Semi-annual Report

July 1, 2016 – December 31, 2016

Viticulture and Enology programs for the Colorado Wine Industry

PRINCIPAL INVESTIGATORS

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COLLABORATING INSTITUTIONS

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

Summary

The majority of the work performed during the reporting period included seasonal vineyard tasks such as vine training, canopy management, crop thinning, harvest, preparing vineyards for dormant season, bud cold hardiness evaluations, a continuation of a study on methods to increase bud cold hardiness, data entry and analysis, and the annual Colorado Grape Grower Survey. Most of the vineyard work was performed by two student interns (one from the Viticulture & Enology program at CSU, one from the Horticulture Science program at Texas A&M), a high school student, and CSU staff at WCRC. Two students from the Viticulture & Enology program at CSU were responsible for all vineyard work in the new variety trial in Fort Collins.

Weather conditions in the Grand Valley were slightly warmer than average in July, but slightly cooler in August. September was slightly warmer than average followed by the second-warmest October and warmest November since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964. The mean temperature for November was almost 7 F higher than average. A season-ending killing frost occurred on October 20 in the main growing areas in Delta County, but not until November 17 in central and eastern parts of the Grand Valley. December temperatures were slightly above average. There was a gradual decline in minimum temperatures in December 2016 which resulted in good and gradual vine cold acclimation. There was, however, a sharp temperature drop at the end of the first week of January 2017 when once again temperatures dropped below 0 F in many parts of Western Colorado. Weekly bud evaluations from vines growing at the Western Colorado Research Center – Orchard Mesa and commercial vineyards nearby show minimal cold injury to buds as of late January 2017.

The mild winter of 2015/2016 in Western Colorado resulted in no or minimal bud damage. Similar to 2015, most of the 48 varieties grown in the research vineyards produced a crop. Preliminary data from the 2016 Colorado Grape Grower Survey indicate

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that the 2016 harvest was the biggest ever, surpassing the record set in 2015. Similar to the 2015 harvest, there was a surplus of grapes. This surplus appears to have been even larger than in the previous year. With close to 200 acres reaching full production potential within the next 2-3 years, the oversupply of grapes during the past two vintages raises serious concerns about the future balance in grape supply and demand.

Phylloxera (*Daktulosphaira vitifoliae*) was discovered in a Grand Valley vineyard planted with self-rooted *Vitis vinifera* vines in November 2016. Since then, an additional three Mesa County vineyards have tested positive for the insect.

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Growing conditions, July – December 2016

Temperatures recorded at the Western Colorado Research Center - Orchard Mesa (WCRC-OM) and Western Colorado Research Center - Rogers Mesa (WCRC-RM) were near average during July, August, and September 2016. Temperatures in October and November were much higher than normal, while mean temperatures in December were near average. Precipitation from July to December were near average. Annual precipitation at WCRC-OM and WCRC-RM was 7.15" and 7.70", respectively, slightly below normal.

The very warm October and November allowed for most grapes to be harvested prior to killing frosts. Most of the vineyards in Delta County had a killing frost before the end of October. In contrast, most vineyards in Mesa County did not have a killing frost until the second half of November. Temperatures throughout December were near average, and unlike December 2015 there were no extreme temperature swings.

Research Update

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 2009 as part of the USDA Multistate NE-1020 project (see below). Also in 2009 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 2015/16 resulted in minimal bud damage to the remaining test varieties. Six varieties were harvested between 19 and 21 October, 2016. Results are summarized in Table 1. Only Traminette was used for micro-vinification.

Table 1: Harvest dates and yield information for 6 (out of 8) grape varieties planted in 2004 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Variety	Harvest date 2016	Yield (ton/acre)[1]
Chambourcin	21 October	3.63
Corot noir	19 October	2.70
Noiret	21 October	2.35
Rkatsiteli	19 October	2.85
Traminette	19 October	3.49
Valvin Muscat	21 October	1.32

[1] Yield calculation based on number of vines with crop. Vine survival is >90 % for all varieties.

- Multi-state evaluation of wine grape cultivars and clones. (Caspari and Menke)

This long-term (2003-2017), 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. All participating states follow the same experimental protocol. In Colorado, 10 varieties were established in 2009 and 2010 at Rogers Mesa, and 25 varieties at Orchard Mesa between 2009 and 2012.

