CLIMATE, WEATHER AND WINE GRAPES

Lois Wright Morton | Walt Mahaffee
Mark Gleason

Sociology Technical Report 1043   February 2017

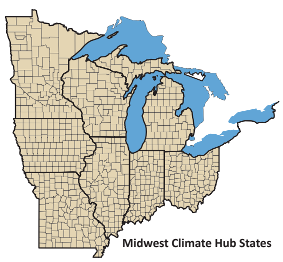
Climate, Weather, and Wine Grapes

This document may be cited as:

Morton, Lois Wright, Walt Mahaffee and Mark Gleason. 2017. Climate, Weather and Wine Grapes. Sociology Technical Report 1043. Department of Sociology, Iowa State University, Ames, Iowa. 18 pp.

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/

Report design and format by Renea Miller, Department of Sociology, Iowa State University, Ames, Iowa. February 2017. USDA Census of Agriculture data tables and figures by Anna Johnson.



This research, North Central Fruit, Vegetable and Wine Growers' Assessment of Soil and Water Vulnerability Under Changing Climate Conditions and Extreme Weather Events funded by USDA-Agricultural Research Service (ARS) Midwest Climate Hub.

This project was funded in part by the USDA National Institute of Food and Agriculture, through the Western Integrated Pest Management Center.

This work was supported by Western IPM Center project 2014-70006-22629 and USDA-ARS CRIS 5358-22000-039-OOD.

Contents

List of Figures

List of Tables

Wine grape production and a changing climate: growers' views and priorities to manage uncertainty in production systems

Lois Wright Morton, Walt Mahaffee, Mark Gleason

Pacific Northwest climate

Grape production and quality are sensitive to temperature, water availability, solar radiation, and carbon dioxide (CO_2) (Walthall et al. 2012). Average temperatures in the United States (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 grape production (Melillo et al. 2014). Warming in the Pacific NW 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 0-30 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 0-15% (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. grape production, especially pests and pathogen risks. For example, in the Pacific NW powdery mildew is a primary management concern for wine grape growers (Gent et al. 2013). Relative humidity in the 40-100% range is particularly conducive to the production of powdery mildew. Rainfall causes discharge of the ascospores and wind carries them to grape vines that have leafed out. Infection and spore reproduction occurs in the 43°-90° F range, affecting leaves and fruit, and if unchecked can give wine an off-flavor. Epidemics can explode virtually overnight, but there is a great deal of uncertainty as to when major outbreaks will occur (Gadoury et al. 2012) and the best timing of fungicide sprays. This uncertainty is linked to variability in weather conditions, early-spring spore release, the wine grape growth and development phase, and other biophysical and management relationships which are not yet well understood.

As climate and weather become more variable, wine grape 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 constrain or limit knowledge needed to make timely, good decisions. **What is not well understood is how wine grape growers perceive climate-weather risks to their production systems and what kind of adaptations have potential to reduce uncertainties associated with their management decisions.** This technical report is a preliminary effort to summarize information gathered from Pacific NW wine grape growers to better understand what they are thinking and how they view uncertainty and decisions associated with a variety of production challenges. First, a brief overview of U.S. and Pacific NW grape production with a focus on wine grape production is presented. This is followed by the concept mapping methodology used to gather and analyze grower information. Then, conceptual maps of 16 Pacific NW wine grape grower leaders' views and priorities associated with managing their production systems under increasing uncertainties are shown and discussed. Supporting data are found in Appendices I and II.

U.S. grape production

Over 7.8 million tons of grapes valued at $5.8 billion were grown commercially in the United States in 2014 (Figure 1). Grape production has considerable economic impact on small farms and surrounding rural economies (e.g., 1.1 million jobs, $33 billion wages paid, and $162 billion economic impact in 2007 (MKF-Research 2007)). Grapes are eaten fresh, dried as raisins, made into wine, and processed into jams, jellies, and juices. Wine production is the leading use of grapes which are valued at $3.5 billion annually. The 2012 U.S. Census of Agriculture reports that grapes are grown throughout the United States (U.S.) by 27,878 farms (Figure 2) on 1,139,146 acres, an 8% increase from 2007. California had 41% of all farms with grapes (Figure 2) and a total of 55% acres of major U.S. states with wine grape bearing acres in 2014 (Figure 3). Oregon, Washington and New York states each had 5% of all U.S. farms with grapes (Figure 2), and about 12% the acres of major U.S. states with grape bearing acres (Figure 3).

Pacific Northwest wine grape production

Washington and Oregon are the 2nd and 3rd leading grape producing states in the U.S. (Figures 1, 4). Washington had an 11% increase in number of farms from 2007 (1,219) to 2012 (1,355) and a 17% increase in acres bearing grapes during that same period (61,055 in 2007; 71,494 in 2012) (USDA 2012 Census of Agriculture). Washington has 5% grape bearing acres of major U.S. states with grape bearing acres (Figure 3). Oregon lost 5% of its farms growing grapes from 2007 to 2012 but increased its grape producing acres during this same period (18,192 to 20,090 respectively). Grape production continues to be a major driver in both states economies providing $8.2 billion economic activity, 43,000 jobs and $130 million in tax revenue (Full Glass Research 2015; Community Attributes, 2015).

The majority of Pacific NW vineyards are irrigated; with almost all Washington, and Southern and Eastern Oregon vineyards drip-irrigated. However, the majority of the vineyards in the world renowned Willamette Valley are currently non-irrigated. Frost protection is also commonly needed in Eastern Oregon and Washington and Southern Oregon and is achieved

