CLIMATE, WEATHER AND HOPS





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Climate, Weather and Hops

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This weather-based uncertainty and specialty crop production series presents conceptual maps of growers' views and priorities on apples (technical report 1046), wine grapes (technical report 1043), hops (technical report 1045), strawberries (technical report 1047) and sweet corn (technical report 1048). Department of Sociology, College of Agriculture and Life Sciences, Iowa State University, Ames Iowa. www.soc.iastate.edu/research/specialtycrops/

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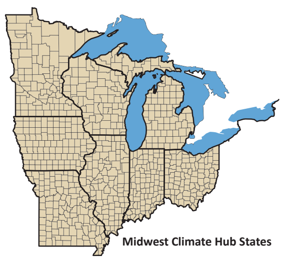

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Oregon and Washington hop production and a changing climate: growers' views and priorities to manage uncertainty in production systems

Lois Wright Morton, David Gent, Mark Gleason

Hop production and climate

Hop production in the United States (U.S.) is concentrated in the temperate climates of the Pacific Northwest. In recent years, it has been expanding into the Upper Midwest and eastern U.S. after a 100-year absence due to the growth of craft and specialty brewers across the U.S. Hop productivity and quality are sensitive to temperature and water availability, among other factors (Walthall et al. 2012). The plant requires heat and long days to flower and produce adequate cone yields, but also has variety-specific chilling requirements of 40°F or less for 1 to 2 months (Sirrine et al. 2010). Ideal conditions for growth and development include consistent, moderate temperature in spring, adequate moisture from irrigation or rain throughout season, and dry weather during harvest (Sirrine et al. 2010).

Shifting climate patterns have important implications for the established commercial hop production of the Pacific Northwest and new hop production areas. Average temperatures in the U.S. have increased by 1.3° F since record keeping began in 1895, with the greatest increases occurring since 1970 (Mote et al. 2014). This changing climate has increased the frost-free season in the Pacific Northwest (NW) by more than 16 days and extended the growing season for hop production (Melillo et al. 2014). Warming in the Pacific Northwest has been linked to changes in the timing and amount of water availability in basins, with significant snowmelt contributions to stream flow. Since around 1950, area-average snowpack on April 1 in the Cascade Mountains decreased about 20% and spring snowmelt occurred 0 to 30 days earlier depending on location. Late winter/early spring stream flow increases ranged from 0% to greater than 20% as a fraction of annual flow, and summer flow decreased 0 to 15% (Mote et al 2014). By 2050, these changes in temperature and water availability are projected to present even more challenges to agriculture, with snowmelt expected to shift to three to four weeks earlier than the last century's average, and summer stream flows projected to be substantially lower (Melillo et al. 2014).

Changes in climate interact with other environmental and societal factors in ways that can either moderate or intensify their impacts on production systems. Current and projected shifts in climate patterns and weather on U.S. agricultural production suggest that climate is an additional risk, joining production, finance and marketing risks already managed by growers (Walthall et al. 2012). Increased climate risk adds complexity and increases uncertainty in agricultural decision-making throughout many aspects of U.S. hop production, especially pest and pathogen risks. For example, powdery (*Podosphaera macularis*) and downy mildew (*Pseudoperonospora humuli*) are primary management concerns for hop growers (Gent et al. 2013; Mahaffee et al. 2009; Sirrine 2010). Plants are most vulnerable to downy mildew during periods of heavy rainfall and temperatures between 60-70° F. In contrast, powdery mildew thrives in dry conditions with high humidity, a combination which occurs commonly in Pacific Northwest hop production regions. At present, the powdery mildew fungus survives season-to-season in association with infected buds, with the disease cycle beginning in spring at the first emergence of infected shoots (Gent et al. 2008). Powdery mildew infection and spore reproduction occur in the range of 50°-86°F, affecting leaves and, more importantly, cone yields, bittering acids, cone appearance, and potentially giving hops an off-flavor (Gent et al. 2014). Epidemics can seemingly develop overnight, but there is a great deal of uncertainty as to when major outbreaks will occur on cones and the best timing of fungicide sprays. This uncertainty is linked to variability in weather conditions, the amount of inoculum, the hop growth and development phase, and other biophysical and management relationships which are not yet well understood (Twomey et al. 2015).

As climate and weather become more variable, hop growers face increased uncertainty in making decisions about their crop. Given the unprecedented nature of these changes, growers may no longer have enough information and intuitive understanding to adequately assess the situation and evaluate their management options. Uncertainty can stem from social, economic, and/or biophysical factors that limit knowledge needed to make timely, good decisions.

It is unclear how hop growers perceive risks to their production systems and what adaptations have potential to reduce uncertainties associated with their management decisions. This technical report is a preliminary effort to summarize information gathered from Oregon and Washington hop growers to better understand how they view uncertainty and decisions associated with a variety of production challenges. First, a brief overview of U.S., Oregon, and Washington hop production is presented. This is followed by an explanation of the concept mapping methodology used to gather and analyze grower information. Then, conceptual maps of Oregon and Washington hop growers' views and priorities associated with managing their production systems under increasing uncertainties are shown and discussed. Supporting data are found in Appendices I-IV.

U.S. and Pacific Northwest hop production

Total U.S. hop total production and crop value were at record levels in 2016. More than 87.1 million pounds of hops were produced in 2016, an 11% increase from 78.8 million pounds in 2015 (NASS 2016). The total value of the 2016 hop production was nearly $500 million, with the Washington crop valued at $382 million, Oregon at $65 million, and Idaho at $51 million (Figure 1) (NASS 2016). While the Pacific Northwest, led by Washington, dominates the number of farms and acres in production, U.S. hop production has expanded dramatically since 2007. According to the 2012 Census of Agriculture, the number of U.S. farms producing hops increased 144% from 68 in 2007 to 166 in 2012 (Figure 2), with farm numbers expanding beyond Washington, Oregon, and Idaho to encompass the Great Lakes Region,

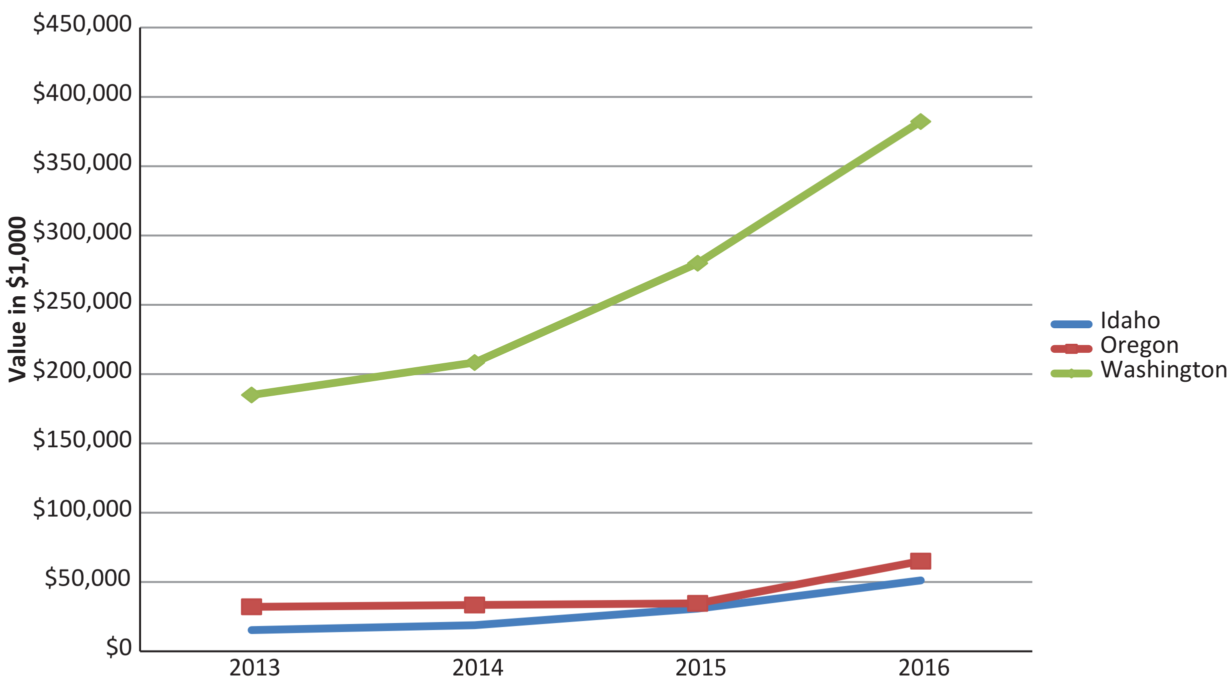


Figure 1. Pacific Northwest hop value of production, 2013-2016.

Washington 2016 value of production, $382,208,000; Oregon 2016 value of production $65,075,000; Idaho 2016 value of production $51,137,000.

National Hop Report: Released Dec 16, 2016: National Agricultural Statistics Service (NASS), Hop Area Harvested, Yield Production, Price and Value-States and United States: 2013-2016 USDA Agricultural Statistics Board, United States Department of Agriculture (USDA).

