Annual Report

July 1, 2017 – June 30, 2018

Viticulture and Enology programs for the Colorado Wine Industry

PRINCIPAL INVESTIGATORS

Horst Caspari[1], Nolan Doesken[2], Peter Goble[2], Stephen Menke[1], Meagan Schipanski[3], Russ Schumacher[2], David Sterle[1], Mary Stromberger[3], Adam Wright[1]

COLLABORATING INSTITUTIONS

- Colorado Department of Agriculture
- The Colorado Wine Industry Development Board
- Colorado State University

Summary

The reporting period covers the second half of the 2017 growing season, the 2017/18 dormant period, and the first half of the 2018 growing season. Consequently, the work performed during the reporting period covers a full seasonal cycle, albeit from two different growing seasons. Work included seasonal tasks such as vine training, canopy management, crop thinning, harvest, winemaking, preparing vineyards for dormant season, bud cold hardiness evaluations, dormant pruning, new plantings, a continuation of a study on methods to increase bud cold hardiness, a study on the climate and climatic trends in Montezuma and Fremont counties as it relates to wine grape production, data entry and analysis, and the annual Colorado Grape Grower Survey. In addition, since the discovery of phylloxera (*Daktulosphaira vitifoliae*) in the Grand Valley in November 2016, significant efforts have been directed towards outreach, grower education, phylloxera surveys, and new research projects on rootstock suitability, replanting options, and graft union management.

Four student interns (two from the Viticulture & Enology program at CSU; one from the Viticulture & Enology program at WCCC) and a high school student assisted with the vineyard work during the summer months. Two other student interns from the Viticulture & Enology program at CSU were responsible for all vineyard work in the new variety trial in Fort Collins. Staff from WCRC also helped with vineyard tasks at OM and RM throughout the season. The climate study in Montezuma and Fremont counties was conducted by staff from the Colorado Climate Center.

With the exception of October 2017, weather conditions in the Grand Valley were warmer and drier throughout the reporting period. In fact, November 2017 was the warmest November since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964, breaking the record set in November 2016. The mean temperature for November was 6.2 F higher than average. A season-ending killing frost occurred on 25 September for many vineyards in Montezuma County, on 10 October in

[1]Department of Horticulture and Landscape Architecture
[2]Department of Atmospheric Science
[3]Department of Soil and Crop Sciences
Colorado State University, Fort Collins, CO 80523

the main growing areas in Delta County, but not until 8 November in the Grand Valley. Similar to the previous season, there was a gradual decline in minimum temperatures in December which resulted in good and gradual vine cold acclimation. The lowest minimum temperature of the dormant season recorded at WCRC-OM was 8.8 F on 22 January 2018. The lowest minimum at WCRC-RM was 8.5 F on 12 December 2017. Weekly bud evaluations from vines growing at the Western Colorado Research Center – Orchard Mesa and commercial vineyards nearby showed zero bud injury throughout the dormant season. There was no damage from spring frosts as the last spring frost (26.7 F) at WCRC-OM occurred on 18 April, prior to bud break of most varieties. Similarly, the last spring frost (31.5 F) at WCRC-RM on 25 April preceded bud break.

Similar to 2015 and 2016, most of the 48 varieties grown in the research vineyards produced a crop in 2017. Data from the 2017 Colorado Grape Grower Survey indicate that the 2017 harvest was the biggest ever, surpassing the record set in 2016. Similar to the 2016 harvest, there was a surplus of grapes, but this surplus appears to have been smaller than in the previous two years.

For further information please contact:

Dr. Horst Caspari, Professor & State Viticulturist
Colorado State University
Western Colorado Research Center
3168 B½ Rd
Grand Junction, CO 81503

Phone: 970-434-3264 x204 horst.caspari@colostate.edu

Growing conditions, July 2017 – June 2018

Temperatures recorded at the Western Colorado Research Center - Orchard Mesa (WCRC-OM) and Western Colorado Research Center - Rogers Mesa (WCRC-RM) were above average for all but October 2017. Annual precipitation (July 2017 to June 2018) at WCRC-OM and WCRC-RM was 5.47" and 7.21", respectively, significantly below normal. In fact, at the end of June 2018 most of Western Colorado is in severe to exceptional drought conditions.

In the Grand Valley a killing frost didn't occur until the second week of November, so most grapes were harvested prior to the frost event. Most of the vineyards in Delta and Montrose counties had a killing frost in the second week of October, while many vineyards in Montezuma County had a killing frost in the fourth week of September. Monthly mean temperatures during the dormant period were above average, and there were no extreme low temperature events. All of the CoAgMet weather stations located in the main grape growing areas of Western Colorado show winter minimum temperatures above 0 F.

Once again there was an early warmup in February and March, but not as extreme as in 2017. Intermittent colder periods slowed bud de-acclimation, and timing of bud break was near normal. An earlier than normal last spring frost meant no or minimal spring frost damage.

May and June temperatures were well above average, with high temperatures in the Grand Valley reaching 100 F as early as 13 June. By the end of June growing degree days (GDD) were 23 % higher than average, and close to the GDDs of 2000 and 2012 (the two hottest growing seasons on record).

Research Update

I. Cropping Reliability

1. Grape varieties and clones suited to Colorado temperature conditions

Since 2004 we have greatly expanded the number of varieties under testing. The first-ever replicated variety trial in Delta County was planted at the Western Colorado Research Center - Rogers Mesa site in 2004. This trial was expanded with new entries in 2008-2009 as part of the USDA Multistate NE-1020 project (see below). Also in 2008 and as a part of NE-1020, 26 "new" varieties were planted at the WCRC Orchard Mesa site. An additional replicated trial focused on cold-hardy, resistant varieties was established on a grower cooperator site in Fort Collins in 2013 to identify grape varieties that can be grown successfully along the Front Range. And in 2014, a fourth trial focused on cold-hardy, resistant varieties was established with a grower-cooperator in the Grand Valley.

- Rogers Mesa variety trial (Caspari and Menke)

  A new vineyard was planted at the Rogers Mesa site in the spring of 2004, with additional vines added in the spring of 2005 and 2006. With the exception of a few missing vines, this planting is complete. Genetic backgrounds of the varieties include both cold-hardy, resistant varieties, mainly from the grapevine breeding program from Geneva, NY, and *Vitis vinifera* varieties. Vines of Pinot noir, P. Meunier, and Malbec were removed from this trial in the spring of 2015 due to very poor performance.

The comparatively mild temperatures during winter 2016/17 resulted in minimal bud damage to the remaining test varieties. However, due to the time demands and harvest conflicts with other trials no harvest data are available for 2017.

The vines were removed prior to bud break in the spring of 2018. Posts and trellis system remain intact, and the site could again be used for future plantings. The site will be fallowed during the 2018 growing season.

- Multi-state evaluation of wine grape cultivars and clones (Caspari, Menke, Sterle, and Wright)

This long-term (2004-2017), USDA multi-state research project (NE-1020) tests the performance of clones of the major global cultivars and new or previously neglected wine grape cultivars in the different wine grape-growing regions within the U.S. and is a collaboration of more than 20 states. In 2017, this project was renewed for another five years (now called NE-1720). All participating states follow the same experimental protocol. In Colorado, 10 varieties were established in 2008 and 2009 at Rogers Mesa, and 25 varieties at Orchard Mesa between 2008 and 2012. At Orchard Mesa, we have continued to remove poor performing varieties and replant with new entries. For example, in 2016 we added MN 1285, a white variety from the breeding program at the University of Minnesota. MN 1285 was released in 2017 under the variety name 'Itasca'.

At Rogers Mesa, five out of ten varieties were harvested between 4 and 18 October 2017. Yields ranged from 0.3 to 1.4 ton/acre (Table 1). The very low yields are due to various factors, including shatter (>50 % loss on Aromella), bird damage, and berry shrivel due to late harvest. Micro-vinification was used to produce one varietal wine.

Table 1: Harvest dates and yield information for 5 (out of 10) grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Variety	Harvest date 2017	Yield (ton/acre)[1]
Aromella	4 October	0.32
Auxerrois		0
Bianchetta trevigiana		0
Blauer Portugieser		0
Chambourcin	18 October	0.42
Grüner Veltliner		0
Marquette	4 October	0.61
MN 1200	4 October	0.42
NY 81.0315.17		0
Vidal	18 October	1.39

[1] Yield calculation based on number of vines with crop. Vine survival (out of 24 vines planted originally) ranges from 46 % for Auxerrois to 100 % for Marquette and MN 1200.

At Orchard Mesa, all 25 varieties produced a crop but no yield data are available for Refosco. Harvest started with Marquette on 14 August 2017, and ended with five varieties on 18 October 2017. A summary is presented in Table 2. Averaged across all varieties, yields were up by 60 % compared to the 2016 season. Despite the higher yield all varieties were harvested earlier than in 2016 (on average by 12 days). Twenty varietal wines were produced using micro-vinification techniques.

Table 2: Harvest dates and yield information for 24 grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Variety	Harvest date 2017	Yield per vine (lb)[1]	Yield (ton/acre)[2]
Albarino	14 September	7.72	3.68
Barbera	17 October	12.22	3.60
Cabernet Dorsa[3]	25 August	3.73	1.35
Cabernet Sauvignon	11 October	7.99	4.17
Carmenere[4]	17 October	1.70	0.77
Chambourcin[3]	11 October	5.68	2.19
Cinsault	3 October	10.96	3.48
Durif[3]	17 October	8.33	3.40
Graciano[4]	14 September	11.90	1.62
Grenache	18 October	10.13	1.84
Malvasia Bianca	11 September	6.98	2.85
Marquette[3]	14 August	3.30	1.20
Marsanne	14 September	9.56	2.39
Merlot	8 September	4.88	1.55
Mourvedre	18 October	7.04	3.19
Petit Verdot[4]	18 October	6.98	1.74
Roussanne	14 September	7.99	2.36
Souzao	18 October	6.16	1.54
Tinta Carvalha[4]	18 October	3.04	0.34
Tocai Friulano	12 October	12.31	0.56
Touriga Nacional	3 October	8.66	1.96
Verdejo	12 October	11.46	0.52
Verdelho	11 September	5.55	1.89
Zweigelt[3]	8 September	4.50	2.35

[1] Yield calculation based on vines with crop.

[2] Yield calculation taking into account percentage of surviving vines. Vine survival (out of 24 vines planted originally) ranges from 4 % for Tocai Friulano to 96 % for Zweigelt.

[3] Planted in 2011 and 2012.

[4] Planted in guard rows; not part of the NE-1020 study. However, experimental design and management follow NE-1020 protocol.

- Variety evaluation for Front Range locations, Fort Collins (Caspari, Menke and grower cooperator)

  A new vineyard was established on a grower cooperator site in Fort Collins in 2013 to identify grape varieties best suited along the Front Range. Repeated cold events have led to a slow vine establishment. Two extreme cold temperature events during dormancy (-9 F on 12 November, and -22 F on 30 December 2014) caused near 100 % bud and trunk damage to Chambourcin, Noiret, and Traminette. In contrast, Aromella, Frontenac, and Marquette had about 90 % live fruitful buds (primary and secondary). However, a severe freeze event on 11 May 2015, when most varieties were near or already past bud break, caused significant cold damage to emerging shoots and near 100 % crop loss. Consequently, many vines needed re-training during 2015. Milder minimum temperatures during the 2015/16 dormant season resulted in no bud or trunk damage, and there were no late spring freezes. However, yields again were low. In 2017, a series of late spring frosts caused damage to all varieties, leading again to very low yields (Table 3). Additionally, vine vigor at this site is much less than desired, contributing to the low yields.

Table 3: Harvest dates and yield information for 6 (out of 8) grape varieties planted in 2013 at a commercial vineyard in Fort Collins, CO.

Variety	Harvest date 2017	Yield (ton/acre)[1]
Aromella	4 October	0.94
Chambourcin	4 October	0.92
Frontenac	4 October	0.88
La Crescent	18 September	1.58
Marquette	18 September	1.71
Vignoles	4 October	0.82

[1] Yield calculation based on number of vines with crop. Vine survival is >95 % for all varieties.

- Cold-hardy, resistant varieties for the Grand Valley (Caspari, Menke, and grower cooperator)

  A new replicated variety trial was established in 2014 on a grower cooperator site near Clifton to identify grape varieties that can be grown successfully in cold Grand Valley sites. All varieties produced a crop (Table 4). On average, yields were down by 23 % compared to 2016 while harvest was nine days earlier. Only Noiret and Traminette had higher yields in 2017 than 2016. Nine varietal wines and one blended wine were produced.

  This vineyard is located near the Colorado river. There is a large tree shelter belt at the South side of the vineyard. Additionally, many small and large trees and bushes are growing on properties to the South and East. As a result, there is a high bird population in the area which leads to high to very high yield losses, especially on very early ripening varieties. For example, the estimated losses from bird damage were 91 % for Brianna, and ~20 % for Marquette and La Crescent. Bird damage was minimal for all other varieties.

Vines were pruned in early April 2019. Initially, all varieties were pruned to long (8-10 buds) spurs to delay bud break. Once bud break was completed spurs were cut back to two live shoots.

Consistent with observations in previous years, Brianna, Marquette, and La Crescent is the first group of varieties to break bud, followed by Noiret, Corot noir, and Aromella. At this site, Traminette, Vignoles and Chambourcin are the last varieties to reach bud break.

Table 4: Harvest dates and yield information for 12 grape varieties planted in 2013 at a commercial vineyard near Clifton, CO.

Variety	Harvest date 2017	Yield (ton/acre)[1]
Arandell	25 August	1.11
Aromella	1 September	2.72
Brianna	8 August	0.53[2]
Cayuga White	31 August	2.46
Chambourcin	16 October	1.54
Corot noir	8 September	1.58
La Crescent	31 August	1.77[3]
Marquette	18 August	1.63[3]
Noiret	8 September	2.30
St Vincent	16 October	3.15
Traminette	8 September	1.58
Vignoles	7 September	0.60

[1] Yield calculation based on number of vines with crop. Vine survival is >90 % for all varieties except St Vincent (79 %).
[2] Yield reduced by an estimated 90 % from bird damage.
[3] Yield reduced by an estimated 20 % from bird damage.

- Clonal trial with Cabernet Franc (Caspari, Menke, and grower cooperator)

Cabernet Franc is one of Colorado's most-planted varieties, and varietal wines made from this variety have received national recognition. A recent review of data from Colorado's annual grape growers survey from 2000 to 2015 showed that Cabernet Franc was the only variety that produced above-average yields in all 16 years, and returned the second-highest average grape sales revenue per acre (Caspari, 2015). It may indeed be one of the best-suited *Vitis vinifera* varieties for the Grand Valley AVA.

Most older-aged blocks of Cabernet Franc are planted with clone FPS 01. While this clone is high yielding and appears to have very good cold hardiness, it is also considered as having lower fruit quality. Since no information on Cabernet Franc clonal performance is available in Colorado, a trial with four clones (FPS 01, 04, 09, 11) was established in 2009 on a grower cooperator's vineyard[2].

On 27 September 2017, approximately 250 lbs of fruit per clone were harvested from 4 to 7 replicates per clone. The number of vines harvested was recorded separately for each clone. Fruit was taken to WCRC-OM, weighed, and then used to

[2] The trial was set up as a randomized complete block design with 10 full-row replications, and a total number of 500 vines per clone. Rows are 2 m apart with vines spaced in-row at 5 feet.

produce triplicate small-scale wine lots. Must samples were analysed using an OenoFoss analyser (Foss North America, Gusmer Enterprises Inc., Fresno, CA). Following must analyses, must of each wine lot was adjusted to a target of 22.5 Brix soluble solids and 6.5 g/l total titratable acidity. Wines will be used for future analysis, formal wine evaluations, and industry tastings.

Consistent with observations in the previous two years, yields were highest for clones FPS 01 and 09, and lowest for clone FPS 11 (Table 5). It should be noted, however, that vines of clone FPS 11 are grafted to rootstock 110 Richter whereas vines of all other clones are own-rooted. Grafted vines of clone FPS 11 are less vigorous than own-rooted vines.

Table 5: Clonal effects on 2017 yield of Cabernet Franc growing in the Grand Valley AVA in Western Colorado.

Clone / rootstock	Yield (lb/vine)	Yield (ton/acre)
FPS 01 / own	3.71	2.46
FPS 04 / own	3.41	2.27
FPS 09 / own	4.47	2.97
FPS 11 / 110R	2.16	1.43

Compared to 2016, yields were down by 40 % for clones 1 and 9, 27 % for clone 4, but only 3 % for clone 11. The lower yields are the result of two late spring freezes (30 April, 1 May) that occurred right at / after bud break, causing damage to many primary shoots. As a result, much of the crop came from secondary shoots.

