CLIMATE, WEATHER AND APPLES

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Lois Wright Morton | Daniel Cooley
Jon Clements | Mark Gleason

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This document may be cited as:

Morton, Lois Wright, Daniel Cooley, Jon Clements and Mark Gleason. 2017. Climate, Weather and Apples. Sociology Technical Report 1046. Department of Sociology, Iowa State University, Ames, Iowa. 16 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/
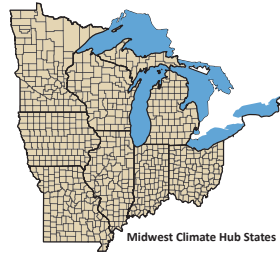
This research, North Central Fruit, Vegetable and Wine Growers' Assessment of Soil and Water Vulnerability Under Changing Climate Conditions and Extreme Weather Events funded by USDA-Agricultural Research Service (ARS) Midwest Climate Hub.

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Northeast U.S. apple production and a changing climate: growers' views and priorities to manage uncertainty in production systems

Lois Wright Morton, Daniel Cooley, Jon Clements, Mark Gleason

Apple production and climate

Apple production is sensitive to temperature, water availability, solar radiation, air pollution, and carbon dioxide (CO_2). Walthall et al. (2012) document current and projected shifts in climate patterns and weather and their impacts on United States (U.S.) agricultural production. They note that climate risk is an additional risk joining production, finance and marketing risks already managed by growers. Climate risk will add complexity and increase uncertainty in decision environments throughout many dimensions of U.S. apple production systems.

Changes in climate interact with other environmental and societal factors in ways that can either moderate or intensify its impacts on production systems. Photosynthesis can be affected by CO_2 levels with increases in atmospheric CO_2 generally increasing growth rates and yields, resulting in high accumulation of biomass, fruit production and quality in fruit trees. There is also growing evidence that increased CO_2 when combined with heat stress, drought and nutrient deficiencies can diminish this growth enhancement. Critical temperature thresholds affect tree fruit reproductive physiology and stress resistance such as winter hardiness, freeze susceptibility of buds, pre-bloom flower development, pollination, fruit set and fruit drop, chemical thinning and harvest maturity. These thresholds are shifting under changes in local and regional climates and affect yield and crop quality such as the red coloring on apples. In some regions, warmer temperatures can lead to changes in taste and textural attributes of different apple varieties with effects on acid concentration and fruit firmness in response to earlier blooming and higher temperatures during maturation periods (Sugiura et al. 2013). Some regions may see a decrease in chilling units necessary to complete dormancy and impact bloom and yield (e.g. Darbyshire et al. 2013).

In conjunction with changes in the timing and distribution of precipitation, warmer growing season temperatures result in greater crop water requirements, with potential to affect yield and profits. Precipitation and temperature as well as other weather and climate variables are region, sub-region, and locale specific; and thus their impacts are localized also. The Northeast U.S. region over the past 50 years has experienced a 71% increase in very heavy precipitation with frequent and unexpected downpours exceeding 2-4 inches in a single event (Melillo et al. 2014) that can interrupt routine crop management practices. The region also has seen a 5% to greater than 15% increase in total annual precipitation change during the 1991-2012 period compared to 1902-1960 (Melillo et al. 2014). Average temperatures have increased 0.5°F to >1.5°F in sub-regions of Northeast U.S., with an observed increase of 10-14 frost free days during the 1991-2012 period compared to 1902-1960. Although Northeast U.S. has a wet climate, increased variability in precipitation and temperatures throughout the growing season can lead to intra-seasonal drought with implications for crop management decisions. In Northeast U.S. a few apple growers have some irrigation equipment, however most have not invested in enough equipment to fully optimize irrigation scheduling and meet apple evapotranspiration requirements of all their crop acres.

As climate and weather become more variable, apple growers face increased uncertainty in making decisions about their crop. One interpretation of this uncertainty is that growers may not have quite enough information to adequately evaluate their management options in the context of climate risk. Uncertainty can stem from social, economic, relational and/or biophysical factors that constrain or limit knowledge needed to make timely, good decisions. **What is not well understood is how apple 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 apple growers to better understand what they are thinking and how they view uncertainty and their production challenges. First, a brief overview of United States (U.S.) and Northeast U.S. apple production is presented, followed by the methodology used to gather and analyze grower information. Then, conceptual maps of Northeast U.S. apple growers' 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.

Apple production in the United States

The 2012 U.S. Census of Agriculture reports that apples are grown throughout the United States (U.S.) by 25,129 farms (Figure 1) on 384,237 acres (Figure 2), a 4% decrease from 2007. Eighteen percent of the production occurs in Northeast United States (New York 6%; Pennsylvania 6%; other Northeast states 6%). West coast states (Washington 11%; California

10%, and Oregon 5%) are also major growing areas. Apple production has two major markets, fresh use and processed, which combined represent over $2 billion total value (2010) (Figure 3) across all U.S. states.

Northeast U.S. apple production, weather and climate

A total of 59,445 acres of apples were grown by 2,936 farmers in Northeast U.S. in 2012 (Figures 4 and 5). Apples are the most economically important specialty crop in the Northeast, with production valued at just over $400 million. Most states in the region have significant apple production, with the majority of the production going to sales of fresh fruit. Direct sales from farms account for an increasing percentage of production, particularly near the large urban centers in the region, though there is still a significant wholesale industry.