At Rogers Mesa, eight out of ten varieties were harvested between 21 September and 19 October 2016. Yields ranged from 0.7 to 3.9 ton/acre (Table 2). Micro-vinification was used to produce six varietal wines.

Table 2: Harvest dates and yield information for 8 (out of 10) grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Variety	Harvest date 2016	Yield (ton/acre)[1]
Aromella	29 September	2.70
Auxerrois		0
Bianchetta trevigiana	7 October	0.70
Blauer Portugieser		0
Chambourcin	19 October	3.86
Grüner Veltliner	7 October	1.62
Marquette	21 September	1.52
MN 1200	21 September	1.27
NY 81.0315.17	19 October	3.67
Vidal	19 October	2.35

[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. Harvest started with Marquette on 22 August 2016, and ended with six varieties on 31 October 2016. A

summary is presented in Table 3. Ten varietal and one blended wine were produced using micro-vinification techniques.

Table 3: Harvest dates and yield information for 25 grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Variety	Harvest date 2016	Yield (ton/acre)[1]
Albarino	19 September	3.84
Barbera	27 October	4.56
Cabernet Dorsa[2]	2 September	2.66
Cabernet Sauvignon	17 October	2.29
Carmenere[3]	31 October	1.29
Chambourcin[2]	17 October	2.08
Cinsault	18 October	2.76
Durif[2]	31 October	0.53
Graciano[3]	18 October	1.64
Grenache	31 October	2.23
Malvasia Bianca	19 September	1.85
Marquette[2]	22 August	1.65
Marsanne	17 October	1.57
Merlot	9 September	0.82
Mourvedre	31 October	1.93
Petit Verdot[3]	31 October	1.70
Refosco[3]	18 October	4.50
Roussanne	18 October	1.33
Souzao	26 October	2.70
Tinta Carvalha[3]	31 October	1.00
Tocai Friulano	31 October	4.45
Touriga Nacional	26 October	2.98
Verdejo	31 October	6.29
Verdelho	19 September	3.64
Zweigeltrebe[2]	9 September	2.38

[1] Yield calculation based on number of vines with crop. Vine survival (out of 24 vines planted originally) ranges from 4 % for Tocai Friulano to 96 % for Zweigeltrebe.

[2] Planted in 2011 and 2012.

[3] 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 damage, and there were no late spring freezes. Fruit was harvested from all varieties (Table 4), and six varietal wines were produced.

Table 4: 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 2016	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. Not all vines had sufficient vigor during 2015 for shoots to be tied down to the fruiting wire. However, all varieties produced at least a small amount of fruit (Table 5). Nine varietal and one blended wine was produced.

Table 5: Harvest dates and yield information for 12 grape varieties planted in 2013 at a commercial vineyard near Clifton, CO.

Variety	Harvest date 2016	Yield (ton/acre)[1]
Arandell	1 September	1.34
Aromella	9 September	3.47
Brianna	22 August	3.05
Cayuga White	12 September	3.37
Chambourcin	17 October	3.07
Corot noir	21 September	2.45
La Crescent	1 September	1.86
Marquette	22 August	2.00
Noiret	21 September	1.48
St Vincent	17 October	4.01
Traminette	22 September	1.43
Vignoles	22 September	1.65

[1] Yield calculation based on number of vines with crop. Vine survival is >90 % for all varieties.

- 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 2014 showed that Cabernet Franc was the only variety that produced above-average yields in all 15 years, and returned the greatest average revenue per acre (Caspari and Lumpkin, 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 6 October 2016, approximately 285 lbs of fruit per clone were harvested from 5 to 6 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 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 were adjusted to a target of 24 Brix soluble solids and 7 g/l total titratable acidity. Wines will be used for future analysis, formal wine evaluations, and industry tastings.

  Consistent with observations in previous years, yields were highest for clones FPS 01 and 09, and lowest for clone FPS 11 (Table 6). 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 6: Clonal effects on 2016 yield of Cabernet Franc growing in the Grand Valley AVA in Western Colorado.