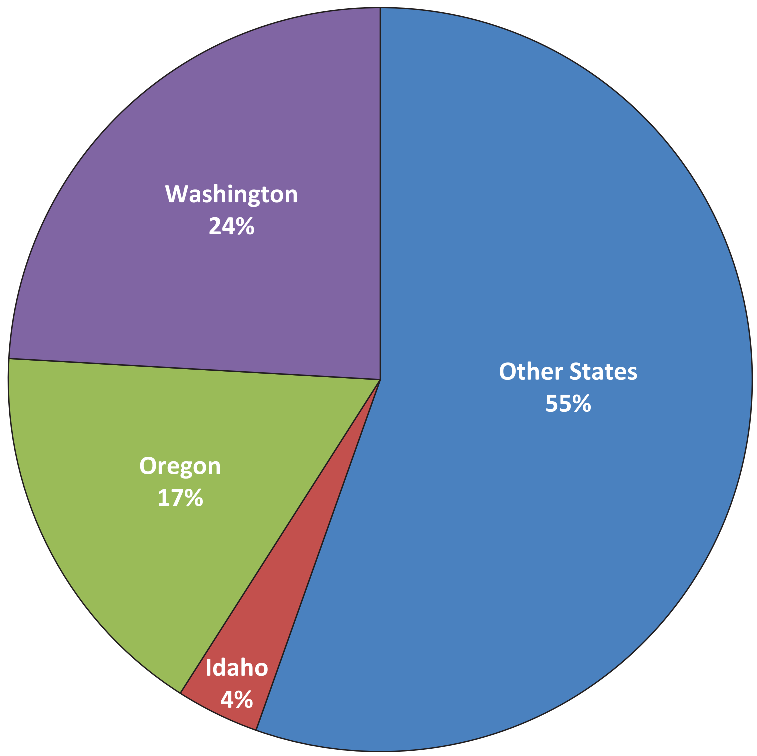


Figure 2. Total 2012 number of U.S. farms in hop production, 166.

Washington, 40; Oregon, 28; Wisconsin, 22; Michigan, 19; New York, 12; Colorado, 9; Idaho, 6; Nebraska, 6; California, 8; Illinois, 4; other states, 15. USDA NASS U.S. Census of Agriculture. 2012.

Nebraska, California, Colorado, New York State, and elsewhere (U.S. Census of Agriculture 2012). The Hop Growers of America report a new wave of growth in craft and specialty brewers throughout the U.S., and estimated 2016 U.S. commercial hop production at a total of approximately 52,000 acres (Hop Growers of America 2016). The Pacific Northwest dominates commercial production at 50,857 acres or 98% of 2016 hop production acres (Washington 37,444 acres; Oregon, 7,765 acres; Idaho, 5,648 acres) (Figure 3). This represents a considerable increase in pounds of production over 2014 and 2015 (Figure 4).

More than 99% of all U.S. hop acres are irrigated (NASS 2012) because of crop requirements for high soil moisture during the growing season. Irrigation is a necessity during the growing period in commercial hop production in the Pacific Northwest because the 20 to 40 inches of annual precipitation predominately occurs during the dormant season resulting in dry conditions during the summer production season. Production areas in Washington and southern Idaho are semi-arid, receiving less than 10 inches of precipitation annually. Irrigation water may be from groundwater or surface waters, with both being impacted by recharge from winter precipitation and mountain snowpack. The uncertainty surrounding water demand and availability is expected to increase with larger demand for non-agricultural uses, greater regulations on water withdraws, and climate change. Specifically, changes in seasonal precipitation and snow melt may require greater water use efficiency to maintain production capacity and quality. Similarly, lack of winter chilling and greater frequency of atypically warm spring and summer temperatures have important implications for the timing of critical cultural practices such as spring pruning and training. Changes in established production practices, and potentially a shift in cultivars produced in the region, may be necessary to mitigate these risks.

Concept mapping views and priorities

Hop growers are seeking strategies to better assess risks and vulnerabilities in order to reduce uncertainty in their production systems under changing short and long-term weather conditions

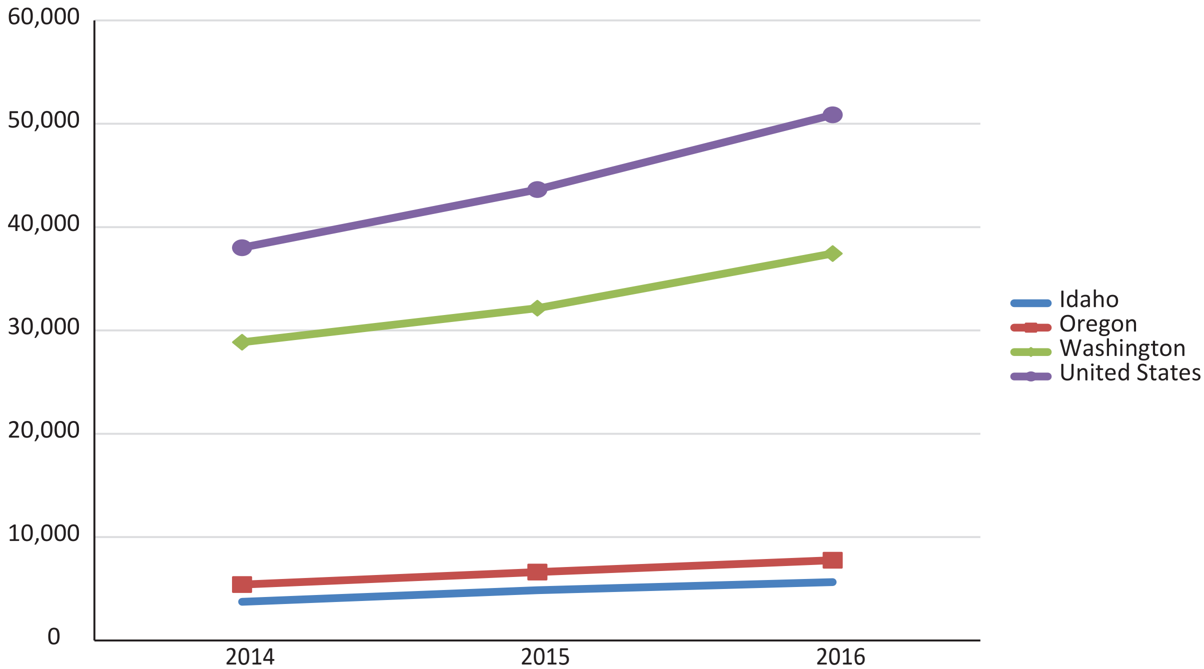


Figure 3. U.S. hop acres harvested, 2014-2016.

2016 harvested acres: Washington 37,444 acres; Oregon 7,765 acres; Idaho 5,648 acres.
National Hop Report: Released Dec 16, 2016: National Agricultural Statistics Service (NASS), Hop Area Harvested, Yield Production, Price and Value-States and United States: 2013-2016.
USDA Agricultural Statistics Board, United States Department of Agriculture (USDA).

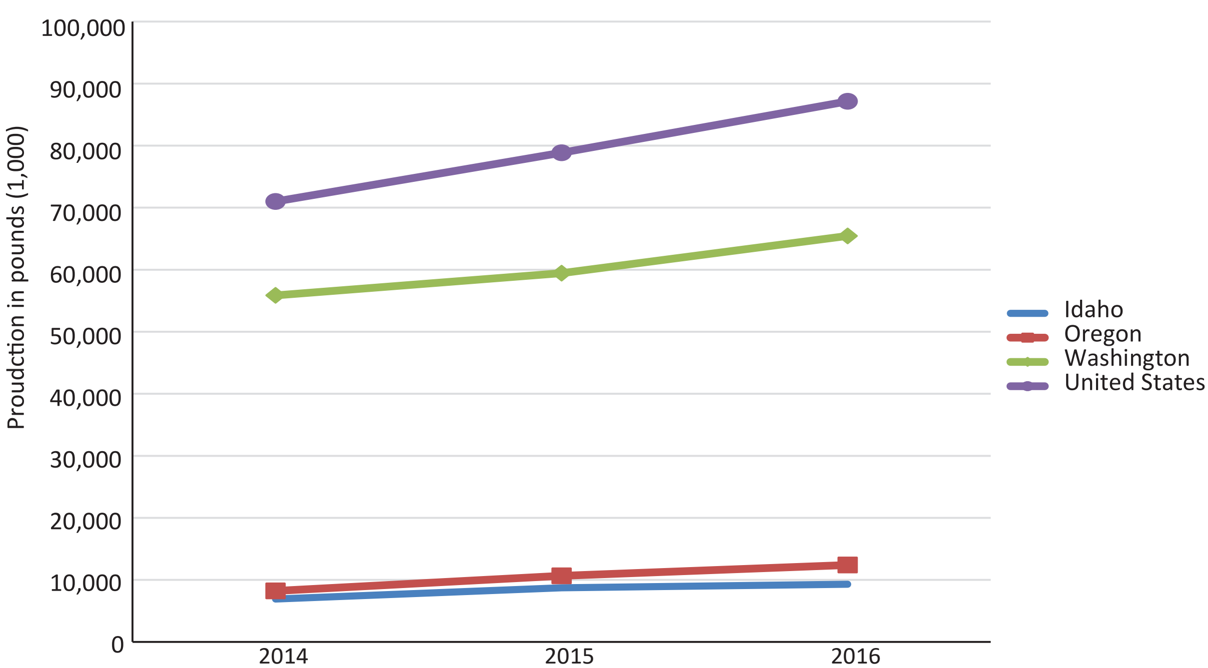


Figure 4. U.S. pounds of hop production, 2014-2016.