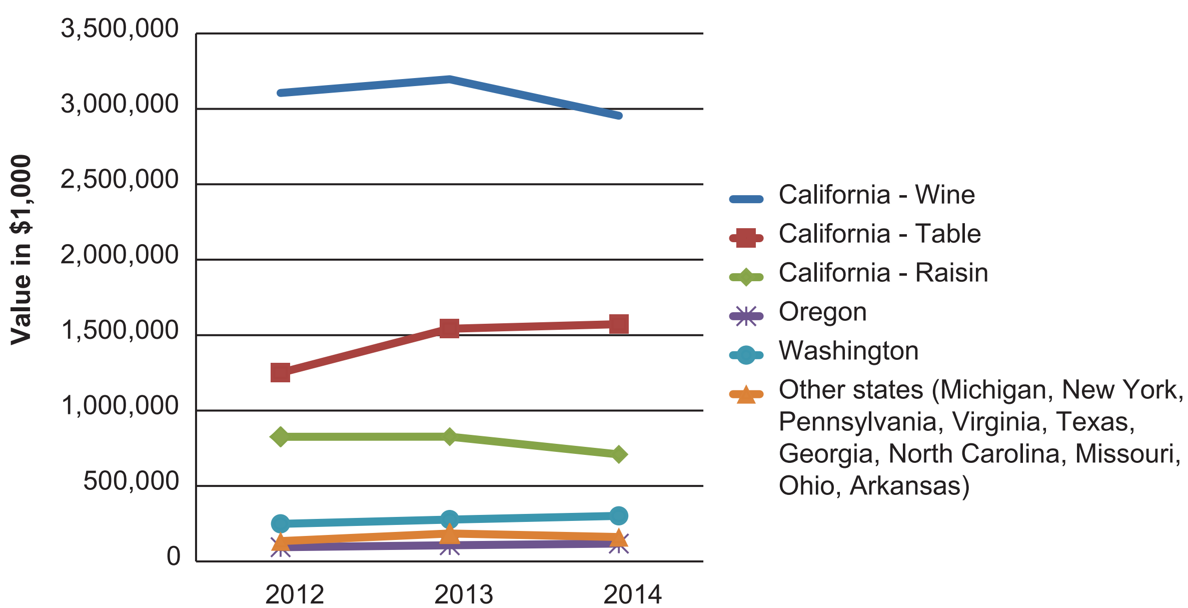


Figure 1. Value of U.S. grape production from 2012 to 2014 by selected states. Total value of 2014 U.S. grape production, $5.8 billion.

Noncitrus Fruits and Nuts 2014 Summary: Released July 17, 2015, by the National Agricultural Statistics Service (NASS),USDA Agricultural Statistics Board, United States Department of Agriculture (USDA). Grape Bearing Acreage, Yield, Production, Price, and Value – States and United States: 2012-2014.

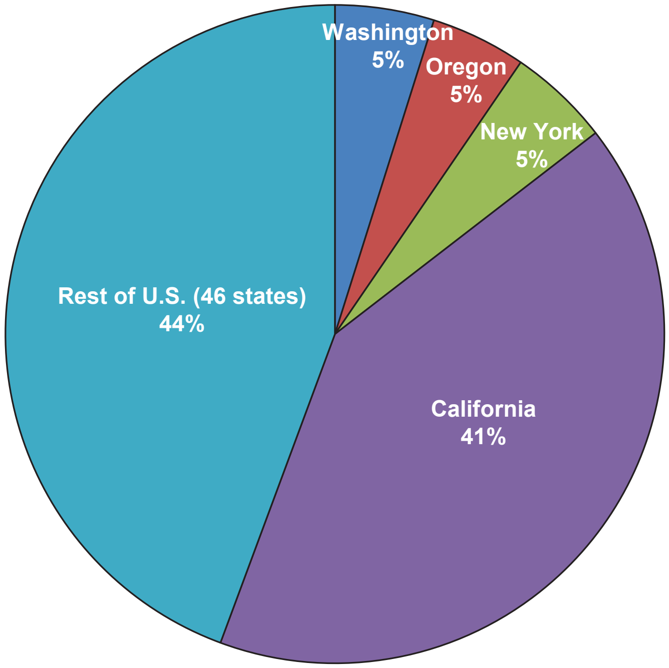


Figure 2. Total number of U.S. farms in grape production, 27,878. USDA U.S. Census of Agriculture. 2012.

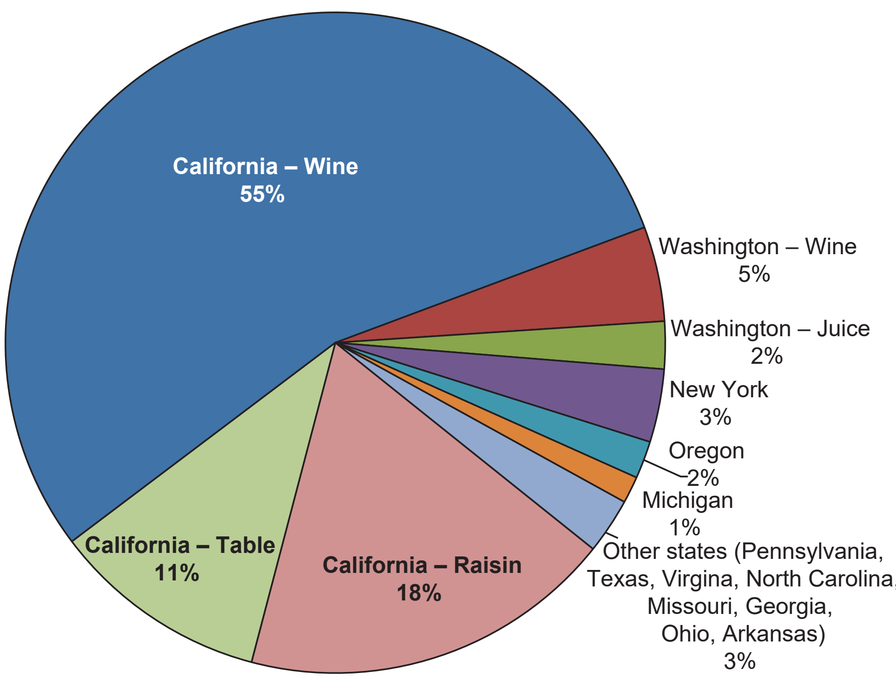


Figure 3. Major U.S. states with grape bearing acres.

Noncitrus Fruits and Nuts 2014 Summary: Released July 17, 2015, by the National Agricultural Statistics Service (NASS),USDA Agricultural Statistics Board, United States Department of Agriculture (USDA). Grape Bearing Acreage, Yield, Production, Price, and Value – States and United States: 2012-2014.