Clone / rootstock	Yield (lb/vine)	Yield (ton/acre)
FPS 01 / own	6.16	4.09
FPS 04 / own	4.56	3.03
FPS 09 / own	7.50	4.98
FPS 11 / 110R	2.22	1.47

As was the case in 2015, despite having the lowest yield, musts of clone FPS 11 also had the lowest nitrogen concentration (Table 7). Musts of clone FPS 09 had the lowest pH, and highest titratable acidity and malic acid concentration. The result on must composition as well as those on yield are consistent with the results from the 2015 season.

[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.

Table 7: Clonal effects on 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	3.64	26.1	4.67	5.89	2.08	72	79
FPS 04 / own	3.59	26.4	4.92	5.44	1.99	86	70
FPS 09 / own	3.47	26.5	5.23	5.49	2.26	71	82
FPS 11 / 110R	3.59	28.0	4.52	5.60	1.70	59	74

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 and Sterle)

  There are substantial varietal differences in cold hardiness. Understanding the patterns of acclimation, mid-winter hardiness, and deacclimation 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, Rkatsiteli that differ in rate and timing of acclimation and deacclimation, 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-wide 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 are made available via our Webpage, and growers are using this information when deciding if freeze/frost protection is needed. In addition to the ~weekly tests on Chardonnay and Syrah we are testing the mid-winter hardiness of Albarino and Souzao, two varieties that appeared to have suffered less damage than many other *Vitis vinifera* varieties from the extreme cold events in January and December 2013. Chambourcin and Traminette from a commercial vineyard near the research center have also been included in the 2016/17 dormant season testing. Clonal differences in cold hardiness are being tested under the "Clonal trial with Cabernet Franc" project (see above).

- Advancing cold hardiness. (Caspari and Sterle)

  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.

  Based on the results from the previous two seasons a follow-up study was conducted in 2016 using mature Chardonnay and Syrah vines growing at WCRC-OM. A foliar application of ABA (500 ppm) was applied 20 days after veraison. A controlled freezing test in mid November showed no treatment effect on cold hardiness of either Chardonnay or Syrah (data not shown).

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 and Menke)

  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.

  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

[3] ProTone, manufactured by Valent BioSciences.

block, and these areas may be picked on separate dates, based on the fruit analysis results. In 2016, the entire block was harvested on 12 October. Yields ranged from 0.9 ton/acre with Pendelbogen to 2.9 ton/acre with Lyre (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.

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	21.4	1.72
Vertical Shoot Positioning	17.1	1.27
Sylvoz	30.6	2.35
Pendelbogen	11.9	0.87
Lyre	32.7	2.85
Geneva Double Curtain	28.1	2.17

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 will serve as an instructional resource for workshops on pruning and training of varieties with downward shoot growth habits.

4. Identifying areas suitable for expanded wine grape production

- Western Slope microclimates suitable for wine grape production. (Doesken, Goble, and Caspari)

The high elevation of Colorado's Western Slope in combination with frequent sunshine, low humidity, and diurnal temperature fluctuations offer unique growing conditions for some varieties of wine grapes. Unfortunately, only small areas are likely available with appropriate soils, available water, and microclimatic conditions that minimize the occurrence of damaging spring freezes and mid-winter extreme cold events. This project offers an initial approach to identify areas with medium- and high-potential for expanded grape production by examining climate trends to assess the likelihood of improved or reduced site potential.

Nolan Doesken and Peter Goble traveled to Montezuma County in October 2016 equipped with maps and the first-cut plant-hardiness maps and vineyard locations that were produced last year (Caspari et al., 2016). With local help from Tom Hooten, CSU Montezuma County Extension Office, we made contacts with several growers and met with Jude and Addie Schuenmeyer of the Montezuma Orchard Restoration Project, Bob Schuster, a local wine grape grower operating in west end of McElmo Canyon, the staff of CSU's SW Colorado Research Center near Yellow Jacket, and the CSU Extension director for Dolores County. These interviews allowed us to improve our knowledge of and catalog some of the

challenges of local wine grape growers in recent years, and identify parts of the county where fruit that prefer similar climatic conditons have been grown in the past. Some highlights from these interviews include the following:

- There are areas to the north of Cortez near Lebanon Road and Road T where apple orchards have been located in the past. Some orchard activity persists in this area. While the land slopes generally down from north to south, there is considerable local terrain creating potential favorable local microclimates.
- Grape activity has been successful in the area north of town as well. While this area is higher in elevation than Cortez, and temperatures on average cool with height, it still has the potential to sustain less hardy flora as the coolest air drains into the valleys below at night. Bill Russell is growing grapes in this area of the county.
- Bob Schuster claims that while large summer rainfall events are seen as a detriment to wine grape growth, his property in the McElmo Canyon is dry enough that summer rain events are typically welcome.
- North facing slopes just above the valley floor in McElmo Canyon appeared to have the most "success". Schuster's grapes had not experienced winterkill or spring freezes at his location.