USDA National Hop Report: Released Dec 16, 2016: National Agricultural Statistics Service (NASS), Hop Area Harvested, Yield Production, Price and Value-States and United States: 2013-2016.
USDA Agricultural Statistics Board, United States Department of Agriculture (USDA).

and to improve their decision-making capacity. On March 30 and 31, 2016 Oregon hop growers and several of their crop advisors were convened in Hubbard/Woodburn, Oregon to discuss challenges to their production systems, including impacts of temperature, precipitation, and other weather-related issues. A day later, a group of Washington hop growers and crop advisors convened in Moxee, Washington. During the first day of their session, scientists from USDA Agricultural Research Service (ARS) and Iowa State University invited the growers in each of the groups to identify production concerns and uncertainties in their systems that they have difficulty managing. In later follow-up sessions, growers rated and sorted the concerns they identified based on their individual perspectives. A concept mapping process was used to capture individual growers' challenges as well as areas of common concern among the group. The goal of the science team was to gather information to guide future research and extension-outreach programming that would reduce uncertainty in different aspects of hop production decisions.

Concept mapping is a participatory planning process which spatially maps the thoughts and knowledge of a particular group of people and enables the creation of a common framework for planning and evaluation of issues that matter to that group (Kane and Trochim 2007). The process begins with the group brainstorming key ideas together, then individually rating each of the idea statements by how critical or important it is to them, followed by individual sorting of the statements into groups of related concepts.

In the Oregon hop grower meeting, nine participants first brainstormed by completing the statement: "One uncertainty in my production system I have difficulty managing is…" The brainstormed statements were recorded on a large screen where the entire group could read them and discuss each as the list was made. The Oregon group generated 52 statements (see Appendix II for the complete list). Then, participants individually rated each statement using a 1-5 Likert scale based on how critical they thought it was to reduce uncertainty in their production system related to this statement (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical). Lastly, participants individually sorted the 52 statements into separate piles or groups based on perceptions of statement similarities and gave them labels. Some participants lumped statements together, whereas others split the statements into many groupings. The smallest number of groups created by a participant in the Oregon group was four; the largest contained 11 groupings. The Washington hop grower meeting followed a similar process, with 10 hop growers and advisors first brainstorming 52 items using the identical statement. Different participants sorted the statements into as few as four groupings and as many as 14.

Conceptual maps for the Oregon and Washington hop growers were computed separately using multi-dimensional scaling analysis, which locates each statement as a separate point on a map based on how the participants in that particular group sorted the statements they generated. A similarity matrix from the sorts was constructed from statements based on how they were grouped together by the participants. Statements that were conceptually viewed as similar are located closer to each other on the point map and statements that were grouped together less frequently have more distance separating them on the map. The point map for Oregon is presented in Figure 5 and the point map for Washington in Figure 8. Hierarchical cluster analysis was then used to partition the statements on the point map into clusters representing conceptual groupings. Then, the average ratings for each statement and each cluster were computed and overlaid on the spatial map based on how critical it is to reduce uncertainty.

Oregon growers' conceptual maps and priority ratings

The Oregon hop growers' point map (Figure 5) and cluster maps represented by the polygons in Figures 6 and 7 offer a visual way to understand the conceptual thinking of the hop growers. The maps along with the cluster lists (Table 1/ Appendix I) and statement ratings list (Table 2/ Appendix II) provide data that help interpret what these growers view as critical uncertainties in their production systems and which uncertainties are more difficult for them to manage. These three maps - the point map and two different cluster maps - illustrate different ways of portraying the conceptual structure of the data. The point map (Figure 5) represents an integration of where all participants located each statement in relationship to other statements, i.e., the way statements were categorized as similar or different. Each of the 52 different statements brainstormed by growers is uniquely located on the point map. Note that some numbers group together and other numbers are quite distant from other numbers. Thus, even without drawing polygons around the grouped numbers, it is apparent that the statements group into two, three or more distinct clusters.

Oregon cluster maps and priority ratings

One value of the conceptual maps is that they identify and prioritize general and specific areas where research and programming would most benefit growers and guide where to invest resources. The Oregon two-cluster (Figure 6) and four-cluster (Figure 7) rating maps show how the statements were grouped, with average cluster ratings overlaid. The cluster names were chosen subjectively by the researchers using a combination of the labels given by growers and the items within each cluster. Layers in the polygons represent the relative importance of the different clusters. For example, the five layers of cluster 1 (Disease) in Figure 6 indicate that a large number of items in that cluster were rated as very critical to reduce uncertainty by many of the participants.

The two-cluster rating map in Figure 6 shows two major conceptual areas of uncertainty identified by the Oregon hop growers: disease and weather. Although the disease polygon has the higher priority weightings compared to weather polygon as critical to reduce uncertainty, it is important to note that the average value range (3.25-3.44)

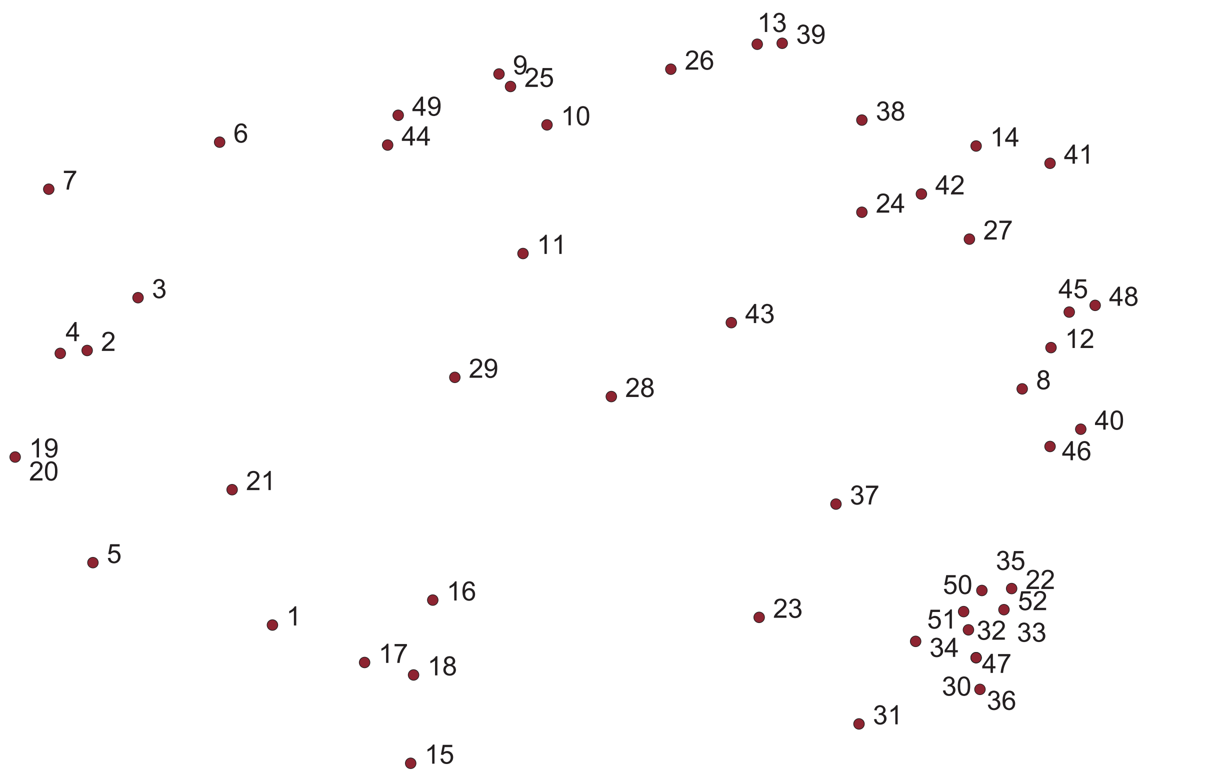
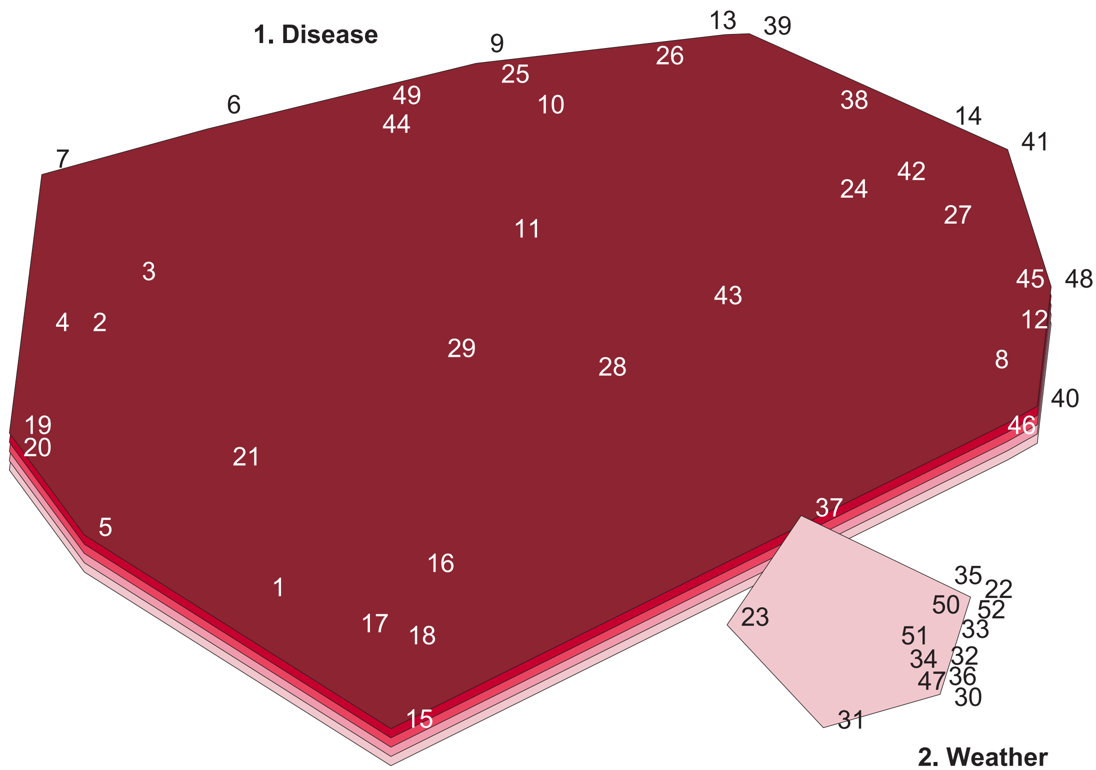


