Annual Report

July 1, 2015 – June 30, 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 reporting period covers the second half of the 2015 growing season, the 2015/16 dormant period, and the first half of the 2016 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, a continuation of a study on methods to increase bud cold hardiness, a study on the climate and climatic trends in SW Colorado as it relates to wine grape production, data entry and analysis, and the annual Colorado Grape Grower Survey. Most of the vineyard work was performed by five student interns (three from the Viticulture & Enology program at CSU), a high school student, a visiting scholar from Spain, and CSU staff at WCRC. Another student intern from the Viticulture & Enology program at CSU was responsible for all vineyard work in the new variety trial in Fort Collins. The climate study in SW Colorado was conducted by staff from the Colorado Climate Center.

The very mild winter of 2014/2015 in Western Colorado resulted in no or minimal bud damage. Weather conditions in Western Colorado were much cooler than average in July 2015, followed by a warmer-than-average August. Both September and October were the warmest since record-keeping began at the Western Colorado Research Center in 1964. For the first time since 2000, all 48 varieties grown in the research vineyards produced a crop. All fruit from 12 out of 16 varieties grown at the Rogers Mesa site were lost due to wildlife damage. Small-scale varietal wine lots were made from 18 varieties, and a further 10 varieties were used for blends. Data from the 2015 Colorado Grape Grower Survey indicate that the 2015 harvest was a record crop (first time over 2,000 ton produced in Colorado) with an average yield of 3.31 ton/acre (the second-highest after 1997).

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Temperatures in November were slightly warmer, those in December slightly cooler than average. A season-ending killing frost did not occur until the first week of November for the main growing areas in Delta County, and not until the fourth week of November in the eastern part of the Grand Valley. The minimum temperatures in December 2015 were much colder than in the very mild December 2014, resulting in good and gradual cold acclimation. Once again temperatures dropped below 0 F at the end of December 2015 and again in the first week of February 2016 in most areas of Western Colorado, except the eastern part of the Grand Valley. However, weekly bud evaluations from vines growing at the Western Colorado Research Center – Orchard Mesa and commercial vineyards nearby showed minimal cold injury to buds. Similar to 2014, temperatures from mid February to late March 2016 were well above average, leading to early de-acclimation (loss of cold hardiness) and a potential for early bud break. However, two prolonged periods of much colder-than-average temperatures in late March / early April and mid April slowed down bud development, and resulted in average to slightly delayed bud break. Vine growth was slow in May primarily due to cooler temperatures in the second half of May. However, vine growth accelerated during a record warm June, and vine development appears to be back to average by the end of June.

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Growing conditions

Temperatures recorded at the Western Colorado Research Center - Orchard Mesa (WCRC-OM) and Western Colorado Research Center - Rogers Mesa (WCRC-RM) were much below normal during July 2015, above normal from August through to October, near normal in November, and slightly below normal in December 2015. After a dry January to March, precipitation during the 2015 growing season was well above average. Monthly precipitation was more than twice normal from April to August, and again in October. Only September had less-than-average precipitation, with November precipitation being 97 % above normal. Annual precipitation for 2015 at WCRC-OM was 15.2", more than 70 % above normal.

In response to the wetter-than-normal conditions many growers increased the number of fungicide applications to control powdery mildew. However, based on the experience in our research vineyards it is at least questionable if more fungicide application were indeed needed - even in the comparatively wet 2015 we achieved good control of powdery mildew with a single fungicide application on all but one variety. The only exception was Chardonnay, a variety highly susceptible to powdery mildew, which required two applications.

The record warm September and October allowed for most grapes to be harvested prior to killing frosts. Most of the vineyards in Delta County and in the western part of the Grand Valley had a killing frost in the first week of November. The more eastern areas within the Grand Valley did not have a killing frost until the fourth week of November. Temperatures throughout much of December were near average but well below average 27-29 December when temperatures in the western part of the valley dropped below 0 F. Below 0 F temperatures were also recorded in other grape growing areas in Western Colorado (e.g. Delta, Montrose, Montezuma counties). Temperatures dropped again below 0 F in much of Western Colorado during the first week of February. Temperatures were well above average from mid February to the third week of March, raising concerns about early bud break. However, two prolonged cold spells – one in late March and one in mid April – slowed down bud development. May temperatures were below average, whereas data from WCRC-OM indicate that June 2016 was the warmest since records started in 1964.

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 (WCRC) 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 2014/15 resulted in no bud damage to the remaining test varieties. All varieties carried a crop, but despite bird netting all fruit were destroyed by raccoons and birds.

  All varieties carry a crop in 2016.

- 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, Aromella, Marquette, and MN 1200 were harvested 29 September 2015, and Grüner Veltliner on 9 October 2015. Yields ranged from 0.4 to 0.9 ton/acre; the low yield primarily due to damage from wildlife. The fruit of all later ripening varieties was 100 % destroyed by raccoons and birds. Micro-vinification was used to produce Aromella and a Marquette/MN1200 blend.

  At Orchard Mesa, all 25 varieties produced a crop. Harvest started with Marquette on 26 August 2015, and ended with Tinta Carvalha on 30 October 2015. A summary is presented in Table 1. Seventeen varietal and four blended wines were produced using micro-vinification techniques.

Table 1: Harvest dates and yield information for 25 grape varieties growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Variety	Harvest date 2015	Yield (ton/acre)[1]
Albarino	24 September	3.54
Barbera	15 October	4.70
Cabernet Dorsa	4 September	0.75
Cabernet Sauvignon	7 October	3.02
Carmenere[2]	15 October	2.20
Chambourcin	7 October	1.94
Cinsault	7 October	5.27
Durif	15 October	2.93
Graciano[2]	15 October	4.32
Grenache	28 October	4.72
Malvasia Bianca	17 September	2.52
Marquette	26 August	1.49
Marsanne	7 October	2.30

Table 1 (cont.) Harvest dates and yield information for 26 grape varieties growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Variety	Harvest date 2015	Yield (ton/acre)[1]
Merlot	7 October	0.81
Mourvedre	28 October	4.00
Petit Verdot[2]	15 October	7.65
Refosco[2]	15 October	8.81
Roussanne	7 October	4.20
Souzao	28 October	2.73
Tinta Carvalha[2]	30 October	4.59
Tocai Friulano	16 October	11.82
Touriga Nacional	15 October	3.68
Verdejo	16 October	11.25
Verdelho	25 September	3.36
Zweigeltrebe	4 September	1.24

[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 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. Two extreme cold temperature events during dormancy (-9 F on 12 November, and -22 F on 30 December 2014) caused near 100 % bud 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, the focus of the vineyard work during the 2015 growing season was retraining of cold-damaged vines. All work was carried out by a student intern from the CSU Viticulture and Enology program.

  Although minimum temperatures dropped below 0 F several times during the 2015/16 dormant season they did not drop lower than -6 F in early February 2016. And unlike the 2015 season there was no late spring frost after bud break. Vines were pruned in early May with the help from students in CSU's Vine to Wine Club. Seasonal vineyard work is being performed by a student from the CSU Viticulture and Enology program.

- 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. Initial focus during 2015 following establishment was on vine training. Most of the young vine training was carried out by two student interns from the CSU Viticulture and Enology program. All fruit was removed on the vines in the replicated trial block to promote vegetative growth (shoots and roots). However, one of the varieties growing in another part of this commercial vineyard produced a small crop, and a small batch of wine was made at CSU's research winery.

Dormant season minimum temperature recorded at cordon height was -4.5 F on 28 December 2015. The last spring frost occurred on 19 April 2016, prior to bud break. Consequently, there was no cold injury to any of the varieties grown at that site. Vines were pruned in late April / early May. Fruitfulness on most varieties was very high (up to 4 inflorescences per shoot) so that crop was thinned in mid June. We expect to harvest sufficient fruit from all 12 varieties for small-scale wine lots.

- 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, 2015a). Furthermore, according to data from the 2014 Grape Growers Survey, Cabernet Franc is the only variety out of the top ten planted varieties that is still expanding acreage (Caspari and Lumpkin, 2015b). 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 8 October 2015, 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 the Western Colorado Research Center, 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 2). 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. Interestingly, despite having the lowest yield, musts of clone FPS 11 also had the lowest nitrogen concentration (Table 3). Musts of clones FPS 09 had the lowest pH and concentration of soluble solids, and highest titratable acidity and malic acid concentration.

[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 2: Clonal effects on yield of Cabernet Franc growing in the Grand Valley AVA in Western Colorado.

Clone / rootstock	Yield (lb/vine)	Yield (ton/acre)
FPS 01 / own	7.87	5.23
FPS 04 / own	4.89	3.23
FPS 09 / own	6.89	4.58
FPS 11 / 110R	2.90	1.93

Table 3: Clonal effects on must parameters of Cabernet Franc growing in the Grand Valley AVA in Western Colorado.

Clone / rootstock	pH	Brix	TA	Tartaric acid	Malic acid	α-amino nitrogen	Ammonia
FPS 01 / own	3.67	27.4	5.13	4.63	2.00	111	56
FPS 04 / own	3.65	27.7	4.99	4.54	1.59	97	58
FPS 09 / own	3.52	26.5	5.81	4.15	2.35	107	66
FPS 11 / 110R	3.64	26.9	4.89	5.19	1.43	86	55

Vines were pruned by the grower cooperator during April 2016. All seasonal vineyard work during the 2016 growing season will be performed by the grower cooperator. At harvest time (likely in October 2016), we plan to harvest approximately 285 lb of fruit per clone for small-scale winemaking and juice and wine analysis, as described above.