In 2015 and 2016, despite having the lowest yield, musts of clone FPS 11 also had the lowest nitrogen concentration. This was not the case in 2017 (Table 6). Overall, differences in both yields and must parameters were less pronounced in 2017 than in the previous two years, most likely the result of the spring frost damage.

Table 6: Clonal effects on 2017 harvest must parameters of Cabernet Franc growing in the Grand Valley AVA in Western Colorado.

Clone / rootstock	pH	Brix	TA (g/l)	Tartaric acid (g/l)	Malic acid (g/l)	α-amino nitrogen (mg/l)	Ammonia (mg/l)
FPS 01 / own	3.87	26.1	4.01	5.62	1.64	104	84
FPS 04 / own	3.97	26.3	3.85	5.31	1.64	119	80
FPS 09 / own	3.85	26.8	4.08	5.49	1.60	90	79
FPS 11 / 110R	3.85	25.2	4.12	5.52	1.49	113	72

Wines were analyzed using the OenoFoss analyzer. Table 7 shows the average values of wine analysis data of the triplicate wine lots from June 2018.

Table 7: Clonal effects on 2017 wine parameters of Cabernet Franc growing in the Grand Valley AVA in Western Colorado.

Clone / rootstock	Ethanol (%)	pH	TA (g/l)	Tartaric acid (g/l)	Malic acid (g/l)	Glucose & Fructose (g/l)
FPS 01 / own	13.22	3.68	5.24	0.75	0.81	0.03
FPS 04 / own	13.39	3.74	5.18	1.10	0.67	0.04
FPS 09 / own	13.72	3.69	5.23	0.80	0.82	0.00
FPS 11 / 110R	12.88	3.65	5.48	1.04	0.79	0.17

2. *Cold temperature injury mitigation and avoidance.*

Low yields and large year-to-year yield fluctuations are characteristic of Colorado grape production, even in the Grand Valley AVA, due to cold temperature injury. The research projects outlined below try to identify best methods to either avoid cold injuries altogether, or mitigate cold temperature negative effects on vine survival, yield, quality, and vineyard economics. It should be noted that the identification of varieties that are best suited to Colorado's climate (see variety trials above) is a fundamental component for avoiding cold injury.

- Characterizing cold hardiness (Caspari, Sterle, and Wright)

  There are substantial varietal differences in cold hardiness. Understanding the patterns of acclimation, mid-winter hardiness, and de-acclimation is a prerequisite to developing strategies that reduce cold injury. Since 2004, we have been testing bud cold hardiness during dormancy of Chardonnay, Syrah, Chambourcin, and Rkatsiteli that differ in rate and timing of acclimation and de-acclimation, as well as mid-winter hardiness. During the 2013/14 and 2014/15 dormant seasons, we have done the first-ever characterization of the seasonal pattern changes for Aromella.

  Since fall of 2004 we have used a freezing protocol with a step-wise temperature drop in a programmable freezer, followed by bud dissection and visual inspection of oxidative browning (Caspari and Sterle, 2017). In the fall of 2016, and in collaboration with Dr Ioannis Minas and the Pomology Program at WCRC-OM and assistance from Dr Todd Einhorn at Oregon State University, we developed a new system to test cold hardiness using Differential Thermal Analysis (DTA) (Gerard and Schucany, 1997; Mills et al., 2006). Similar state-of-the-art systems are used by viticulture programs at Washington State University (Dr Keller lab), Ohio State University (Dr Dami lab), and Cornell University (Dr Martinson lab), amongst others. The main components of the DTA system consist of a new programmable freezer (Tenney, model TUJR-A-WF4, TPS Thermal Products Solutions, New Columbia, PA), Keithley data loggers (Model 2700 Integra Series, Keithley Instruments Inc., Cleveland, OH) with software, three plates of cells containing thermoelectric modules, and a dedicated computer for data capture. For a brief description of our system see Minas et al. (2017).

  With two systems we are now able to run simultaneous tests on the same varieties using different freezing protocols, or run the same protocols with a larger number of varieties.

Cold hardiness test were initiated in mid-September. Since late October, tests have been conducted on an approximately weekly basis. Results were made available via our Webpage, and growers are able to use this information when deciding if freeze/frost protection is needed. In addition to the ~weekly tests on Chardonnay and Syrah the following varieties were tested at a less frequent interval: Albarino, Aromella, Cabernet Franc, Chambourcin, Marquette, Merlot, Souzao, and Traminette. While Chambourcin from the WCRC-RM site has been included in cold hardiness tests in previous years, these were the first data for Chambourcin, as well as Marquette and Traminette, growing in the Grand Valley.

- Advancing cold hardiness (Caspari, Sterle, and Wright)

Cold injury to buds and trunks frequently occurs in late fall prior to vine tissues reaching maximal cold hardiness. One approach to reduce this type of cold damage is to advance cold hardiness acclimation. Several recent studies have shown that a new plant growth regulator product containing 20 % abscisic acid (ABA)[3] can advance cold acclimation. Initial trials by M.S. candidate Ms. Anne Kearney during the 2014/15 dormant season tended to confirm earlier bud cold acclimation in three-out-of-four tested varieties. However, the best timing for the ABA application differed between varieties. In the 2015/16 dormant season, four different ABA treatments were tested on three varieties. Not all treatments were applied to all varieties. Results once again suggested a potential advancement in fall acclimation but no effect on cold hardiness for the remainder of the dormant season.

In early October 2017 a new study was initiated using mature Chardonnay vines growing at WCRC-OM. There are two significant changes compared to previous studies. First, we doubled the ABA concentration (from 500 ppm in previous tests to 1,000 ppm). Second, the foliar application was applied post-harvest, shortly before the onset of natural leaf senescence. Controlled freezing tests in late October indicated a small increase (-1.7 F) in cold hardiness with ABA, but tests in early and late November, late December, early February, and early March showed treatment differences of less than 0.8 F. The practical significance of such small differences in cold hardiness is questionable.

3. *Alternatives to bilateral VSP to optimize yield and quality with different trellis/ training systems.*

- Training system and pruning method effects on grape yield and wine quality of Syrah (Caspari, Menke, Sterle, and Wright)

Vines with bilateral cordon, spur pruned, and trained into a Vertical Shoot Positioning (VSP) system are the standard in Colorado. Our research on bud survival, shoot density, and yield following cold events in 2009, 2013, and 2014 show a limited capacity of this system to overcome high levels of cold damage. From 2010 to 2012, we have demonstrated the advantages of simple adjustments to change the bilateral VSP to a quadrilateral system. As a result, many growers are now training to four cordons or canes. Other training/trellis systems (Pendelbogen, Sylvoz, Lyre, High Cordon, Low Cordon, and Geneva Double Curtain) have been tested since 2006 using own-rooted Syrah vines growing at the Orchard Mesa site.

[3] ProTone, manufactured by Valent BioSciences.

Yield and fruit maturity differs from the South to the North end of the Syrah block. Consequently, pre-harvest fruit samples are taken from three areas within the block, and these areas may be picked on separate dates, based on the fruit analysis results. In 2017, the block was harvested on 6 and 12 October. Yields ranged from 0.9 ton/acre with Geneva Double Courtain to 2.5 ton/acre with VSP (Table 8). Yields were almost linearly related to cluster number. Higher cluster number in itself is an outcome of a higher bud number left after pruning resulting in higher shoot numbers per vine on systems like the Lyre, GDC, and Sylvoz.

Since 15-20% of Colorado's vineyard area has recently been planted to cold-hardy resistant varieties – most of which having a "droopy" growth habit and are thus not suited for VSP trellising – this training/trellis system block serves as an instructional resource for workshops on pruning and training of varieties with downward shoot growth habits.

Table 8: Effect of training/trellis system on yield and yield components of Syrah growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Treatment	Clusters per vine	Yield (ton/acre)
Low Cordon	19	1.65
Vertical Shoot Positioning	27	2.47
Sylvoz	17	1.19
Pendelbogen	20	1.60
Lyre	23	1.45
Geneva Double Curtain	17	0.94

4. *Mitigating damage from grape phylloxera*

Grape phylloxera (*Daktulospheira vitifoliae*) is an aphid-like insect that feeds on grape roots. Phylloxera is native to the northeastern United States and many American grape species are tolerant to phylloxera. However, the European grape (*Vitis vinifera*) has no tolerance and phylloxera feeding on roots will eventually kill the vines. The first recording of phylloxera in a commercial vineyard in Colorado occurred in August 2015. During a routine Grape Commodity Survey, personnel working for the Cooperative Agricultural Pest Survey (CAPS) found phylloxera on leaves of hybrid vines in Larimer county. In November 2016, CSU personnel assisting a grower in Mesa County discovered phylloxera on the roots of young *Vitis vinifera* vines. In subsequent surveys by CSU, phylloxera was discovered in six further vineyards in Mesa County, and one vineyard in Delta County. Phylloxera was found in vineyards planted with hybrid as well as *Vitis vinifera* cultivars. It is likely that in some vineyards phylloxera has been present for more than 10 years.

Phylloxera represents a major threat to the Colorado grape and wine industry. Vineyards in Mesa and Delta County produce >90 % of Colorado's grape crop. About 85 % of these vineyards are planted with own-rooted vines of European cultivars, making them susceptible to phylloxera damage. Initially, feeding of phylloxera on roots of susceptible grape vines leads to reduced vine vigor and lower yields. However, phylloxera feeding, in combination with fungal and bacterial infections of the damaged root system, will eventually kill the vines. While phyto-sanitary practices and insecticide applications can slow the spread of phylloxera, the long-term solution is the removal of own-rooted vines of cultivars that are not phylloxera tolerant (all *Vitis vinifera* and some hybrid cultivars) and then replanting with susceptible cultivars grafted to tolerant rootstocks or with tolerant hybrid cultivars.

While there is a large body of research on the performance of rootstocks in many grape growing areas around the world, there is very limited information for Colorado. Only two replicated rootstock studies have been conducted in Colorado. The first, using Chardonnay grafted to four different rootstocks, was planted at the Western Colorado Research Center – Orchard Mesa (WCRC-OM) in 1992/93. The second, planted in 2009 also at WCRC-OM, uses Viognier grafted to five different rootstocks. More rootstock trials covering a range of cultivars and locations (soil types, climates) are needed so that local rootstock recommendations can be developed.

Two other phylloxera-related questions are also being addressed: how to best manage the graft union; and what is the best method for replanting.

- 2009 Rootstock trial with Viognier (Caspari, Sterle, and Wright)

A rootstock trial with Viognier (clone FPS 01) grafted to 5 different rootstocks as well as own-rooted Viognier was planted at WCRC-OM in late April, 2009. Some replanting took place in the spring of 2010. The trial is set up with a randomized block design with seven replications, and four vines per replication. Vine x row spacing is 5 feet x 8 feet. Vines are irrigated by drip. The following rootstocks are included: 110 Richter, 140 Ruggeri, 1103 Paulsen, Kober 5BB, and Teleki 5C.

The mild temperatures during winter 2016/17 resulted in no bud damage. Average yield per vine was 8.7 lb. However, vine survival is very low for several rootstocks, resulting in very low yields per acre (Table 9).

Table 9: Effect of rootstock on vine survival and yield of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield (ton/acre)
110R	61	2.74
140Ru	18	1.01
1103P	50	2.45
5BB	64	2.47
5C	86	3.79
Own-rooted	96	4.05

- Inter-planting of grafted vines (Caspari, Sterle, and Wright)

Once vineyards planted with own-rooted *Vitis vinifera* cultivars become infested with phylloxera, vine vigor and productivity will start declining. It may take several years from the initial infection for symptoms to appear. Currently it is not known how fast phylloxera spreads throughout a vineyard following initial infestation under Colorado conditions. Based on experiences in other areas of the world it is reasonable to assume that it will take at least 5-10 years from infestation before vine productivity has declined to such a low level that it requires replanting.

Generally at this point, vines are pulled in fall shortly after harvest, then the vineyard is prepared for replanting with grafted or phylloxera-tolerant cultivars the next spring. With this approach, similar to a newly-planted vineyard, the first crop is expected in year 3. Another option, however, is to interplant with vines of the new cultivar 2 to 3 years before the anticipated removal. While at that time the vineyard productivity is already declining, vines are still productive enough to not yet warrant removal. With good management, the inter-planted vines can be grown so that at the end of the second or third season, when own-rooted vines need to be removed, canes can be tied to the cordon wire, and a crop can be produced the following season. The advantage of the interplant approach is that there is no two year break in crop production. However, it requires good management of the inter-planted vines.

A new trial to evaluate the inter-planting approach was established in early May 2017 at WCRC-OM. A total of 120 dormant Chardonnay (clone 99) vines grafted to SO4 rootstock were inter-planted in a block of Chardonnay planted with own-rooted vines in 1991. Phylloxera was discovered in this block in December 2016. For several years prior to the discovery of phylloxera, vine vigor and yield have been severely depressed at the northern end of the block while the southern part was not affected. Original vine spacing is 5 feet, and interplants were planted midway between the existing vines. As this block is also used for the cover crop / irrigation study (see below), some areas of the block are drip irrigated while other areas are irrigated by micro-sprinklers.

Vine establishment in year 1 was good. Most vines established, and many vines had >0.5 m shoot growth. Unfortunately, due to the complications from the cover crop / irrigation study, some vines received insufficient irrigation water and died. Graft unions were covered with soil in late fall 2017, and uncovered again in late spring 2018. Vines were pruned in late spring 2018, leaving no more than two spurs per vine, and two nodes per spur.

- Develop planting and maintenance practices for grafted vines that reduce management costs and vine losses due to cold temperature damage to the graft union (Caspari, Sterle, and Wright)

  In Colorado, where low temperatures can cause trunk injuries, the graft union has to be protected during the coldest part of the year to avoid lethal damage to the cultivar. Common methods of graft union protection are hilling up soil around the graft union or covering the graft union with mulch materials. After the risk of cold temperature damage has passed, the graft union needs to be uncovered to avoid self-rooting from the scion. Due to the semi-arid climate of western Colorado, the top part of the soil is very dry and hot during the growing season. Dry and hot soil conditions are generally not conducive for root growth. A field study to test the effect of planting depths, in combination with irrigation method, on the propensity of self-rooting was established at WCRC-OM in early May 2017. Chardonnay (clone 99) grafted to SO4 rootstock was planted with the graft union 2” above ground (Control = standard practice), or with the graft union 2”, 4”, or 6” below the soil surface. Half the vines are irrigated by drip, the other half by micro-sprinkler. Drip emitters are positioned so that the trunks are not wetted during irrigation events, while micro-sprinklers wet 100 % of the vineyard floor area.

Initially, for treatments with the graft union below the soil surface, the planting hole was only partially filled so that the graft union did not get covered by soil. In late fall, more soil was added to those holes right up to the level of the soil surface. Graft unions will remain covered for the remainder of the experiment. Graft unions of Control vines with graft unions placed 2” above the soil were covered with soil in late fall. Soil was removed again in late spring after risk of damage from cold temperatures had passed. Five vines were lost in the first growing season and/or after the first winter: one control vine; one vine with graft union at 2” below ground; and three vines with the graft union at 4” below ground. Two of the lost vines were drip irrigated and three were irrigated by micro-sprinkler.

- 2017 Rootstock trial with Cabernet Sauvignon (Caspari, Sterle, Wright, and grower cooperator)

  A new rootstock trial with Cabernet Sauvignon (clone 33) grafted to 11 different rootstocks was established in early June 2017 on a grower cooperator’s vineyard in the western part of Orchard Mesa using green potted vines. The following rootstocks are included: 110 Richter, 140 Ruggeri, 1103 Paulsen, 1616C, 101-14 Mgt, 3309 Couderc, Riparia Gloire, Salt Creek, Schwarzmann, SO4, and Teleki 5C. The site is located about 1.5 miles East of WCRC-OM. The trial is set up as a randomized complete block design with 5 replications, and 5 vines per replication. The vineyard is irrigated by micro-sprinklers. Vine establishment in year 1 was very good (255 out of 258 vines planted). In late spring of 2018, vines were pruned back to no more than two spurs per vine, and two buds per spur. On 20 April 2018, two missing entries were replanted using leftover vines from the original planting that had been grown in pots at WCRC-OM.