Figure 5. Point map of Oregon hop growers' sorting of 52 statements, "One uncertainty in my production system I have difficulty managing is…".



Cluster Legend

Layer	Value
1	3.25 to 3.29
2	3.29 to 3.33
3	3.33 to 3.37
4	3.37 to 3.41
5	3.41 to 3.44

Figure 6. Two-cluster Oregon hop growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical).".

for these clusters is very narrow and represents an assessment above moderately critical (3.00) for both. This is not unexpected; growers were asked to identify areas of uncertainty and all items brainstormed by the group are substantive challenges they are facing. The variation in ratings between these two clusters is a nuance, rather than a substantial difference.

Further analysis of the point map (Figure 5) reveals that the disease and weather groupings can be more finely divided into smaller, more focused sub-areas for improved targeting. The two-cluster map naturally breaks into four sub-areas of uncertainty (Figure 7): *1) labor, neighbors & regulations; 2) optimizing inputs under variable weather; 3) market access & volatility; and 4) weather & crop quality*. Note that the four-cluster map shows that uncertainties associated with hop production are both social and biophysical in nature.

Table 1 provides summary data on the four-cluster map, the grand means and the top-ranked statements in each cluster. Although all four polygons have grand means above moderately critical (3.00) and below very critical (4.00), the clusters can be ranked from high to low.

A closer look at the statements within each of the four clusters (Figure 7; Table 1) offers a deeper understanding of what each cluster conceptually represents (Appendix I).

Figure 7. Four-cluster Oregon hop growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5

Labor, neighbors & regulations consisting of 14 statements, is the highest rated cluster with a grand mean of 3.61, representing an overall value that rounds up to very critical (4.00) level of importance for reducing uncertainty. The top ranked statement, labor availability for two peak periods per season (4.78), is driving this concern, which was considered by almost all participants to be extremely critical (5.00). The next three top-ranked statements (Appendix I) were rated 4.00 (very critical) or slightly above: labor cost (4.33); labor-retention of quality permanent employees (4.11); and increasingly restrictive government regulations on pesticides (4.00). The next grouping in this cluster ranged between 3.56 and 3.78, representing very critical priority to reduce uncertainty: quarantine to keep out powdery mildew mating type is routinely violated (3.78); increasingly restrictive government regulations on labor (3.78); labor scarcity of farming and management skills (3.56); and lack of understanding by hop growers of reasons for quarantines (3.56). Three statements were rated 3.44 (moderately critical): limited water availability for irrigation; labor-missing work ethic among younger workers; and increasingly restrictive government regulations on water. The last three statements in this cluster ranged from 2.67 to 2.89 (moderately critical): disconnect of consumers from realities of crop production (2.89); disconnect of consumers from realities of rural living (2.78); and newly arrived residents (to rural places) misunderstand agriculture (2.67).

Table 1. Oregon hop growers' priority ratings of uncertainties in their production systems. "One uncertainty in my production system I have difficulty managing is…"

Cluster Name	Grand Mean	# Statements	Top-ranked Statement	Statement Rating
Labor, neighbors & regulations	3.61	14	2. Labor availability for two peak periods per season	4.78
Market access & volatility	3.35	12	9. Volatility of hop markets due to changes in marketing demands	4.22
Optimizing inputs under variable weather	3.34	12	8. Need for more effective genetic resistance to major diseases	4.00
			24. Rising costs of inputs and capital	4.00
Weather & crop quality	3.25	14	22. Weather-driven uncertainties associated with mildew risk	3.78
			33. Yield impacts due to weather	3.78
			34. Weather impacts on hop quality	3.78

Market access & volatility, is the second highest rated cluster at 3.35 (moderately critical) consisting of 12 statements ranging from a high of 4.22 (very critical to reduce uncertainty) to 2.67, slightly below moderately critical (3.00) priority to reduce uncertainty (Appendix I). Two other statements were also rated very critical: volatility of hop markets due to rapidly changing variety preferences by breweries (4.00) and uncertainty about durability of growth in the hop market (3.89). Six statements were viewed as moderately critical, falling just above 3.00: keeping up with rapid changes in hop production technology (3.44); competition from Washington hop growers due to more favorable growing conditions there (3.33); risk of scaling up with a 20-year planting decision in a volatile market (3.33); unprecedented demand from craft brewers has amplified market volatility (3.33); deciding whether to invest in new harvest technology (3.22); and balancing risks and rewards of growing public vs proprietary varieties (3.11). The last three statements in this cluster were moderately critical, falling below 3.00 but higher than 2.50: economic pressure to over-apply pesticides and fertilizer due to high price of crop (2.89); small-scale industry is at a competitive disadvantage for research funding (2.78); and government funding for marketing data (2.67).

Optimizing inputs under variable weather, a sub-cluster of the weather two-cluster map, has a grand mean of 3.34 (moderately critical) which is almost identical to the grand mean of the market access & volatility cluster. Consisting of 12 statements (Appendix I), the two highest ranked statements in this group are rated very critical: need for more effective genetic resistance to major disease (4.00); and rising cost of inputs and capital (4.00). Two additional, very critical to reduce uncertainty, statements rated slightly below 4.00 are, uncertainty about optimal control measures for powdery and downy mildews (3.67); and determining optimal balance of inputs (3.56). Six statements at 3.00 (moderately critical) or slightly above are precision management decision making carries higher risks (3.44); investing in new ways to monitor plant stress (3.33); when to make the final spray of the season for pests and diseases (3.33); better and more integrated access to historical (past 7 days) as well as current pest and disease risk (3.11); decision making whether to invest in new technologies associated with precision agriculture (3.00); and timing of fertilizer strategies (3.00). The last two statements in this cluster are slightly below 3.00, moderately critical: adding evapotranspiration (ET) into irrigation timing decisions (2.89), and rapid changes in irrigation technology to drip from overhead irrigation that are driven by disease pressure (2.78).

Weather & crop quality, also a sub-cluster of the weather two-cluster map has a grand mean rating of 3.25 representing moderately critical to reduce uncertainty. All 14 statements in this cluster fall below 4.00 (very critical) (Appendix I). However, the five top rated statements round up to very critical: weather-driven uncertainties associated with mildew risk (3.78); yield impacts due to weather (3.78); weather impacts on hop quality (3.78); wet spring weather impacts field activities and raises disease risk (3.67); and warm winters impact crop dormancy and disease pressure (3.67). Six statements fall at 3.00 (moderately critical) or slightly above: rain at harvest reduces hop quality (3.33); weather-driven uncertainties associated with planning labor needs (3.33); difficulty of pest management decision during rapidly changing springtime weather conditions (3.22); hop quality issues–bitterness, color, and aroma–can lead to lower prices (3.11); El Niño-La Niña weather patterns impact disease risk (3.00) and wind and rain damage to trellis systems near harvest (3.00). Two statements falling below 3.00 are considered moderately critical: heat damage to hop quality during springtime (May) raises risk of expression of virus symptoms (2.78) and wet weather delays drying of hops and can lead to crop rejection (2.67). The last statement in this cluster, September rains can cause collapse of hop trellis (2.44), is rated somewhat critical.