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 LaFantasie)

  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, and Rkatsiteli that differ in rate and timing of acclimation and deacclimation, as well as mid-winter hardiness. For the past two years, we have done the first-ever characterization of the seasonal pattern changes for Aromella.

  Cold hardiness test were initiated in early November 2015 and were conducted on an approximately weekly basis until late March 2016. Results were made available via our Webpage so growers can use this information when deciding if freeze/frost protection is needed. In addition to the ~weekly tests on Chardonnay and Syrah we tested 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. Cabernet Franc cold hardiness was tested under the "Advancing cold hardiness" project (see below). Full results and more details are available on the web page: Grape Cold Hardiness

- Advancing cold hardiness. (Caspari and LaFantasie)

  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 tend to confirm earlier bud cold acclimation in three-out-of-four tested varieties. However, the best timing for the ABA application differed between varieties. Initial results were very encouraging, but more research is needed on the best timing, concentrations, and differences in varietal response.

  Four different ABA treatments were tested on three varieties during the 2015/16 dormant season. Not all treatments were applied to all varieties. None of the ABA treatments appeared to have affected the bud cold hardiness of Chardonnay and Cabernet Franc in November, but cold hardiness appeared to have been improved for Syrah (Table 4). Tests in mid December suggested a slight increase in hardiness for Chardonnay and Syrah with an ABA application 20 days after veraison, but again no effect of a pre-veraison ABA application for Cabernet Franc (Table 5).

Table 4: Effect of foliar applications of abscisic acid (ABA) on the percentage survival of fruitful buds (primary and secondary) of Cabernet Franc, Chardonnay, and Syrah exposed to a controlled freezing test in early to mid November, 2015.

Treatment[1]	15 F	10 F	5 F
	Cabernet Franc (13 Nov 2015)		
Control	100	100	60
Pre-Veraison	100	95	55
	Chardonnay (6 Nov 2015)		
Control	80	58	0
Veraison	84	50	0
V20	89	30	0
	Syrah (17 Nov 2015)		
Control	95	100	65
Veraison	95	100	65
V20	100	100	100

[1] Pre-Veraison, Veraison, V20: foliar application of ABA immediately prior to the onset of veraison, at veraison, and 20 days after veraison, respectively.

[3] ProTone, manufactured by Valent BioSciences.

Table 5: Effect of foliar applications of abscisic acid (ABA) on the percentage survival of fruitful buds (primary and secondary) of Cabernet Franc, Chardonnay, and Syrah exposed to a controlled freezing test in early to mid December, 2015.

Treatment[1]	0 F	-5 F	-10 F
	Cabernet Franc (18 Dec 2015)		
Control	100	100	30
Pre-Veraison	100	100	30
	Chardonnay (16 Dec 2015)		
Control	100	95	5
Veraison	95	100	15
V20	100	100	10
V + V20	100	95	31
	Syrah (17 Dec 2015)		
Control	100	100	5
Veraison	100	100	0
V20	100	100	15

[1] Pre-Veraison, Veraison, V20: foliar application of ABA immediately prior to the onset of veraison, at veraison, and 20 days after veraison, respectively. V + V20: foliar application of ABA at veraison and a second application at 20 days after veraison.

Table 6: Effect of foliar applications of abscisic acid (ABA) on the percentage survival of fruitful buds (primary and secondary) of Cabernet Franc, Chardonnay, and Syrah exposed to a controlled freezing test in late February, 2016.

Treatment[1]	0 F	-5 F	-10 F
	Cabernet Franc (24 Feb 2016)		
Control	100	100	5
Pre-Veraison	100	95	10
	Chardonnay (25 Feb 2016)		
Control	95	65	10
Veraison	95	68	10
V20	100	95	15
V + V20	95	75	10
	Syrah (26 Feb 2016)		
Control	95	85	40
Veraison	80	75	60
V20	90	85	45

[1] Pre-Veraison, Veraison, V20: foliar application of ABA immediately prior to the onset of veraison, at veraison, and 20 days after veraison, respectively. V + V20: foliar application of ABA at veraison and a second application at 20 days after veraison.

Tests in late February again suggested a slight increase in hardiness for Chardonnay with an ABA application 20 days after veraison, but no effect from ABA treatments for Cabernet Franc and Syrah (Table 6). The data have not yet been statistically analysed.

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 block, and these areas may be picked on separate dates, based on the fruit analysis results. In 2015, the first harvest was on 30 September, followed by a second and final harvest on 20 October. Yields ranged from 2.6 ton/acre with Low Cordon to 3.8 to 4.0 ton/acre with Sylvoz, Lyre, and quadrilateral VSP (Table 7). Higher yields on those systems are mainly due to higher cluster number per vine, in itself an outcome of a higher bud number left after pruning resulting in higher shoot numbers per vine. It should be noted that we are in the process of converting two rows from a high cordon system to the GDC and not all vines have been fully established on the GDC trellis, thus reducing overall yield for this system.

Table 7: 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	27.8	2.59
Vertical Shoot Positioning	58.2	4.02
Sylvoz	42.0	3.75
Pendelbogen	31.8	2.67
Lyre	47.5	3.77
Geneva Double Curtain	34.8	2.64

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 well 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. Fifteen growers attended a vineyard demonstration on 30 July 2015 explaining the different trellis/training systems and discussing training and re-training options. On 16 March 2016, pruning options for the different trellis/training were demonstrated to ~45 participants enrolled in the CSU Extension Master Gardener class.

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

- Western Slope microclimates suitable for wine grape production. (Doesken, Wells, 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.

The Colorado Climate Center at Colorado State University recently began a small study to explore Western Slope microclimates suitable for wine grape production. The initial target this past year was Montezuma County where fruit has been grown successfully in some areas since at least the 1880's but where vine-killing early-winter cold temperature events and spring killing freezes have limited, at least so far, the expansion of wine grape production. This area bears some similarity climatically to the better known wine grape areas of Mesa and Delta County in west central Colorado with its fairly reliable nocturnal "drainage winds" that moderate temperatures. These favorable conditions, considering our high altitude environment, is the result of the combination of canyons, valleys, tall, steep mesas and nearby mountains and their impact on clouds and precipitation, but especially on winds and temperature. The industry has not yet flourished as much in SW Colorado and this is likely due at least in part, to climate limitations.

Based on industry interests and needs and Colorado Climate Center capabilities, a research plan was proposed that included 12 activities.

(1) Map historical areas of fruit production and gather indigenous knowledge of wine grape production successes and failures,

(2) Identify where water is available,

(3) Map known data sources (weather data) for temperature and wind,

(4) Overlay existing USDA plant hardiness zone map to narrow down regions of greatest potential.

(5) Use Geographic Information System software to identify elevation/slope/aspect characteristics for areas with the most favorable growing season climatic conditions and provide climate statistical characteristics,

(6) Identify known dates of damaging freeze conditions,

(7) Use regional high-resolution, mesoscale atmospheric model to map wind and temperature patterns over the terrain for typical winter nightimet conditions and then for extreme events identified in #6 above,

(8) Compare observations to limited initial model results,

(9) Develop a first-cut site suitability map,

10) Utilizing available climate records for this area, examine historic trends in local climate data. Are conditions trending towards more suitable or less?

(11) Explore the potential for microclimate mapping using a combination of low-cost temperature sensors installed within a vineyard and satellite imagery of surface temperatures on clear nights,

(12) Engage Grand Junction National Weather Service forecasters in this study with the intent of improving local frost and freeze forecasting for the region.

This did prove to be an over ambitious work plan for one year, but progress was made on most of these activities. Task 7 and 8 were not addressed as the magnitude and resources needed for that effort simply exceeded our capacity.

Work began in late summer 2015. We began by surveying available climate data resources in the Four Corners areas (Task 3) In addition to a few National Weather Service and airport weather stations, we also have some CoAgMet and RAWS observing sites in relevant areas. Several SNOTEL stations were also available from high mountain locations NE of our target area. These are the primary data sources for mapping temperature patterns and growing season conditions in the area.

On 30 September 2015 Brad Wells, research assistant, met with Guy Drew of Guy Drew Vineyards to tour his vineyards, as well as the greater Montezuma County area. Much of what was discussed was the terrain throughout the area, including potential land areas that were sloped in the ideal direction, soil types, and climatology. Based on grower input, favored slopes for wine non-hardy grape varieties were east facing and north facing although that was not necessarily the orientation of current vineyards. CoAgMet weather stations throughout the county were also visited, and their usefulness in determining variables specific to wine grape growing were evaluated. Nolan Doesken followed up with several phone visits with the Montezuma County CSU Extension Director identifying additional growers and identifying sources for documenting historical areas of fruit production in the county, their relative productivity and limitations. This involved identifying irrigated areas and their source of water (Task 2). Montezuma County was the relatively recent beneficiary of new water supplies in the 1990's when the Dolores Project was finally completed. Thus, land that might not have had adequate water for orchards and vineyards when they were first planted years ago might now be candidate growing area. We also procured paleoclimate data from the Crow Canyon Archaeological Center giving some insight on previous climates in the area and what types of fruits have grown in Montezuma County in the past.

