrogen ratios and less long-term nitrogen availability, limiting long-term growth (Luo et al. 2006). Kimball et al. (2001) note FACE experimental results show a wide range of effects on nitrogen removal under higher CO2 concentrations, both positive and negative, depending on the crop.

Researchers have documented some interesting secondary effects to crops due to the CO2 fertilization effect. Coviella and Trumble (1999) and Hunter (2001) note insects sometimes feed more on leaves having lower nitrogen content in order to obtain sufficient nitrogen. Free-air concentration enrichment (FACE) experiments show 57% more insect pest damage to soybeans in higher CO2 concentrations, which researchers hypothesize is due to increases in levels of simple sugars in leaves. Aphid populations have also been shown to increase under higher CO2 concentrations, independent of temperature changes (Bezemer et al., 1998; Doherty et al., 1997; Salt et al., 1996).

It is possible crop response to higher CO2 levels may be temporary. Some experiments predict greater plant nitrogen uptake to maintain carbon to nitrogen ratios and less long-term nitrogen availability, limiting long-term growth (Luo et al., 2006).

4.5 Water Availability and Irrigation Requirements

The most pressing limitation to future agricultural production may be the quantity, quality and cost of water. In addition to shifts in temperature, changes in precipitation are likely which will alter the variability, timing, frequency, intensity, and spatial coverage of rainfall. Since many agricultural production regions rely on rain-fed production systems, these changes may have severe impacts on agricultural production. Extreme daily and prolonged rainfall during planting seasons could damage seedlings, reduce growth, and provide conditions promoting plant pests and diseases. Moreover, the resultant rise in the frequency and intensity of floods may result in soil erosion and flooding of agricultural lands leading to greater crop losses in more vulnerable regions. On the other hand, drought combined with higher temperatures may lead to greater evaporation, reduced availability of water for agriculture, and added thermal stress on plants. Oregon has substantial experience with water limitations as a result of drought. The Klamath Basin has been particularly hard-hit in the need to respond to competing water demands. Boehlert and Jaeger (2010) provide a excellent review of the issues faced in that region (see Chapter 8).

For irrigation managed cropping systems small changes in water availability will necessitate the need for more water and greater efficiencies in irrigation infrastructure. For a rise in temperature, irrigation demands are projected to increase. Moreover, decreases in water from snow- and glacial-melt could, over time, impact smallholder irrigation systems and hence food production. However, shifts in the amount and timing of precipitation (e.g., snow falling later, melting earlier) will likely have greater impacts, at least in the near term.

In California, history has shown farmers increasingly employ new water conservation technologies as drought becomes more severe (Cavagnaro et al., 2005). Examining the past resiliency of Oregon agricultural producers in dealing with climate-related events, one can speculate that the same would hold true for Oregon.

In recent years, toxic algal blooms appear to be more frequent and widespread in Oregon. Additional research is needed on how to predict and limit these toxic blooms which can lead to illness and death of livestock and other animals (See Chapter 7).

4.6 Mitigation Capacity of Oregon Agricultural Producers:

There are several types of mitigation opportunities in Oregon agriculture: soil carbon sequestration, reduction of nitrous oxide emissions through nutrient, manure, and irrigation water management; reduction of methane emissions from livestock diet and manure management, and reduction of energy consumption.

Soil tillage buries and mixes crop residue into the soil to prepare a seedbed for crop planting. Tillage accelerates oxidation of organic matter within soil, thus contributing to greenhouse gas emissions that negatively impact air quality and global climate-related processes (Reicosky, 1997). In contrast, conservation tillage systems plant directly into crop residues (no-till, or direct seeding) or only till part of the soil area (zone-till). Long-term research trials comparing conventional tillage with conservation tillage show significant improvements in soil quality in conservation tillage, including elevated levels of soil carbon sequestered in organic matter (Johnson and Hoyt, 1999).

Other research shows little difference between the overall sequestration benefits of conventional vs. no-till agriculture (Blanco-Canqui and Lal, 2008), but the two tillage systems result in carbon being stored in different locations within the soil. Under conservation tillage, organic matter remains near the soil surface, while under conventional tillage organic matter is distributed deeper into the soil. Liebig et al. (2005) summarize the available literature regarding soil organic carbon and carbon dioxide, nitrous oxide, and methane fluxes in cropland and rangeland in the western U.S. continuous no-till cropping. Generally, continuous no-till cropping and grazing increases soil organic carbon in the top 10 - 30 centimeters of the soil.