Top quartile statements. Another way to examine the findings is to list all 52 statements arranged by highest to lowest rating (Appendix II). The top quartile (25%) of hop growers' statement rankings based on ratings is shown in Table 2. These top 14 statements range from 4.78, in the extremely critical range, to 3.78, very critical levels of uncertainty that growers view as needing addressed to reduce risk in hop production systems. The highest rated statements reflect extremely critical levels of uncertainty associated with labor and very critical uncertainties associated with volatility in markets, rising costs of inputs and capital, and government regulations. A second area of uncertainty is issues related to diseases and weather-driven powdery and downy mildew risks, yield impacts, and hop quality.

Table 2. Top quartile (25%) Oregon hop growers' ranked statements. "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical)."

Statement Number		Average Rating	Cluster Number
2	Labor availability for two peak periods per season	4.78	1
1	Labor cost	4.33	1
9	Volatility of hop markets due to changes in marketing demands	4.22	3
3	Labor—retention of quality permanent employees	4.11	1
18	Increasingly restrictive government regulations on pesticides	4.00	1
24	Rising costs of inputs and capital	4.00	2
8	Need for more effective genetic resistance to major diseases	4.00	2
10	Volatility of hop markets due to rapidly changing variety preferences by breweries	4.00	3
25	Uncertainty about durability of growth in hop market	3.89	3
6	Quarantine to keep out powdery mildew mating type is routinely violated.	3.78	1
17	Increasingly restrictive government regulations on labor	3.78	1
22	Weather-driven uncertainties associated with mildew risk	3.78	4
33	Yield impacts due to weather	3.78	4
34	Weather impacts on hop quality	3.78	4

Washington growers' conceptual maps and priority ratings

The Washington hop growers' point map is presented in Figure 8 and cluster maps represented by the polygons in Figures 9 and 10. Cluster lists are given in Table 3/Appendix III and the statement ratings list is presented in Table 4/ Appendix IV.

Washington cluster maps and priority ratings

The two-cluster (Figure 9) and four-cluster (Figure 10) rating maps show how the statements were grouped, with average cluster ratings overlaid. The two-cluster rating map in Figure 9 shows two major conceptual areas of uncertainty identified by the hop growers: climate & agronomy and growing the farm to meet market demand. Although the climate & agronomy polygon has the higher priority weightings for its criticalness to reduce uncertainty, it is important to note that the value range (3.55 to 3.61) for these clusters is very narrow and represents an average assessment above moderately critical and close to very critical (4.00). This two-cluster map reflects that uncertainties associated with hop production in Washington are both social-economic and biophysical in nature.

One value of the conceptual maps is that they identify and prioritize general and specific areas where research and programming would most benefit growers and guide where to invest resources. Further analysis of the point map (Figure 8) reveals that the climate & agronomy and growing the farm to meet market demand groupings can be more finely divided into smaller, more focused sub-areas for improved targeting. Figure 10 shows a four-cluster map that breaks the climate & agronomy polygon from Figure 9 into two sub-areas of uncertainty: *1) soil-water-plant interactions*, and *2) weather & plant stress*. The growing the farm to meet market demand polygon breaks into two sub-areas representing *3) labor & business development*, and *4) regulatory & consumer demands*.

Table 3 provides summary data on the four-cluster map, the grand means and the top-ranked statements in each cluster. *Labor & business development* (3.66) is the highest rated cluster;

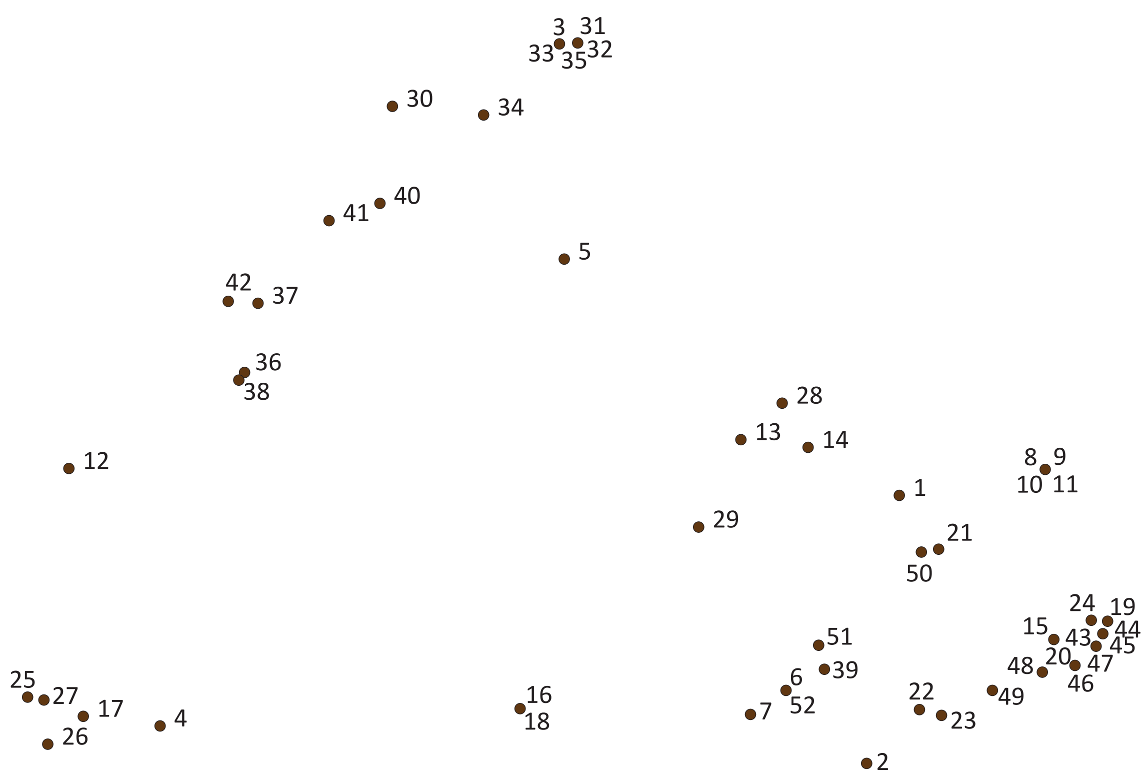


Figure 8. Point map of Washington hop growers' sort of 52 statements, "One uncertainty in my production system I have difficulty managing is…".

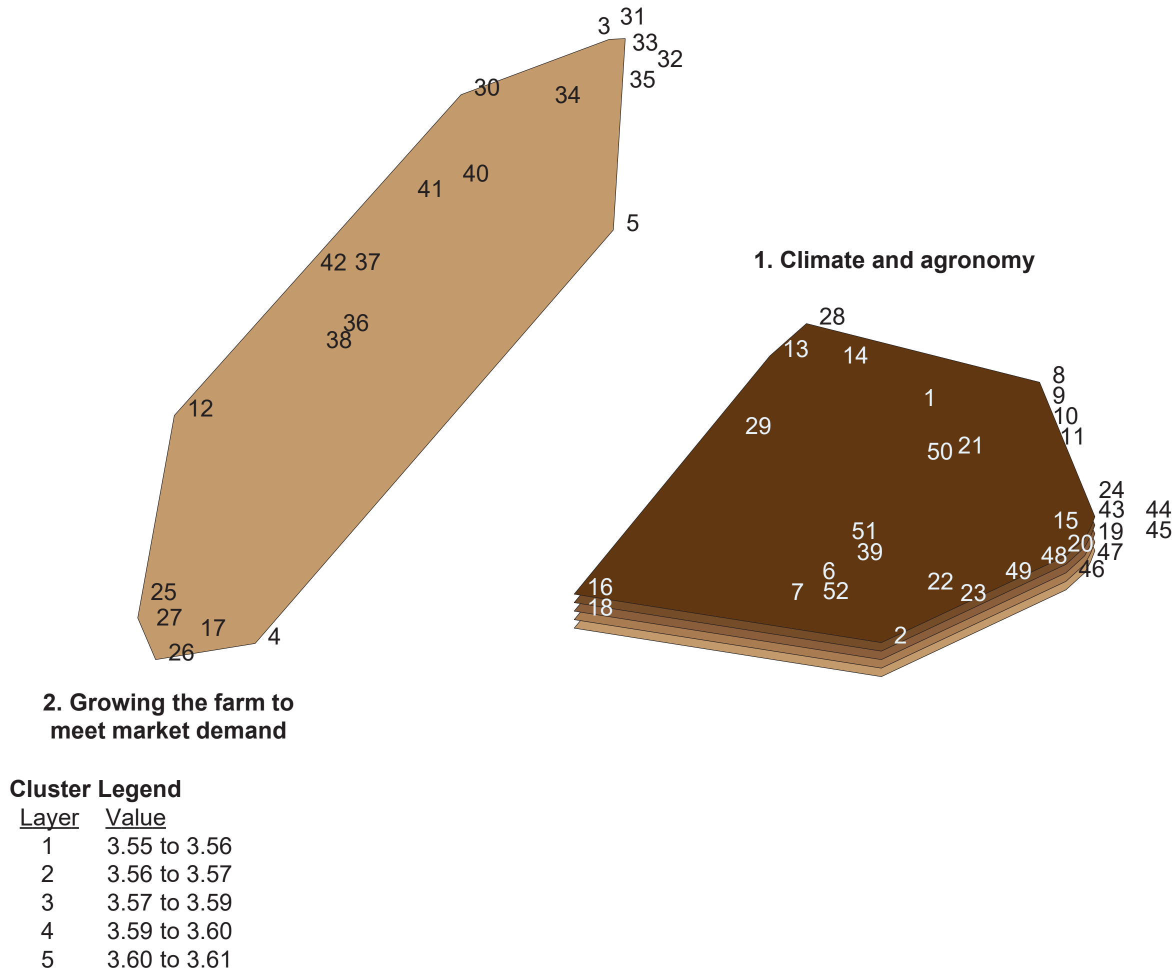


Figure 9. Two-cluster Washington hop growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical).".

and interpreted as between moderately critical (3.00) and very critical (4.00) to reduce levels of uncertainty. The second highest rated cluster, *soil-water-plant interactions* has a grand mean (3.63) only slightly lower than the top ranked cluster (Appendix III). The *weather & plant stress* cluster has a grand mean of 3.60 (very critical to reduce uncertainty) and is the third ranked cluster.