- 2018 Rootstock trial with Cabernet Sauvignon (Caspari, Wright, and grower cooperator)

  A new rootstock trial with Cabernet Sauvignon (clone 33) grafted to 11 different rootstocks was established in May/June 2018 on a grower cooperator’s vineyard in the central part of Orchard Mesa. The following rootstocks were planted on 24 May 2018 using dormant potted vines: 110 Richter, 140 Ruggeri, 1103 Paulsen, 1616C, 101-14 Mgt, 3309 Couderc, Riparia Gloire, Salt Creek, Schwarzmann, and SO4. Green potted vines on rootstock Teleki 5C were planted on 14 June 2018. The site is located about 3.5 miles East of WCRC-OM. The trial is set up as a randomized complete block design with 6 replications, and 4 vines per replication. The vineyard is irrigated by micro-sprinklers.

5. *Identifying areas suitable for expanded wine grape production*

- Fremont and Montezuma County microclimates suitable for wine grape production. (Doesken, Goble, and Schumacher)

  The Colorado Climate Center has completed another year of county-scale temperature investigation. Focal areas in this year’s study were Montezuma County (southwest Colorado), and eastern Fremont County in the Arkansas River Valley. While Colorado grape growers have a myriad of crop-threatening issues to deal with, the most common weather-related hazard is killing freezes. The Colorado

Climate Center's mission is to pinpoint areas suitable for Colorado wine industry expansion.

The objectives for the reporting period were as follows:

a) Establish a thermometer network in Fremont County on current and prospective vineyards, similar to what has been established in Montezuma County.
b) Study the killing cold snaps that occurred in Montezuma County in 2017.
c) Analyze the temperature pattern on cold winter nights in Fremont and Montezuma Counties for winter 2017-2018.
d) Complete a long-term climate analysis of Fremont County similar to what has been accomplished in Montezuma County (Caspari et al., 2017) using Cooperative Observing Network Data.
e) Identify next steps for detecting ideal vineyard locations in Fremont and Montezuma Counties.

The Climate Center has set up concentrated networks of thermometers with the purpose of tracking nocturnal minimum temperatures on current and prospective vineyard locations. The networks are in place in both Montezuma and Fremont Counties. This project has been running for three years now in Montezuma County, and only one in Fremont County. The Montezuma County network is larger and better established. The Fremont County network has room to grow. Montezuma County also has more available supplemental weather data available from networks such as the Cooperative Observing Network (COOP), and the Colorado Agricultural Meteorological Network (CoAgMET). Data from supplemental networks, specifically CoAgMET, should be viewed as helpful as thermometers installed specifically for this project measured very similar temperatures to the Yellow Jacket CoAgMET station in side-by-side comparison.

The 2017 growing season dealt two killing freezes to most, but not all, producers in Montezuma County: one on 19 May following bud break, and one on 25 September prior to harvest. Fiscal Year 2016 and 2017 reports have shown late spring freezes to be a common threat in Montezuma County, but pre-harvest freezes weren't on our radar for this project previously. Clearly these events require more attention as, in the case of 2017, it was ultimately the pre-harvest freeze that ruined the year's crops for most.

Higher resolution data are still needed to determine how much of McElmo Canyon is optimal for supporting grapes, a problem that will be addressed with both models and additional observations in FY 2019. Evidence continues to pile up that downstream areas of the canyon are appreciably warmer than upstream on cold winter nights. The McElmo W station stayed above freezing during both killing events in 2017. Where rich soils and irrigable land exist south and west of the Sleeping Ute Mountain, there appears to be potential for expansion of the local industry. The stations in Montezuma County with the first and second highest minimum winter temperatures were west of the Sleeping Ute Mountain. There is also promise for expansion of the viticulture industry from Lebanon on road T all the way up to Yellow Jacket on road Z. This area does not stay as warm on cold winter nights as stations to the south and west of Sleeping Ute Mountain. It is, however, consistently warmer than the valley below where Cortez is located, and has more irrigable land than McElmo Canyon.

A network of thermometers in Fremont County was deployed in November of 2017. Fremont County has a long, well established growing history. It is not climatologically conducive to grape growth over as large a spatial extent as Montezuma County may be. Wintertime night temperatures over the area sampled in Fremont County were more spatially homogeneous than those sampled over Montezuma County. The northwest side of Cañon City stayed warmer on cold winter nights than anywhere else in the study. Cooler winter minimum temperatures were recorded to the south and east.

Winter of 2017-2018 did not bring any damaging cold snaps to Fremont or Montezuma County. There are other, less prevalent, weather-related threats to the viticultural communities of Montezuma and Fremont County, and one of them reared its ugly head this year: drought. Lack of local precipitation, nearby snowpack, and reservoir storage has parlayed into irrigation restrictions for Montezuma County.

The Cañon City COOP station, which has a record extending back to the 1890s, was used to investigate observed changes to the area's climate. The station's complex history makes attribution of long-term trends difficult. The station's average temperature has cooled by a rate of 0.3 degrees Fahrenheit/decade between 1951 and 2016. The decline is statistically significant even given large interannual variability. Annual minimum temperatures do not show a significant positive or negative trend. Other potentially damaging weather situations, such as spring freezes and late fall cold blasts, are variable, but also not trending in either direction. Interestingly, Fremont County appears to be less vulnerable to spring freeze damage, but more vulnerable to late fall cold blasts than Montezuma County.

Cañon City's cooling trend makes it an outlier among long-term COOP weather stations, but not a completely isolated case. Other long-term stations in the Arkansas River Basin, such as Lamar, have also shown statistically significant cooling. Cañon City has warmed over the last two decades, and based on climate change projections, will likely continue to do so.

There is no substitute for ground truth weather observations, but Montezuma County in particular produces impressively heterogeneous temperature patterns on cold winter nights. In the coming year the Climate Center will seek to fill in gaps with thermometers in Montezuma and Fremont County, but also supplement the thermometers with high resolution model data. Data from thermometer networks will be used to check the accuracy of the model. Areas showing promise based on temperature data will also be investigated with a web soil survey for the perfect combination of warmth, good soil, and irrigation access.

Section 1 – Setting and expanding thermometer networks

1.1 - Fremont County producer interviews: In September, Peter Goble met with Fremont County extension agent Tommy Covington to learn more about locations of current wine grape growth, suitable thermometer locations, and establish contacts with local producers.

In November, Peter came back to Cañon City and installed a network of 15 thermometers across the county. Not all 15 were ultimately used in this year's study. He also met with producers. It was learned that Cañon City has a long, well-established history of growing grapes. This dates back to the 1910-1920 time frame when Italian immigrants began growing grapes. The largest vineyard in the county is currently located at the prison, which is where the Cañon City Colorado Agricultural Meteorological (CoAgMET) station is located. There have been successful harvests in Fremont County from in the Arkansas River Valley at 5,330 ft elevation, and up in the Wet Mountains south of town at 6,700 ft; an elevation range that is similar to what has been observed in Montezuma County.

1.2 - Thermometer installations in Fremont County: As in FY 2017 for Montezuma County, thermometer installations in Fremont County were focused on areas where successful harvests have occurred in previous years. Several stations were installed in areas where orchards have been grown, but not grapes. The station in Wetmore is a successful wheat growth location, but not tested for fruits. These sites were used in conjunction with weather stations from the Cooperative Observing Network (COOP) and CoAgMET to search for relative warm spots on cold winter and spring nights in 2018. Fremont County is less generously covered by previously existing weather station networks than Montezuma County, so installations for this project made up a larger proportion of the data. One to three thermometers were installed in each of the locations shown below in yellow (Fig. 1).

Fremont County Station Map 2018

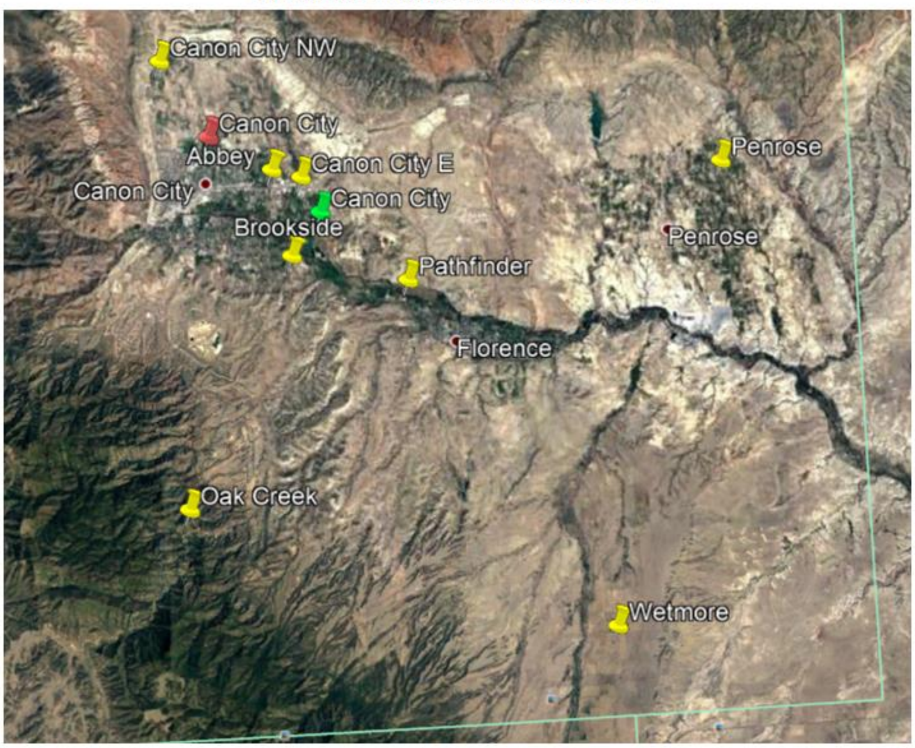

Fig. 1: This Google Earth Image shows the locations of temperature measurements used in our FY 2018 investigation of Fremont County. County lines are shown in green. Yellow pins are locations of thermometers installed for this study, green

pins are CoAgMET stations, red pins are COOP stations, and purple pins are RAWS stations.

1.3 - Additional thermometer installations in Montezuma County: In order to build on findings from FY 2017, additional thermometers were installed in Montezuma County. An emphasis was placed on obtaining temperature readings in areas that are not currently growing grapes, but were identified in FY 2017 as having potential based on temperature patterns on cold winter nights. Findings from last year's report (Caspari et al., 2017) showed that all ten of the coldest winter nights came under high atmospheric pressure, clear skies, and with snow cover across most of the county. In these situations, drainage winds dominate, and temperature inversions form where lower elevation stations become colder. Because of this, installations at or near the elevation crest between Cortez and Pleasant View were made (Fig. 2). The Ute Mountain Farm and Ranch also became a focal point because the CoAgMET site located on the farm was the second warmest on cold winter nights of the sites analyzed in FY 2017 despite sitting in a bit of a valley. More thermometers were installed in the high spots on the farm and ranch. One to three thermometers have been installed at each location shown below in yellow.

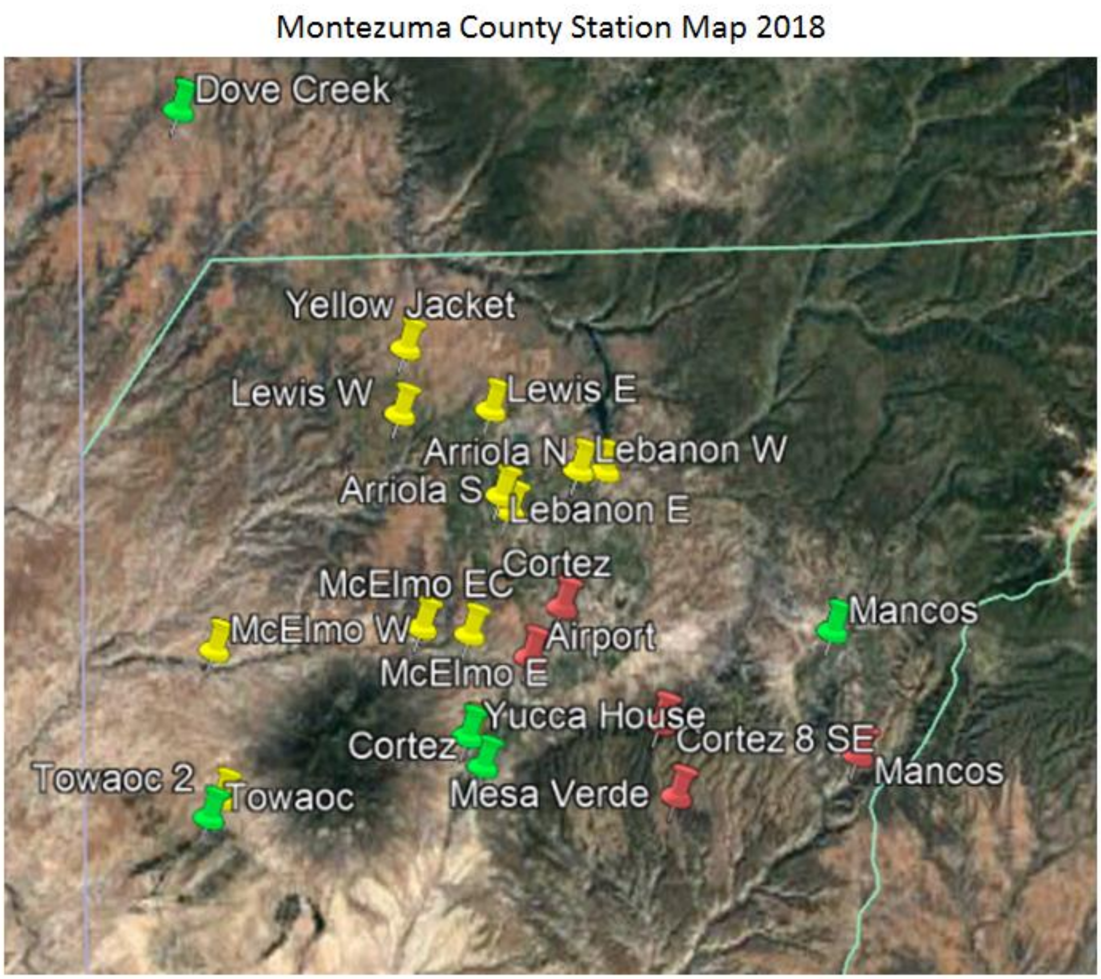

Fig. 2: This Google Earth Image shows the locations of temperature measurements used in our FY 2018 investigation of Montezuma County. County lines are shown in green. State lines are shown in gray. Yellow pins are locations of thermometers

installed for this study, green pins are CoAgMET stations, red pins are COOP stations, and purple pins are RAWS stations.

We are currently seeking several more contacts in McElmo Canyon, particularly nearer the Utah state line, and have a few thermometers available. Another producer in this area joined the project as of April 2018, but will not yet have data included in this report.

1.4 - Thermometer comparison: All thermometers installed specifically for this project are USB-501-Pro thermometers from Measurement Computing. All thermometers were installed at 4’ above ground level (vine height). COOP and CoAgMET stations use different equipment, and are generally at 4.5-6’. One thermometer was installed directly adjacent to the Yellow Jacket CoAgMET station at the Southwest Colorado Agricultural Experiment station. Minimum daily temperature readings from these two thermometers confirm the validity of direct comparison between the two data sources. Correlation between readings was 0.9993. Daily minimum temperatures were lower for the USB-501-Pro thermometer by an average of 0.17 F.