We also visited and photographed the locations of existing long-term NOAA weather stations and CoAgMET stations used in previous analyses. We were very pleased to see first hand that CoAgMET stations in Montezuma County are well positioned to support the current study. We spent time with the Dolores Water Conservancy District general manager to gain a better appreciation for historic irrigation in Montezuma County and the expanded irrigation opportunities that came in the early 1980s with the completion of the Dolores project.

Previous work and growing experience has shown that the greatest limiting factor to potential wine grape growth in southwestern Colorado is plant hardiness – including extreme cold in early winter and killing freezes during spring. Wintertime low temperatures on occasion are sufficiently cold for damaging or totally killing grape vines. On cold winter nights, usually with some fresh snow cover, the large-scale airflow is often nearly calm, and the coldest, most dense air, drains to the lowest elevations. This can create stark temperature contrasts over horizontal spatial scales on the order of hundreds of meters.

To explore this further, we deployed a network of thermometers in several grape-growing areas. A self-contained, sturdy sensor/data logger combination recommended by Horst Caspari was first tested for a few weeks in Fort Collins side-by-side with the official thermometers at the official Fort Collins weather station on the CSU campus. Peter Goble then returned to Montezuma County in the third week of December. Fifteen thermometers were installed at a total of six locations across Montezuma County. Locations of installation were primarily current vineyards, but included one prospective vineyard land recently acquired by Guy Drew.

Thermometers are battery powered. They take a reading every five minutes, and have an advertised lifespan of 120 days when recording at five-minute intervals. The thermometers will be collected in April 2017 for analysis. Important details of installation are as follows:

- All thermometers were installed at vine height (4ft above ground)

- All thermometers were the same make and model (Measurement Computing, model USB-501-PRO)
- At each location where two or more thermometers were installed, at least one was installed at the high end of the property, and one at the low end
- At each location where three thermometers were installed, two were installed at the high end of the property. One thermometer of the two was sheltered by a PVC housing with air holes drilled for ventilation. These thermometers were installed in order to allow for accurate temperature readings in the event that exposed thermometers become snow or ice-covered.

Locations of thermometer installations are as follows:

- Three thermometers each were installed at these four locations:
  - Vineyard Behind the Yucca House Monument (County Road 20.5)
  - Bill Russel's vineyard at 16473 Road 26
  - Montezuma Orchard Restoration Project at 17312 County Rd G (McElmo Canyon)
  - Bob Schuster's vineyard at 6090 County Road G (McElmo Canyon west end)
- Two thermometers were installed at Guy Drew's new property at 27244 Rd T
- One thermometer was installed at Jerry Fetterman's grape plot near Yellow Jacket off of County Road 16.5

Primary analysis goals of thermometer installations are as follows:

- Winter daily minimum temperatures will be compared to the Cortez Cooperative Observing Network station. Areas suitable for wine grape growth should be warmer than the city of Cortez, ideally by as much as 3 F.
- Wintertime daily minimum temperatures for 2016-2017 for Cortez, CO will be compared to the historical record. This will enable us to determine how much cooler the thermometer sites may become in more harsh winters.
- Thermometers positioned at a high point on a growing property will be compared with thermometers positioned at a low point on a growing property, which will help to quantify the impact of cold air drainage on calm, cold nights.
- Sheltered thermometers will be compared with neighboring unsheltered thermometers. The most obvious difference will be higher daytime temperatures for unsheltered thermometers, but large differences in reading overnight may indicate that unsheltered thermometers were snow or ice-covered.

Depending upon the fruitfulness of this data analysis, thermometers may be installed at the same, or similar locations again to catalog which areas of Montezuma County are most likely to stay warmest during other harmful event types. These event types include the following:

1. Freezes after bud break
2. Summer heat waves

3. Intense cold waves in late fall

We will combine data from these sites with the fixed long-term NOAA and CoAgMET weather stations to help put the 2016-2017 season into historic perspective.