Table 3. Washington hop growers' priority ratings of uncertainties in their production systems. "One uncertainty in my production system I have difficulty managing is…"

Cluster Name	Grand Mean	# Statements	Top-ranked Statement	Statement Rating
Labor & business development	3.66	15	33. Labor regulations	4.50
			34. Labor cost	4.50
Soil-water-plant interactions	3.63	11	50. Cause of yield decline	4.30
Weather & plant stress	3.60	21	7. Irrigation water supply/availability	4.70
Regulatory & consumer demands	3.20	5	8. Powdery mildew management	4.50

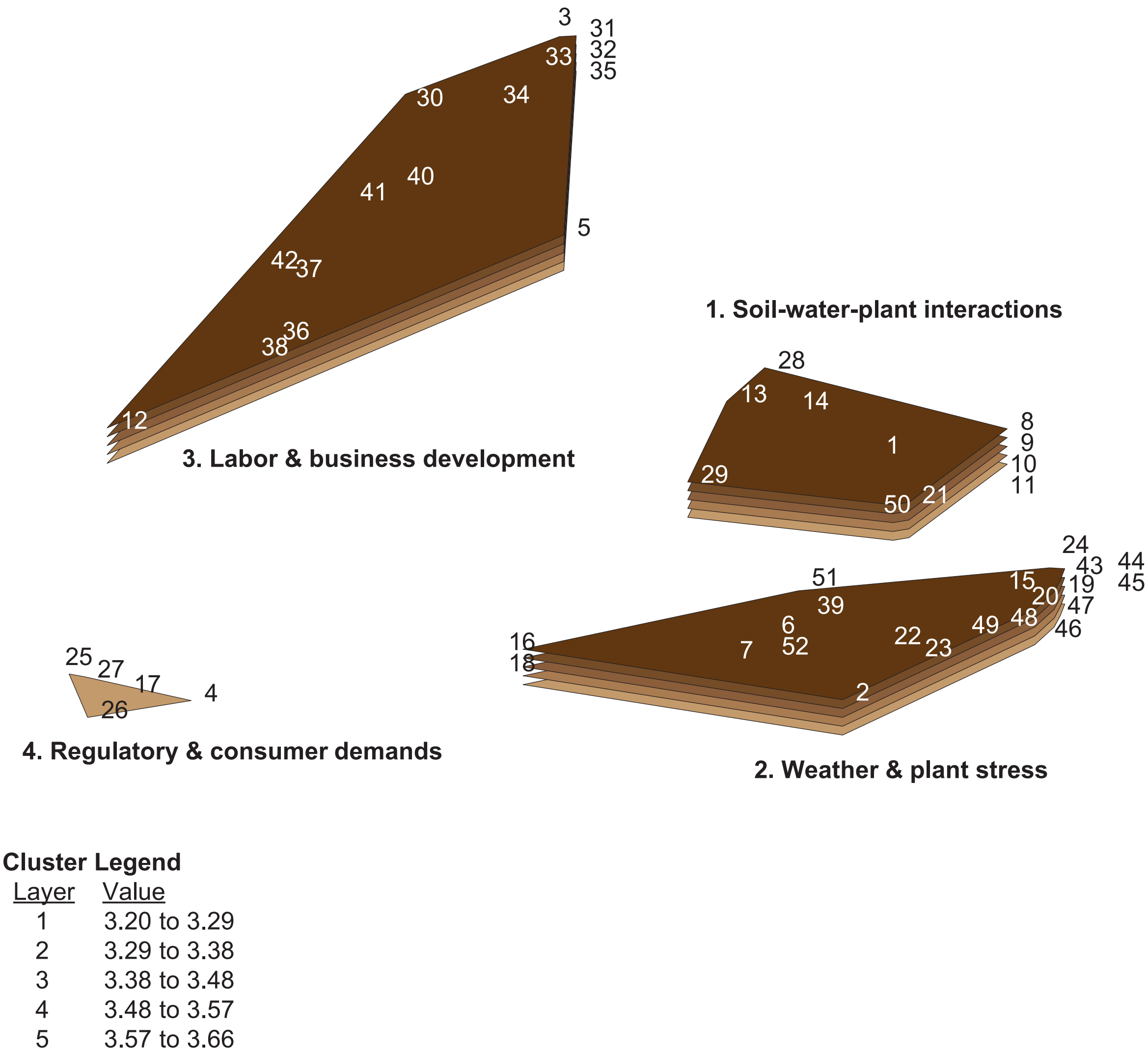


Figure 10. Four-cluster Washington hop growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical).".

Regulatory & consumer demands is the fourth cluster with a grand mean of 3.20, moderately critical to reduce uncertainty.

A closer look at the statements within each of the four clusters (Figure 10; Table 3) offers a deeper understanding of what each cluster conceptually represents (Appendix III).

Labor & business development, consisting of 15 statements, is the highest rated cluster with a grand mean of 3.66, representing an overall value between moderately and very critical to reduce uncertainty. The two top-ranked statements (4.50) in this cluster are labor regulations and labor cost rated mid-way between very and extremely critical to reduce uncertainty. Three additional highly rated labor related statements in the very critical range are labor regulations (state and federal H2A rules, and consistency) (4.40); labor work ethic (4.30); and availability of skilled labor (3.90) (Appendix III). Market volatility (4.20) and capital investment and market uncertainty (3.80) reaffirm the very critical nature of the social-economic issues associated with this cluster. Five statements rated moderately critical to reduce uncertainty elaborate on the labor force and cost of production: motivation of younger generation in the labor force (3.40); return on investment

(ROI) on inputs (3.40); rural infrastructure for recruiting educated labor/staff (3.20); supply of production inputs (3.20); and enterprise cost accounting (3.20). The last three statements in this cluster rated moderately important are succession planning (3.20); interpreting data/research in the context of commercial farming, especially issues of scaling up at the farm level (3.00); and rural vs urban perspectives with a focus on the disconnect with agriculture (2.70).

Soil-water-plant interactions, is the second highest rated cluster (3.63) consisting of 11 statements ranging from a high of 4.30 (very critical to reduce uncertainty) to 2.70, moderately critical to reduce uncertainty. The highest rated statement, cause of yield decline (4.30), followed by defining optimal fertility programs (4.10) are agronomic concerns rated very critical (Appendix III). Six soil-water-plant interactions in production systems statements rated at 4.00 (very critical) or just below are pruning timing in warm spring (4.00); nutrient management in soil and plant (nutrient demand curve) (3.90); nutrient management and interactions with soil and water (3.90); timing of spring pruning each season (3.60); efficacy of nutrient options, microbiological interaction (3.50); and production practices specific to a given variety, especially new varieties (3.50). Two additional statements above 3.00, moderately critical, are real time yield monitoring to assess on-farm research and yard-to-yard variability (3.30). The last statement in this cluster is changing existing practices at 2.70, moderately critical.

Weather & plant stress, a subset of the climate and agronomy two-cluster map, has a grand mean of 3.60 (very critical) with 21 statements ranging from 4.70 (extremely critical) to 2.80 (moderately critical). The top-ranked statement in this cluster, irrigation water supply/availability, is also the highest rated of all 52 statements at 4.70, extremely critical to reduce uncertainty. The second highest rated statement in this cluster is also water related: irrigation, actual water demands at 4.20 (very critical) (Appendix III). The influence of weather and plant stress permeates this cluster, with the next 10 statements in the very critical range: how weather influences plant physiology –all aspects (4.20); temperature impacts on pruning/training (4.10); impact of viruses/viroids on yield stability (4.00); IPM program, unpredictable pest/disease outbreaks (3.90); how does heat stress impact yield (3.90); new normal in weather is variability (3.80); changing climate conditions in winter and spring (3.60); microclimate impacts on production (3.60); warming winter and springs (3.60), and seasonal variation of mildews (3.50). Nine additional statements are rated moderately critical and continue to reflect weather and plant impacts: spring weather-long term forecasts (3.40); real time plant stress analysis (3.40); new technologies for assessing plant stress-aerial imagery (3.40); mite thresholds that are field specific (3.30); variation in microclimate between regions and farms (3.20); wind, especially near vine training time (3.10); spray drift from neighboring or distant fields (3.00); winter temperature and lack of chilling in certain varieties (3.00); and pesticide residue on organic crops (2.80).