Climate information was then assembled and analyzed. Figure 1 and 2 show average daily temperatures for National Weather Service cooperative stations in Cortez and near Yellow Jacket compared to a station in Palisade, Colorado (the heart of Colorado's wine grape industry). While these Montezuma County weather stations are not directly in grape growing areas, this does give a sense that temperatures average slightly cooler in SW Colorado compared to Palisade. Another interesting difference is precipitation. Both areas are very dry but SW Colorado receives more late summer precipitation than the Mesa County grape growing areas.

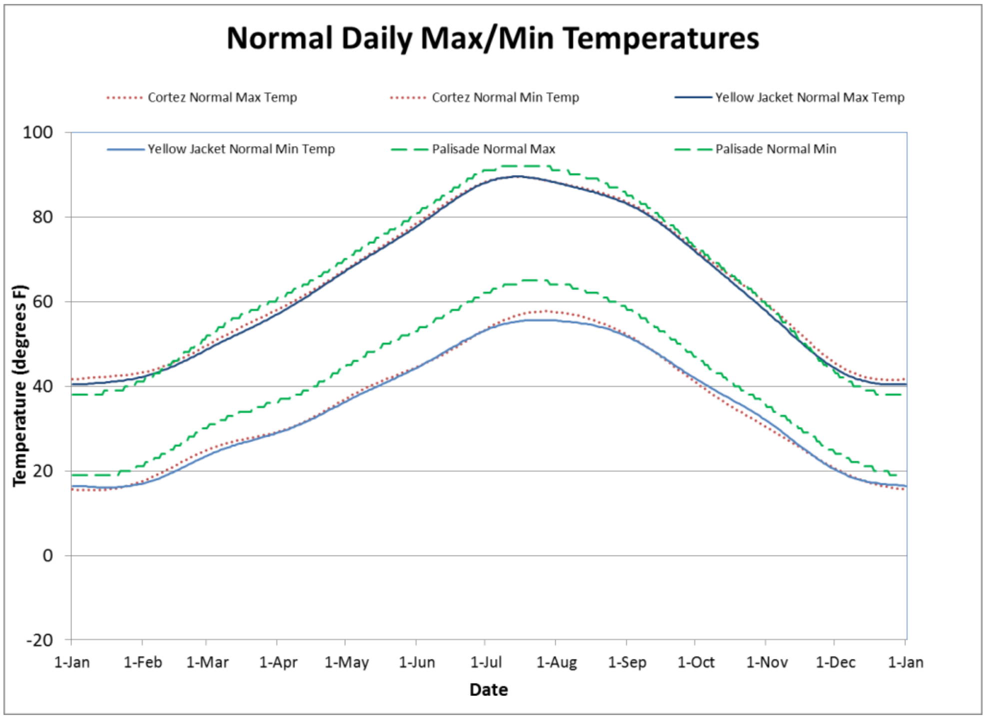


Fig. 1: Average daily high and low temperatures based on 1981-2010 data for Cortez and Yellow Jacket in Montezuma County, Colorado compared to Palisade in Mesa County.

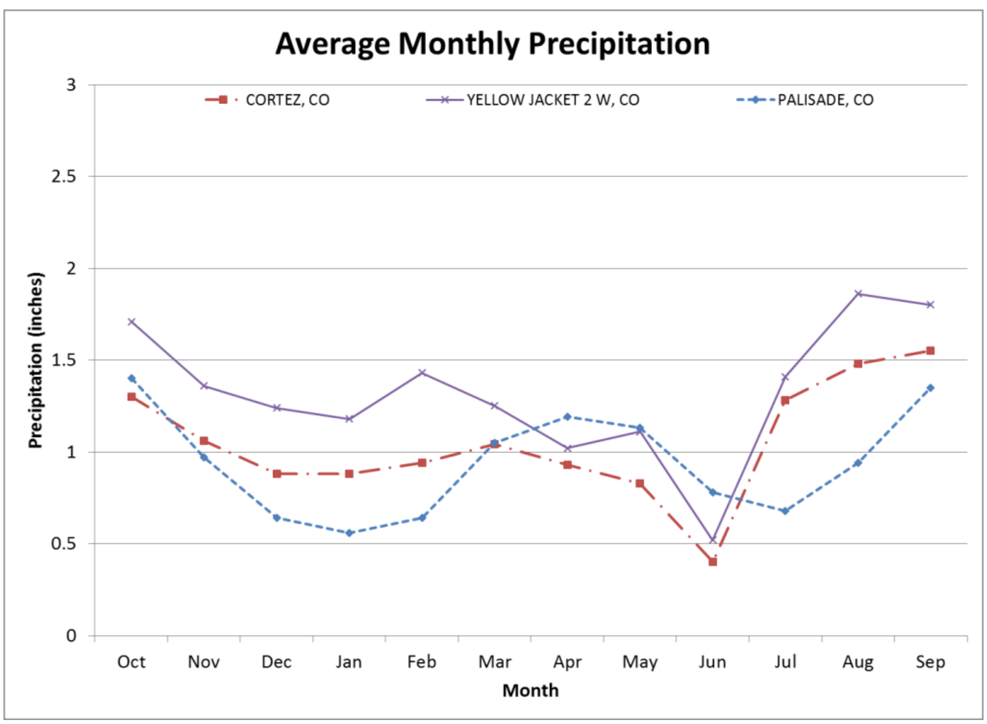


Fig. 2: Average monthly precipitation, based on 1981-2010 data, for Cortez and Yellow Jacket in Montezuma County, Colorado compared to Palisade in Mesa County.

Working with local growers, we attempted to identify some critical thresholds that have limited production in recent years. (Task 6) While damaging freezes in late spring are sometimes problematic, late autumn/early winter episodes of extremely cold temperatures prior to the vines being fully dormant for winter have appeared to have caused the greatest setbacks to local growers. We attempted to identify these events and graph them over time to examine frequency and severity of these “winter kill” episodes. It proved harder than expected since it is more complicated than just looking at date of first subzero temperature or some similar indicator. The combination that appeared to produce the most damage were when relatively mild falls with few cold episodes where then followed by rapid onset of intense cold such as what was experienced in the fall of 2014. We will come back to this topic near the end of this report.

A key goal for this project was to develop climate maps for the region of interest to hopefully help identify areas with the greatest climate assets for wine grape production. The most efficient approach was to utilize the modeled PRISM climate data available from Oregon State University. PRISM provides high resolution gridded climate estimates for each month based on carefully developed interpolation schemes that utilize elevation in combination with terrain slope and aspect.. We produced maps of minimum and maximum temperatures as well as precipitation. These monthly maps are all available on request.

The best and most relevant analysis that we performed was the high resolution “plant hardiness zone map” with overlayed existing major vineyards and weather stations on the climate map. Plant hardiness zones are defined by the average of each year’s coldest individual minimum temperature over a period of recent years (generally 30 years). While this does not necessarily determine optimal growing areas, it does clearly help identify areas where mild winter temperatures are most prevalent. We did local maps both for the Montezuma County area and also, for comparison, the Mesa-Delta County fruit growing regions (Fig. 3). This provided an excellent starting point to demonstrate how well current climate maps match with areas where grapes are being grown or where other fruits have been grown in the past. To a first approximation, zone 7a represents climate conditions that should be largely free of vine-killing winter freezes. Zone 6b may support wine grapes but will have a much higher likelihood of occasional killing winter temperatures. In the Grand Valley area, most vineyards are in the zone 7a area while in Montezuma County, most current vineyards are in the more vulnerable 6b zone. However, there are numerous 7a areas, some of which may have adequate water supplies for irrigated grape growing.