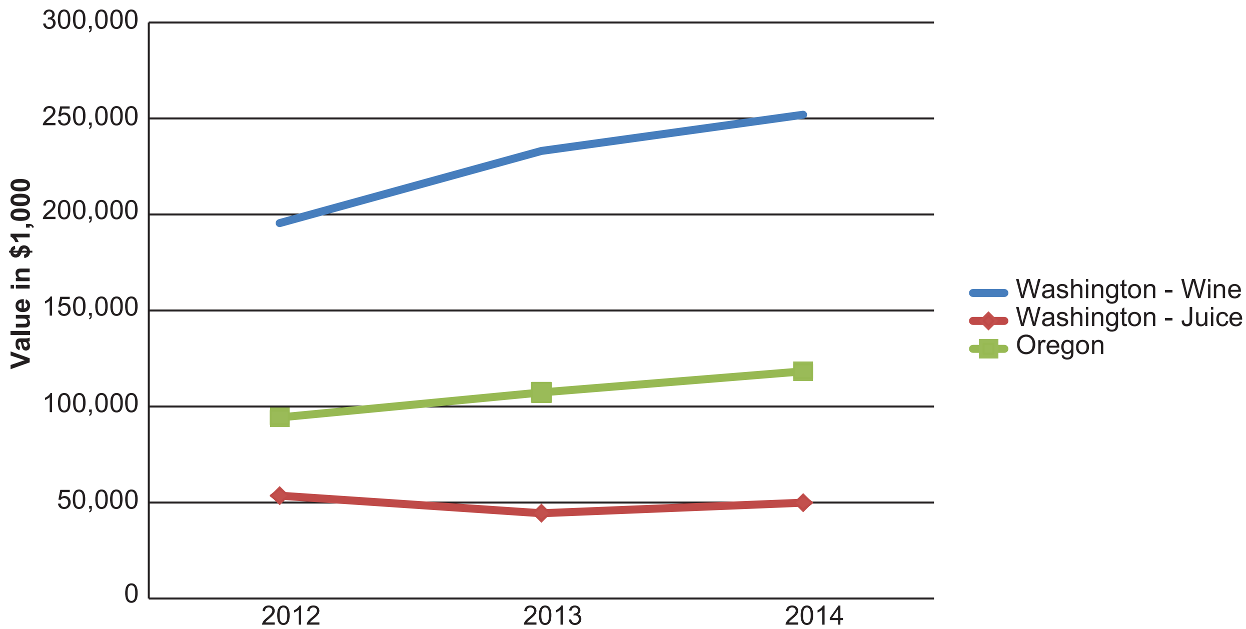


Figure 4. Pacific Northwest grapes-value of utilized production. Washington (wine) 2014 value of production $251,970,000; Washington (juice) value of production $49,875,000; Oregon value of all grape production $118,320,000.

Noncitrus Fruits and Nuts 2014 Summary: Released July 17, 2015, by the National Agricultural Statistics Service (NASS),USDA Agricultural Statistics Board, United States Department of Agriculture (USDA). Grape Bearing Acreage, Yield, Production, Price, and Value – States and United States: 2012-2014.

with overhead irrigation or wind machines. Overhead irrigation can also be used to cool grape canopies during the extreme July and August heat. Since many regions in Eastern Oregon and Washington and Southern Oregon are served by irrigation district water, availability can be problematic especially during the early spring for frost protection and irrigating in the late season during years of low snow pack. The uncertainty surrounding water demand and availability will only increase with continued industry growth and climate change. In addition, the changing climate will require significant adaptation to maintain the region's focus on premium and super-premium grape and wine quality and potentially could cause a shift in the grape varieties that are suitable for the future regional climate and the diseases and pests that have to be managed (Caffarra et al. 2012).

Concept mapping views and priorities

Wine grape 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 and improve their decision making capacities. On March 28-29, 2016 Pacific NW wine grape grower leaders and several of their crop advisors were convened in Corvallis, Oregon to discuss challenges to their production systems including impacts of temperature, precipitation, and other weather-related issues. This purposeful sample of wine grape growers and their crop advisors represented small (2-15 acres), mid-sized (80-250 acres), and large scale (400-1275) production systems and owned and/or managed a total of almost 5, 000 acres. Scientists from USDA Agricultural Research Service (ARS) and Iowa State University invited the growers to identify and prioritize production concerns and uncertainties in their systems that they have difficulty managing. 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 wine grape production decisions.

The concept mapping methodology 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 Pacific NW wine grape grower meeting, 16 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 as the list was made. Sixty-six statements were generated (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 66 statements into separate piles or groups based on perceptions of statement similarities and gave them labels. Some participants lumped statements together, others split the statements into many groupings. The smallest number of groups created by a participant was three; the largest contained fourteen groupings.

Conceptual maps were computed using multi-dimensional scaling analysis which locates each statement as a separate point on a map based on how the participants sorted the 66 statements. 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 those which were grouped together less frequently, have more distance separating them on the map (Figure 5). Hierarchical cluster analysis was then used to partition the statements on the map into clusters representing conceptual groupings. Then the average ratings for each statement and each cluster based on how critical it is to reduce uncertainty were computed and overlaid on the spatial map.