Regulatory & consumer demands, a sub-cluster of the growing the farm to meet market demand two-cluster map, with a grand mean of 3.20 (moderately critical) has 5 statements. The top-ranked statement in this cluster is powdery mildew management (4.50) rated half-way between very and extremely critical to reduce uncertainty. Changing food safety regulations (3.50) at mid-way between very critical and moderately critical is the second highest rated statement (Appendix III). The next three statements reflect the moderately critical nature of reducing uncertainty associated with organic regulatory issues: spray drift impacts on organic certification (3.10); standardized certification programs (common sense sustainability issues) (3.10); and consumer perceptions of organic vs conventional production safety and benefits (2.70).

Top quartile statements. Another way to examine the findings is to list all 52 statements arranged by highest to lowest rating (Appendix IV). The top quartile (25%) of Washington hop grower leaders' statement rankings based on ratings is shown in Table 4. These top 13 statements range from 4.70, in the extremely critical range, to 4.00, very critical that levels of uncertainty be reduced in hop production systems. Highly rated statements reflect high levels of uncertainty associated with water supply and demand, causes of yield decline, and viruses and viroid diseases. A second area of uncertainty is issues related to labor including labor scarcity at harvest, safety and accidents, and availability of labor in general. A third grouping of highly rated statements center on climate and weather impacts on management

Table 4. Top quartile (25%) Washington hop growers' ranked statements. "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical)."

Statement Number		Average Rating	Cluster Number
7	Irrigation water supply/availability	4.70	2
33	Labor regulations	4.50	3
34	Labor cost	4.50	3
3	Labor regulations; state and federal H2A rules, consistency	4.40	3
50	Cause of yield decline	4.30	1
35	Labor work ethic	4.30	3
2	Irrigation: Actual water demands	4.20	2
48	How weather influences plant physiology; all aspects	4.20	2
42	Market volatility	4.20	3
10	Defining optimal fertility program	4.10	1
45	Temperature impacts on pruning/training	4.10	2
21	Pruning timing in warm spring	4.00	1
51	Impact of viruses/viroids on yield stability	4.00	2

decisions associated with pruning, fertility, and all aspects of plant physiology.

Observations

This preliminary report offers a snapshot of Pacific Northwest hop growers' observations, thoughts, concerns, and priorities for their crops and businesses. Using the concept mapping process, they identified social and biophysical areas where uncertainty makes managing their production systems difficult. Although Oregon and Washington growers raise crops in different climates, both groups identified issues of labor, markets, and weather concerns that affect plant stress and crop quality and management decisions.

Unknown risks and uncertainties linked to increases in temperature, variability in precipitation, shifts in the timing of snow melt, and a changing climate, as well as concerns about timing of standard practices, disease, pests, and labor were common themes in discussions with Pacific Northwest growers. Future challenges to growers will come not only from familiar past experiences such as known pests and diseases but also from a host of unknown risks which can emerge from nonlinear interactions among climate-weather, production systems, and the larger agroecosystem. For example, changes in weather patterns in spring already appear to be creating uncertainty on the timing of age-old practices such as pruning and training. Growers in both Oregon and Washington articulated a need for more detailed information to reduce uncertainty associated with basic agronomic decisions—the timing and amount of irrigation water, nutrients, and other aspects of whole plant physiology. Perhaps unexpectedly, the availability of new technologies (and more information) related to these inputs appears to have its own set of uncertainty. This suggests an increasing need for hop production research, decision support tools, information, and training that can help growers to better address risk and uncertainty and guide management decisions.

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Appendix I. Oregon hop growers' four cluster rankings

Oregon hop growers' statements (52) sorted by cluster derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical)."

One uncertainty in my production system I have difficulty managing is…

		Average Rating
1. Labor, neighbors, & regulations		**3.61**
2	Labor availability for two peak periods per season	4.78
1	Labor cost	4.33
3	Labor—retention of quality permanent employees	4.11
18	Increasingly restrictive government regulations on pesticides	4.00
6	Quarantine to keep out powdery mildew mating type is routinely violated	3.78
17	Increasingly restrictive government regulations on labor	3.78
4	Labor scarcity of farming and management skills	3.56
7	Lack of understanding by hop growers of reasons for quarantine	3.56
15	Limited water availability for irrigation	3.44
5	Labor—missing work ethic among younger workers	3.44
16	Increasingly restrictive government regulations on water	3.44
19	Disconnect of consumers from realities of crop production	2.89
20	Disconnect of consumers from realities of rural living	2.78
21	Newly arrived residents misunderstand agriculture	2.67

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
14	0.57	0.32	2.67	4.78	3.61	3.56

		Average Rating
2. Optimizing inputs under variable weather		**3.34**
24	Rising costs of inputs and capital	4.00
8	Need for more effective genetic resistance to major diseases	4.00
12	Powdery and downy mildews uncertainty about optimal control measures	3.67
42	Determining optimal balance of inputs	3.56
27	Precision management decision making carries higher risks	3.44
41	Investing in new ways to monitor plant stress	3.33
46	When to make the final spray of the season for pests and diseases	3.33
48	Better and more integrated access to historical (past 7 days) as well as current pest and disease risk	3.11
38	Deciding whether to invest in new technologies associated with precision agriculture	3.00
40	Timing of fertilization strategies	3.00
45	Adding evapotranspiration into irrigation timing decisions	2.89
14	Rapid changes in irrigation technology to drip from overhead irrigation driven by disease pressure	2.78

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
12	0.39	0.15	2.78	4.00	3.34	3.33

One uncertainty in my production system I have difficulty managing is…

		Average Rating
3. Market access & volatility		**3.35**
9	Volatility of hop markets due to changes in marketing demands	4.22
10	Volatility of hop markets due to rapidly changing variety preferences by breweries	4.00
25	Uncertainty about durability of growth in hop market	3.89
13	Keeping up with rapid changes in hop production technology	3.44
11	Competition from WA hop growers due to more favorable growing conditions there	3.33
26	Risk of scaling up with a 20-year planting decision in a volatile market	3.33
44	Unprecedented demand from craft brewers has amplified market volatility	3.33
39	Deciding whether to invest in new harvesting technology	3.22
49	Balancing risks and rewards of growing public vs. proprietary varieties	3.11
43	Economic pressure to over-apply pesticides and fertilizer due to high price of crop	2.89
28	Small-scale industry is at competitive disadvantage for research funding	2.78
29	Government funding for marketing data	2.67

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
12	0.46	0.21	2.67	4.22	3.35	3.33

		Average Rating
4. Weather & crop quality		**3.25**
22	Weather-driven uncertainties associated with mildew risk	3.78
33	Yield impacts due to weather	3.78
34	Weather impacts on hop quality	3.78
32	Wet spring weather impacts field activities and raises disease risk	3.67
31	Warm winters impact crop dormancy and disease pressure	3.67
35	Rain at harvest reduces hop quality	3.33
23	Weather-driven uncertainties associated with planning labor needs	3.33
47	Difficulty of pest management decisions during rapidly changing springtime weather conditions	3.22
37	Hop quality issues—bitterness, color, and aroma—can lead to lower prices	3.11
30	El Niño-La Niña weather patterns impact disease risk	3.00
36	Wind and rain damage to trellis systems near harvest	3.00
50	Heat damage to hop quality during springtime (May) raises risk of expression of virus symptoms	2.78
52	Wet weather delays drying of hops and can lead to rejection of bales	2.67
51	September rains can cause collapse of hopyards	2.44

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
14	0.43	0.18	2.44	3.78	3.25	3.28

Appendix II. Oregon hop growers' ranked statements

Oregon hop growers' statements (52) sorted by rating (high to low) derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical)."