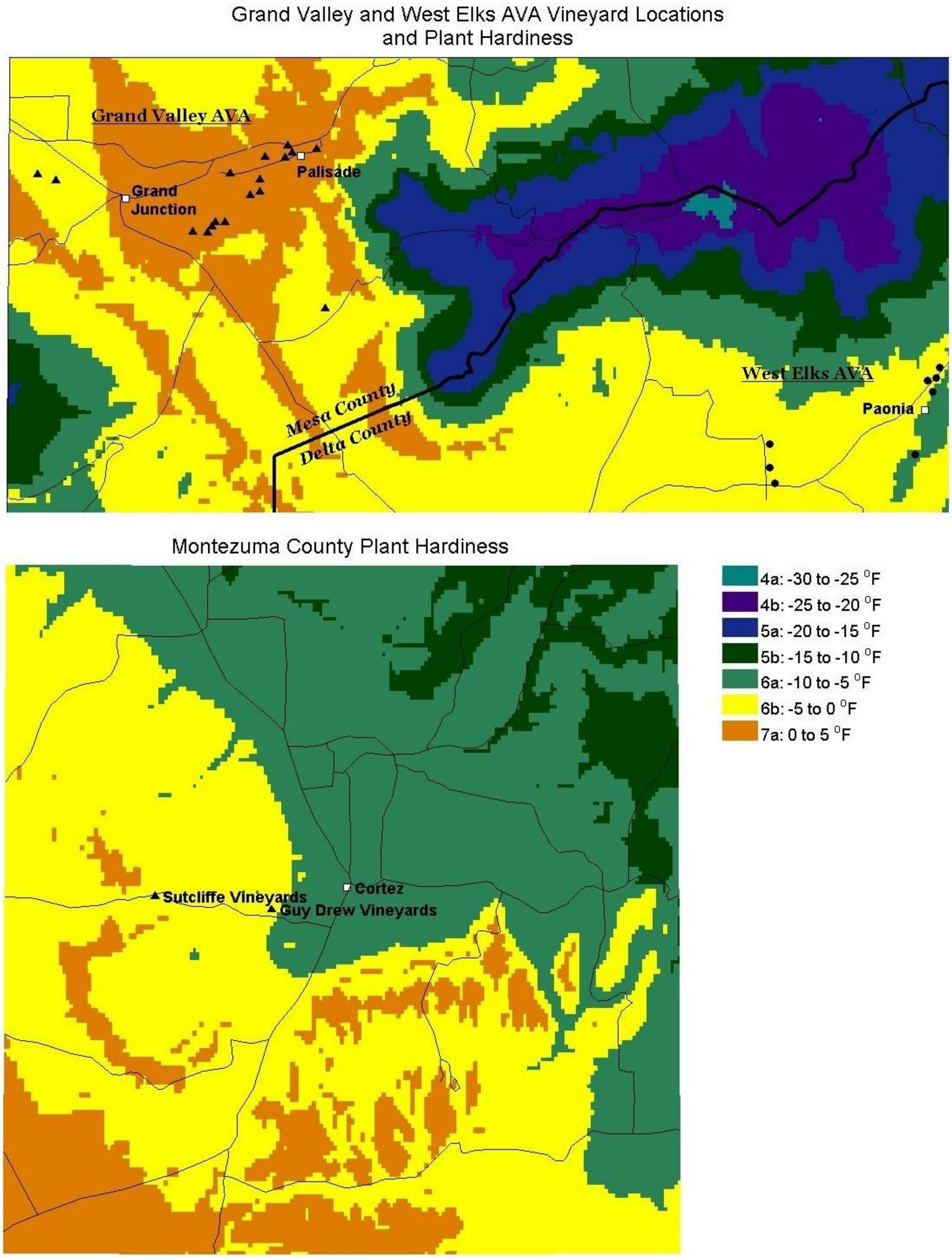


Fig. 3: Plant Hardiness Zone Map with overlays of vineyard locations for Mesa/Delta County in W. Central Colorado and Montezuma County (bottom).

At this point, this map represents our first effort to identify suitable sites (task 9). This, in combination with sloping terrain (ideally towards the east or north) with appropriate soil type and water availability would suggest that there are more sites in Montezuma County where wine grapes could be grown with a reasonable chance of success. No sites, however, are in plant hardiness zones 7b or higher, which would be preferable.

Climate trends in Montezuma County.

Cortez Long Term Temperature and Precipitation Trend Analysis: A long term climate trend analysis was conducted based on observed temperature and precipitation records from Cortez CO. Records analyzed came from the Cooperative Observing Network Station at Cortez, Colorado. This is the only weather station in the region close to irrigated vineyards in the county with a reasonable long data record. Daily precipitation accumulation, average temperature, maximum temperature, and minimum temperature data were gathered for this station from the National Centers for Environmental Information. The data record extends from 1 January 1950 to 31 December 2015. Weather station data could not be obtained for late 1974 through mid-1977. The data are reasonably historically consistent, but relocations of the weather station may have introduced minor discontinuities affecting the following analysis. Caution is recommended whenever interpreting climate trends from weather station data.

Yearly and seasonal precipitation accumulation, average temperature, maximum temperature, and minimum temperature were computed and plotted for each year in the period of record. Ten-year average yearly and seasonal precipitation accumulation, average temperature, maximum temperature, and minimum temperature were computed and plotted for each 10-year period from 1950-1959 to 2006-2015. Seasons in this study are defined as follows: spring (March-May), summer (June-August), fall (September-November), and winter (December-February).

Decadal trends in yearly and seasonal precipitation accumulation, average temperature, maximum temperature, and minimum temperature were computed. This was done in each case using the 2006-2015 decade as the end of the trend, and using the 50's, 60's, 70's, and 80's as the beginning.

Two types of events that are potentially detrimental to wine grape growth had previously been identified: extreme cold early in the winter, and anomalous cold snaps in the late spring following the onset of the growing season. These events were searched for in the Cortez data record. The problematic events were sorted into three types based on somewhat arbitrary, yet indicative thresholds: temperatures below 22 F occurring after 1 May, temperatures below 0 F that occurred prior to 1 January, and early winter extreme minimum temperatures that are both below 10 F and at least 10 F below the season's previous lowest temperature. The number of years in which each of these three event types occurred/decade was recorded for each decade.

Averages: Using the entire 66-year record collected the average yearly precipitation accumulation is 12.44". The average yearly temperature is 49.3 F. The average highest temperatures in a year is 96.6 F. The average lowest temperature in a year is -7.9 F.

Variation: Precipitation is quite variable from year-to year. One standard deviation in yearly precipitation is 3.46". The 1957 season saw an accumulation of 26.34", which is over 5" greater than any other year in the 66-year data record analyzed. One standard deviation in annual average temperature was only 1.77

degrees. Extremes, particularly in terms of low temperature, varied much more. One standard deviation in annual minimum temperature was 7.37 degrees.

Annual Trends: It is important to note when analyzing all trends for the Cortez station that while a background warming signal due to anthropogenic emissions likely does exist there have not been constant increases or decreases in any quantity since the 1950's. Temperatures trended downwards and precipitation trends slightly upwards between the 50's and 80's (Fig. 4). From the 1980's to the mid-2000's there was an aggressive warming trend with a joining decline in precipitation. Over the last ten years temperatures have been nearly constant. Precipitation changes since the 1950's are very small when scaled against expected year-to-year variation. Recalling that one standard deviation in annual precipitation is 3.46" the 0.25" decrease in annual average precipitation from the 1950's to today is small. Yearly extreme maximum temperatures have trended upwards at a rate of 0.53 F/decade since the 50's. Yearly extreme minimum temperatures have trended upwards at a rate of 0.4 F/decade since the 50's.

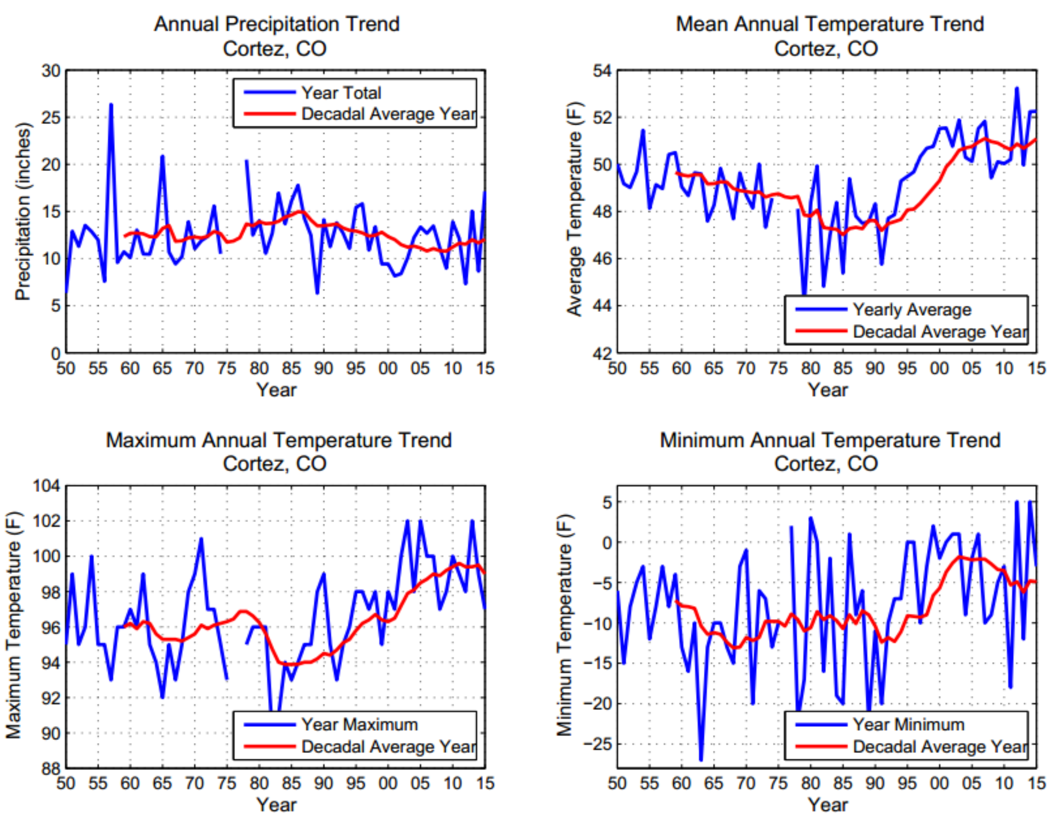


Fig. 4: Annual values for precipitation, mean, maximum, and minimum temperatures, as well as their decadal trends for Cortez, Montezuma County.

Spring Trends: Spring is the only season that has actually cooled with reference to 1950-1959 levels (Fig. 5). Spring has cooled at an average rate of 0.34 F/decade. More than 100% of this cooling was observed between the 50's and 80's, so spring conditions have actually warmed since the 1980's. Spring has dried since the 50's at a rate of 0.17"/decade. The 80's have been the wettest decade on record. The lowest spring temperature of the year has trended upwards at a fairly consistent rate of 0.75 F/decade, but it is likely largely due to chance that this rate has been so consistent.