The weather in northeastern U.S. plays a critical role in apple production. Disease and insect development are driven by temperature, rain, humidity and other environmental factors. Pest and disease management is a big part of apple
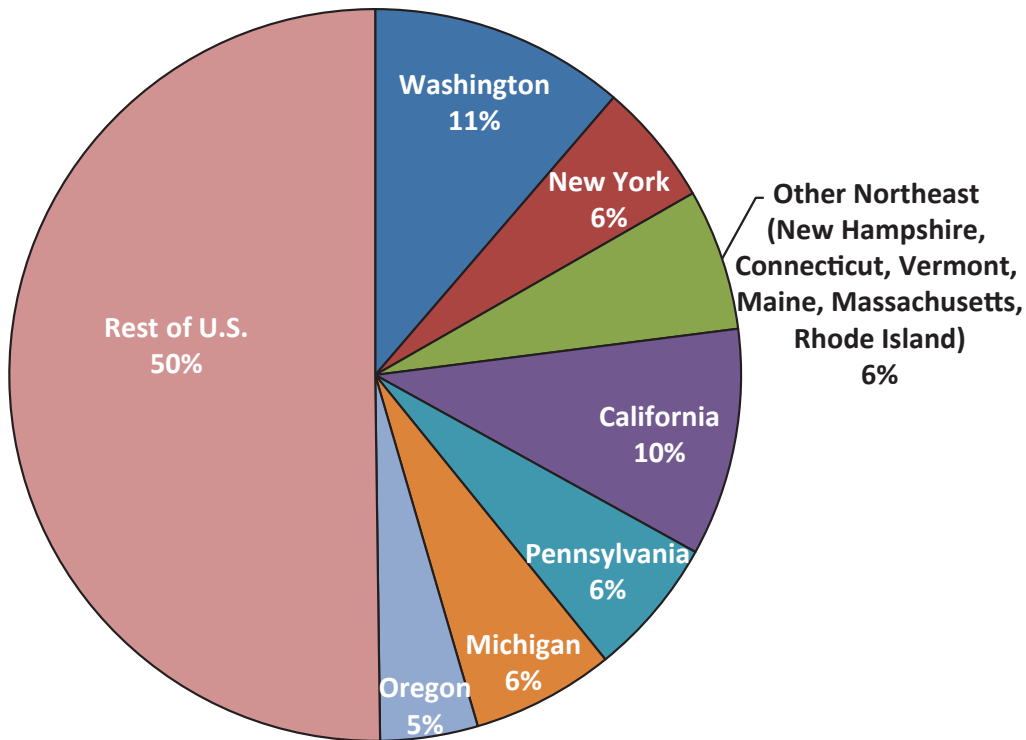
Figure 1. Number of United States (U.S.) farms in apple production, 25,591. U.S. Census of Agriculture. 2012.
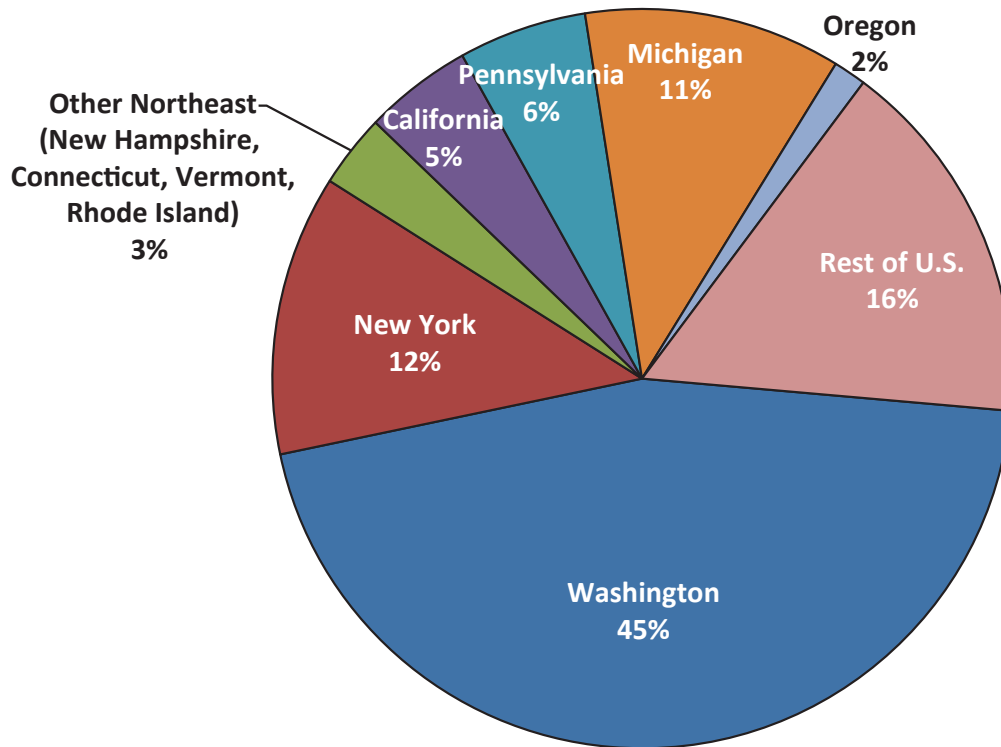
Figure 2. Total United States (U.S.) acres in apple production, 384,237 acres. U.S. Census of Agriculture. 2012.
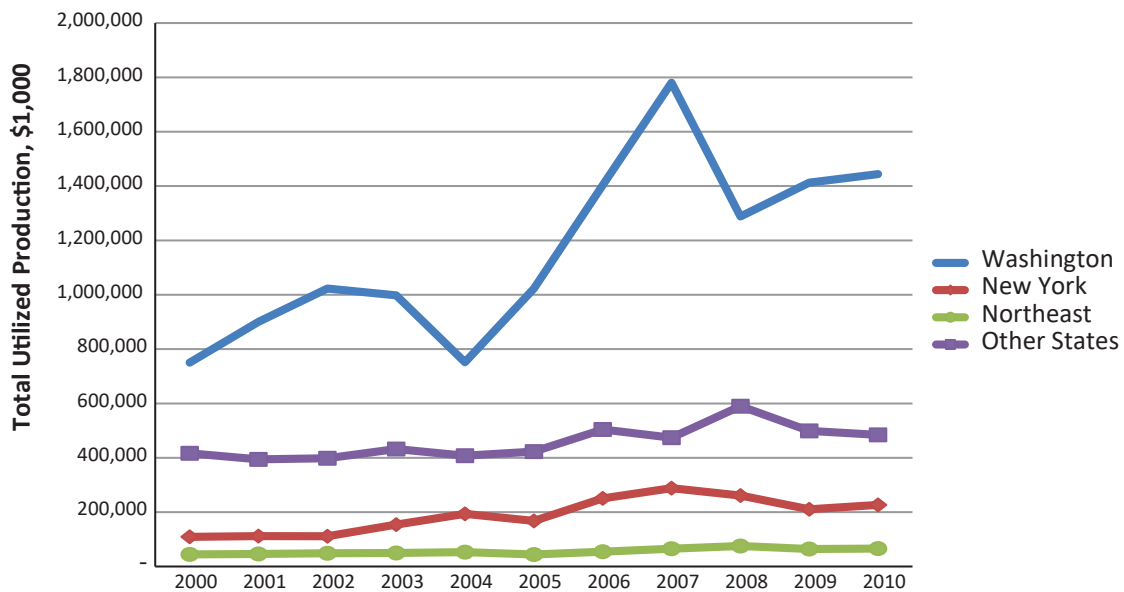
Figure 3. Total value of U.S. apple production from 2000 to 2010. Total value of 2010 U.S. crop $2,220,817,000. U.S. Apple Statistics, May 2012. Table 4 Value of U.S. apple production, by state, 1980-2010.