Conservation tillage is not widely practiced in Western Oregon for a number of reasons, primarily due to the extended cold and wet periods in the spring that often interrupt planting schedules, particularly when crop or cover crop residues remain on the soil. Scientists at Oregon State University (OSU) are collaborating with farmers to evaluate the potential of using zone tillage to overcome some of the obstacles associated with conservation tillage on both organic and conventional farms. Less tillage will directly reduce carbon emissions because of reduced equipment use (Luna and Staben 2002, 2003), and indirectly by reversing the loss of carbon from the soil. Conservation tillage has the potential to stabilize losses of organic carbon from soil, and may allow farmers in Oregon to capture carbon from the atmosphere and sequester it in organic matter within the soil.

Scientists at the Columbia Plateau Soil Conservation Research Center (CPSCRC) at Pendleton, operated jointly by Oregon State University and the USDA-Agricultural Research Service (ARS) have conducted several long-term experiments to evaluate carbon sequestration potential in low rainfall areas of eastern Oregon. This research suggests that permanent grass cover promotes the highest rate of carbon storage in the top 30 centimeters of soil, and that no-till results in net carbon storage in the top 30 centimeters of soil, but the overall carbon sequestration potential of these soils is relatively low (Albrecht et al., 2008). Nevertheless, the carbon accumulated in the upper soil profile boosts soil tilth and quality, and strategies that increase carbon near the soil surface will help agricultural producers adapt to warmer temperatures and other consequences of climate change.

In the summer of 2009, ARS researchers at the CPSCRC also published the results of a ten-year study evaluating several cropping patterns on soil organic carbon up to 150 centimeters in soil depth (Gollany et al., 2009). One of the findings in the study is that soil organic carbon levels increase significantly throughout the soil depth evaluated under a continuous wheat no-till system.

Studies in other parts of the United States show nitrogen management strategies such as proper application rate matched to crop needs, proper timing, and using slow-release forms of fertilizer can reduce nitrous oxide emissions associated with fertilizer application (Snyder et al., 2007; Halvorson et al., 2009). Emissions rates vary widely by soil and location, and soil emission rates for Oregon have not yet been researched.

Livestock diet and manure management can affect methane and nitrous oxide emissions. Odongo et al. (2007) find that adding an ionophore, monensin, to the diet of lactating dairy cows achieves long-term reduction of methane emissions. Some other studies also find long-term benefits from monensin, while others find only short-term effects. Many fertilizer application strategies that reduce greenhouse gas emissions also apply to manure management strategies, such as applying the right amount of nitrogen for the crop, and timing the application appropriately.

Agricultural producers in Oregon have implemented a variety of energy efficiency and renewable energy strategies to reduce electricity, natural gas, propane, diesel, and gasoline use, directly and indirectly reducing carbon dioxide emissions. No comprehensive assessment of the amount of reductions or the potential for further reductions currently exists. This year, USDA National Agricultural Statistics Service plans to conduct the first on-farm renewable energy survey, so it is possible that additional energy and agriculture statistics will be available for Oregon in the future.

Some other states, such as Washington, have conducted assessments of the greenhouse gas mitigation potential by agricultural producers, but no comprehensive assessments have been conducted in Oregon.

4.7 Adaptation options

Recommendations from the Climate Change Integration Group (2008) specific to Oregon agriculture include:

- Introduction and study of more heat and drought tolerant species and animal breeds
- Developed genetic tools for adaptation
- Avoid over-management that could lead to greater risk
- Short-term: adaptive management
- Long-term: new crop varieties
- Foster no-till soil management
- Improve water-use efficiency and infrastructure

- Develop more accurate seasonal to annual climate forecasting

The International Food Policy Research Institute (Nelson et al., 2009) summarizes the top eight policy and program priorities for agriculture:

1. Design and implement good overall development policies and programs.
2. Increase investments in agricultural productivity.
3. Reinvigorate national research and extension programs.
4. Improve global data collection, dissemination, and analysis.
5. Make agricultural adaptation a key agenda point within the international climate negotiation process.
6. Recognize that enhanced food security and climate-change adaptation go hand in hand.
7. Support community-based adaptation strategies.
8. Increase funding for adaptation programs.

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