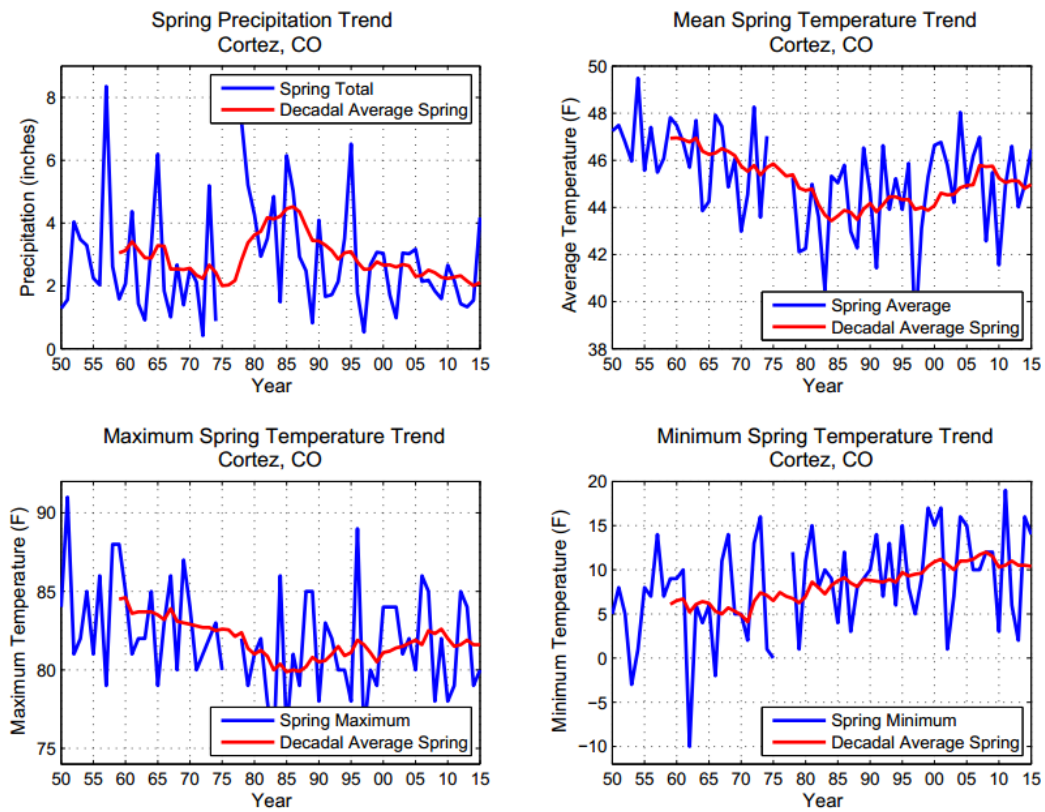


Fig. 5: Trend in spring precipitation, and mean, maximum, and minimum temperatures, as well as their decadal trends for Cortez, Montezuma County.

Summer Trends: Summer is the driest season of the year for Cortez and the nearby area, but precipitation is highly variable (Fig. 6). Both 1957 and 2015 were characterized by nearly two inches more summer precipitation than any other of the 64 remaining years. There has been zero decadal trend in summer precipitation since the 1950s. Maximum temperatures have been rising at a rate of 0.53 F/decade since the 50's, but minimum temperatures have only trended upwards at a rate of 0.05 F/decade. Mean summer temperature took a dip from around 69 to 66.5 F from the 60's and 70's to the 80's, but went back up to about 70 F by the mid 2000's.

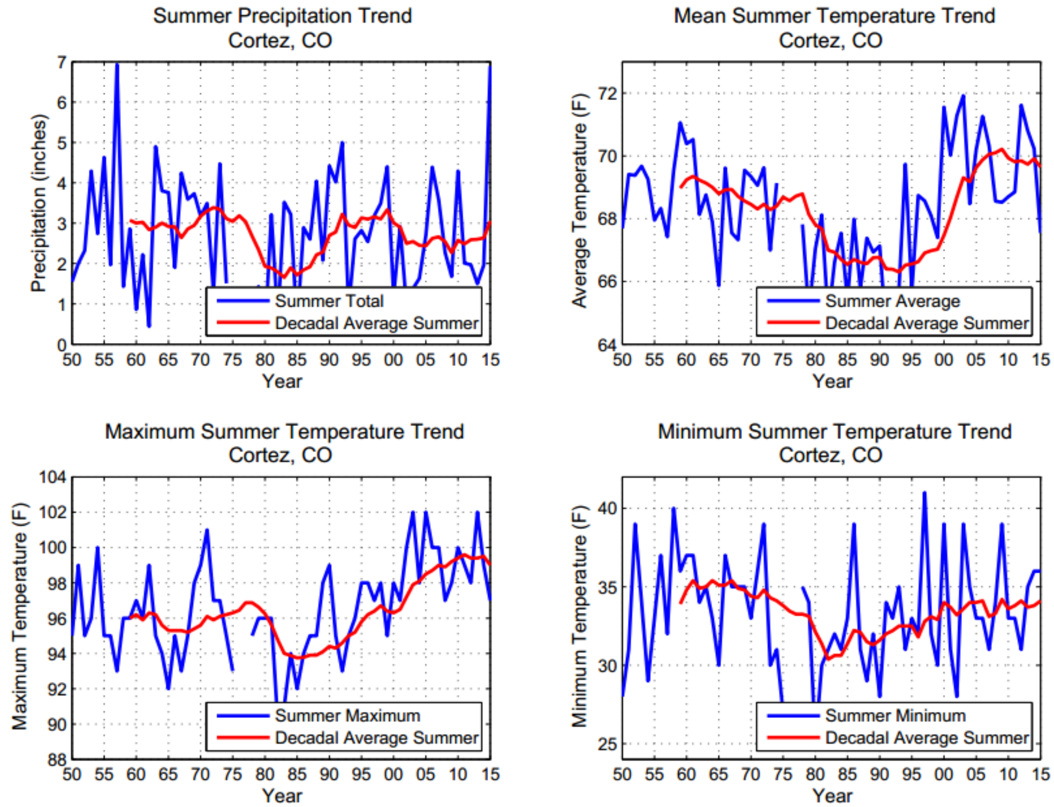


Fig. 6: Trend in summer precipitation, and mean, maximum, and minimum temperatures, as well as their decadal trends for Cortez, Montezuma County.

Fall Trends: Fall in Cortez has warmed more than any other season (Fig. 7). Average fall temperatures have increased from just under 52 F to just under 58 F. Minimum fall temperature has increased by over 10 F from the 50's to today's levels, which is a huge margin.

Winter Trends: There is almost no trend in winter precipitation for Cortez, CO since the 1950's (Fig. 8). Winter precipitation accumulations are decreasing at a rate of only 0.03"/decade, which is very low with respect to year-to-year variability. The late 1970's and early 1980's produced some of the wettest winters on record. Winter average temperatures and maximum temperatures follow a similar pattern to annual average temperatures. There is a slight downward trend from the 1950's to the 1980's. The 1990's and early 2000's were a period of rapid warming. Winters have been closer to constant since 2005. Yearly minimum temperatures have been on a downward trend over the past decade, but on average have gone up at a rate of 0.05 F/decade since the 1950's.

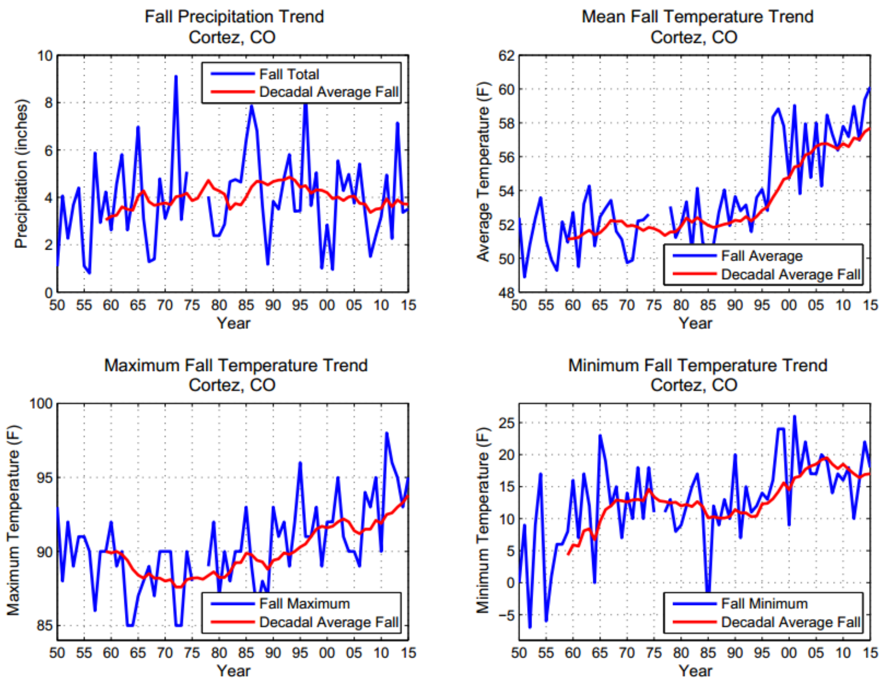


Fig. 7: Trend in fall precipitation, and mean, maximum, and minimum temperatures, as well as their decadal trends for Cortez, Montezuma County.