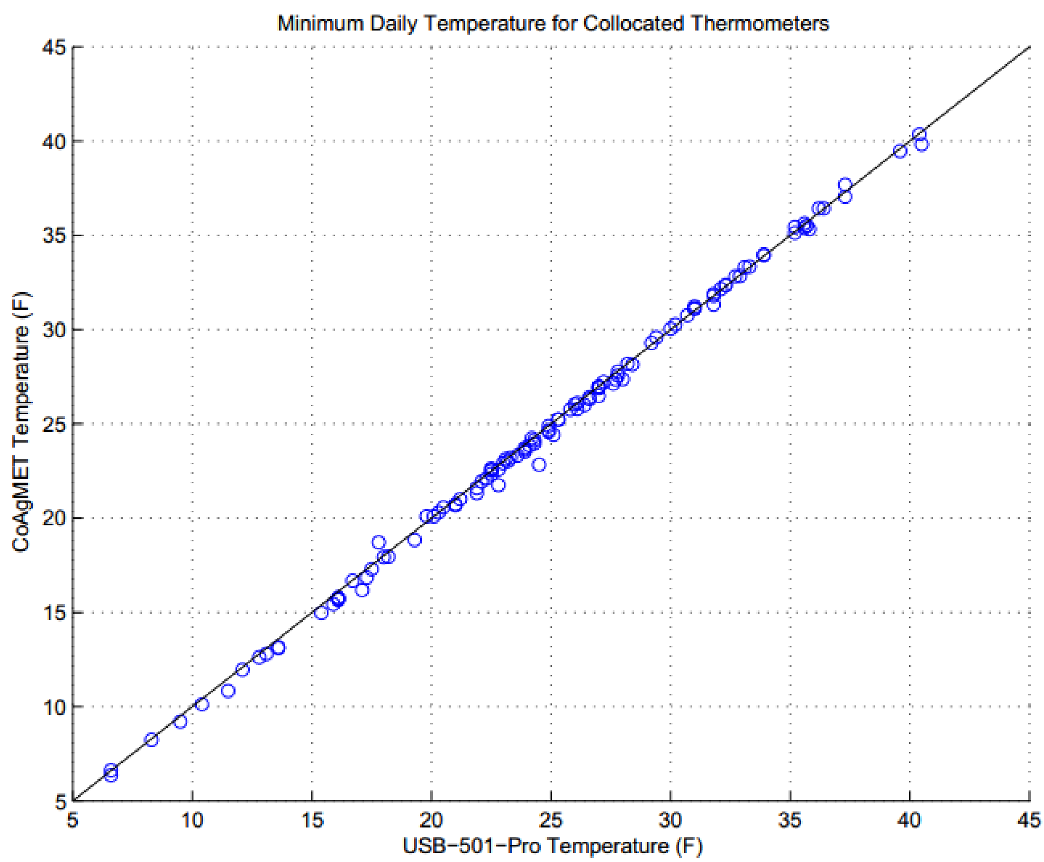

Fig. 3: Minimum daily temperatures measured by both thermometers at the Colorado State University Southwest Agricultural Experiment Station in Yellow Jacket from 17 November 2017 to 9 March 2018. The x-axis displays temperatures from the USB-501-Pro thermometer. The y-axis data comes from the CoAgMET thermometer. The black line is indicative of where minimum temperature readings are exactly 1:1.

Section 2 - Spring and fall freezes in 2017

Montezuma County's 2017 growing season was ruined for many producers by two freezes: the first on 19 May (Fig. 4), and the second on 25 September (Fig. 5). The first freeze came shortly after bud break, and killed early growth for most producers. Of the thermometers placed throughout the county, only McElmo W stayed above freezing. The plants adapted marvelously as secondary shoots thrived. Crops grew full and lush through the summer. The final devastating blow was dealt on 25 September when temperatures sunk below freezing shortly prior to harvest. During this event, McElmo W only fell to a temperature of 38 F. Furthermore, the Mesa Verde and Cortez 8 SE (also on the mesa) stations, and the Yellow Jacket CoAgMET station stayed above the freezing mark. All stations staying above freezing in this event were near the mouth of a canyon or near the top of a ridge. Daily minimum temperatures atop the mesa are often warmer than in the town of Cortez, but not always. The mouth of McElmo Canyon is consistently warmer than town on cold nights. The Towaoc CoAgMET station, which was the second warmest station on cold winter nights in winter 2016-2017, dipped below freezing during both events. It was not even among the top five warmest stations in the county for the fall freeze event (Fig. 5).

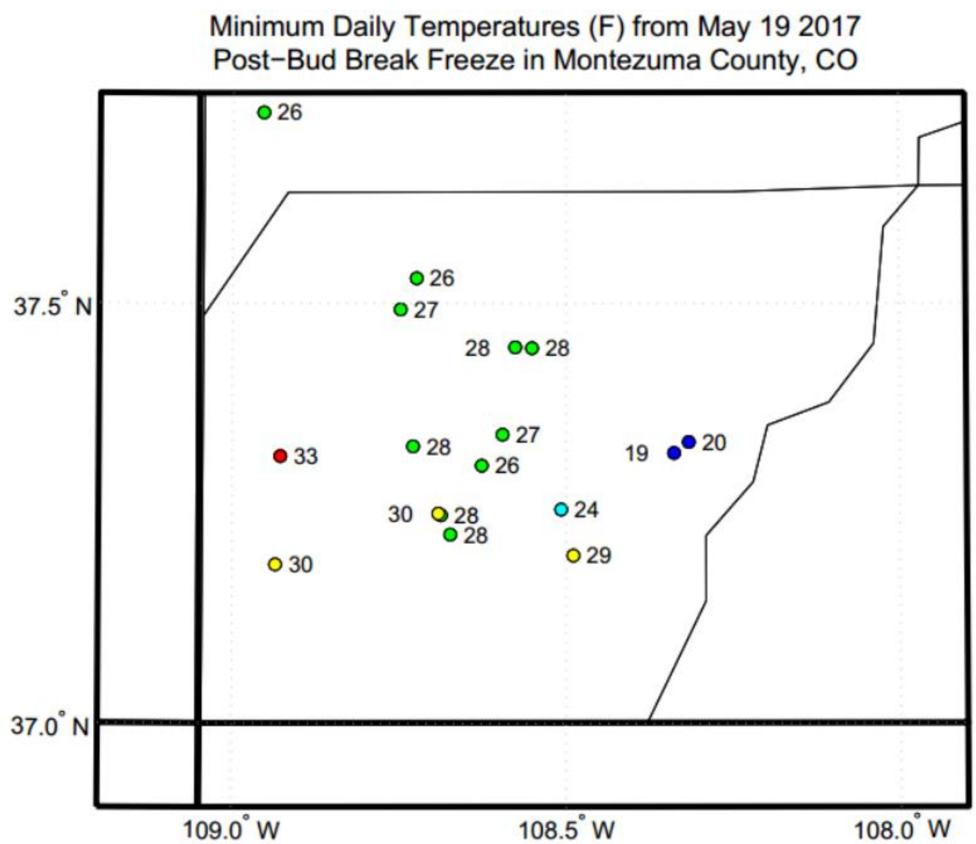

Fig. 4: Map of Montezuma County daily minimum temperature (F) observations from 19 May 2017.

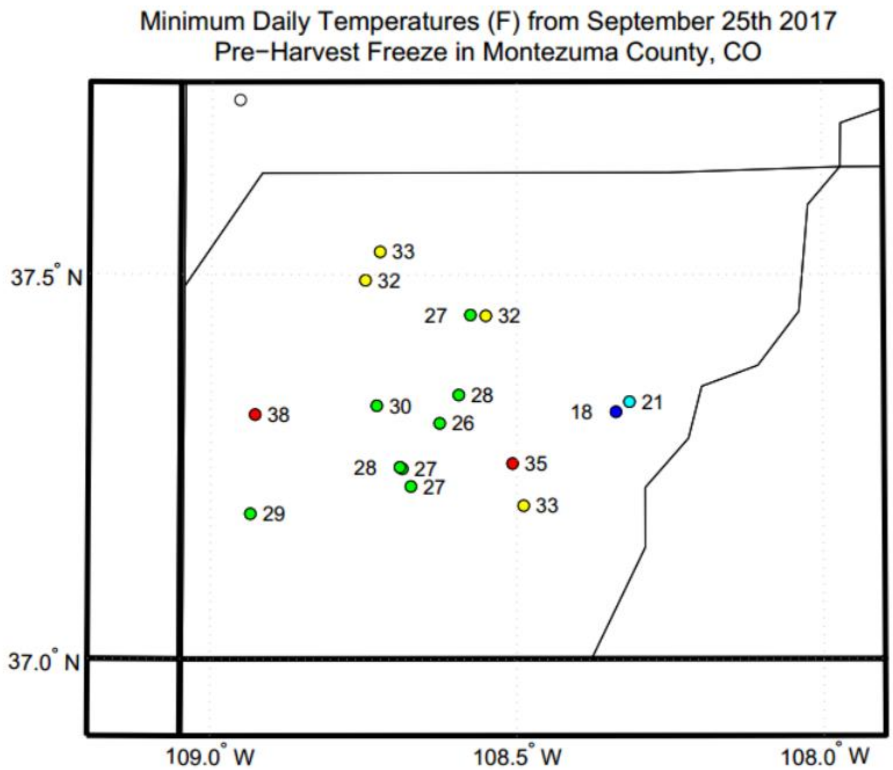

Fig. 5: Map of Montezuma County daily minimum temperature (F) observations from 25 September 2017.

Both killing freezes of 2017 occurred under high atmospheric pressure conditions (Figs. 6, 7). The cold air originated to the north, and, in both cases, forced a cold frontal passage digging all the way through to southern New Mexico. The coldest air did not hit until about 30-36 hours after the cold front passed. This is important because if the coldest air arrived more quickly following frontal passage, there would have been more large-scale air mixing. These conditions favor relatively higher temperatures at lower elevation stations. As is, high pressure had time to settle in behind the front, which is associated with calm large-scale winds. In a region with complex topography, like Montezuma County, high pressure makes drainage winds the dominant driver of nocturnal airflow. Cold air pools into the valleys. That, in turn, favors relatively high temperatures at higher elevation stations. The large-scale weather patterns associated with both freezes helps to explain why the Mesa Verde station at 7,142 ft was one of the warmest stations in the county on both occasions.

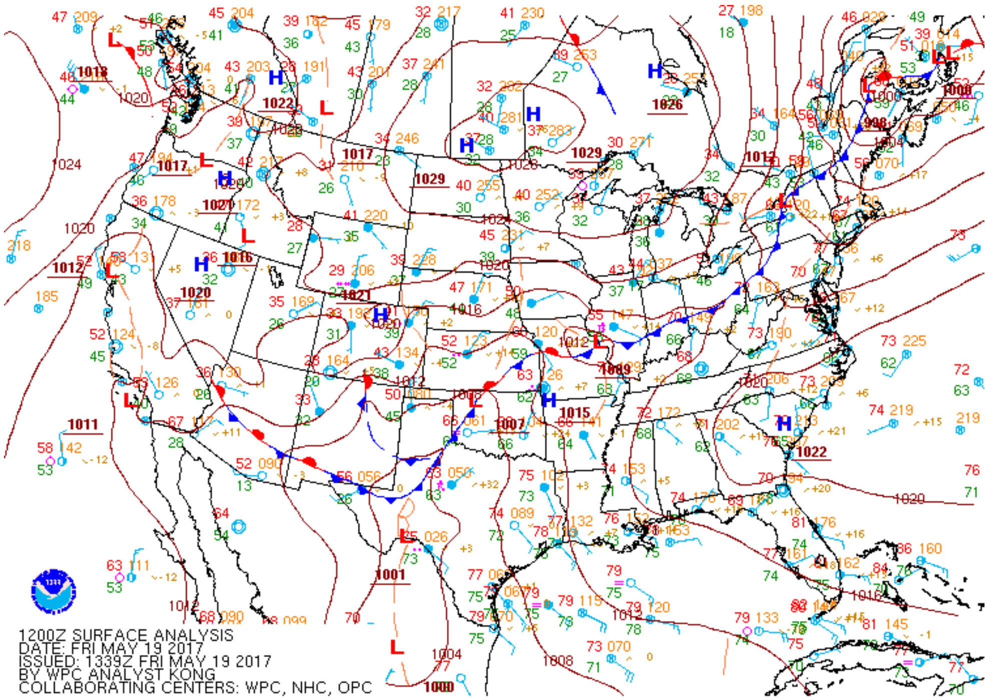

Fig. 6: Nationwide weather map from the morning of 19 May 2017. Blue "H" marks indicate high surface pressure. Red "L" marks indicate low surface pressure. Blue lines with attached blue triangles indicate cold fronts.

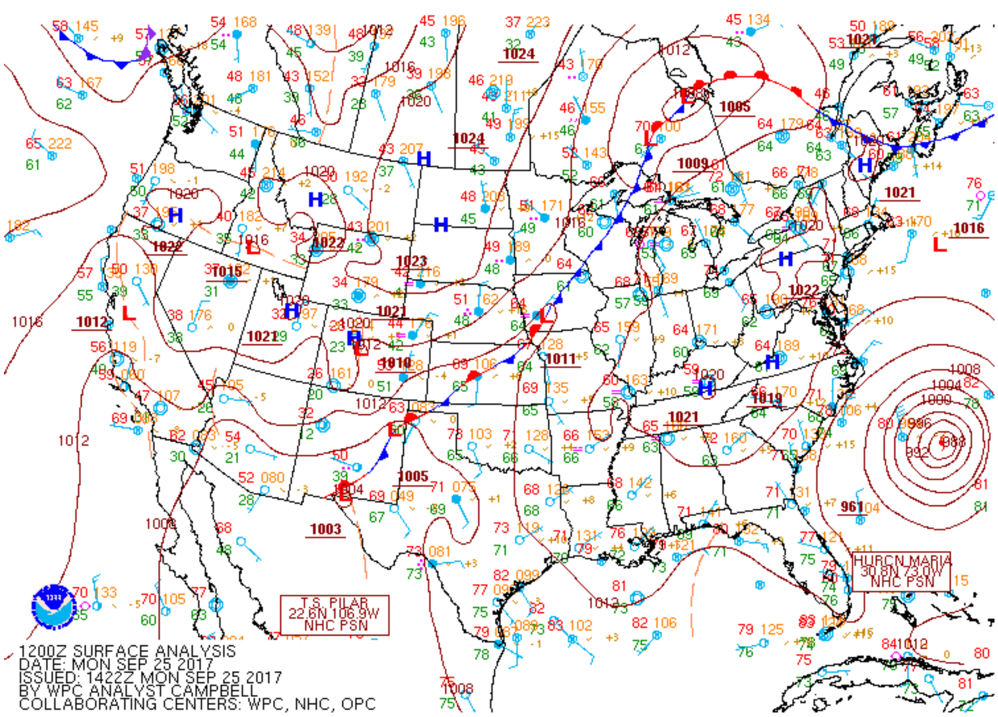

Fig. 7: Nationwide weather map from the morning of 25 September 2017. Blue "H" marks indicate high surface pressure. Red "L" marks indicate low surface pressure. Blue lines with attached blue triangles indicate cold fronts.

Section 3 - Coldest days of winter 2017-2018: The winter of 2017-2018 was benign from a killing freeze perspective. The coldest temperature measured by the Cañon City Cooperative Observing Network Weather Station was -2 F, which is tied for the 11th warmest winter minimum temperature since 1951. The coldest temperature measured by the Cortez Cooperative Observing Network Weather Station was +2 F, which is tied for the 3rd warmest winter minimum since 1951. An analysis is included here of the temperature patterns in Fremont (Cañon City) and Montezuma (Cortez) Counties for winter 2017-2018. While these events were not damaging, the relative temperatures recorded do offer key insight into where the most-and-least vulnerable locations to damaging freeze lie.

3.1 - Montezuma County: Temperature patterns from cold winter nights in Montezuma County during winter 2017-2018 were similar spatially to winter 2016-2017. McElmo Canyon and higher elevation locations north of Cortez usually stay warmer than the city on cold winter nights. A large temperature gradient typically sets up on cold winter nights between the entrance of McElmo Canyon to near the state line. Added thermometers on the Ute Mountain Farm and Ranch and north of Cortez help solidify these findings. The Arriola S station on road P recorded temperatures more similar to in town, whereas the Lewis E station on road V.6 more closely matched temperatures from operational vineyards north of town. There is a greater abundance of irrigable land west of 491 between Lewis and Yellow Jacket that may be suitable based on these findings. Ideal vineyard placements west of town are likely above road P, and situated where cold, dense air can drain into a nearby canyon.

There were several thermometers omitted from this study period, two of them were on the Ute Mountain Farm and Ranch, and all thermometers omitted were due to interactions with cows. When data were collected in April, two thermometers had been knocked off of their stands by cows. These were moved to more secure locations. One thermometer on the Ute Mountain Farm and Ranch was inaccessible due to bulls who weren't interested in sharing their space.

The thermometer with the second highest average minimum temperature during the previous (2016-2017) winter was the Towaoc CoAgMET station on the Ute Mountain Farm and Ranch. This weather station is not located in a favorable spot for avoiding cold air drainage. As such, it was hypothesized that the Farm and Ranch may have even more freeze-resistant locations for growing grapes. Thankfully, one of the three thermometers placed on the ranch was undisturbed by cows. Towaoc 2 (Fig. 2), located on plot 3020 of the Ute Mountain Farm and Ranch, tied the McElmo W station for the warmest wintertime minimum temperature in Montezuma County (14 F) (Fig. 8). This was 7 F warmer than the nearby CoAgMET station. The average temperature on the 10 coldest winter nights was 7.8 degrees warmer at Towaoc 2 than the Towaoc CoAgMET station (Fig. 8).