One uncertainty in my production system I have difficulty managing is…

Statement Number		Average Rating	Cluster Number
2	Labor availability for two peak periods per season	4.78	1
1	Labor cost	4.33	1
9	Volatility of hop markets due to changes in marketing demands	4.22	3
3	Labor—retention of quality permanent employees	4.11	1
18	Increasingly restrictive government regulations on pesticides	4.00	1
24	Rising costs of inputs and capital	4.00	2
8	Need for more effective genetic resistance to major diseases	4.00	2
10	Volatility of hop markets due to rapidly changing variety preferences by breweries	4.00	3
25	Uncertainty about durability of growth in hop market	3.89	3
6	Quarantine to keep out powdery mildew; mating type is routinely violated	3.78	1
17	Increasingly restrictive government regulations on labor	3.78	1
22	Weather-driven uncertainties associated with mildew risk	3.78	4
33	Yield impacts due to weather	3.78	4
34	Weather impacts on hop quality	3.78	4
12	Powdery and downy mildews uncertainty about optimal control measures	3.67	2
32	Wet spring weather impacts field activities and raises disease risk	3.67	4
31	Warm winters impact crop dormancy and disease pressure	3.67	4
4	Labor scarcity of farming and management skills	3.56	1
7	Lack of understanding by hop growers of reasons for quarantine	3.56	1
42	Determining optimal balance of inputs	3.56	2
15	Limited water availability for irrigation	3.44	1
5	Labor—missing work ethic among younger workers	3.44	1
16	Increasingly restrictive government regulations on water	3.44	1
27	Precision management decision making carries higher risks	3.44	2
13	Keeping up with rapid changes in hop production technology	3.44	3
41	Investing in new ways to monitor plant stress	3.33	2
46	When to make the final spray of the season for pests and diseases	3.33	2
11	Competition from Washington hop growers due to more favorable growing conditions there	3.33	3
26	Risk of scaling up with a 20-year planting decision in a volatile market	3.33	3

One uncertainty in my production system I have difficulty managing is…

Statement Number		Average Rating	Cluster Number
44	Unprecedented demand from craft brewers has amplified market volatility	3.33	3
35	Rain at harvest reduces hop quality	3.33	4
23	Weather-driven uncertainties associated with planning labor needs	3.33	4
39	Deciding whether to invest in new harvesting technology	3.22	3
47	Difficulty of pest management decisions during rapidly changing springtime weather conditions	3.22	4
48	Better and more integrated access to historical (past 7 days) as well as current pest and disease risk	3.11	2
49	Balancing risks and rewards of growing public vs. proprietary varieties	3.11	3
37	Hop quality issues—bitterness, color, and aroma—can lead to lower prices	3.11	4
38	Deciding whether to invest in new technologies associated with precision agriculture	3.00	2
40	Timing of fertilization strategies	3.00	2
30	El Niño-La Niña weather patterns impact disease risk	3.00	4
36	Wind and rain damage to trellis systems near harvest	3.00	4
19	Disconnect of consumers from realities of crop production	2.89	1
45	Adding evapotranspiration into irrigation timing decisions	2.89	2
43	Economic pressure to over-apply pesticides and fertilizer due to high price of crop	2.89	3
20	Disconnect of consumers from realities of rural living	2.78	1
14	Rapid changes in irrigation technology to drip from overhead irrigation driven by disease pressure	2.78	2
28	Small-scale industry is at competitive disadvantage for research funding	2.78	3
50	Heat damage to hop quality during springtime (May) raises risk of expression of virus symptoms	2.78	4
21	Newly arrived residents misunderstand agriculture	2.67	1
29	Government funding for marketing data	2.67	3
52	Wet weather delays drying of hops and can lead to rejection of bales	2.67	4
51	September rains can cause collapse of hopyards	2.44	4

Appendix III. Washington hop growers' four cluster rankings

Washington hop growers' statements (52) sorted by cluster derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on,

"How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical)."

One uncertainty in my production system I have difficulty managing is…

		Average Rating
1. Soil-water-plant interactions		**3.63**
50	Cause of yield decline	4.30
10	Defining optimal fertility program	4.10
21	Pruning timing in warm spring	4.00
8	Nutrient management in soil and plant; nutrient demand curve	3.90
9	Nutrient management and interactions with soil water	3.90
1	Timing of spring pruning each season	3.60
14	Production practices specific to a given variety, especially new varieties	3.50
11	Efficacy of nutrient options, microbiological interactions	3.50
29	Real time yield monitoring to assess on farm research and yard-to-yard variability	3.30
13	Selecting varieties	3.10
28	Changing existing practices	2.70

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
11	0.45	0.20	2.70	4.30	3.63	3.60

2. Weather & plant stress		**3.60**
7	Irrigation water supply/availability	4.70
2	Irrigation: Actual water demands	4.20
48	How weather influences plant physiology; all aspects	4.20
45	Temperature impacts on pruning/training	4.10
51	Impact of viruses/viroids on yield stability	4.00
6	IPM program; unpredictable pest/disease outbreaks	3.90
49	How does heat stress impact yield	3.90
47	New normal in weather is variability	3.80
20	Changing climate conditions in winter and spring	3.60
24	Microclimate impacts on production	3.60
46	Warming winter and springs	3.60
39	Mildews; seasonal variation	3.50
43	Spring weather; long term forecast	3.40
23	Real time plant stress analysis	3.40
22	New technologies for assessing plant stress; aerial imagery	3.40
52	Mite thresholds that are field specific	3.30

One uncertainty in my production system I have difficulty managing is…

								Average Rating
15	Variation in microclimate between regions/farms							3.20
44	Wind, especially near training							3.10
16	Spray drift from neighboring or distant fields							3.00
19	Winter temperature and lack of chilling in certain varieties							3.00
18	Pesticide residue on organic crops							2.80
	Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median	
	21	0.47	0.22	2.80	4.70	3.60	3.60	
3. Labor & business development								**3.66**
33	Labor regulations							4.50
34	Labor cost							4.50
3	Labor regulations; state and federal H2A rules, consistency							4.40
35	Labor work ethic							4.30
42	Market volatility							4.20
31	Availability of skilled labor							3.90
41	Capital investment and market uncertainty							3.80
32	Motivation of younger generation labor force							3.40
36	Return on investment on inputs							3.40
30	Rural infrastructure for recruiting educated labor/staff							3.20
37	Enterprise cost accounting							3.20
40	Succession planning							3.20
38	Supply of production inputs							3.20
5	Interpreting data/research in context of commercial farming; issues of scaling up at farm							3.00
12	Rural vs. Urban perspectives; disconnect from agriculture							2.70
	Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median	
	15	0.58	0.34	2.70	4.50	3.66	3.40	
4. Regulatory & consumer demands								**3.20**
4	Powdery mildew management							4.50
26	Changing food safety regulations							3.50
17	Spray drift impacts on organic certification							3.10
25	Common sense sustainability issues; standardized certification programs							3.10
27	Consumer perceptions of organic vs. convention safety/benefits							2.80
	Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median	
	5	0.27	0.07	2.80	3.50	3.20	3.10	

Appendix IV. Washington hop growers' ranked statements

Washington hop growers' statements (52) sorted by rating (high to low) derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical)."

One uncertainty in my production system I have difficulty managing is…

Statement Number		Average Rating	Cluster Number
7	Irrigation water supply/availability	4.70	2
33	Labor regulations	4.50	3
34	Labor cost	4.50	3
3	Labor regulations; state and federal H2A rules, consistency	4.40	3
50	Cause of yield decline	4.30	1
35	Labor work ethic	4.30	3
2	Irrigation: Actual water demands	4.20	2
48	How weather influences plant physiology; all aspects	4.20	2
42	Market volatility	4.20	3
10	Defining optimal fertility program	4.10	1
45	Temperature impacts on pruning/training	4.10	2
21	Pruning timing in warm spring	4.00	1
51	Impact of viruses/viroids on yield stability	4.00	2
8	Nutrient management in soil and plant; nutrient demand curve	3.90	1
9	Nutrient management and interactions with soil water	3.90	1
6	IPM program; unpredictable pest/disease outbreaks	3.90	2
49	How does heat stress impact yield	3.90	2
31	Availability of skilled labor	3.90	3
47	New normal in weather is variability	3.80	2
41	Capital investment and market uncertainty	3.80	3
1	Timing of spring pruning each season	3.60	1
20	Changing climate conditions in winter and spring	3.60	2
24	Microclimate impacts on production	3.60	2
46	Warming winter and springs	3.60	2
14	Production practices specific to a given variety, especially new varieties	3.50	1
11	Efficacy of nutrient options, microbiological interactions	3.50	1
39	Mildews; seasonal variation	3.50	2
4	Pesticide MRL restrictions; unable to use due to restrictions	3.50	4
26	Changing food safety regulations	3.50	4
43	Spring weather; long term forecast	3.40	2
23	Real time plant stress analysis	3.40	2
22	New technologies for assessing plant stress; aerial imagery	3.40	2
32	Motivation of younger generation labor force	3.40	3

One uncertainty in my production system I have difficulty managing is…

Statement Number		Average Rating	Cluster Number
36	Return on investment on inputs	3.40	3
29	Real time yield monitoring to assess on farm research and yard-to-yard variability	3.30	1
52	Mite thresholds that are field specific	3.30	2
15	Variation in microclimate between regions/farms	3.20	2
30	Rural infrastructure for recruiting educated labor/staff	3.20	3
37	Enterprise cost accounting	3.20	3
40	Succession planning	3.20	3
38	Supply of production inputs	3.20	3
13	Selecting varieties	3.10	1
44	Wind, especially near training	3.10	2
17	Spray drift impacts on organic certification	3.10	4
25	Common sense sustainability issues; standardized certification programs	3.10	4
16	Spray drift from neighboring or distant fields	3.00	2
19	Winter temperature and lack of chilling in certain varieties	3.00	2
5	Interpreting data/research in context of commercial farming; issues of scaling up at farm	3.00	3
18	Pesticide residue on organic crops	2.80	2
27	Consumer perceptions of organic vs. convention safety/benefits	2.80	4
28	Changing existing practices	2.70	1
12	Rural vs. Urban perspectives; disconnect from agriculture	2.70	3