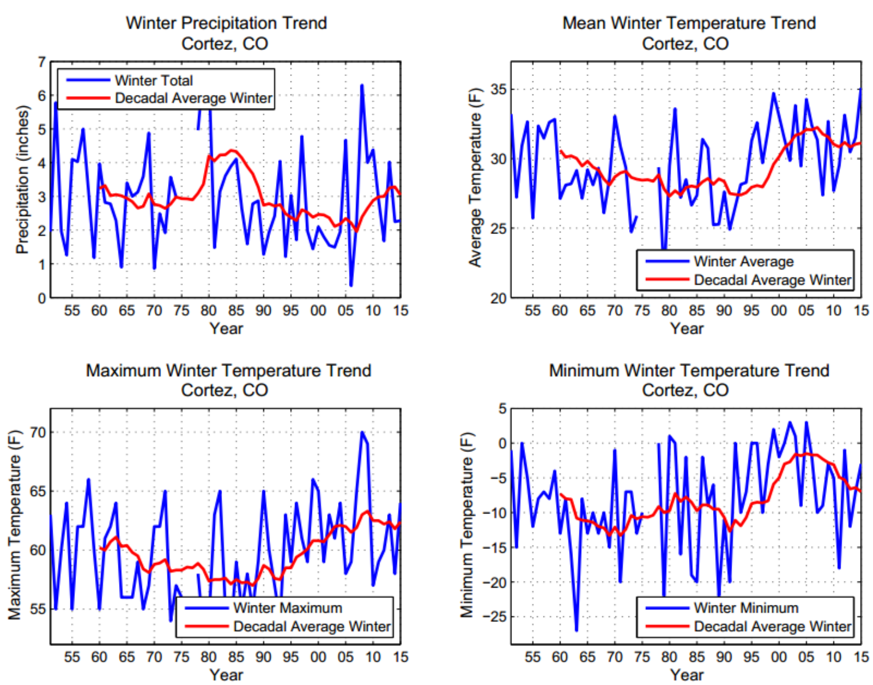


Fig. 8: Trend in winter precipitation, and mean, maximum, and minimum temperatures, as well as their decadal trends for Cortez, Montezuma County.

Precipitation in Thirds: Upon dividing the 66-year period of record into thirds (1950-1971,1972-1993,1994-2015) it becomes apparent that the middle third was the wettest third (Fig. 9). The 1970's and 1980's averaged more precipitation than the 21 year periods before and after both in the early springtime and in the late fall. Timing of expected annual precipitation increases and decreases has stayed close to constant. Looking at the data one could make a weak argument that summer monsoons are trending towards later arrival. 15-day running average precipitation accumulations take a week and a half longer to come out of the expected early summer precipitation lull in the most recent 21-year period than in previous periods.

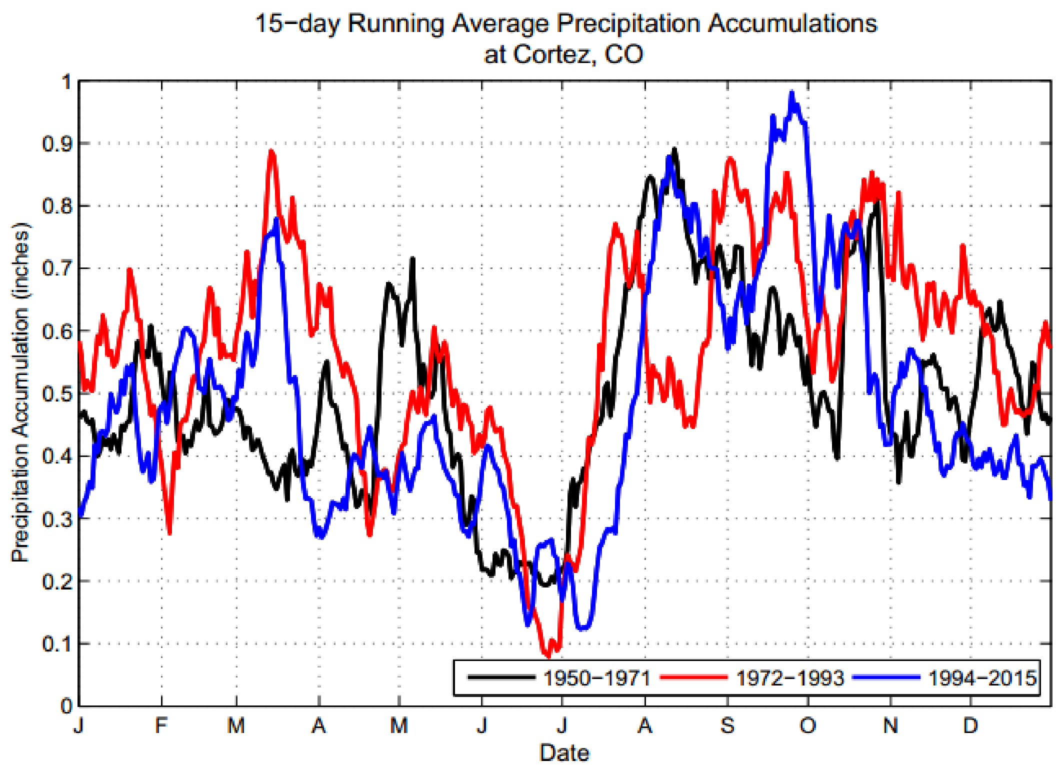


Fig. 9: Fifteen-day running averages in precipitation for the periods 1950-1971, 1972-1993, and 1994-2015 for Cortez, Montezuma County.

Detrimental Event Occurrences: Sub-zero temperatures in the late fall and early winter are on the decline since the 50's and 60's (Table 8). These events, however, have been more common since the 1990's. Days in which the new lowest temperature for the season is both below 10 F, and at least 10 F lower than the previous seasonal low were quite common in the 50's and 60's. This threshold was met 14/20 years in those two decades. Conversely, this threshold was met only 2/20 years in the 1980's and 90's. Since the turn of the millennium these occurrences have been trending upwards once more. The number of years with a temperature colder than 22 F on or after 1 May has been trending upwards for Cortez, Co. This happened only twice in the 1950's and 60's, but has happened four times since 2010.

Table 8: Number of potentially damaging cold events to wine grapes for Cortez, Montezuma County.

Number of Dangerous Occurrences:	Years with a temperature below 22 F after 1 May	Years with a temperature below 0 F before 1 January	Years with a new most extreme Min > 10 F cooler than the previous extreme Min, and < 10 F
1950s	0	6	7
1960s	2	7	7
1970s*	2	5	3
1980s	3	2	1
1990s	4	1	1
2000s	2	2	4
2010s*	4	3	2

* Indicates incomplete data record

Conclusions with respect to SW Colorado climate trends

Conditions have become hotter and drier since the 1980's, but looking back to the 1950's the decadal trends in temperature and precipitation become more subtle. Conditions cooled slightly from the 1950's to the 1980's. Cortez has dried slightly since the 1950's, but the downward trend in precipitation is small with reference to the year-to-year variation that has been measured. There is not a discernable trend in the expected seasonality of precipitation. Warming has occurred in every season except spring, which has actually cooled slightly. Fall has warmed the most. Minimum temperatures in the fall have increased by an especially wide margin. The severity of early winter cold snaps has decreased, and the number of occurrences of temperatures below 0 F before 1 January in a given winter has declined. The occurrence of temperatures below 22 F on 1 May or later in the season has increased from the 1950's to today.

As it pertains to grape growing, the observed warming trends would seem favorable for the area. With fewer pre-January cold waves below 0F, it would seem to bode well for improved vine survival. But the significant warming trend for autumn temperatures suggest that there also be delayed onset of full dormancy meaning that vulnerability to freeze damage may still be as great, if not increased. The spring findings are consistent with local experience with an increase in May hard freezes despite overall warmer temperatures the rest of the year. That may not continue, but it has been an aggravating part of the recent experience.

Opportunities for local microclimate investigations

Based on analysis of hardiness zones, the limited long-term climate data that exist for the area, and the very important role that microgeography may likely play on wine grape success in Montezuma County, we began exploring the potential for targeted microclimate assessment and microclimate mapping using low-cost sensors and data loggers (Task 11). Dr. Caspari has had good experiences and success using these sensors. One dozen new sensor-loggers were purchased and more may be borrowed from Dr. Caspari. These will be deployed this fall (2016) in selected areas with favorable climate/soil/slope/aspect conditions. We plan to also use satellite imagery of surface temperatures on clear nights to compare with surface observations.

National Weather Service interactions and collaboration on Montezuma County freeze forecasting (Task 12).

The Colorado Climate Center enjoys close working relationships with the Grand Junction National Weather Service Forecast office. At this point, progress on this wine grape climate study has been insufficient to impact freeze forecasting, but we will be briefing the forecast staff on project findings and future plans the next time we have business in Grand Junction.

Conclusion

The Colorado Climate Center has greatly enjoyed working with the Colorado Wine industry on this study. The climate of Montezuma does not appear ideal for non-hardy wine grape varieties, but there are areas of the county that may be comparable to the Mesa County grape growing areas. There appear to be areas of the county that are climatically more favorable than the areas where grapes are currently grown. This suggests that expanding the areas of wine grape production in the region may be feasible. Warming trends are being observed over SW Colorado over the past few decades suggesting, if these trends continue, that wine grape potential may improve over time. This has not yet been realized, however. Hard freezes in May and occasional vine-killing cold extremes in late fall remain a harsh hazard for the industry.