USDA, National Agricultural Statistics Service (NASS), Noncitrus Fruits and Nuts Summary, various issues. Prior to 1992, from various National Agricultural Statistics Service Field Offices. http://usda.mannlib.cornell. edu/MannUsda/viewDocumentInfo.do?documentID=1825.
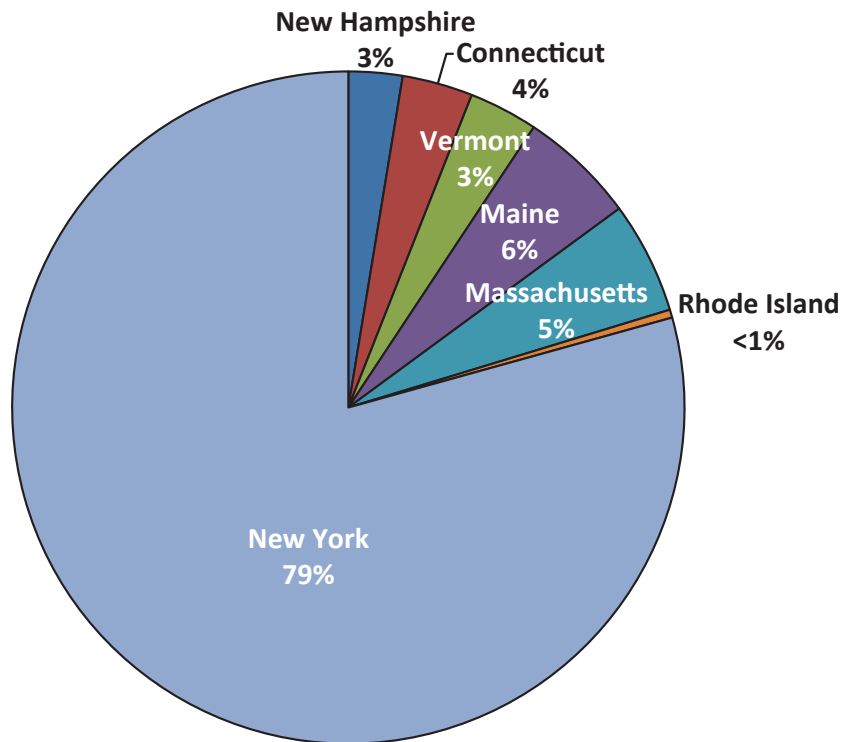
Figure 4. Total apple acres in Northeast U.S. (2012), 59,445 acres. U.S. Census of Agriculture. 2012.
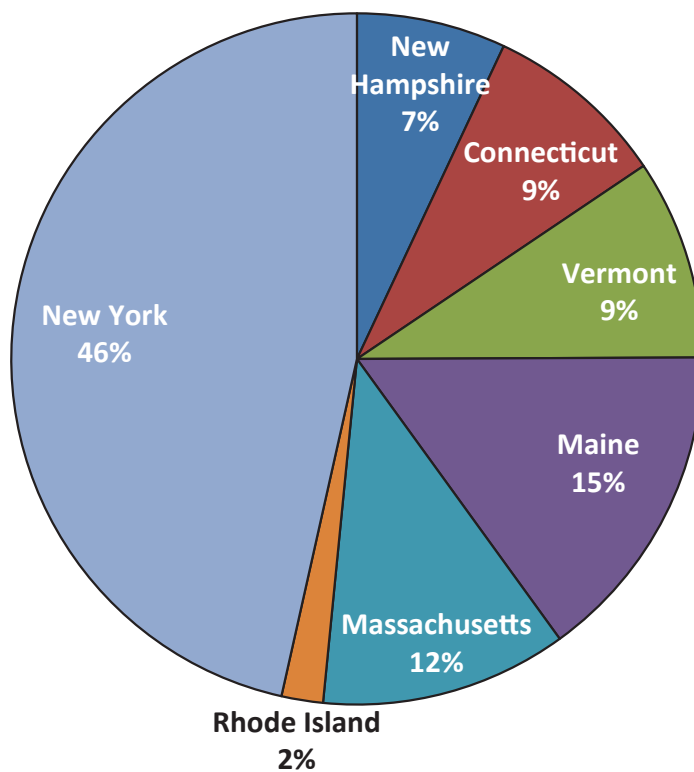
Figure 5. Total apple farms in Northeast U.S. (2012), 2,936. U.S. Census of Agriculture. 2012.

production, and apples are among the crops with the heaviest use of pesticides, particularly in humid production areas like the Northeast. At the same time, Integrated Pest Management (IPM) programs have been widely adopted in the region as a way to control pest management costs, maintain effective management while reducing pesticide use. IPM programs in the Northeast rely heavily on weather data and forecasting models to guide pesticide applications. For example, fungicide and antibiotic applications for some of the most important apple diseases including apple scab, fire blight and sooty blotch/flyspeck have weather-based models that forecast the risk of disease, enabling growers to optimize treatment applications. Similarly, weather-based models often guide pesticide applications for important insect pests including plum curculio, codling moth and apple maggot.