As was the case with the damaging spring and fall freezes of 2017, the Mesa Verde, and Cortez 8SE COOP Stations (both located on the mesa) were an interesting case. On some cold nights these stations were the warmest, or near the warmest in the county. This is likely due to cold air draining off of the mesa into the valleys. This is not reliably the case on all cold nights. The Mesa Verde station recorded a wintertime low temperature of -4 degrees (Fig. 8), the second lowest of any station in the county. Because the mesa stays warmer on some cold nights, it will avoid some damaging freezes. This may be particularly useful in short potential freeze seasons such as the spring just after bud break, or the fall just before harvest. The mesa is not the best location for supporting sensitive plants through a whole winter season.

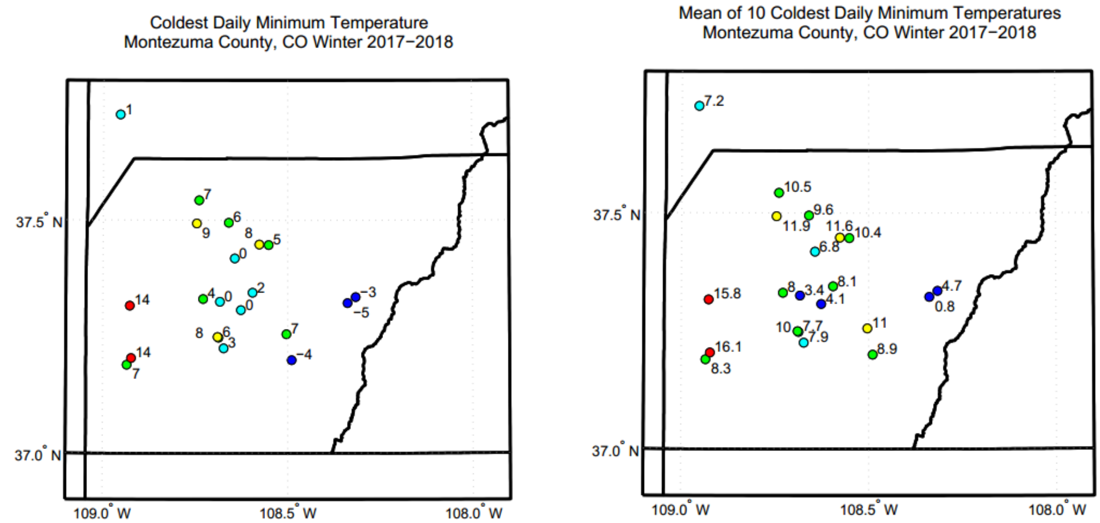

Fig. 8: Left: lowest minimum daily temperature (F), and right: the average of the ten lowest minimum daily temperatures (F) recorded in winter 2017-2018 from each thermometer used in Montezuma County.

3.2 – Fremont County: Locations sampled in Fremont County covered a smaller spatial extent than Montezuma County. Unsurprisingly, temperatures also covered a smaller spread. Temperatures were generally warmer directly in and around Cañon City than areas further east and south such as Penrose, Wetmore, and Oak Creek Grade. Much like Palisade, Cañon City lies at the mouth of a large canyon where drainage winds may blow through the night and keep the surface layer mixed/warmer. It may therefore be difficult to find a warmer area in the county.

The station with the warmest average temperature from the 10 coldest winter nights of 2017-2018 was the Cañon City NW vineyard (Fig. 9), the furthest northwest location in the county. There is not much room for exploration to the west of this property as an escarpment just a few hundred meters away divides the valley from more rugged terrain. There is some room for exploration directly to the north near the mouths of Wilson Creek and Fourmile Creek Canyons. This area should be looked at further in fiscal year 2019. Cañon City NW's warmer average coldest 10 winter days can be largely attributed to the pattern that set up on 11 February 2018 (Fig. 10). On this morning, the Cañon City NW vineyard stayed 9 degrees warmer than any other station in the county.

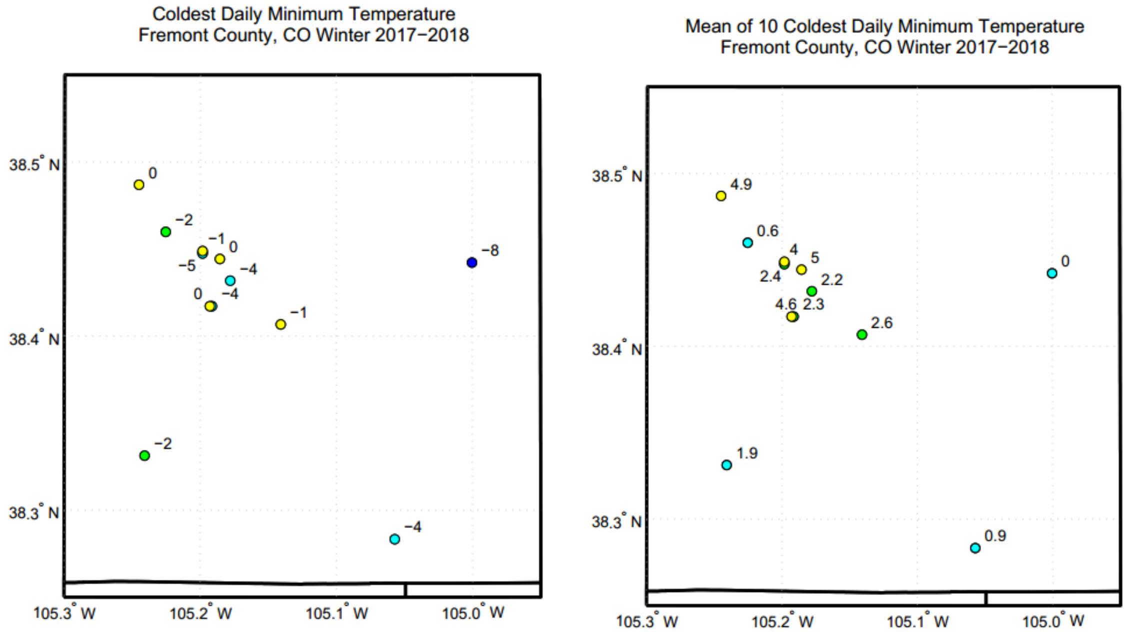

Fig. 9: Left: Lowest minimum daily temperatures (F), and right: the average of the ten lowest minimum daily temperatures (F) recorded in winter 2017-2018 from each thermometer used in Fremont County.

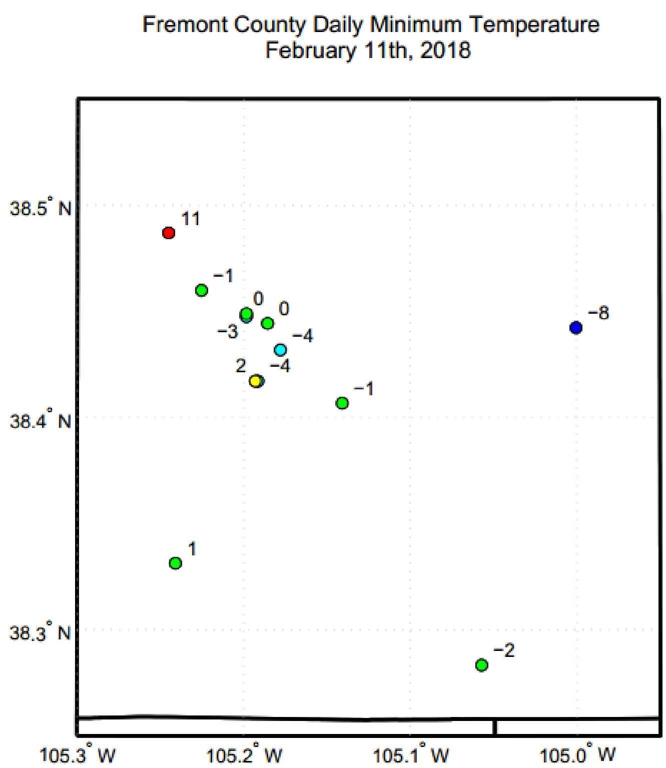

Fig. 10: Map of Fremont County daily minimum temperature (F) observations from 11 February 2018.

Two microclimates were explored in Cañon City: thermometers were placed on the north and south side of the Abbey vineyard, and on the east and west side of the Brookside site. The south side of the Abbey vineyard is directly adjacent to a major roadway whereas the north side is several hundred meters away. The west side of the Brookside vineyard is on top of a hill, and the east side is at the bottom. The north side of Abbey Vineyard averaged 1.6 F warmer than the south side. The top of the hill at Brookside measured warmer than the bottom by an average of 2.3 F on cold winter nights (Fig. 9).

The Oak Creek station resides much higher than any other vineyards in the Cañon City area at 6,700 ft elevation. This vineyard site is consistently cooler than others in the county during the daytime, but records similar winter nighttime temperatures. This vineyard recorded a coldest winter temperature of -2 F and the mean of the coldest 10 mornings was 1.9 F.

Comparisons between Montezuma County and Fremont County for winter of 2017-2018 should be drawn with caution as large-scale weather patterns impact these areas quite differently. Winter 2017-2018 was warmer than average for both locations, but more anomalously warm for Montezuma County than Fremont County. That said, all stations in Fremont County received much colder air over the winter than the warmest stations in Montezuma County. The average wintertime minimum temperature is only 0.7 F greater in Cortez than Cañon City for 1951-present, but the coldest air of winter 2017-2018 was 14 F warmer for the McElmo W station and Towaoc 2 than any stations in Fremont County. Based on the data collected in this study, it appears likely that areas on the south and west side of Sleeping Ute Mountain are truly capable of supporting a wider variety of vines than either the Cortez or Cañon City areas.

3.3 – Large-scale weather patterns associated with freezes: In FY 2017's report the large-scale weather environments associated with each cold snap were investigated (Caspari et al., 2017). All major cold snaps from winter 2016-2017 occurred with high atmospheric pressure, clear skies, and snow-covered ground. Winter 2017-2018 brought a dearth of cold air. Instead of exploring just the coldest events of the most recent winter, the large-scale weather patterns of the deepest cold events since the start of the decade were investigated. Five variables were chosen as potential ingredients for a cold snap. These ingredients were looked for in each deep freeze using weather station data and archived weather maps. The ingredients chosen were snow covered ground, deep snow cover (6" snow depth or greater), surface high pressure, a frontal boundary within roughly 150 miles, and surface winds at or below 5 knots.

Not all killer cold snaps may be the result of similar large scale weather patterns. The more different the large scale weather patterns are that cause deep freezes, the more likely it is that the county-wide temperature pattern will also be different. For example, the mouth of the Royal Gorge opens up right upstream of Cañon City. This area is typically warmer than surroundings due to surface mixing from west-to-east-moving canyon drainage winds, but if a deep freeze occurred when the large scale weather pattern was forcing east-to-west winds, it may lead to cooler conditions at the canyon mouth.

All of the top ten ranking deep freezes in Montezuma County occurred with snow on the ground, and without a frontal boundary nearby. Winds recorded at 5:00

AM on the morning of freezes at the Cortez Municipal Airport were five knots or less in all but two cases. High atmospheric pressure was present in all but two cases (Table 10).

Table 10: Date, rank, and temperature of the lowest temperatures recorded at the Cortez COOP weather station in the 2010s. The green-shaded "y's" and red-shaded "n's" indicate for each row whether the following ingredients were present on the morning of the low temperature: measurable snow on the ground, more than six inches of snow on the ground, high surface atmospheric pressure, a frontal boundary within roughly 150 miles, and winds less than or equal to five knots.

Coldest Temperatures at Cortez COOP since Jan 1^{st}, 2010							
Date	Rank	Temperature	Snow Covered Ground	> 6" Snow Cover	Surface High Pressure	Frontal Passage	Winds <= 5kts
1/2/2011	1	-18	y	y	y	n	y
1/1/2011	2	-13	y	y	y	n	y
1/15/2013	3	-12	y	n	y	n	n
1/3/2011	4	-10	y	y	y	n	y
1/27/2017	5	-8	y	y	y	n	y
2/10/2011	5	-8	y	n	y	n	y
1/11/2011	5	-8	y	y	y	n	y
12/27/2015	8	-7	y	y	n	n	y
12/9/2013	8	-7	y	n	n	n	y
2/12/2013	8	-7	y	n	y	n	n
1/16/2013	8	-7	y	n	y	n	y
1/12/2013	8	-7	y	n	y	n	y

Ingredients for deep cold in Cañon City turned out to be a little less clear cut. Snow cover and calm winds were both present in all of the top ten-ranking cases but one. Unlike with Cortez, there were cases where surface high pressure was not present overhead, and there were cases where a frontal boundary was present nearby, usually to the south or east of Cañon City.

Exploring the patterns behind deep freezes is not as useful without a network of thermometers across the county vineyards already in place to evaluate the impact of the large scale on the surface. Computer estimations that interpolated observed temperature data based on topography can help, but in order to truly understand the variation in temperature patterns on cold winter nights, and spring nights after bud break, a high-resolution observation network would have to be kept in place for a number of years.

Table 11: Date, rank, and temperature of the lowest temperatures recorded at Cañon City COOP weather station in the 2010s. The green-shaded "y's" and red-shaded "n's" indicate for each row whether the following ingredients were present on the morning of the low temperature: measurable snow on the ground, more than six inches of snow on the ground, high surface atmospheric pressure, a frontal boundary within roughly 150 miles, and winds less than or equal to five knots.

Coldest Temperatures at Cañon City COOP since Jan 1st, 2010							
Date	Rank	Temperature	Snow Covered Ground	> 6" Snow Cover	Surface High Pressure	Frontal Passage	Winds <= 5kts
12/18/2016	1	-19	y	n	n	y	y
2/2/2011	1	-19	y	n	y	n	y
2/6/2014	3	-17	y	y	n	y	y
2/7/2014	4	-15	y	y	n	y	y
2/3/2011	4	-15	n	n	y	n	y
12/31/2014	6	-14	y	y	y	n	y
2/9/2011	7	-12	y	n	y	n	y
12/6/2013	8	-11	y	n	y	n	y
1/12/2011	9	-9	y	n	n	n	y
2/5/2014	10	-8	y	y	n	y	n
1/6/2014	10	-8	y	n	n	n	y

3.4 - From freezes to drought: Winter 2017-2018 may have been warm for Montezuma County, but the warmth came partially at the cost of a disturbing deficit in local precipitation and nearby mountain snowpack (Figs. 11, 12). The San Juan Mountains received near-record-low snowpack and melted out record early in the spring of 2018 (Fig. 12). McPhee reservoir failed to receive even a slight boost from the spring snowmelt season, but began quickly dipping instead (Fig. 13). Irrigation allotments to Montezuma County producers have been limited to 16.7" as opposed to the usual 22.9" by the Dolores Water Conservancy District for summer 2018. The combination of low rainfall totals and curtailed irrigation allotments may lead to crop damage or failure from plant stress. Freezes are still the most prominent meteorological threat to vineyards in southwest Colorado, but not the only threat.

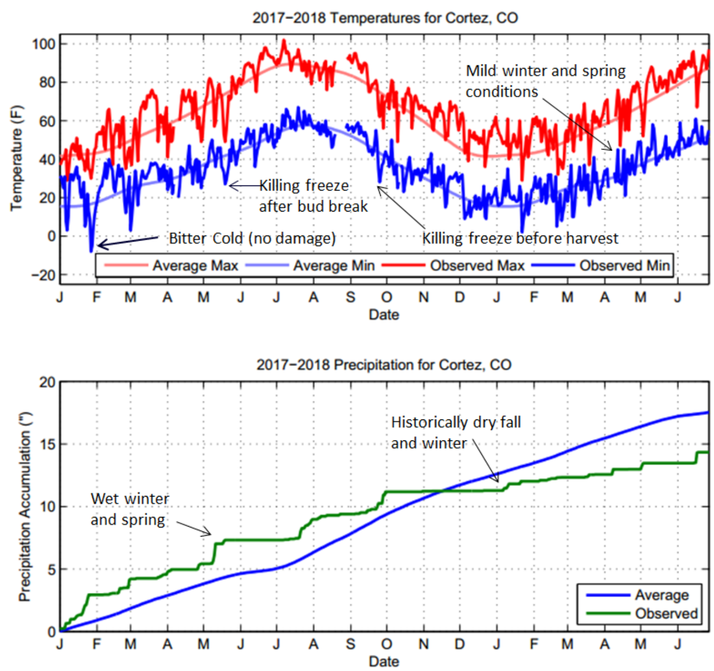

Fig. 11: Top: average and observed temperature, and bottom: and average (blue) and observed (green) precipitation accumulation at the Cortez COOP station in Montezuma County. The red lines indicate average (faded) and observed (full) maximum daily temperatures. The blue lines indicate average (faded) and observed (full) minimum daily temperatures.