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 2015, we continued a study on water use of young vines using potted Noiret vines to determine water use by a mass balance approach. 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 on 30 June 2015; any laterals emerging after this date where removed as they emerged. Photos 1, 2, 3, and 4 show one of the vines on 1 July, 31 July, 2 September, and 28 October, 2015, respectively.

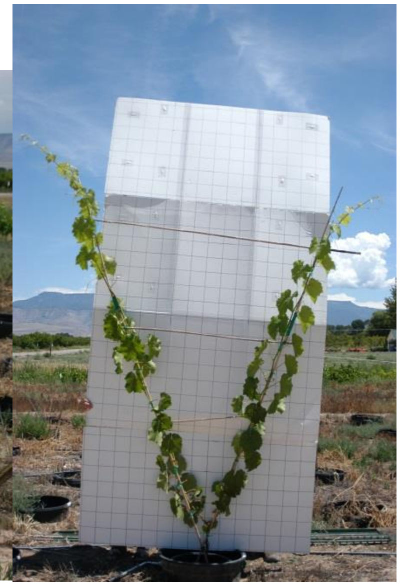


Photo 1 (left): Appearance of potted Noiret vine on 1 July, 2015. Shoot length approximately 1.3 m.

Photo 2 (right): Appearance of potted Noiret vine on 31 July, 2015. Shoot length approximately 2.4 m.

Average leaf number per vine increased from 12 leaves on 26 May to 57 leaves on 22 June, 2015 (Fig. 10). However, as approximately 35 % of the leaves were on lateral shoots the main leaf number declined to 37 leaves per vine when laterals were removed on 30 June, 2015. Leaf number increased to 61 leaves per vine by 27 July and peaked at 71 leaves on 24 August, 2015. Thereafter leaf number per vine declined as the rate of leaf abscission on the lower part of the shoots exceeded the rate of new leaf emergence. Shoot extension ceased in early to mid September, 2015.

Calculated water use increased from 0.3 liter per vine per day at the end of May to 2.4 liter per day by the end of June (Fig. 10). Daily water use declined to 1.8 liter in early July, proportional to the loss of leaf area due to the removal of laterals. Vine water use peaked at 3.8 liter per day at the end of July and during the early part of August, then gradually declined for the remainder of the growing season. It should be noted that the term “water use” includes water lost through both vine transpiration as well as evaporation from the surface of the pots. Water loss due to drainage out of the pot is considered to be zero.

Vines in this study grew exceptionally well. Most Noiret vines planted in the research vineyard in the spring of 2015 had shoot length of less than 1 m at the end of the growing season, or less than a quarter of the potted vines. Hence, the water use of the potted vines represents an upper threshold for water use in a vineyard even if first-year growth is very strong.


Photo 3 (left): Appearance of potted Noiret vine on 2 September, 2015. Shoot length approximately 3.6 m.

Photo 4 (right): Appearance of potted Noiret vine on 28 October, 2015. Shoot length approximately 4.0 m. Note the color change of the leaves and the advanced defoliation on the lower part of the shoots due to leaf senescence.

In 2016, we planned to repeat this study on water use of young vines using potted Chambourcin vines, following the procedures described above. Dormant, own-rooted Chambourcin vines were planted in a 50:50 mix of native soil and aged compost. Four out of eight vines failed to grow. The vines that grew showed signs of salt damage. A composite sample taken from all pots tested very high in salts (7.3 mmhos/cm) with a high sodium adsorption ratio (SAR; 11.5). According to White (2003), own-rooted vines are severely affected by soil salinity levels of 4-8 mmhos/cms, and cannot be grown successfully at levels >8 mmhos/cm. Vines that did grow were excessively irrigated to leach salts out of the pots. At the end of June vine growth appears to have recovered, but this study will need to be repeated with a fresh set of vines in a different potting media during the 2017 growing season.

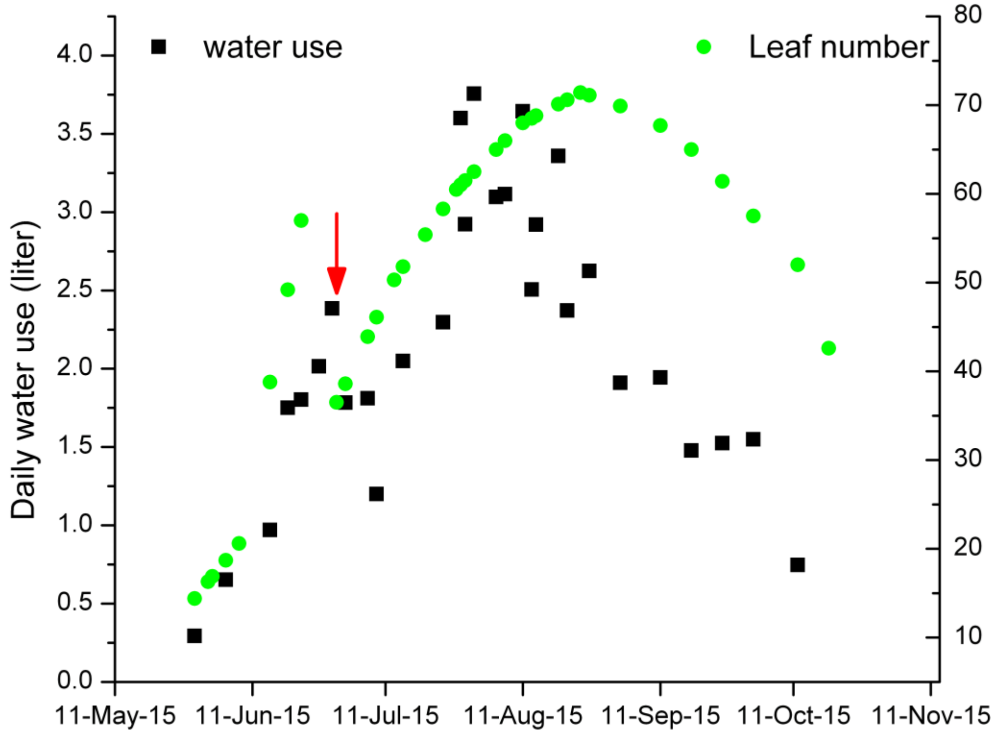


Fig. 10: Leaf number and water use of potted Noiret vines growing at the Western Colorado Research Center – Orchard Mesa during the 2015 season. Arrow denotes when laterals were removed.

- Vineyard floor management - soil health, fertility, and water requirements (Caspari, LaFantasie, 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 which potentially could have 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).

2015 Season

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 three times during the remainder of the 2015 season, and each time fresh and dry weight of the cover crop biomass was determined. Seasonal cover crop biomass production was significantly ($p = 0.004$) affected by treatment, being two to four times higher in the sprinkler-irrigated plots than in the drip-irrigated crested wheatgrass plots (Fig. 11; Photo 5, 6).

Soil samples for microbial analysis were taken in July 2015 from inter-row areas and immediately under the vines. Resin strips were placed in the inter-row areas and in the vine row three times during the 2015 season, each time keeping them in place for one month. Similar samples were taken from two varieties in our long-term cover crop / irrigation study at the Western Colorado Research Center – Rogers Mesa. Analysis of soil samples and resin strips is not yet complete.

Leaf samples were taken at veraison and send to a commercial laboratory for analysis. Results suggests that two years after sowing the cover crops the vine nutritional status is being affected. Specifically, the nitrogen concentration in leaf blades was slightly higher with a legume cover crop than with the other treatments (Fig. 12). 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 must (Fig. 13). Further, phosphorus and potassium were lower while calcium and magnesium were higher with crested wheatgrass than with the other cover crops (data not shown). However, none of those cover crop effects were statistically significant.

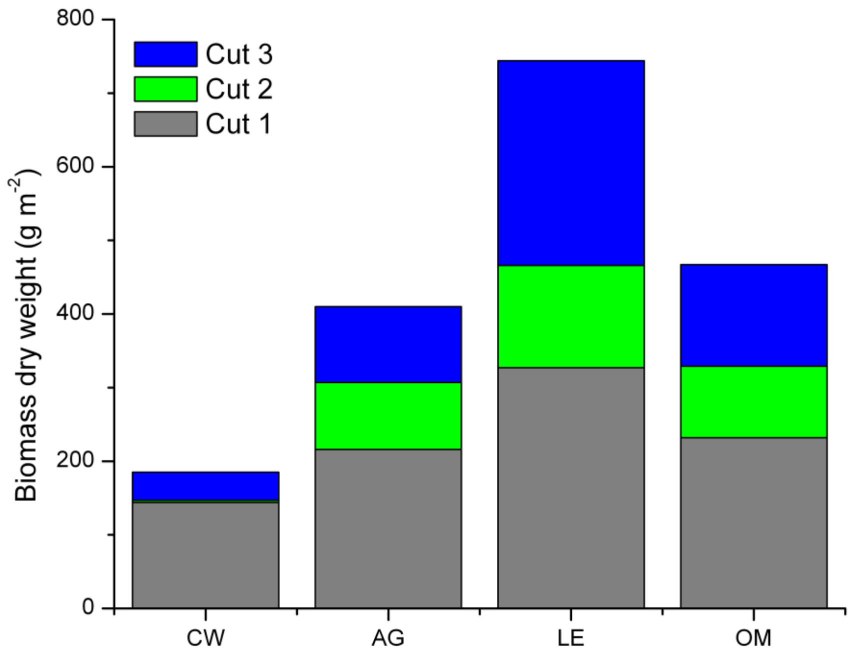
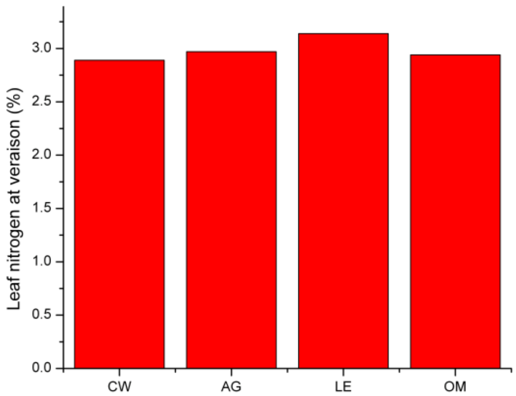


Fig. 11: Biomass production of cover crops in a Chardonnay vineyard at the Western Colorado Research Center – Orchard Mesa during the 2015 season.
CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated, vines in AG, LE, and OM are irrigated by micro-sprinklers.