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 LaFantasie)

  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 2016, we planned to continue a study initiated in 2015 on water use of young vines using potted vines to determine water use by a mass balance approach. However, high salt concentration in an aged compost used to make a 50:50 soil/compost blend caused half the potted vines to die shortly after planting in spring 2016. The remaining vines had poor growth and the experiment was terminated. We plan to repeat this study with a new set of vines in 2017.

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

  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].

[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.

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 2016, 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 four times higher in the sprinkler-irrigated plots than in the drip-irrigated crested wheatgrass plots (Fig. 1; Photo 1, 2).

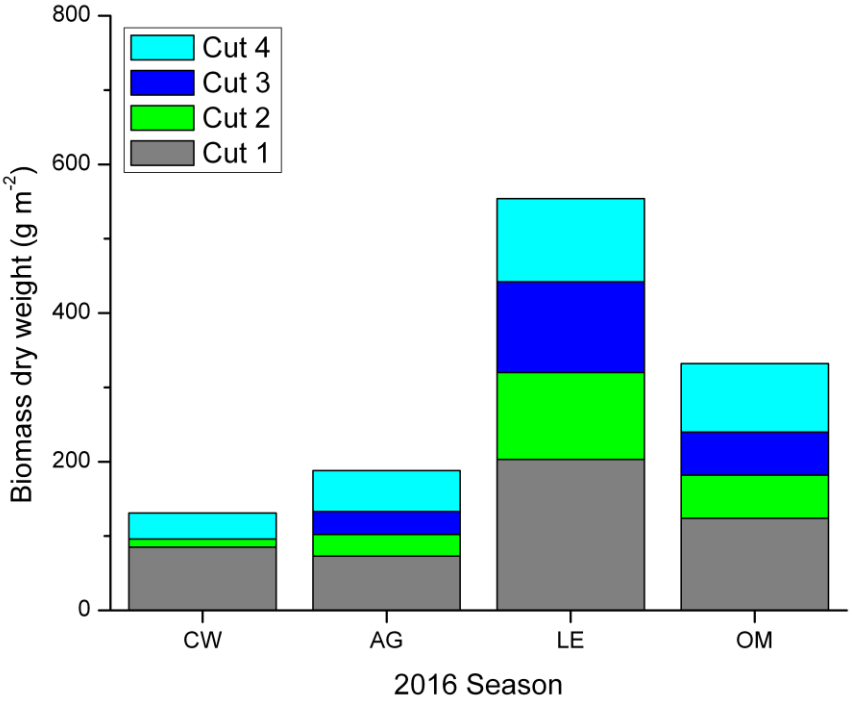

Fig. 1: Seasonal biomass production of cover crops in a Chardonnay vineyard at the Western Colorado Research Center – Orchard Mesa. Note that the CW was mowed only three times due to lack of regrowth in the middle of summer (see Photo 1).

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.

Photo 1 (left): A crested wheatgrass plot on 24 August, 2016.
Photo 1 (right): A legume mix plot right before mowing on 24 August, 2016.

Soil samples for microbial analysis were taken in May, June, July, August, 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.

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 3.6 % over the season (Fig. 2; Table 9). The Aurora Gold hard fescue and orchard mix biomass had nitrogen concentrations averaging 2.4 %, while crested wheatgrass averaged 1.8 %. Nitrogen concentration in the crested wheatgrass declined during the season whereas the nitrogen concentrations remained more or less stable in the other cover crops. 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 9).

Table 9: 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	1.85	0.19	1.30	0.22	24	2,064
AG	2.38	0.32	2.08	0.31	30	579
LE	3.58	0.28	2.87	0.42	29	630
OM	2.42	0.34	2.30	0.36	19	329

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 season 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. 2). 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 in both the 2015 and 2016 season (Fig. 3). Further, and consistent with the differences in nutrient concentrations in the cover crop biomass, phosphorus and potassium were lower while iron, calcium, and magnesium were higher with crested wheatgrass than with the other cover crops. However, there was no cover crop effect on the sulfur concentration of Chardonnay leaves at veraison (data not shown). It is worth noting that there has been no application of sulfur fungicides over the past two seasons.