The weather impacts many aspects of the Northeast U.S. apple business. As a deciduous perennial fruit, trees must go through a minimum amount of chilling each winter in order to flower and produce normally. It has been suggested that climate change, which would generally lead to warmer winters in the Northeast, may make it difficult to produce some apple varieties in parts of the region. Several varieties popular in the region, such as McIntosh, do not develop as much red color or fruit that are as crisp when late summer and early fall temperatures are too high. Flower buds must survive minimum cold temperatures in the winter, and flowers need to survive spring frosts. Greater variability in weather, such as warm periods followed by cold snaps in winter, can damage both flower buds and trees. Further, longer periods of dry weather and heavier rains over a short period can stress trees. These are a few of the many negative impacts that increasing variability in weather and changes in the regional climate may have on Northeast U.S. apple production.

Concept mapping views and priorities

Apple growers are seeking strategies to better assess the risks and vulnerabilities of their production systems under changing short and long-term weather conditions. The goal is to reduce uncertainty in their production systems in ways that improve their decision-making capacities. On March 2, 2016, 24 Northeast U.S. apple growers and several of their crop advisors were convened at the University of Massachusetts in Amherst to discuss impacts of temperature, precipitation, and other weather-related issues on their production systems with a focus on critical production and marketing decision points throughout the year for the apple crop. Scientists from the University of Massachusetts Amherst and Iowa State University invited the growers to identify and prioritize production concerns and uncertainties that they have difficulty managing in their systems. A concept mapping process was used to capture individual grower's challenges as well as areas of common concern among the group. Of interest to the science team was gathering information to guide future research and extension-outreach programming that would reduce uncertainty in different types of production decisions.

The concept mapping methodology is a participatory planning process that 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, creating a set of statements about these ideas, then individually rating each of the idea statements by how critical or important it is to them, followed by individual conceptual sorting of the statements into groups of similar concepts.

In the Northeast U.S. apple meeting, the 24 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. Forty-nine statements were generated (see Appendix II for the list of 49 statements). 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 49 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 four; 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 49 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 6). 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.

Northeast U.S. apple growers' conceptual maps and priority ratings

The point map (Figure 6) and cluster maps represented by the polygons in Figures 7 and 8 offer a visual way to understand the conceptual thinking of the meeting participants. 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 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. The maps are inter-related and reflect different lenses from which to view the apple growers' thinking. The point map (Figure 6) shows how participants categorized statements as similar or different. Each of the 49 statements about uncertainty in apple production are uniquely located on the point map, with similar statements located nearer to each other than statements that were considered different, so some numbers group together but may be quite distant from other numbers. Thus, even without drawing polygons around grouped numbers, it is apparent that the statements group into at least two distinct clusters.

Northeast U.S. cluster maps and priority ratings

We next looked at what type of uncertainty in apple production each grouping might reflect using two (Figure 7) and five (Figure 8) clusters. The cluster names were chosen subjectively
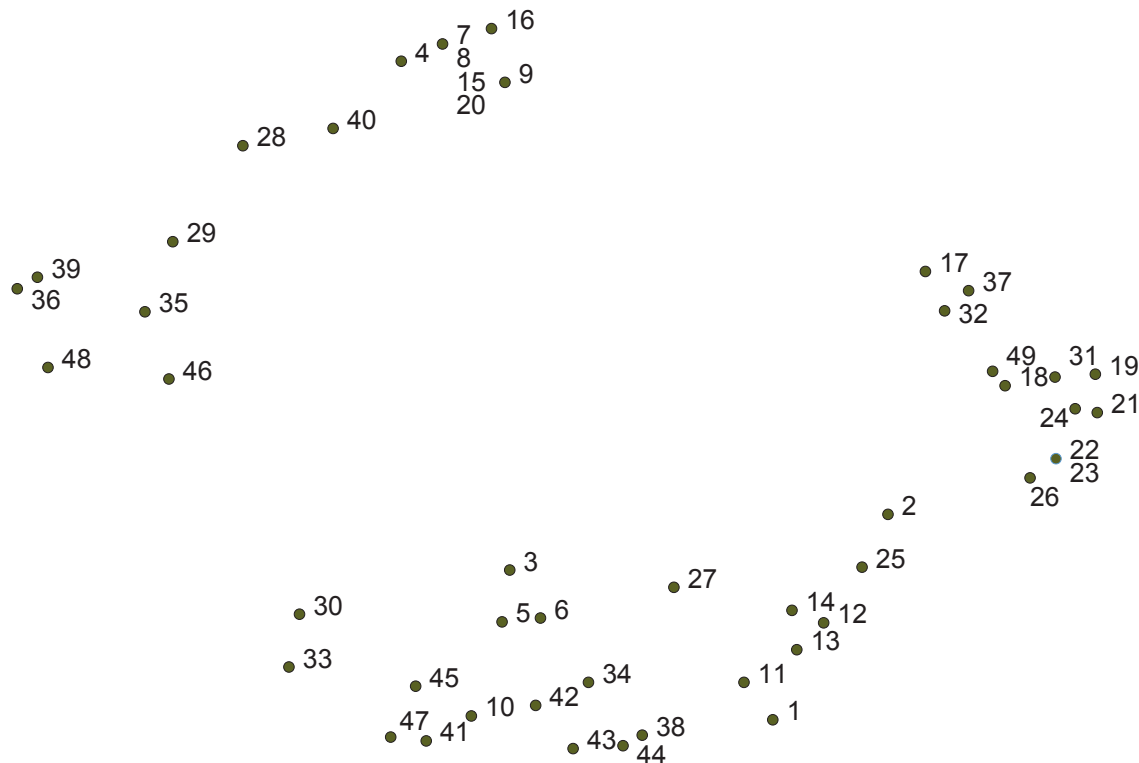
Figure 6. Point map of apple growers' sort of 49 statements, "One uncertainty in my production system I have difficulty managing is…".