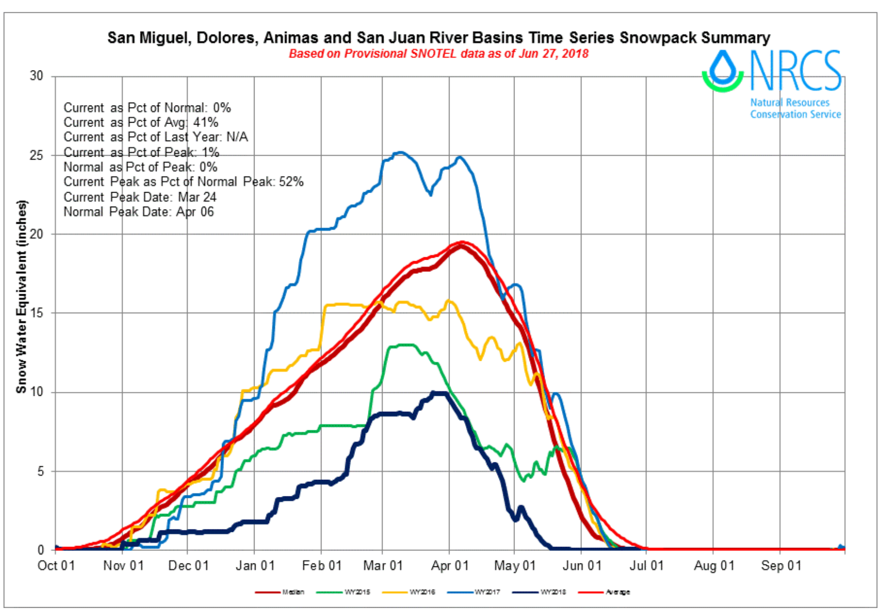

Fig. 12: Cold season snowpack in the San Miguel, Dolores, Animas, and San Juan River Basin Snowpack Telemetry station group. The x-axis shows day of the year, and the y-axis shows station average snow liquid water content (inches). The dark blue line shows daily snowpack for the 2017-2018 cold season. The thin red line shows average daily snowpack, and the thick red line shows median daily snowpack.

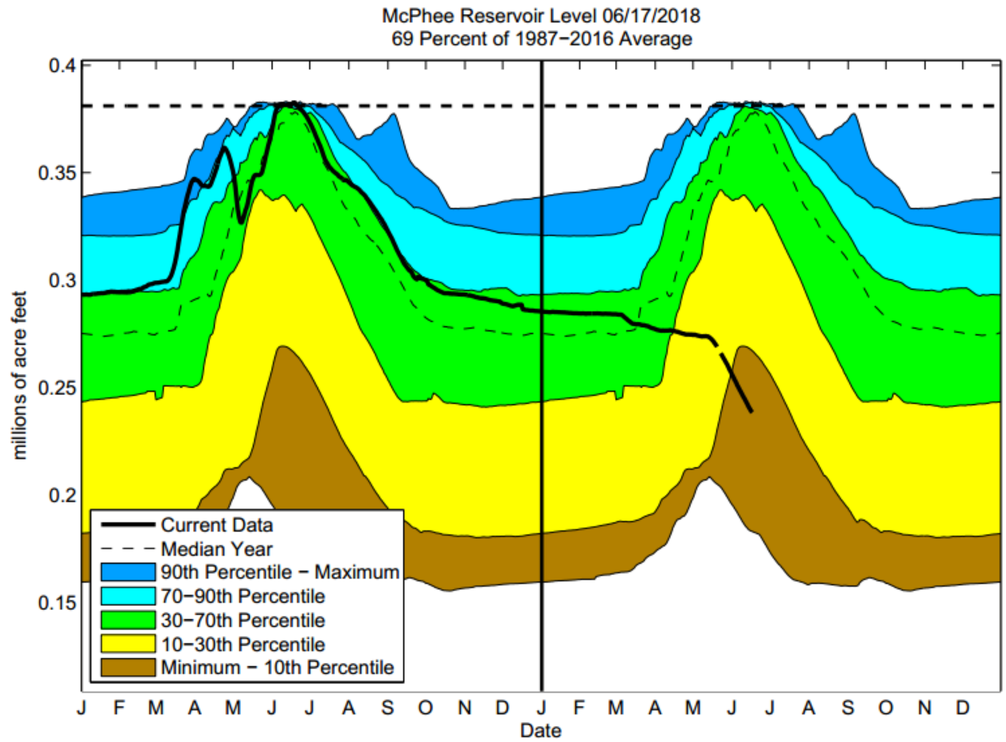

Fig. 13: Reservoir storage for McPhee Reservoir in Montezuma County. Date is displayed on the x-axis beginning with 1 January 2017. The solid black line shows daily observed storage. The thick, dashed black line indicates the reservoir's capacity. The thin, dashed black line shows 50th percentile storage. The color shading shows various reservoir storage percentile ranges for 1987-2016. 0-10th (brown), 10-30th (yellow), 30-70th (green), 70-90th (light blue), 90-100th (blue).

Section 4 - Long Term Trends in Fremont County

4.1 – Observed Trends: Capturing weather conditions that impact the success of wine grape growth is not just important spatially. Colorado climate is variable, and subject to change over time. The long term temperature and precipitation records for the Cañon City Cooperative Observing Network Station are used in this section to investigate trends for Fremont County. Focal points of this section are changes in temperature and precipitation over time, shifts in the seasonality of precipitation, and changes in potentially hazardous weather events for grapes over time. Similar analysis was conducted for Cortez and Mesa Verde Stations in Montezuma County in previous reports (Caspari et al., 2016, 2017).

The Cañon City cooperative observing network station has a temperature and precipitation record dating back to 1893. The Colorado Climate Center was fortunate to have some recent service records for the station on file, but not the complete record. What record of the station does exist is somewhat precarious. For example: the station has been moved four times just since 1980: 1983, 1985, 1999, and 2009. New thermometers were installed in 1985. For much of the 1930s-70s the station was located at the prison, which is slightly climatologically warmer on average than other station locations. There is also a period of missing data in 1994 and 1995 between the tenure of different weather observers. Because of these station moves and equipment changes, it is possible that detected temperature trends occurred for reasons extraneous to the success of local vineyards.

The recent data shows a trend that is quite pervasive across the state of Colorado: 1980-1999 was a cooler period than 2000-present date (Fig. 14). The long-term data show a clear and significant positive trend in mean annual temperature from the 1890s to the 1930s followed by a slower, but also significant, cooling trend from the 1930s to the 1990s, which actually accelerates in the 70s and 80s. The data do not show a clear trend since the station was reactivated in 1995. More importantly for local viticulturists, the station shows no long-term trend to this point in annual minimum temperature or annual precipitation.

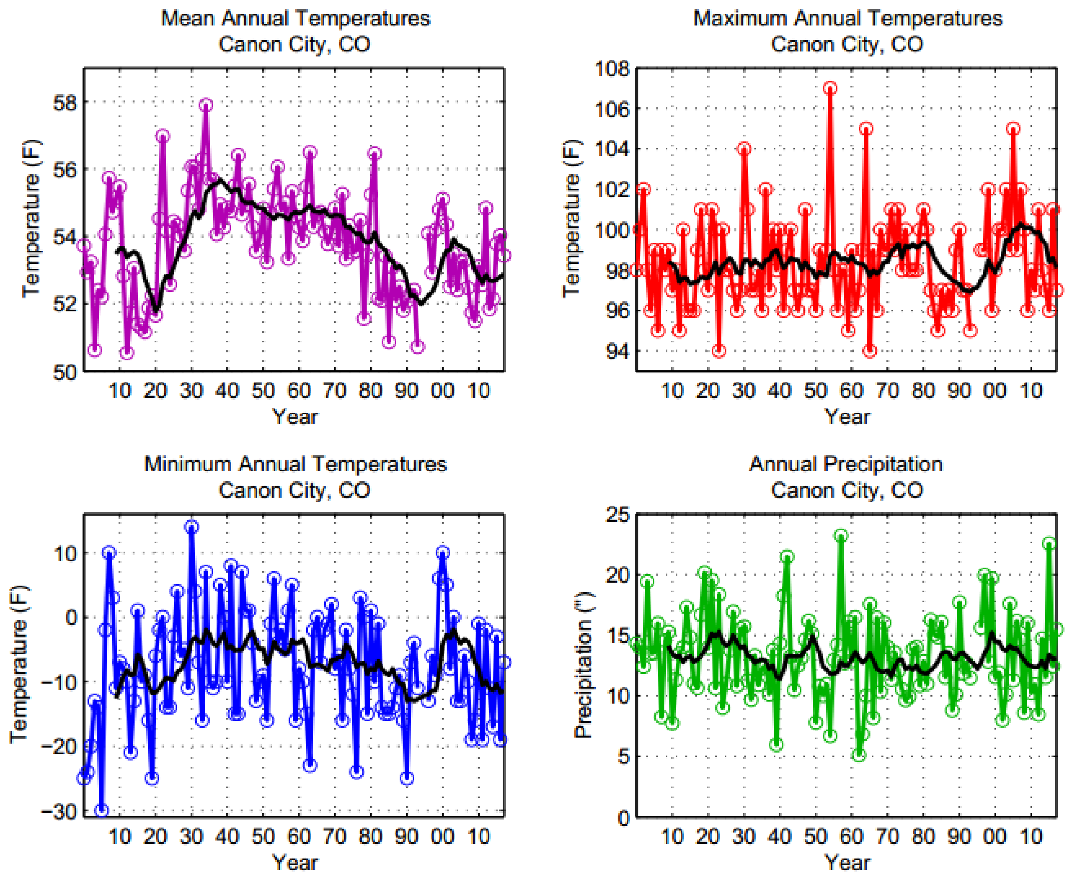

Fig. 14: Annual mean (upper left), maximum (upper right), and minimum (lower left) temperatures, and annual precipitation accumulation (lower right) for the Cañon City Cooperative Observing Network Station. Colored lines show values for individual years, and black lines show decadal averages.

Trends for the 1951-2016 period were broken down by season (Table 12). Average annual temperature has cooled -0.3 F/decade since 1951. This cooling is statistically significant at 95% confidence, consistent across seasons, and strongest in the winter. The only positive trend that is significant at 95% confidence is a 1.0 F/decade increase in springtime maximum temperature.

Table 12: Temperature and precipitation trends for the Cañon City COOP station. Temperature trends are given in Fahrenheit/decade, and precipitation in inches/decade. Color-shaded trends are statistically significant using a Mann Kendall test with at least a 95% confidence. Positive significant trends are shaded in red. Negative significant trends are shaded in blue.

Cañon City Temperature Trends (1951-2016)	Annual	Spring	Summer	Fall	Winter
Maximum Temperature	0.0 F/decade	-0.3 F/decade	0.0 F/decade	-0.2 F/decade	-0.2 F/decade
Minimum Temperature	-0.8 F/decade	1.0 F/decade	0.3 F/decade	0.4 F/decade	-0.8 F/decade
Average Temperature	-0.3 F/decade	-0.2 F/decade	-0.1 F/decade	-0.2 F/decade	-0.6 F/decade
Accumulated Precipitation	0.1 ”/decade	-0.1 “/decade	0.1 “/decade	0.1 “/decade	0.1”/decade

The National Centers for Environmental Information has developed procedures for bias correcting station data if the time of observation or location are changed, as is the case with Cañon City. Even after making adjustments for station moves and differences in observation time, Cañon City did cool from the 1930s to the 1990s, and has warmed recently (Fig. 15).

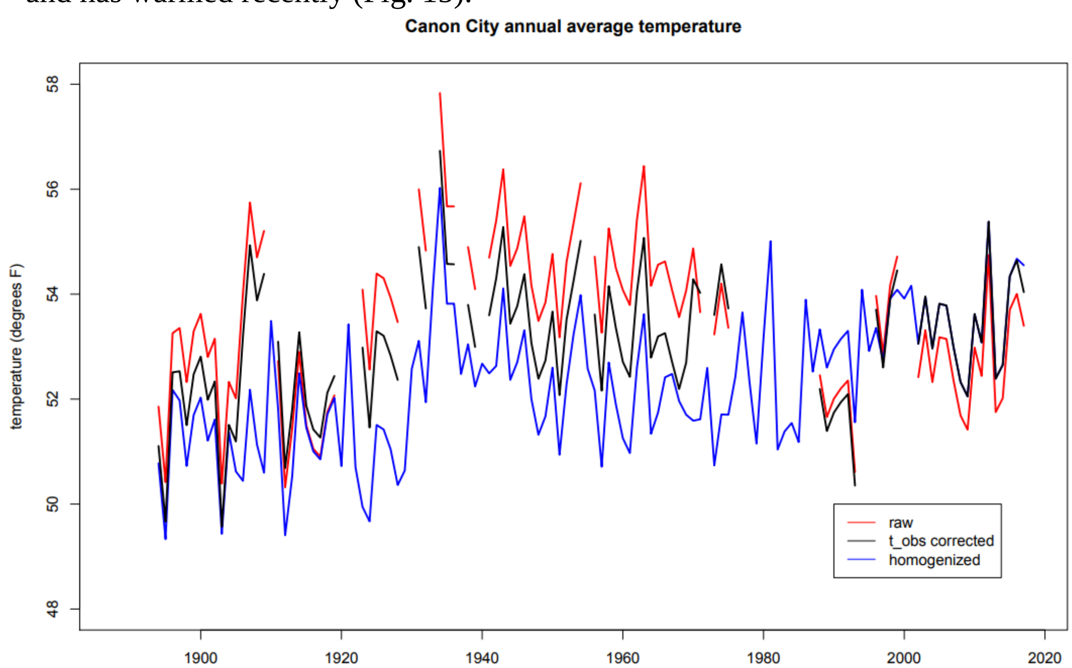

Fig. 15: Annual average temperature values for Cañon City for 1893-2017. Raw data are shown in red, temperatures corrected for bias based on time of observation are in black, and data homogenized to account for station moves are shown in blue.

The seasonal precipitation pattern for Cañon City has remained fairly consistent since the 1930s (Fig. 16). The cold season is also the dry season, and there are two expected annual spikes in precipitation. The first peak is in early May at just over 1.2” of precipitation/15 days. The second, larger peak comes in late July or August, and ramps up to about 1.5” of precipitation/15 days. This is the larger peak. The first wet peak has occurred earlier on average over the most recent 30-year period, leaving a longer lull between wet spells during the warm season. The second peak has been stronger in the most recent 30-year period than earlier in the historic record. The story is different every year, especially when dealing with precipitation. In recent history, 1999 and 2015 were particularly wet years with accumulations of 19.86 and 22.55” respectively.

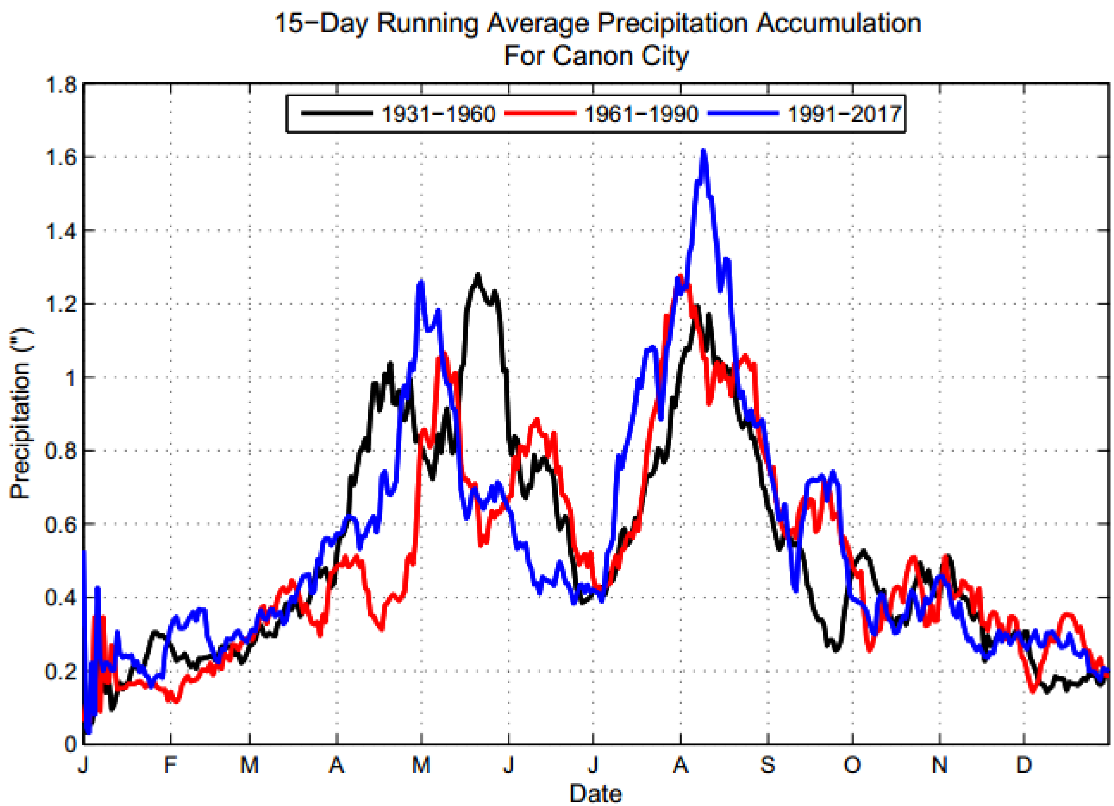

Fig. 16: Average 15-day running precipitation accumulation averages for three different time periods for Cañon City. Day of year is given on the x-axis, and precipitation accumulation in inches is shown on the y-axis. Historic precipitation was divided into 1931-1960 (black), 1961-1990 (red), and 1991-2017 (blue).