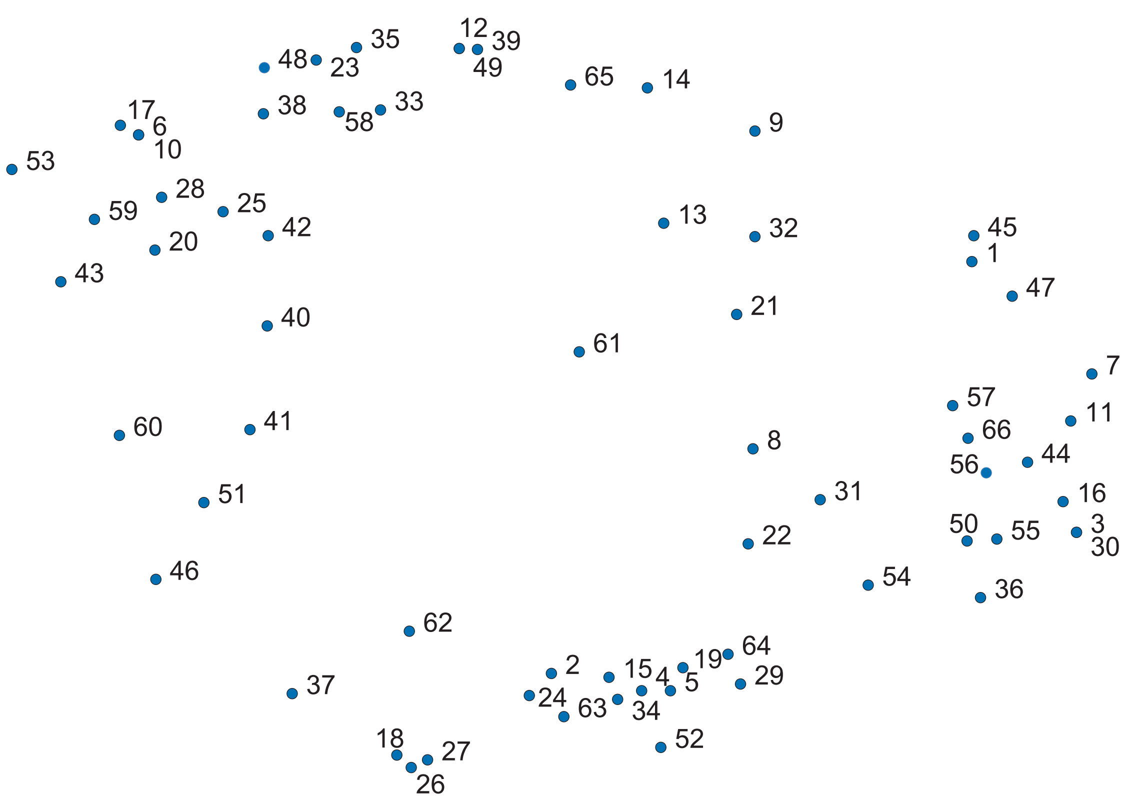


Figure 5. Point map of Pacific Northwest wine grape growers' sort of 66 statements, "One uncertainty in my production system I have difficulty managing is…".

Pacific Northwest wine grape growers' conceptual maps and priority ratings

The 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 wine grape 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 are different ways of portraying the conceptual structure of the data. However, the maps are inter-related and reflect different lenses from which to view the wine growers' thinking. 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 66 different statements growers brainstormed 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 statement numbers group into several distinct clusters.

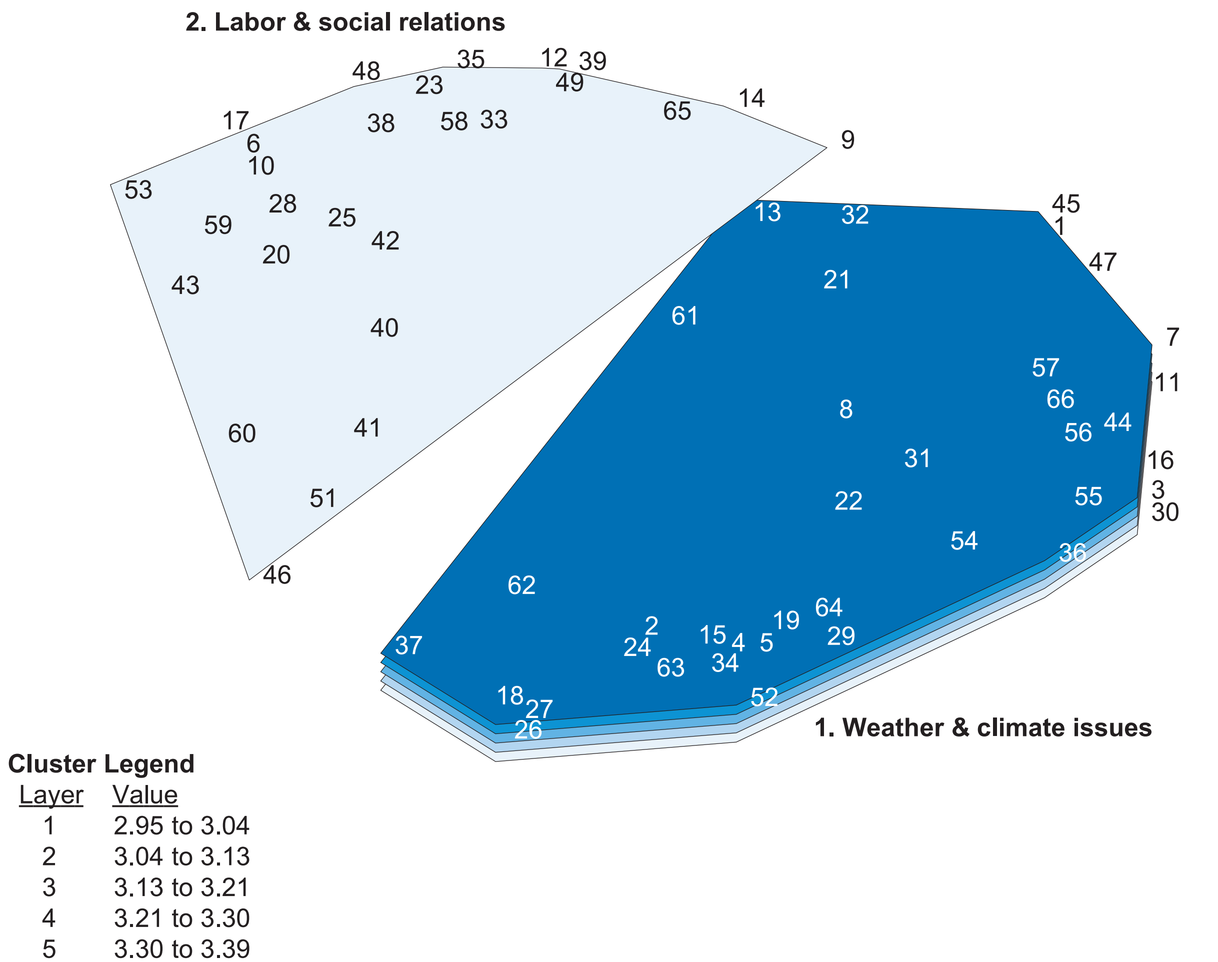


Figure 6. Two-cluster wine grape growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions?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