Cluster Legend

Layer	Value
1	3.04 to 3.10
2	3.10 to 3.15
3	3.15 to 3.20
4	3.20 to 3.25
5	3.25 to 3.30
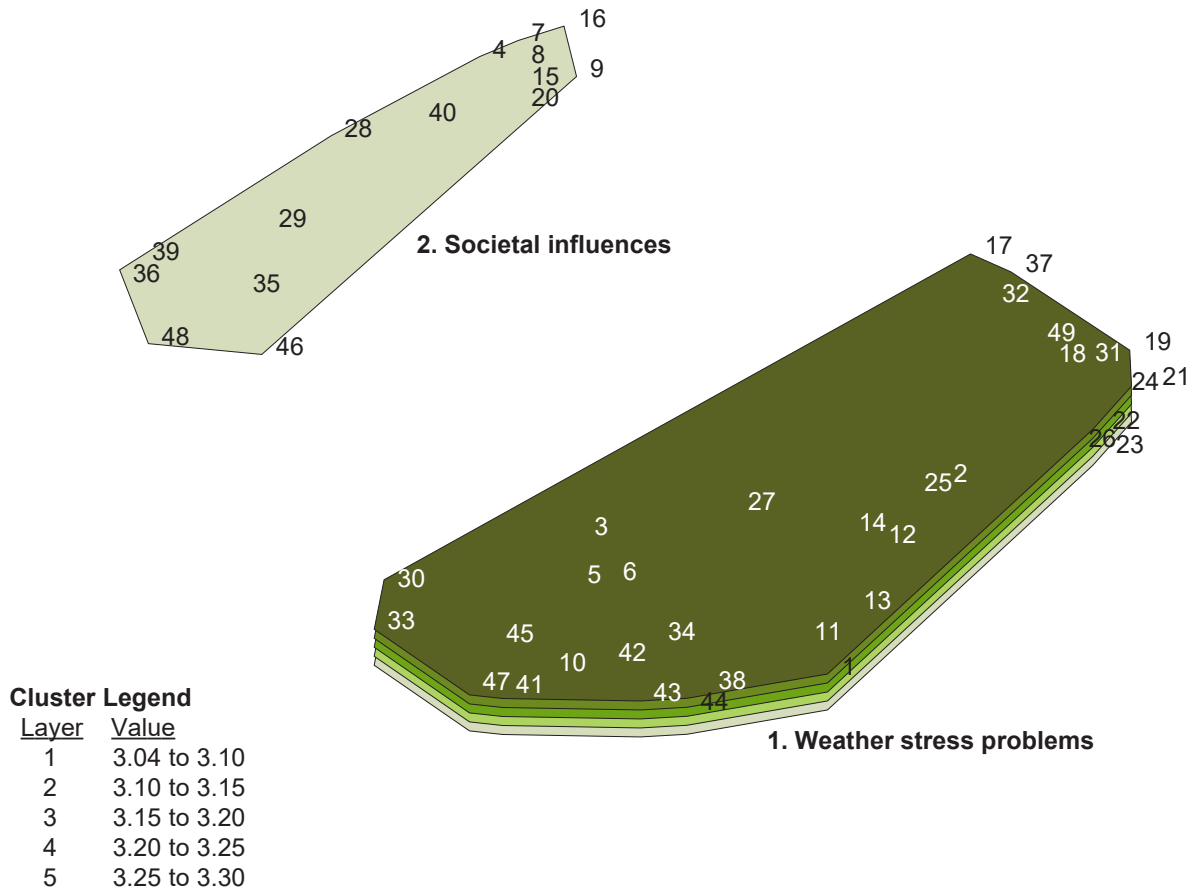
Figure 7. Two-cluster apple growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical).".

by the researchers using a combination of the labels given by growers and the items within each cluster. For the two-cluster map, one cluster was labelled *Weather stress problems*, and the other *Societal influences*. The five-cluster map breaks *Weather stress problems* into three smaller clusters, *Weather-based crop management, Production issues,* and *Weather data delivery and forecast,* while splitting *Societal influences* into *Labor* and *Customers and neighbors issues*. Table 1 provides summary data for the five-cluster map, with grand means and the top-ranked statements in each cluster.

The participant ratings of how critical it is to reduce the uncertainty described in each statement were compared using the mean rankings of the participants. The relative importance is represented by layers in each cluster in Figures 7

and 8 according to respondent rankings. The stacked layers of the *Weather stress problems* cluster in Figure 7 indicate that a large number of items in that cluster were rated as very critical by most of the participants as compared to the items in the *Societal influences* cluster. However while *Weather stress problems* has a higher priority weighting (3.04-3.30) compared to *Societal influences* (3.04-3.10), the difference between the value ranges for these clusters is very small, indicating growers evaluated all these issues as 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 indicates that uncertainties associated with apple production are both social and biophysical in nature.