Two potentially deadly weather events for grapes that have caused trouble for Colorado growers in the past are hard freezes after bud break, and early winter bitter cold temperatures that occur before vines reach maximum cold hardiness. Table 13 breaks down the number of occurrences/decade of weather events that may signify a killing freeze: years with a temperature below 28 F after 1 May, years with a temperature below 0 F before 1 January, and years where the minimum temperature both dips below 10 F, and breaks the season’s previous minimum temperature by at least 10 F. For example, if the lowest fall temperature recorded prior to 15 November was 18, and the minimum temperature on 15 November was 5 F, this would be classified as a type three dangerous event. The latter two categories are quite common for Cañon City, occurring an average of 4 and 3 times/decade respectively. All three weather event types reached a minimum frequency during the warm 1930s and 1940s. Temperatures have increased from the 1980 and 1990s to present, but a related drop in dangerous weather events has not yet been observed. Interestingly, Cañon City appears to be less vulnerable to spring freeze damage than Cortez, but more vulnerable to late fall cold blasts than Cortez. Referencing FY 2017's report (Caspari et al., 2017) , the Mesa Verde long-term COOP station shows only about one type two and one type three event/decade going back to the 1930s. It does, however, show more type one events than Cañon City (3.3/decade).

Table 13: Number of years/decade in which each of three dangerous weather events occurred. Decades are listed in the left-hand column. An asterisk indicates incomplete data for the decade. Type one is a proxy for hard spring freezes after bud break. Types two and three show dangerous late fall/early winter events.

Number of dangerous occurrences:	Type One: Years with a temperature below 28 F after May 1st	Type Two: Years with a temperature below 0 F before January 1	Type Three: Years with a new most extreme min > 10 F cooler than the previous extreme min, and < 10 F
1900s	0	5	4
1910s	3	5	3
1920s	1	5	3
1930s	0	1	1
1940s	0	1	1
1950s	2	2	1
1960s	3	6	3
1970s	1	4	4
1980s	2	4	3
1990s*	2	5	5
2000s	2	5	4
2010s*	1	5	4

4.2 - Projected changes: Fremont County is likely to continue the current recent warming trend based on the fundamental physics of adding greenhouse gases to the atmosphere. It is possible for regional climate variability and regional/local land use changes to either enhance or mitigate this trend on a local scale. Data from the Coupled Model Intercomparison Project, which is run by the Intergovernmental Panel on Climate Change (IPCC) shows Fremont County is likely to warm significantly in coming decades (Fig. 17). The amount of warming observed will depend in part on how humans choose to alter their greenhouse gas emissions. The direst of projections, in which no action is taken, produce a model mean warming of 9 F in the winter and 14 F in the summer (Taylor et al., 2012). This would allow much a wider variety of plants to grow in Fremont County if it is accompanied by a concomitant increase in minimum winter temperature and decrease in extreme temperature drops in the late fall and early winter (type 3 events). Such a warming trend would also have significant and unresolved implications on irrigation demand and water availability (Lukas et al., 2014).

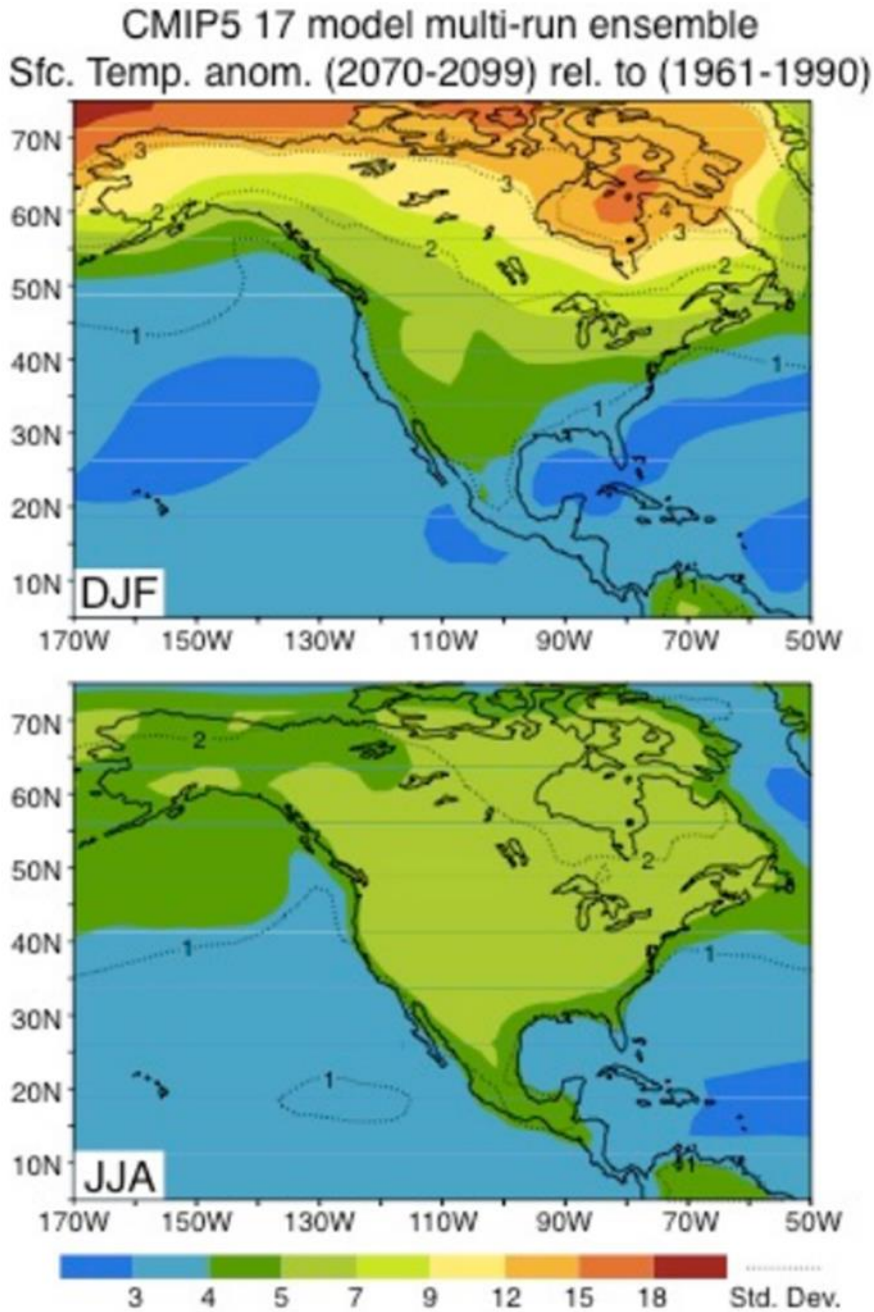

Fig. 17: Multi-model projected warming in North America by the end of the 21st century. Lines give the mean projected warming, and dashed lines give the standard deviation. The top panel shows projections for winter (December-February), and the bottom panel shows projections for summer (June-August). This figure is courtesy of the IPCC 2013 report. Temperature values are in Celsius.

Section 5: Next steps: There is no substitute for ground truth weather observations, but Montezuma County in particular produces impressively heterogeneous temperature patterns on cold winter nights. In the coming year, the Climate Center will seek to fill in gaps with thermometers in Montezuma and expand in Fremont County, but also supplement the thermometers with high resolution model data. Our goals for the next 12 months are given below:

a) Create high resolution plant hardiness map for Fremont and Montezuma Counties: The Colorado Climate Center created a plant hardiness map for Montezuma County in FY 2016 using Parameter-elevation Relationships on Independent Slopes Model (PRISM) data at 4 km resolution. The Climate Center would like to repeat this effort for Montezuma County, and extend the effort to Fremont County, but use 800 m resolution data rather than 4 km resolution (16 times as many pixels). In FY 2017 the Colorado Climate Center found that all of the ten coldest winter events occurred under high pressure atmospheric conditions where surface winds were near calm and dominated by drainage flow (Caspari et al., 2017). In these scenarios, microclimates are important, so 800 m resolution adds value to the product.

b) Compare field site thermometer data to overlaying 800 m PRISM grid cells: The Climate Center has been collecting data from vineyards and prospective vineyard sites in Fremont County since fall of 2017, and Montezuma County since fall of 2016. The Climate Center proposes a comparison of these data with the data used to make county-wide plant hardiness maps. Given the thermometers the Climate Center has installed do not feed into PRISM, they are an ideal source for ground validating the high resolution gridded product. The Climate Center will investigate where inconsistencies between observations and the gridded product are largest, and what the underlying reasons may be.

c) Expand thermometer coverage in Fremont County and Montezuma County: The Climate Center used temperature data from current vineyards in FY 2017 to identify areas of Montezuma County that are not currently utilized for grape growth, but show promise based on nighttime temperatures. Coverage was extended to these areas in FY 2018. FY 2018 was the first year of thermometer coverage for Fremont County. The Colorado Climate Center proposes an expansion in thermometer coverage in Fremont County for FY 2019, similar to what was done in FY 2018 in Montezuma County. Several thermometers will also be kept on hold for producers in Montezuma County who have not yet been integrated in our study, but show interest.

d) Create a potential growth hot spots map: Using a combination of thermometer data, PRISM 800 m temperature data, USDA web soil survey data, and Fremont and Montezuma County irrigated acreage data, the Colorado Climate Center proposes a map of hot spots for wine grape growth. This map would be used to specifically identify pieces of land that experience relatively mild winter and springtime nocturnal temperatures, are within reach of accessible irrigation, and are covered by soil types conducive to a generous moisture storage profile (ie: loam, clay loam).

II. Development of Integrated Wine Grape Production

1. Sustainable resource use

An Integrated Vineyard Production System requires a sustainable use of all resources, including soil, water, and air. The projects listed below are the continuation of our long-term program.

- Water use by young grapevines (Caspari and Sterle)

  There is a lack of understanding of the water needs for grapevines in the Colorado climate. Irrigation inputs vary widely from too little to grossly excessive watering. An understanding of grapevine water use is needed to develop sound irrigation practices. In addition, irrigation management can influence both grapevine growth and fruit quality. In previous studies using the heat-pulse technique, we determined peak daily water use to be ~8 L per day for mature grapevines trained to VSP and spaced 5’ in the row. However, no data are available on vine water use of newly-planted vines throughout the first growing season.

  In 2017, we continued a study initiated in 2015 on water use of young vines using potted vines to determine water use by a mass balance approach. Four 2-yr old Chambourcin vines were grown in large pots filled with a 50:50 soil/potting mix. Depending on water requirements, vines were watered two or three times a week until water drained freely from the pots, pot weights were determined when drainage had ceased, and weights determined again prior to the next irrigation. Shortly after bud break, shoot number was reduced to 2 shoots per vine. Shoots were trained upwards supported by bamboo inserted to the pots. Shoot lengths and leaf numbers were determined twice a month so that water use could be related to canopy development. All laterals were removed as they emerged.

  Bud break and shoot development was earlier in 2017 compared to 2015. As in 2015, vine water use early in the season was closely related to leaf area development (Fig. 18). Further, water use of Chambourcin vines in 2017 was very similar to the water use of Noiret vines in 2015, both on a per-vine basis as well as per-leaf basis. Two to three weeks after bud break vine water use was approximately 0.25 liter per day. Water use increased to around 1.5 to 2 liter per day by the end of June. Unfortunately, the undergraduate student interns in charge of this experiment did not recognize that during the middle of summer insufficient water was applied to return the soil moisture to pot capacity (Fig. 18). As a result, due to both larger leaf area and higher evaporative demand, vines were water stressed throughout the month of July and into the early part of August. Shoot growth almost ceased and vine water use dropped to about 1/3 of what was found for rapidly growing vines in the 2015 study. Vine water use increased again once watering was increased and soil moisture returned to pot capacity, but shoot growth remained depressed.

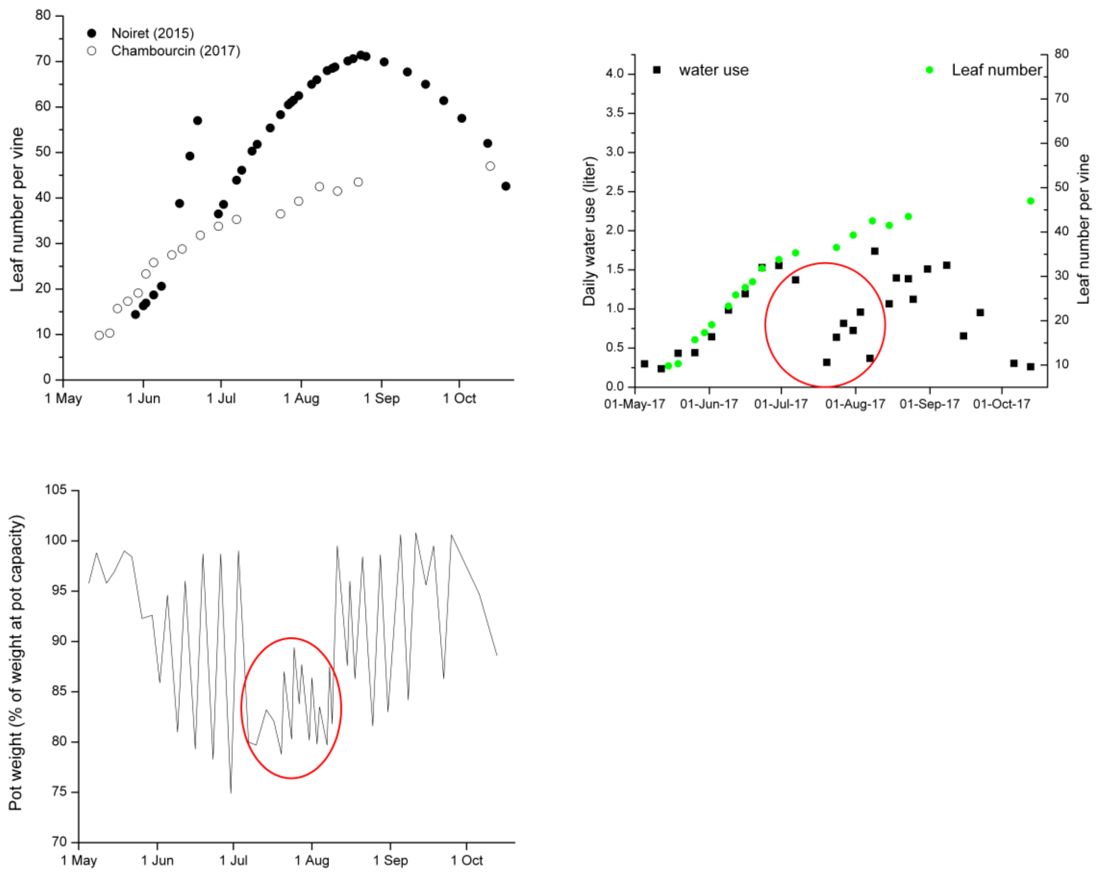

Fig. 18:Seasonal development of leaf number per vine for potted Noiret (2015) and Chambourcin vines (2017) (top left); water use and leaf number per vine (top right) and pot soil water content for Chambourcin vines during the 2017 season (bottom left). The red circle highlights period during which insufficient irrigation water was applied, resulting in vine water stress.