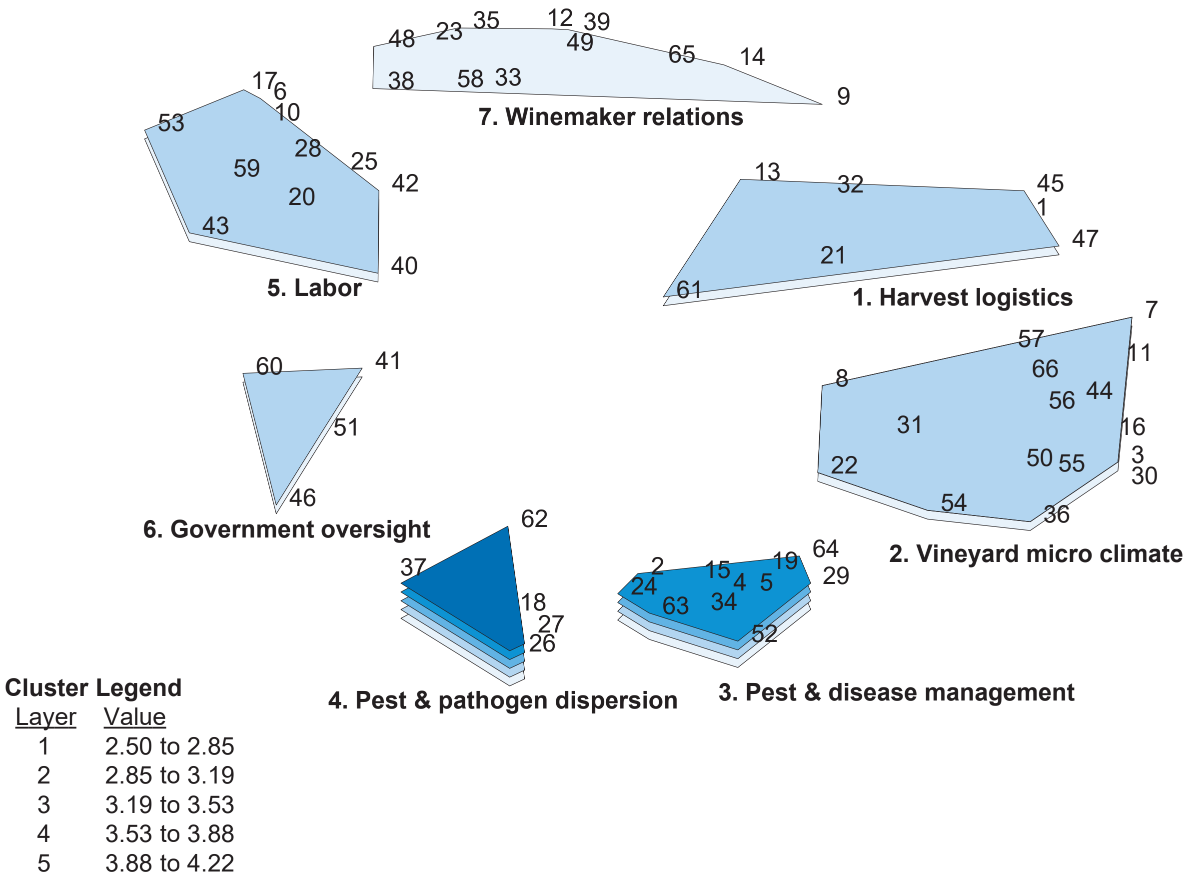


Figure 7. Seven-cluster wine grape growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions?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

Pacific Northwest cluster maps and priority ratings

The two-cluster (Figure 6) and seven-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 (*Weather & climate issues*) in Figure 6 indicate that a large number of items in that cluster were rated as very critical to reduce uncertainty by the participants.

The two-cluster rating map in Figure 6 shows two major conceptual areas of uncertainty identified by the wine grape growers: *weather & climate issues* and *labor & social relations*. Although the *weather & climate issues* polygon has the higher priority weightings compared to *labor & social relations* as critical to reduce uncertainty, it is important to note that the value range (2.95 to 3.39) for these clusters is very narrow and represents an average assessment of moderately critical. 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. This two-cluster map reflects that uncertainties associated with wine grape production are both social 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 5) reveals that the *labor & social*

Table 1. Pacific Northwest wine grape 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
Pest & pathogen dispersion	4.22	5	62. Powdery mildew management	4.31
Pest & disease management	3.55	11	4. Control of pests	4.56
Government oversight	3.17	4	51. Pesticide levels/MRLs (minimum residual levels) in wine	3.69
Labor	3.10	11	10. Labor crunch at harvest	4.06
Vineyard micro climate	2.98	16	66. Climate change	3.81
Harvest logistics	2.88	7	47. Predicting timing of optimal ripening	3.69
Winemaker relations	2.50	12	9. Picking date uncertainty	3.13

relations and *weather & climate* production groupings can be more finely divided into smaller, more focused sub-areas for improved targeting. Figure 7 shows a seven-cluster map that breaks the *weather & climate issues* polygon from Figure 6 into four sub-areas of uncertainty: *1) harvest logistics, 2) vineyard micro climate, 3) pest & disease management,* and *4) pest & pathogen dispersion*. The *labor & social relations* polygon breaks into three sub-areas representing *5) labor*, *6) government oversight*, and *7) winemaker relations*.

Table 1 provides summary data on these seven clusters, their grand means and the top-ranked statements in each cluster. *Pest & pathogen dispersion* (4.22) is the highest rated cluster; and interpreted as between very critical (4.0) and extremely critical (5.0) to reduce levels of uncertainty. The second highest rated cluster, *pest & disease management* (3.55) is about halfway between moderately critical (3.0) and very critical (4.0). Four clusters are rated in the moderately critical range in terms of reducing uncertainty: *government oversight* (3.17); *labor* (3.10); *vineyard micro climate* (2.98, and *harvest logistics* (2.88). The last cluster, *winemaker relations*, with a 2.5 rating is halfway between somewhat critical (2.0) and moderately critical (3.0) to reduce uncertainties associated with this cluster.