Cluster Legend

Layer	Value
1	2.88 to 3.04
2	3.04 to 3.21
3	3.21 to 3.37
4	3.37 to 3.53
5	3.53 to 3.69
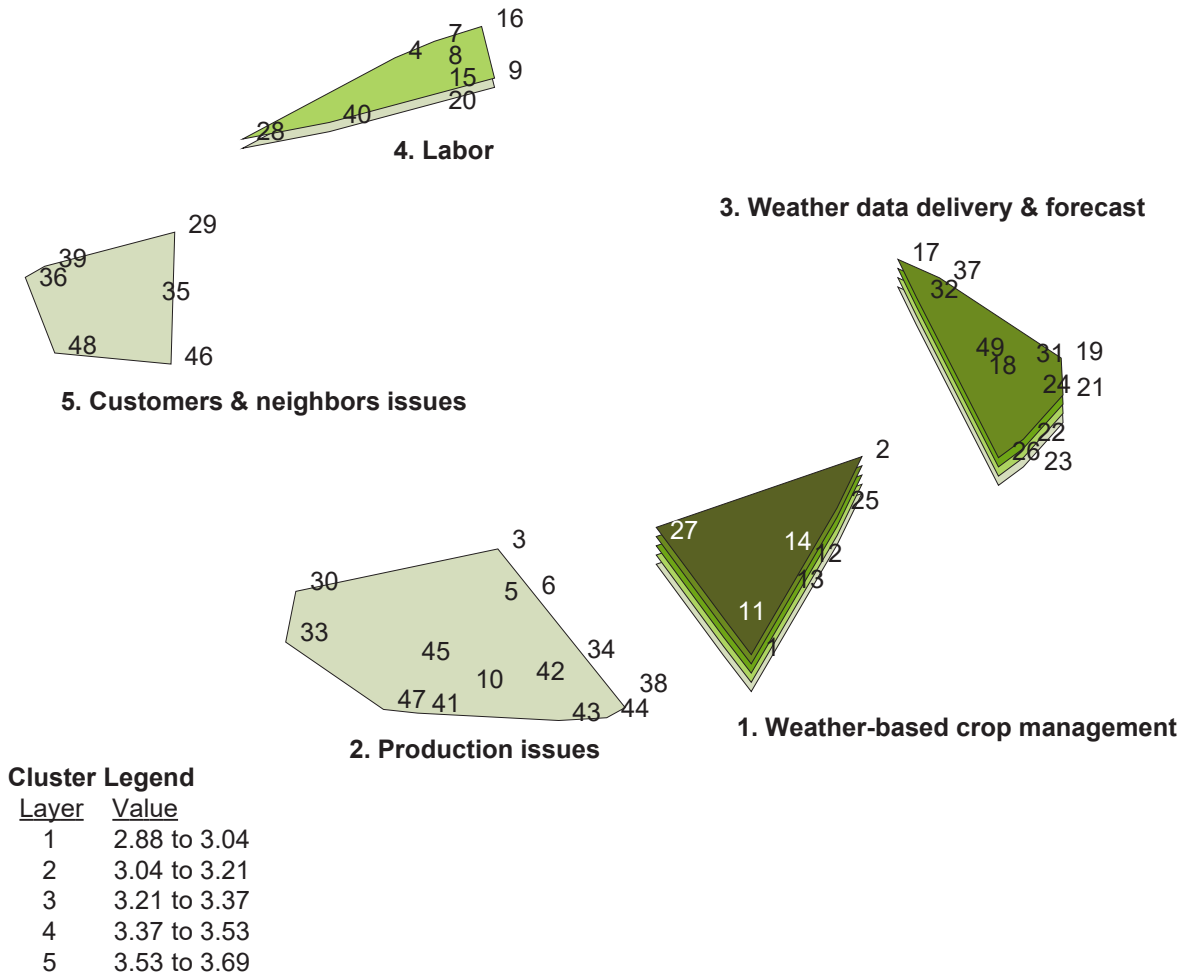
Figure 8. Five-cluster apple growers' conceptual map derived from the prompt, "One uncertainty in my production system I have difficulty managing is…" and rated based on, "How critical is it to reduce levels of uncertainty in your production system related to this statement to make better decisions? (1 = not critical; 2 = somewhat critical; 3 = moderately critical; 4 = very critical; 5 = extremely critical).".

Similarly, the five-cluster map uses layers to help identify and prioritize general and specific areas where research and programming would most benefit growers. Of the new clusters, *Weather-based crop management* (3.69) and *Weather data delivery and forecast* (3.50) are the highest rated, falling between very critical (4.0) and moderately critical (3.0) need to reduce levels of uncertainty.

A look at the statements within each of the five clusters (Figure 8; Table 1) offers a deeper understanding of what each cluster conceptually represents (see Appendix I).

Examining the top-ranked statements in each of the clusters in Table 1, reveals that three clusters (*Weather-based crop management*, *Weather data delivery and forecast,* and *Production issues*) have statements rated between very critical (4) and extremely critical (5) to reduce uncertainty. The other two clusters (*Labor* and *Customers and neighbors issues*) have top-ranked statements between moderately critical (3) and very critical (4) to reduce uncertainty.

Weather-based crop management, consisting of eight statements, is the highest rated cluster (3.69), with growers giving it an overall value of halfway between very and extremely critical to reduce uncertainty. Two statements within this cluster, thinning fruit (when to put on chemical applications) (4.46) and fire blight-loss of tree productivity (4.21) are areas of concern considered very-to-extremely critical

**Table 1. Northeast U.S. apple 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
Weather-based crop management	3.69	8	1. Thinning fruit (when to put on chemical applications)	4.46
Data delivery & forecast	3.50	12	22. Reliability of weather stations	4.21
Labor	3.15	9	40. Labor regulations	3.42
Production issues	2.91	14	38. Introduced pests that are difficult to manage	4.17
Customers & neighbors issues	2.88	6	39. Managing misinformation in media that influences consumers & legislative decisions	3.29

(Appendix I). Five statements are in the very critical range: knowing current pest status (3.79); deciding when to apply sprays based on contradictory IPM-based models and observations (3.71); predicting future pest status within the season (3.63); freezes during/around bloom that threaten crop (3.58); and deciding whether to re-spray when rain follows a spray application (3.58). The lowest rated statement, pruning in winters with erratic temperature conditions: how aggressive or conservative to be (2.58) is considered moderately critical.

Weather data delivery and forecast, the second highest rated cluster, consists of 12 statements ranging from 4.21 (very critical to reduce uncertainty) to 2.79 (moderately critical to reduce uncertainty). The grand mean for this cluster at 3.50 represents the half way point between moderately-to-very critical. Three statements in this cluster are evaluated above or at the very critical threshold: reliability of weather stations (4.21); weather prediction (4.13); and gathering weather data in time to make same-day management decisions (3.96) (Appendix I). Four statements are mid-range between moderately-to-very critical: precipitation, need to predict rain events 6-8 hours in advance to inform spray timing decisions (3.67); site-specific decisions undermined by station reliability (3.63); on-the-fly "push" weather notifications on local basis (3.46); and precipitation extremes (3.42). Four statements are rated slightly above the moderately critical level: year-to-year weather extremes-how to optimize planning (3.29); weather relationship to productivity and sales (3.17); planning for weekend weather (3.13); and short-term variability of weather (3.13). The lowest rated statement, predicting the weather in order

to estimate pick-your-own customer numbers to optimize staffing food service (2.79) is considered moderately critical.