- Vineyard floor management - soil health, fertility, and water requirements (Caspari, Sterle, Stromberger, and Wright)

  Approximately 40% of the vineyards in Colorado are drip irrigated. While drip and sub-surface drip irrigation are the most water efficient methods of irrigation, the question arises how to manage the inter-row area. Precipitation in Colorado's semi-arid climate is generally insufficient to maintain a green cover crop. Many older vineyards were set up with drought tolerant grasses sown in the inter-row area, but over the years those grasses have died out and been replaced by weeds. Some growers opt to clean-cultivate the inter-row, others maintain bare soil through the use of herbicides or mow the resident vegetation. Bare soil or minimal vegetation cover in the inter-row is likely to degrade soil quality that potentially has negative impacts on vine performance. Results from the variety trial at Rogers

Mesa (see Viticulture Webpage) show a very strong effect of soil condition and irrigation system on yield and fruit quality[4].

To further investigate the effects of different soil and irrigation management on long-term vineyard productivity and vine and soil fertility, an experiment was initiated in the fall of 2013 in the Chardonnay block at the Orchard Mesa site that was planted in 1992. These vines have been drip irrigated since planting, with initially a crested wheatgrass cover crop planted in the inter-row area. Over time the grass has been replaced by weeds and/or bare soil. Vine vigor is low in many areas of the block - a situation not uncommon in older commercial vineyards. After the 2013 harvest, the irrigation system was changed from drip to sprinkler, and four replicated cover crop treatments established: two different grass-only cover crops; one grass-legume mix; and one legume mix. During the 2014 growing season the vineyard was sprinkler irrigated to optimize the establishment of the cover crops. In spring 2015 one of the grass-only treatments ("Hycrest" crested wheatgrass) was returned to drip irrigation (the "standard" situation since planting in 1992).

In 2017, cover crops were kept short by mowing in early spring to reduce the risk of damage from late spring frosts. After the risk of frost had passed, the cover crops were allowed to grow tall. Cover crops were mowed four times during the remainder of the season, and each time fresh and dry weight of the cover crop biomass was determined. Seasonal cover crop biomass production was two to five times higher in the sprinkler-irrigated plots than in the drip-irrigated crested wheatgrass plots (Fig. 19).

Each time the cover crops were mowed, a sub-sample of the biomass was taken, dried at room temperature, and send to a commercial laboratory for nutrient analysis (Ward Laboratories Inc., Kearney, NE). As expected, the legume cover crop had the highest nitrogen concentration, averaging 3.2 % over the season (Table 13). The Aurora Gold hard fescue and orchard mix biomass had nitrogen concentrations averaging 2.2 %, while crested wheatgrass averaged 2.0 %. Similar trends for lower nutrient concentrations in the crested wheatgrass biomass compared to the other cover crops were also found for phosphorus, potassium, and sulfur. Other differences to note were high boron concentrations in the legume biomass and extremely high iron concentrations in the crested wheatgrass biomass (Table 13). All of those cover crop treatment effects are consistent with the results from the 2016 season.

Soil samples for microbial analysis were taken in May, June, July, September, and October from both the inter-row areas and immediately under the vines. Samples were kept refrigerated overnight and then send to a commercial laboratory (Ward Laboratories Inc., Kearney, NE) for a soil microbial community analysis using Phospholipid Fatty Acid Analysis (PLFA). Resin strips were placed in the inter-row areas and in the vine row five times during the season, each time keeping them in place for approximately one month. Statistical analyses of PLFA data and chemical extraction and analyses of resin strips are not yet complete.

[4] Sprinkler-irrigated vines with a grass cover crop growing in the inter-row area have produced on average 2.8 times more yield than drip irrigated vines with a bare soil inter-row area. Fruit maturity was almost always enhanced (berries higher in soluble solids and pH, and lower in titratable acidity) under drip irrigation and bare soil. An analysis of data from the 2012 grape grower survey also suggests higher yields with furrow or sprinkler irrigation versus drip irrigation.

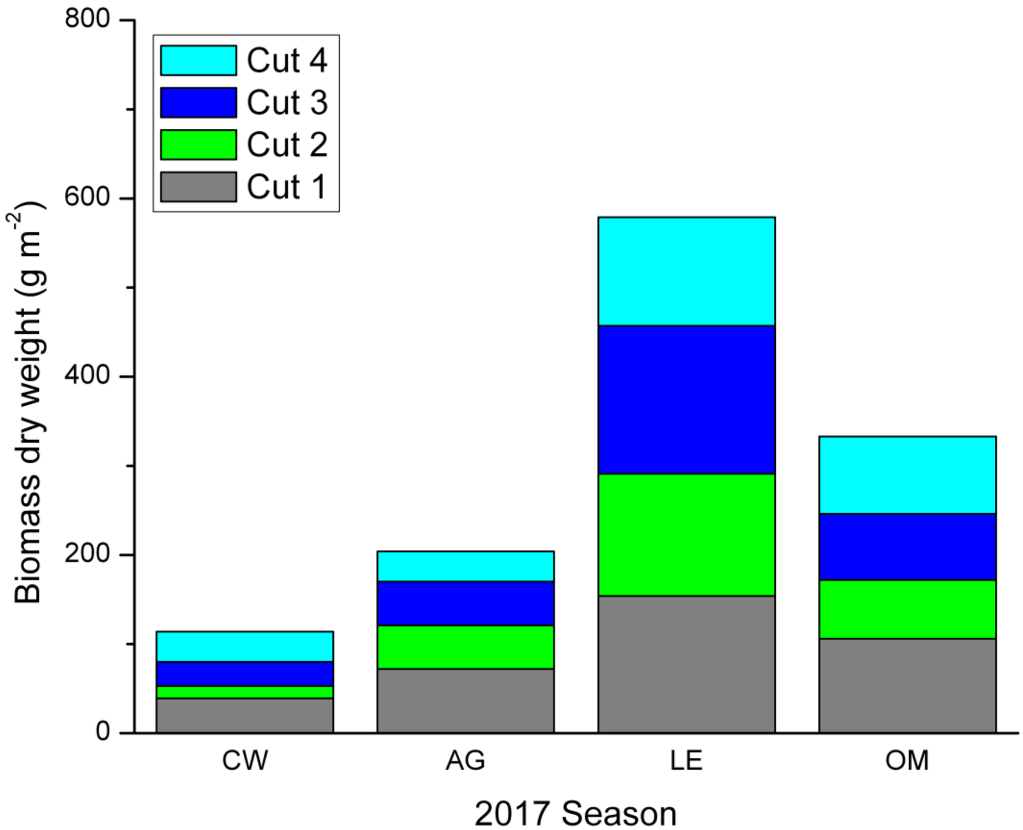

Fig. 19: Seasonal biomass production of cover crops in a Chardonnay vineyard at the Western Colorado Research Center – Orchard Mesa.
CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated, vines in AG, LE, and OM are irrigated by micro-sprinklers.

Table 13: Seasonal average nutrient concentrations in the biomass of cover crops grown in the alleyways of a mature Chardonnay vineyard at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Treatment	N (%)	P (%)	K (%)	S (%)	B (ppm)	Fe (ppm)
CW	1.99	0.21	1.35	0.25	23	2,993
AG	2.18	0.29	1.96	0.32	28	753
LE	3.18	0.25	3.00	0.41	46	610
OM	2.27	0.34	2.32	0.39	19	699

CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated, vines in AG, LE, and OM are irrigated by micro-sprinklers.

Chardonnay leaf samples were taken at veraison and send to a commercial laboratory for analysis (Ward Laboratories Inc., Kearney, NE). The results are consistent with those from the 2015 and 2016 seasons and indicate that the vine nutritional status is being affected by the type of cover crops. Specifically, the nitrogen concentration in leaf blades was again slightly higher with a legume cover crop than with the other treatments (Fig. 20). A higher availability and/or uptake of nitrogen by vines with a legume cover crop is also implied by much higher nitrogen levels in the musts seen in the past 3 seasons (Fig. 20). Treatment effects on all other nutrients have been inconsistent between the years.

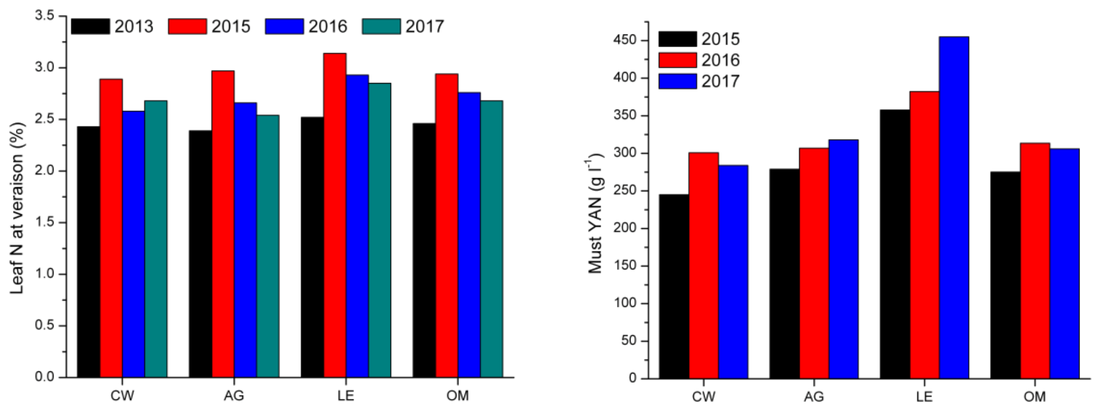

Fig. 20: Effect of cover crops on nitrogen concentration of Chardonnay leaf blades at veraison (left); and on the yeast-assimilable nitrogen (YAN) concentration of Chardonnay musts in 2015, 2016, and 2017 (right). Data for 2013 represent leaf nitrogen concentrations prior to the establishment of the cover crops.

Drip-irrigated vines received 19.9" of irrigation water during the 2017 season whereas a total of 45.7" was applied in the micro-sprinkler irrigated plots. The irrigation volumes applied were much higher than the previous season; however the vineyard received only 3.4" of precipitation between 15 April and 31 October, 2017, while reference evapotranspiration was 51.4". Approximately one third of the irrigation volume was applied post-harvest to ensure that the soil profile was wet going into the dormant season.

All results presented here are preliminary and none of the data have been analysed statistically.

In December 2016, phylloxera was discovered in the Chardonnay block used for the cover crop study. As three out of four replications are planted with own-rooted vines the presence of phylloxera may already have influenced vine performance. The presence of phylloxera also raises questions about the long-term viability of this project.

ENGAGEMENT / OUTREACH / COMMUNICATIONS

The ever-increasing number of growers and wineries in the state means that individual consultations are a very inefficient, and costly way of providing information. We therefore try to conduct our engagement / outreach primarily through industry workshops / seminars, formal presentations (e.g at VinCO), and field days. However, on an annual basis we respond to hundreds of phone and thousands of email inquiries.

1. Field demonstrations/workshops/tours

We provided several tours of the research vineyard and/or the research facilities to individual growers, visiting scientists, and extension staff. Common topics covered included cover crops and irrigation, trellis/training systems with Syrah, crop thinning, powdery mildew management, and vineyard irrigation management.

Stephen Menke assisted with organizing the multi-state wine tasting and formal evaluation of NE-1020 project wines, including wines from several cultivars in the CSU NE-1020 test vineyards, at the NE-1020 annual review meeting in Cape May, MD (14-15 November, 2017). This data will be pooled with data from previous evaluations and shared by outreach.

Both Horst Caspari and Stephen Menke gave research updates and mini-workshops at VinCO 2018 in January. These included: “Viticulture 101 – Canopy Management”, “Grape Survey Results”, and “Viticulture Research Update”, by Horst and “Sensory Analysis of Attributes and Flaws” by Stephen and Jenne Baldwin-Eaton.

Industry workshops for variety tasting and blending, using wines made from variety trial vineyards and wines from industry winemakers, were held: on 13 February, 2018 at WCRC-OM; on 27 February, 2018 at Foxfire Farms Winery in Ignacio, CO; and on 23 April, 2018 at WCRC-RM. Wines from several vintages of both inter-specific cold hardy and *V. vinifera* wine were tasted and blended. Several commercial winemakers plan to use some of the new varieties for the first time and others made test blends that they thought could exploit new product niches.

We continue to use our web site and other internet resources such as our “Fruitfacts” messages to provide information resources for Colorado growers. Also, as part of the “Application of Crop Modeling for Sustainable Grape Production” project, current weather information from seven vineyard sites in the Grand Valley is accessible to grape growers and the public via the internet. We will continue to service both the software and hardware for this weather station network.

2. *Off-station research and demonstration plots*

The uptake of new research results and new production techniques is fastest when growers are directly involved in their development. One way of involving growers in research is to establish research plots on grower properties. Since 2013, we have established two replicated variety trials in grower vineyards. At both sites, vines were trained by CSU student interns. The Fort Collins vineyard was also used for formal education of CSU students during the 2017 fall term. The replicated clonal study with Cabernet Franc (see above) is another example where the research is sited in a commercial vineyard. Buds from this Cabernet Franc vineyard are also used for cold hardiness evaluations. The two new rootstock trials with Cabernet Sauvignon (see above) are further examples of off-station research. We will continue to use the vineyards at the Western Colorado Research Center in the first or early stages of testing of new methods and/or trials that carry a high risk of crop damage.

3. Colorado Wine Grower Survey

Colorado State University has conducted this annual survey for over 20 years. Survey forms were send out in November 2017. The majority of forms were send electronically. By June 2018 we had received 82 responses (representing 142 vineyard sites) totaling 643 acres. Taking into account still outstanding survey returns, the main results are:

- A new record grape production in 2017
- More than 2,000 ton production reported so far
- Expected total production >2,200 ton
- Less surplus grapes than in the previous two years
- Average yield of 3.29 ton/acre; almost identical to 2015
- Average price of $1,718/ton; an increase of 4.3 % over 2016
- Approximately 82 % of vineyard area planted with *V. vinifera* varieties
- The average grower farms 7.8 acres
- Average vineyard size is 4.7 acres
- The median vineyard size is 3.0 acres
- Very few new acres planted in 2017 (<10 acres)
- Vineyard area removed exceeds area planted
- There is a continued expansion of vineyard area outside of Colorado's main growing areas

LITERATURE CITED

Caspari, H. 2015. Long-term economic analysis of growing grapes in Colorado.
Long-term economic analysis of growing grapes in Colorado

Caspari, H. and D. Sterle. 2017. Cold hardiness of grapevine buds in Western Colorado, 2016/17.
Cold hardiness of grapevine buds in Western Colorado

Caspari, H., N. Doesken, S. Menke, M. Schipanski, and M. Stromberger. 2016. Annual Report (July 2015 to June 2016) - Viticulture and enology programs for the Colorado wine industry, 32 pp.
http://coloradowine.com/wp-content/uploads/2016/07/CSU-VE-Annual-report-Jul-2015-to-Jun-2016.pdf

Caspari, H., N. Doesken, P. Goble, S. Menke, M. Schipanski, D. Sterle, and M. Stromberger. 2017. Annual Report (July 2016 to June 2017) - Viticulture and enology programs for the Colorado wine industry, 41 pp.
https://coloradowine.com/wp-content/uploads/2017/07/Annual-report-Viticulture-Research-Jul-2016-to-Jun-2017.pdf

Gerard, P.D. and W.R. Schucany. 1997. Locating exotherms in differential thermal analysis with nonparametric regression. *J. Agric. Biol. Environ. Stat.* 2:255-268.

Lukas, J. J. Barsugli, N. Doesken, I. Rangwala, and K. Wolter. 2014. Climate change in Colorado: A synthesis to support water resources management and adaptation. A Report for the Colorado Water Conservation Board, Western Water Assessment, Second edition, 114 pp.

Mills, L.J., J.C. Ferguson, M. Keller. 2006. Cold hardiness evaluation of grapevine buds and cane tissues. *Am. J. Enol. Vitic.* 57:194-200.

Minas, I., D. Sterle, H. Caspari. 2017. Cold hardiness assessment of peach flower buds using differential thermal analysis (DTA) in Western Colorado (dormant season 2016/17).
[Peach flower cold hardiness in Western Colorado]

Taylor, K.E., R.J. Stouffer, G.A. Meehl. 2012 An Overview of CMIP5 and the experiment design. *Bull. Amer. Meteor. Soc*. 93:485-498.