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

Pest & pathogen dispersion, consisting of 5 statements, is the highest rated cluster with a grand mean of 4.22, representing an overall value between very and extremely critical to reduce uncertainty. All five statements within the cluster are rated above the 4.0, very critical level, with powdery mildew management the top ranked concern (4.31); followed closely by virus issues (4.25); reliability of clean planting material and how to choose it (4.25); virus vectors (4.19) and best practices for introduced virus vectors (4.13) (Appendix I).

Pest & disease management, is the second highest rated cluster (3.55) consisting of 11 statements ranging from a high of 4.56 (very-to-extremely critical to reduce uncertainty) to 1.75 below somewhat critical to reduce uncertainty. The highest rated statement, control of pests (4.56) is a global statement about how extremely critical it is for wine grape growers to control pests in their production systems in order to reduce uncertainty. A second statement, pest and disease risk uncertainty at 4.24, closely reflects the highly rated first statement (Appendix I). Four more specific pest and disease concerns also rated very critical follow these two top ranked global statements: Botrytis management (4.00); trunk pathogens and long term impacts on plant health (3.94); mite management altered by changing temperatures (3.88); and temperature impact on insect pest and virus risk (3.75). Three statements rated above the moderately critical (3.0) are weed control (3.44); which introduced pests will be problems this year? (3.38); and uncertainty of efficacy of pesticides each year (3.38). Rated below 3.0 but still within the moderately critical range was the statement, controlling botrytis with organic practices (2.75). The lowest rated statement in this cluster is off-season pests (1.75), falling slightly below 2.00, somewhat critical.

Government oversight, a sub-cluster of the labor & social relations two-cluster map, with a grand mean of 3.17 (moderately critical) is the third highest rated cluster with 4 statements. Two statements in this cluster have the highest ratings: pesticide levels as measured by minimum residual levels (MRL) in wine (3.69) and how to influence nurseries to raise standards for virus and pest certification (3.69). Both of these statements are just below the very critical (4.0) threshold but considerably above moderately critical (3.0).

Labor, also a sub-cluster of the labor & social relations two-cluster map, has a grand mean rating of 3.10 representing moderately critical to reduce uncertainty. This cluster with 11 statements has six that are explicitly labor related. The three top ranking statements, all focused on labor, are all rated very critical: labor crunch at harvest (4.06); safety and accidents (4.00); and labor uncertainty (3.44). Changes in regulation of labor (3.44) is rated mid-way between moderately and very critical to reduce uncertainty. Statements in the moderately critical range include: mechanization and challenges of selling it to winemakers (3.31); new regulations on water resources (3.25); lack of belief in the value of funding research (3.19); and quality of available labor force (3.00). The last three statements focus more on social relations, two which are considered somewhat critical: data analysis and visualization/explanation (2.44) and managing consumer expectations regarding environmental practices (2.13). The last statement in this cluster, uncertainty of FAA regulations regarding drones (1.31) was rated not critical.

Vineyard micro climate, the fifth ranked cluster, has a grand mean of 2.98 or moderately critical, with 16 statements. Statements in this cluster range from a high of 3.81 (very critical) to 2.13 (somewhat critical). The global statement, climate change (3.81) has the highest rating representing very critical to reduce uncertainty as it relates to wine grape production. The other ten statements within the cluster provide greater detail, linking the micro climate to different plant development and growth stages and production aspects. The second highest rating in this cluster, halfway between moderately and very critical, is controlling soil moisture (3.56). Five statements rated moderately critical fall at the 3.00 or above range: long-term vine nutrition (3.31); weather at harvest (3.31); timing of cultural practices (3.25); vine vigor (3.13); and managing plant water status in different varieties across years of differing rainfall (3.00). Another set of statements within the moderately critical range, falling below 3.00, are: intro-block variability in plant vigor (2.94); fruit set (2.94); grafted vine vulnerability to winter freezes (2.75); climate change is altering species of problem weeds (2.69); warmer springs extend vulnerable period of bud break (2.69); increased weather extremes imperil organic management tactics (2.63); managing vineyard floor under changing rainfall regimes (2.63); and frost risk (2.63). The last statement in this cluster, early-season yield forecasting, at 2.5 is mid-way between somewhat and moderately critical to reduce uncertainty.

Harvest logistics, a sub-cluster of the weather & climate two-cluster grouping, is rated moderately critical with a grand mean of 2.88. There are seven statements within this cluster ranging from very critical to somewhat critical. Predicting timing of optimal ripening is the highest rated statement at 3.69 (very critical) followed by yield estimation at 3.50. Predicting potential wine quality of grapes for wineries, ranked the third highest in this cluster at 3.31, and is rated above moderately critical. Two statements, space and harvest logistics (2.69) and harmonizing supply and winemaker demand under changing weather patterns (2.56) are rated a little less than moderately critical to reduce uncertainty but considerably higher than somewhat critical. The final two statements in this cluster, predicting crop phenology to allocate resources (2.31) and obtaining weather data for widely scattered vineyards (2.13) are slightly above 2.00, somewhat critical.

Winemaker relations, the seventh cluster, has a grand mean of 2.50, mid-way between somewhat and moderately critical to reduce uncertainty. This 12 statement cluster encompasses not only winemaker relationships but also the social and physical infrastructure of the wine grape value-chain. The four top-ranked statements, considered moderately critical, reflect the uncertainties associated with picking date uncertainty (3.13) (which is determined by the winemaker); grower-winemaker relations (3.00); winemaker relations (2.88); and uncertainty/volatility of grape prices (2.88). These relationships are further elaborated by additional statements rated above somewhat critical: harvest scheduling for multiple vineyards (2.50); forecasting capital development plans for vineyards (2.44); balancing multiple "masters" (2.38); timeliness of contributions from

Table 2. Top quartile (25%) wine grape 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)."