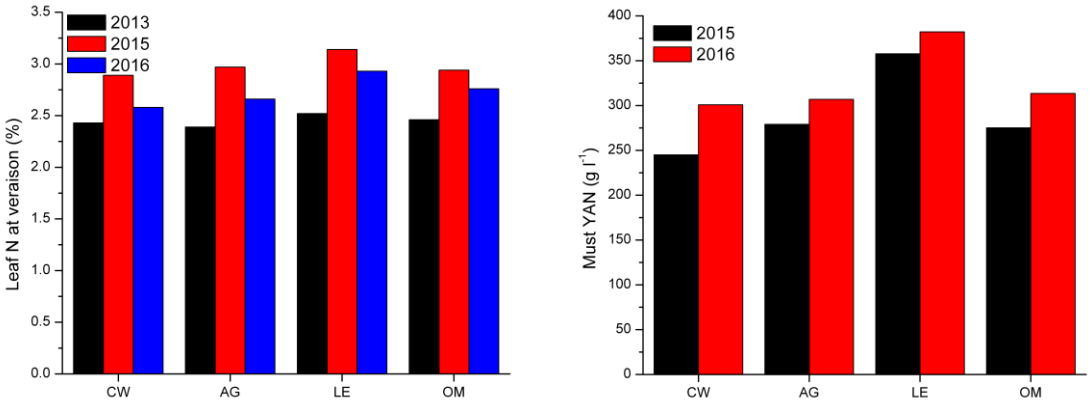

Fig. 2 (left): Effect of cover crops on nitrogen concentration of Chardonnay leaf blades at veraison. Data for 2013 represent nitrogen concentrations prior to the establishment of the cover crops.

Fig. 3 (right): Effect of cover crops on the yeast-assimilable nitrogen (YAN) concentration of Chardonnay musts in 2015 and 2016.

Drip-irrigated vines received 12.5" of irrigation water during the 2016 season whereas a total of 31.1" was applied in the micro-sprinkler irrigated plots. The irrigation volumes applied were much higher than the previous season; however the vineyard received only 4.1" of precipitation between 15 April and 31 October, 2016, compared to 11.7" for the same period the previous year. 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.

A "Crush Readiness" workshop was held at WCRC-OM on 28 July, 2016. The workshops was repeated at Kingman Estate Winery in Denver on 29 July, 2016. Nichola Hall and Michael Jones from Scott Labs and Stephen Menke were the instructors at both workshops.

Stephen Menke organized and conducted a "Berry Sensory Evaluation and Harvest Readiness" workshops at WCRC-OM in Grand Junction on 15 September, 2016. Stephen Menke were the instructors. Included in the evaluations were grapes from several cultivars from the WCRC-OM variety trial, as well as some grapes from a variety of cultivars brought by attendees.

As part of the activities during the Colorado Mountain Winefest, Horst Caspari conducted a "Grape growing for beginners" workshop at WCRC-OM on 18 September, 2016.

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 Burlongton, VT (16-18 November, 2016). This data will be pooled with data from previous evaluations and shared by outreach.

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. In December 2016, as part of system maintenance, we raised the height of the antenna at WCRC-OM which has resulted in much improved signal reception from the weather stations that are furthest removed (Redlands, Grand Junction North). 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 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 used for cold hardiness evaluations. Another example of industry collaboration are three different vineyard sites where we monitor temperature profiles. We will continue to use the vineyard at the Western Colorado Research Center at Orchard Mesa 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. The majority of forms were send electronically. By 18 January, 2016 we had received 49 responses (representing 105 vineyard sites) totaling 547 acres. The main results of the survey are:

- Potentially a new record grape production in 2016, surpassing 2015
- 1,860 ton production reported so far
- expected total production >2,000 ton
- Maybe as much as 10 % of production did not get sold
- Average yield of ~3.8 ton/acre; the highest ever recorded
- Average price of $1,646/ton, virtually unchanged from 2015
- The average grower farms 10.8 acres
- Average vineyard size is 5.1 acres
- The median vineyard size is 3.6 acres
- More than half the new plantings in 2016 were with cold-hardy varieties
- There is a continued expansion of vineyard area outside of Colorado's main growing areas

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