Labor, the third highest rated cluster (3.15) is a *Societal influence* sub-category. Labor has nine statements with six of them falling slightly above the moderately critical range. The highest rated statement is labor regulations (3.42) followed by recruitment of seasonal employees (3.33); full time labor shortage-recruiting and retention (3.29); seasonal employee retention (3.29); field labor shortages-retention and recruitment (3.25); and farm stand, part-time, seasonal labor shortages (3.21) (Appendix I). Slightly below moderately critical are three statements: labor-increasing difficulty of obtaining H2A workers (2.92); regulations-worker protection standards (2.83); and training seasonal employees (2.83).

Production issues with a grand mean of 2.91 representing moderately critical to reduce uncertainty, is the fourth highest rated cluster of interest. Fourteen production issues are identified by growers as areas of uncertainty ranging from very critical (4.17) to below somewhat critical (1.75) (Appendix I). Three highly rated, very critical statements are: introduced pests that are difficult to manage (4.17); managing crop load for present and future years (4.08); and sub-lethal impact of apple pesticides on pollinators (3.92). Three statements fall above moderately critical: spray management to suppress risk of resistance (3.58); managing a perennial crop (3.50); and managing pesticides in diverse perennial crops (3.29). Five statements between moderately and somewhat critical range from 2.83 to 2.25: preharvest fruit drop (McIntosh) (2.83); managing biennial bearing varieties in pick your own

(2.71); increased populations of voles (2.50); deer damage (2.46); and sunburn on fruit (2.25). The three lowest rated statements, rated somewhat critical are fruit scald in storage (related to sunburn in field perhaps?) (1.96); orchard access during wet periods (1.79); and effective pest management under organic production (1.75).

Customer and neighbor issues in the *Societal influence* sub-category with six statements has a grand mean of 2.88 representing moderately critical to reduce uncertainty (Appendix I). Three statements fall slightly above moderately critical: misinformation in media that influences consumer and legislative decisions (3.29); regulations-food safety (3.25); and educating consumers (3.25). The last three statements in this cluster are mid-way between somewhat and moderately critical to reduce uncertainty: development pressure restricts management decision-making (2.58); unrealistic pesticide application notification laws (2.58); and traffic and parking in pick-your-own operations (2.33).

Top quartile statements. Another way to examine the findings is to list all 49 statements arranged by highest to lowest rating (Appendix II). The top quartile (25%) of apple growers' statement rankings based on ratings is shown in Table 2.

These top 13 statements range from 4.46, verging on extremely critical to 3.63, very critical that levels of uncertainty be reduced in apple production systems in order to make timely, good decisions. These highest rated statements focus on decision-making at the intersection of diseases, pests, and availability of reliable and timely weather data.

Observations

Emerging and unknown risks associated with increasingly variable local and regional weather are reverberating throughout U.S. agriculture, including Northeast U.S. apple production. Apples are a perennial crop that is highly sensitive to temperature (frost and excessive heat), prolonged periods of wetness or drought, high winds, hail, and long-term shifts in climate. The increasing uncertainty about future near and long-term weather conditions is one of specialty crop growers' largest challenges. Uncertainties are associated with water availability, disease and pest risk, cultivar selection, timing of planting and harvest, and the new risks that are projected to occur as the earth's climate alters (Adger et al. 2009).

Table 2. Top quartile (25%) Northeast U.S. apple 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
1	Thinning fruit (when to put on chemical applications)	4.46	1
11	Fire blight—loss of tree productivity	4.21	1
22	Reliability of weather stations	4.21	3
38	Introduced pests that are difficult to manage	4.17	2
19	Weather prediction	4.13	3
33	Managing crop load for present and future years	4.08	2
21	Gathering weather data in time to make same-day management decisions	3.96	3
45	Sub-lethal impact of apple pesticides on pollinators	3.92	2
13	Knowing current pest status	3.79	1
12	Deciding when to apply sprays based on contradictory IPM-based models and observations	3.71	1
24	Precipitation: Need to predict rain events 6-8 hours in advance to inform spray timing decisions.	3.67	3
14	Predicting future pest status within the season	3.63	1
23	Site-specific concept undermined by station reliability	3.63	3

Decision support tools and information can help growers address risk and uncertainty now and in the future particularly with regard to an increasingly variable climate, though new research in this area is needed. This preliminary report offers a snapshot of Northeast U.S. apple growers' observations, thoughts, concerns, and priorities for their crop. The concept mapping process identified weather-based crop management as their top concern, specifically fruit thinning decisions, predicting pest and disease threats, precipitation extremes and freezes near bloom time that threaten crops, and managing crop load for present and future years. A second high priority area identified by growers is a need for improved weather data delivery and forecast, enabling them to reduce uncertainties associated with long- and short-term site specific management decisions.

Northeast U.S. apple growers know that their local climate is the key to a productive and profitable crop, and they track local weather daily and over time to manage their crops. Historical climate records are valuable in guiding current and future management decisions. However, with climate change, weather risks move from familiar and generalizable patterns into unknown threats that emerge from nonlinear interactions among system components and processes, leading to deep uncertainties about outcomes (Park et al. 2013). Unexpected hazards occur because emergent phenomena can only be observed in real time, and because complete quantification of risks in advance is not yet possible. This in turn leads to increased uncertainties regarding management decisions. There is an ongoing need for research that helps apple growers to mitigate uncertainties associated with forecasts of short- and long-term weather conditions with intent to reduce risks associated with crop management, stabilize productivity and profitability, and decrease the chances of catastrophic crop loss.