Wine Grape Statement Number		Average Rating	Cluster Number
4	Control of pests	4.56	3
62	Powdery mildew management	4.31	4
19	Pest and disease risk uncertainty	4.25	3
18	Virus issues	4.25	4
37	Reliability of clean planting material and how to choose it	4.25	4
26	Virus vectors	4.19	4
27	Best practices for introduced virus vectors	4.13	4
10	Labor crunch at harvest	4.06	5
63	Botrytis management	4.00	3
28	Safety and accidents	4.00	5
34	Trunk pathogens and long-term impacts on plant health	3.94	3
6	Labor uncertainty	3.94	5
64	Mite management altered by changing temperatures	3.88	3
66	Climate change	3.81	2
29	Temperature impact on insect pest and virus risk	3.75	3
47	Predicting timing of optimal ripening	3.69	1
51	Pesticide levels/MRLs (minimum residual levels) in wine	3.69	6
46	How to influence nurseries to raise standards for virus and pest certification	3.69	6

collaborators (2.38); budgeting capital outlays for equipment (2.38); dealing with corporate structure (2.31; and data management and storage (2.31). The lowest rated statement in this cluster, scheduling public relations and marketing efforts in a volatile market, was rated mid-way between not critical and somewhat critical (1.44).

Top quartile statements. Another way to examine the findings is to list all 66 statements arranged by highest to lowest rating (Appendix II). The top quartile (25%) of wine grape growers' statement rankings based on ratings is shown in Table 2. These top 18 statements range from 4.56, in the extremely critical range to 3.69, very critical that levels of uncertainty be reduced in wine grape production systems. The highest rated statements reflect high levels of uncertainty associated with control of pests and diseases with powdery mildew, virus vectors, botrytis, and mites specified. A second area of uncertainty is issues related to labor including labor crunch at harvest, safety and accidents, and availability of labor uncertainty in general. A third grouping of highly rated statements center on climate change and the interactions of temperature with pests and virus and timing of fruit ripening.

Observations

This preliminary report offers a snapshot of Pacific NW wine grape growers' observations, thoughts, concerns, and priorities for their crops. Using the concept mapping process, they identified a set of seven key areas where uncertainty makes managing their production systems difficult: pest & pathogen dispersion; pest & disease management; government oversight; labor; vineyard micro climate; harvest logistics; and winemaker relations. The 66 individual statements of uncertainty generated encompass both weather & climate related production decisions and labor & social relations associated with their value chain. Although pest and pathogen dispersion and management are the highest ranked areas, all seven of the clusters have aspects of uncertainty that growers are concerned about and must address in their everyday 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 disease, pests, and labor are threads woven throughout discussions with Pacific NW wine grape grower leaders. 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. This suggests an increasing need for wine grape research, decision support tools and information that can help growers to better address risk and uncertainty and guide management decisions.

References

Caffarra, A., Rinaldi, M., Eccel, E., Rossi, V., and Pertot, I. 2012. Modelling the impact of climate change on the interaction between grapevine and its pests and pathogens: European grapevine moth and powdery mildew. Agriculture, Ecosystems & Environment 148:89-101 doi:10.1016/j.agee.2011.11.017.

Community Attributes, Inc., 2105. Economic and fiscal impacts of wine and wine grapes in Washington State. Pages 91.

Full Glass Research. 2015. The Economic impact of the wine and wine grape industries on the Oregon Economy. Pages 65.

Gadoury, D. M., Cadle-Davidson, L., Wilcox, W. F., Dry, I. B., Seem, R. C., and Milgroom, M. G. 2012. Grapevine powdery mildew (Erysiphe necator): a fascinating system for the study of the biology, ecology and epidemiology of an obligate biotroph. Molecular Plant Pathology 13:1-16.

Gent, D.H., W. F. Mahafee, N. McRoberts, and W. F. Pfender. 2013. The use and role of predictive systems in disease management. Annu. Rev. Phytophathol 51:267-89.

Kane, M and W.M.K. Trochim. 2007 *Concept Mapping for Planning and Evaluation.* Thousand Oaks, CA: Sage Publication.

Melillo, J. M., T.C. Richmond, and G. W. Yohe, Eds. 2012. Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. Washington.

MKF-Research. 2007. The Impact of Wine, Grapes and Grape Products on the American Economy 2007: Family Businesses Buliding Value. Pages 30. St. Helena, CA.

Mote, P., A. K. Snover, S. Capalbo, S. D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder, 2014: Ch. 21: Northwest. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 487-513. doi:10.7930/J04Q7RWX.

Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth,C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright Morton, L.H. Ziska. 2012. Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin No. 1935. Washington, DC. 186 pp.

Appendix I. Wine grape growers' seven cluster rankings

Pacific Northwest wine grape growers' statements (66) 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. Harvest logistics		**2.88**
47	Predicting timing of optimal ripening	3.69
1	Yield estimation	3.50
45	Predicting potential wine quality of grapes for wineries	3.31
13	Harvest logistics; space	2.69
32	Harmonizing supply and winemaker demand in changing weather patterns	2.56
21	Predicting crop phenology to allocate resources	2.31
61	Obtaining weather data for widely scattered vineyards	2.13

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
7	0.57	0.32	2.13	3.69	2.90	2.69

		Average Rating
2. Vineyard micro-climate		**2.98**
66	Climate change	3.81
22	Controlling soil moisture	3.56
16	Long-term vine nutrition	3.31
8	Weather at harvest	3.31
50	Timing of cultural practices	3.25
3	Vine vigor	3.13
36	Managing plant water status in different varieties across years of differing rainfall	3.00
30	Intra-block variability in plant vigor	2.94
11	Fruit set	2.94
44	Grafted vine vulnerability to winter freezes	2.75
54	Climate change is altering species of problem weeds	2.69
57	Warmer springs extend vulnerable period of bud break	2.69
31	Increased weather extremes imperil organic management tactics	2.63
55	Managing vineyard floor under changing rainfall regimes	2.63
56	Frost risk	2.63
7	Early-season yield forecasting	2.50

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
16	0.37	0.14	2.50	3.81	3.00	2.94

One uncertainty in my production system I have difficulty managing is…		Average Rating
3. Pest & disease management		**3.55**
4	Control of pests	4.56
19	Pest and disease risk uncertainty	4.25
63	Botrytis management	4.00
34	Trunk pathogens and long-term impacts on plant health	3.94
64	Mite management altered by changing temperatures	3.88
29	Temperature impact on insect pest and virus risk	3.75
52	Weed control	3.44
5	Which introduced pests will be problems this year?	3.38
2	Uncertainty of efficacy of pesticides each year	3.38
24	Controlling Botrytis with organic practices	2.75
15	Off-season pests	1.75

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
11	0.74	0.54	1.75	4.60	3.60	3.80

4. Pest & pathogen dispersion		**4.22**
62	Powdery mildew management	4.31
18	Virus issues	4.25
37	Reliability of clean planting material and how to choose it	4.25
26	Virus vectors	4.19
27	Best practices for introduced virus vectors	4.13

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
5	0.06	0.00	4.13	4.30	4.20	4.30

5. Labor		**3.10**
10	Labor crunch at harvest	4.06
28	Safety and accidents	4.00
6	Labor uncertainty	3.94
42	Changes in regulation of labor	3.44
43	Mechanization; challenges of selling it to winemakers	3.31
40	New regulations on water resources	3.25
53	Lack of belief in value of funding research	3.19
17	Quality of available labor force	3.00
59	Data analysis and visualization/explanation	2.44
25	Managing consumer expectations regarding environmental practices	2.13
20	Uncertainty of FAA regulations re: drones	1.31

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
11	0.81	0.66	1.31	4.10	3.10	3.30

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

		Average Rating
6. Government oversight		**3.17**
51	Pesticide levels/MRLs (minimum residual levels) in wine	3.69
46	How to influence nurseries to raise standards for virus and pest certification	3.69
41	Changes in pesticide regulation	3.00
60	Lack of weather station coverage in key growing areas	2.31

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
4	0.57	0.32	2.31	3.70	3.20	3.30

		Average Rating
7. Winemaker relations		**2.50**
9	Picking date uncertainty	3.13
49	Grower-winemaker relations	3.00
12	Winemaker relations	2.88
65	Uncertainty/volatility of grape prices	2.88
14	Harvest scheduling for multiple vineyards	2.50
48	Forecasting capital development plans for vineyards	2.44
39	Balancing multiple masters	2.38
38	Timeliness of contributions from collaborators	2.38
23	Budgeting capital outlays for equipment	2.38
35	Dealing with corporate structure	2.31
58	Data management and storage	2.31
33	Scheduling PR and marketing efforts in a volatile market	1.44

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
12	0.43	0.18	1.44	3.10	2.50	2.40

Appendix II. Wine grape growers' ranked statements

Pacific Northwest wine grape growers' statements (N=66) 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
4	Control of pests	4.56	3
62	Powdery mildew management	4.31	4
19	Pest and disease risk uncertainty	4.25	3
18	Virus issues	4.25	4
37	Reliability of clean planting material and how to choose it	4.25	4
26	Virus vectors	4.19	4
27	Best practices for introduced virus vectors	4.13	4
10	Labor crunch at harvest	4.06	5
63	Botrytis management	4.00	3
28	Safety and accidents	4.00	5
34	Trunk pathogens and long-term impacts on plant health	3.94	3
6	Labor uncertainty	3.94	5
64	Mite management altered by changing temperatures	3.88	3
66	Climate change	3.81	2
29	Temperature impact on insect pest and virus risk	3.75	3
47	Predicting timing of optimal ripening	3.69	1
51	Pesticide levels/MRLs (minimum residual levels) in wine	3.69	6
46	How to influence nurseries to raise standards for virus and pest certification	3.69	6
22	Controlling soil moisture	3.56	2
1	Yield estimation	3.50	1
52	Weed control	3.44	3
42	Changes in regulation of labor	3.44	5
5	Which introduced pests will be problems this year?	3.38	3
2	Uncertainty of efficacy of pesticides each year	3.38	3
45	Predicting potential wine quality of grapes for wineries	3.31	1
16	Long-term vine nutrition	3.31	2
8	Weather at harvest	3.31	2
43	Mechanization; challenges of selling it to winemakers	3.31	5
50	Timing of cultural practices	3.25	2
40	New regulations on water resources	3.25	5
53	Lack of belief in value of funding research	3.19	5
3	Vine vigor	3.13	2

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

Statement Number		Average Rating	Cluster Number
9	Picking date uncertainty	3.13	7
36	Managing plant water status in different varieties across years of differing rainfall	3.00	2
17	Quality of available labor force	3.00	5
41	Changes in pesticide regulation	3.00	6
49	Grower-winemaker relations	3.00	7
30	Intra-block variability in plant vigor	2.94	2
11	Fruit set	2.94	2
12	Winemaker relations	2.88	7
65	Uncertainty/volatility of grape prices	2.88	7
44	Grafted vine vulnerability to winter freezes	2.75	2
24	Controlling Botrytis with organic practices	2.75	3
13	Harvest logistics; space	2.69	1
54	Climate change is altering species of problem weeds.	2.69	2
57	Warmer springs extend vulnerable period of bud break	2.69	2
31	Increased weather extremes imperil organic management tactics	2.63	2
55	Managing vineyard floor under changing rainfall regimes	2.63	2
56	Frost risk	2.63	2
32	Harmonizing supply and winemaker demand in changing weather patterns	2.56	1
7	Early-season yield forecasting	2.50	2
14	Harvest scheduling for multiple vineyards	2.50	7
59	Data analysis and visualization/explanation	2.44	5
48	Forecasting capital development plans for vineyards	2.44	7
39	Balancing multiple masters	2.38	7
38	Timeliness of contributions from collaborators	2.38	7
23	Budgeting capital outlays for equipment	2.38	7
21	Predicting crop phenology to allocate resources	2.31	1
60	Lack of weather station coverage in key growing areas	2.31	6
35	Dealing with corporate structure	2.31	7
58	Data management and storage	2.31	7
61	Obtaining weather data for widely scattered vineyards	2.13	1
25	Managing consumer expectations regarding environmental practices	2.13	5
15	Off-season pests	1.75	3
33	Scheduling PR and marketing efforts in a volatile market	1.44	7
20	Uncertainty of FAA regulations re: drones	1.31	5