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Appendix I. Northeast U.S. apple growers' five-cluster rankings

Apple growers' statements 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. Weather-based crop management		**3.69**
1	Thinning fruit (when to put on chemical applications)	4.46
11	Fire blight—loss of tree productivity	4.21
13	Knowing current pest status	3.79
12	Deciding when to apply sprays based on contradictory IPM-based models and observations	3.71
14	Predicting future pest status within the season	3.63
2	Freezes during/around bloom that threaten crop	3.58
25	Deciding whether to re-spray when rain follows a spray application	3.58
27	Pruning in winters with erratic temperature conditions: how aggressive or conservative to be	2.58

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
8	0.51	0.27	2.58	4.46	3.69	3.67

		Average Rating
2. Production issues		**2.91**
38	Introduced pests that are difficult to manage	4.17
33	Managing crop load for present and future years	4.08
45	Sub-lethal impact of apple pesticides on pollinators	3.92
44	Spray management to suppress risk of resistance	3.58
34	Managing a perennial crop	3.50
42	Managing pesticides in diverse perennial crops	3.29
10	Pre-harvest fruit drop (McIntosh)	2.83
30	Managing biennial bearing of varieties in a pick-your-own business	2.71
41	Increased populations of voles	2.50
47	Deer damage	2.46
5	Sunburn on fruit	2.25
6	Fruit scald in storage; related to sunburn in field?	1.96
3	Orchard access during wet periods	1.79
43	Effective pest management under organic production	1.75

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
14	0.81	0.66	1.75	4.17	2.91	2.77

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

		Average Rating
3. Data delivery & forecast		**3.50**
22	Reliability of weather stations	4.21
19	Weather prediction	4.13
21	Gathering weather data in time to make same-day management decisions	3.96
24	Precipitation: Need to predict rain events 6-8 hours in advance to inform spray timing decisions.	3.67
23	Site-specific concept undermined by station reliability	3.63
26	On-the-fly "push" weather notifications on local basis	3.46
49	Precipitation extremes	3.42
31	Year-to-year weather extremes: how to optimize planning	3.29
37	Weather relationship to productivity and sales	3.17
32	Planning for weekend weather	3.13
18	Short-term variability of weather	3.13
17	Predicting the weather in order to estimate pick-your-own customer numbers to optimize staffing and food service	2.79

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
12	0.42	0.17	2.79	4.21	3.50	3.44

		Average Rating
4. Labor		**3.15**
40	Labor regulations	3.42
7	Seasonal employees: recruitment	3.33
20	Full-time labor shortage—recruiting and retention	3.29
8	Seasonal employees: retention	3.29
15	Labor shortages—field; retention and recruitment	3.25
16	Labor shortages—farm stand; part-time, seasonal	3.21
4	Labor—increasing difficulty of obtaining H2A workers	2.92
28	Regulations—worker protection standards	2.83
9	Seasonal employees: training	2.83

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
9	0.21	0.05	2.83	3.42	3.15	3.25

		Average Rating
5. Customers & neighbors issues		**2.88**
39	Managing misinformation in media that influences consumer and legislative decisions	3.29
29	Regulations—food safety	3.25
36	Educating consumers	3.25
46	Development pressure restricts management decision-making	2.58
35	Unrealistic pesticide application notification laws	2.58
48	Traffic and parking in pick-your-own operations	2.33

Count	Std. Dev.	Variance	Min.	Max.	Avg.	Median
6	0.39	0.15	2.33	3.29	2.88	2.92

Appendix II. Northeast U.S. apple growers' ranked statements

Apple growers' statements 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
1	Thinning fruit (when to put on chemical applications)	4.46	1
11	Fire blight—loss of tree productivity	4.21	1
22	Reliability of weather stations	4.21	3
38	Introduced pests that are difficult to manage	4.17	2
19	Weather prediction	4.13	3
33	Managing crop load for present and future years	4.08	2
21	Gathering weather data in time to make same-day management decisions	3.96	3
45	Sub-lethal impact of apple pesticides on pollinators	3.92	2
13	Knowing current pest status	3.79	1
12	Deciding when to apply sprays based on contradictory IPM-based models and observations	3.71	1
24	Precipitation: Need to predict rain events 6-8 hours in advance to inform spray timing decisions.	3.67	3
14	Predicting future pest status within the season	3.63	1
23	Site-specific concept undermined by station reliability	3.63	3
2	Freezes during/around bloom that threaten crop	3.58	1
25	Deciding whether to re-spray when rain follows a spray application	3.58	1
44	Spray management to suppress risk of resistance	3.58	2
34	Managing a perennial crop	3.50	2
26	On-the-fly "push" weather notifications on local basis	3.46	3
49	Precipitation extremes	3.42	3
40	Labor regulations	3.42	4
7	Seasonal employees: recruitment	3.33	4
42	Managing pesticides in diverse perennial crops	3.29	2
31	Year-to-year weather extremes: how to optimize planning	3.29	3
20	Full-time labor shortage—recruiting and retention	3.29	4
8	Seasonal employees: retention	3.29	4
39	Managing misinformation in media that influences consumer and legislative decisions	3.29	5
15	Labor shortages—field; retention and recruitment	3.25	4
29	Regulations—food safety	3.25	5
36	Educating consumers	3.25	5
16	Labor shortages—farm stand; part-time, seasonal	3.21	4

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

Statement Number		Average Rating	Cluster Number
37	Weather relationship to productivity and sales	3.17	3
32	Planning for weekend weather	3.13	3
18	Short-term variability of weather	3.13	3
4	Labor—increasing difficulty of obtaining H2A workers	2.92	4
10	Pre-harvest fruit drop (McIntosh)	2.83	2
28	Regulations—worker protection standards	2.83	4
9	Seasonal employees: training	2.83	4
17	Predicting the weather in order to estimate pick-your-own customer numbers to optimize staffing and food service	2.79	3
30	Managing biennial bearing of varieties in a pick-your-own business	2.71	2
27	Pruning in winters with erratic temperature conditions: how aggressive or conservative to be	2.58	1
46	Development pressure restricts management decision-making	2.58	5
35	Unrealistic pesticide application notification laws	2.58	5
41	Increased populations of voles	2.50	2
47	Deer damage	2.46	2
48	Traffic and parking in pick-your-own operations	2.33	5
5	Sunburn on fruit	2.25	2
6	Fruit scald in storage; related to sunburn in field?	1.96	2
3	Orchard access during wet periods	1.79	2
43	Effective pest management under organic production	1.75	2