Photo 5 (left): A crested wheatgrass plot after mowing a 1 m wide strip in the center of the plot on 18 September, 2015.
Photo 6 (right): A legume mix plot after mowing a 1 m wide strip in the center of the plot on 18 September, 2015.



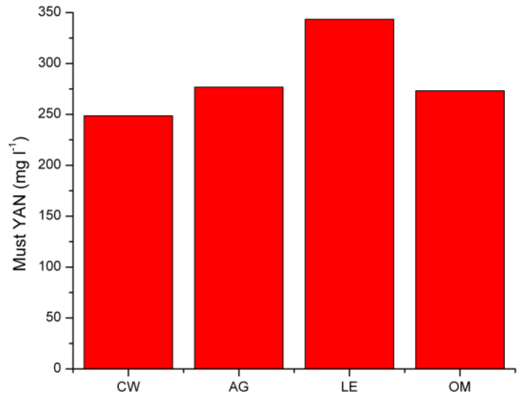


Fig. 12 (left): Effect of cover crops on nitrogen concentration of Chardonnay leaf blades at veraison.

Fig. 13 (right): Effect of cover crops on the yeast-assimilable nitrogen (YAN) concentration of Chardonnay musts.

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.

Yield, yield components, and fruit parameters were not statistically different between cover crop treatments (data not shown).

Drip-irrigated vines received 4.4” of irrigation water during the 2015 season whereas a total of 20” was applied in the micro-sprinkler irrigated plots. The irrigation volumes applied with drip are very low, however the vineyard received 11.7” of precipitation between 15 April and 28 October, 2015, which is about twice the average of precipitation for that period.

Overall, there were many trends during the 2015 season but very few statistically significant treatment effects. Trends seen during the 2015 growing season will need to be confirmed, or not, in future years.

2016 Season

As in the previous year, cover crops were kept short by mowing in early spring to reduce the risk of damage from late spring frosts. The first cut of the cover crops to determine biomass was on 23 May 2016. Results were similar to those shown in Fig. 11 for the 2015 season: biomass was ~2.5-3 times higher for the legume cover crop than the grasses, with the orchard mix being intermediate. Results from samples sent to a commercial laboratory showed large differences between treatments in the nutrient concentrations in the biomass (Table 9). As expected, nitrogen concentration was much higher in the crop residue of the legume cover crop than in the grass cover crops. Other nutrients that were higher in the legume than the other cover crops included K, Ca, Mg, S, B, and Mo. Of interest is also the very high Fe concentration in the crop residue from the crested wheatgrass. There appear to be no or only minor differences in the concentration of P, Zn, Mn, and Cu between treatments (data not shown).

Table 9: Nutrient concentration in the crop residue of four different cover crops grown in the alleyways of a Chardonnay vineyard at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Treatment	N	K	Ca	Mg	S	Fe	B	Mo
CW	2.27	2.05	0.87	0.17	0.20	1,425	9.8	1.89
AG	2.17	1.92	0.69	0.18	0.20	412	14.8	4.69
LE	3.53	3.07	1.64	0.28	0.34	543	40.9	6.11
OM	2.20	2.19	0.76	0.25	0.24	442	12.9	2.91

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. Values for N, K, Ca, Mg, and S are in percent (%); values for Fe, B, and Mo are in parts per million (ppm).

Sets of resin strips were placed in the inter-row areas and in the vine row in mid April, mid May, and mid June. Each time the sets were removed after 30 days. Nutrient extraction and analysis will take place during the winter 2016/17. Soil samples for microbial analysis were taken in mid May and mid June from inter-row areas and immediately under the vines. Samples were send to a commercial laboratory for analysis. None of the 2016 data have yet been statistically analyzed.

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.

1. Field demonstrations/workshops/tours

We provided several tours of the research vineyard and/or the research facilities to individual growers, visiting scientists, CSU extension staff, and local and national media. A "Vineyard Field Visit" for local growers was held on 30 July, 2015 at WCRC-OM. Topics covered included cover crops and irrigation, trellis/training systems with Syrah, crop thinning, powdery mildew management, and water use of young vines.

Two "Berry Sensory Evaluation and Harvest Readiness" workshops were held at the Colorado Department of Agriculture offices in Broomfield and at WCRC-OM in Grand Junction on 11 and 12 September, 2015, respectively. Michael Jones from Scott Labs and Stephen Menke were the instructors. Included in the evaluations were grapes from several cultivars in the WCRC-OM and WCRC-RM trial vineyards, as well as some grapes from cold hardy cultivars brought by attendees.

Ram's Point Winery also supplied blended wines, included in the Specialty Crop Block Grant titled "A new approach to blending Colorado wines and consumer response", made from both *Vitis vinifera* cultivars and inter-specific cultivars, for tasting and evaluation at both the American Society for Enology and Viticulture-Eastern Section conference in Dunkirk, NY (23-25 July, 2015), and for the VitiNord 2015 international conference held in Nebraska City, NE (11-14 November, 2015). Ram's Point Winery is continuing to make inter-specific blends and test sales response.

Stephen Menke organized 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 Rapid City, SD (16-17 November, 2015). This data will be pooled with data from previous evaluations and shared by outreach.

Stephen Menke conducted a tasting of inter-specific wines from several Colorado wineries and gathered consumer-oriented marketing comments, from primarily eastern US wine industry professionals, at the Eastern Wineries Exposition in Harrisburg, PA in March 2016.

A “Wine Sensory Faults Panelist Training” workshop for industry professionals was organized and conducted by Stephen Menke on 18-19 March 2016 at Metro State University. Stephen Menke also presented a mini-session on wine sensory faults to students from CSU’s Vine to Wine Club on 18 April 2016.

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 April 2016 we upgraded the software and purchased a refurbished surplus computer through the College of Agriculture IT Department to act as the server. Now three users can log in simultaneously to the weather station network (compared to two before the upgrade). 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. Further, students from CSU’s Vine to Wine Club assisted with dormant pruning in early May 2016. The replicated clonal study with Cabernet Franc (see above) is another example where the research is sited in a commercial vineyard. Part of this Cabernet Franc vineyard is used in our study on advancing cold hardiness. Other examples of industry collaboration are three different vineyard sites where we monitor temperature profiles, as well as the industry assistance provided to the staff of the Colorado Climate Center during their study in SW Colorado. 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 2015. The majority of forms were send electronically, although about 1/3 still needed to be mailed. In total we received 91 responses representing 158 vineyards for a total area of 689 acres. Initial results were presented to the industry during VinCO in January 2016. Final survey results were uploaded to the Viticulture web page in May 2016 (Caspari et al., 2016). The main results of the survey were:

- RECORD grape production in 2015
- For the first time, more than 2,000 ton grape production
- Close to 10 % of production did not get sold
- Significant over production of Riesling
- Average yield of ~3.3 ton/acre; the second-highest ever recorded
- Average price of $1,636/ton, an increase of 2.5 % over 2014
- The average grape price has increased 21.4 % since 2010
- The average grower farms 7.7 acres
- Average vineyard size is 4.5 acres
- Median vineyard size is 2.5 acres
- More than 80 acres of vineyards were planted or re-planted in the past two years
- After 3 years of decline, total and producing vineyard area is increasing again
- Cabernet Franc continues to be the #1 *Vitis vinifera* variety in new plantings in 2015
- More than half the new plantings in 2015 were with cold-hardy varieties
- Cold-hardy varieties account for approximately 15 % of vineyard area
- There is a continued expansion of vineyard area outside of Colorado's main growing areas
- Looking forward to future vintages (2016 and beyond), the supply of grapes from cold-hardy varieties is likely to exceed winery demand, at least in the short term

Results from all surveys since 2000 are available on the Viticulture web page. Data from the 2015 survey were also used to update two presentations on the economics of growing grapes in Colorado (Caspari, 2016a)) and in Mesa County (Caspari, 2016b).

LITERATURE CITED

Caspari, H. 2016a. Long-term analysis of growing grapes in Colorado. Long-term economic analysis of growing grapes in Colorado

Caspari, H. 2016b. Economics of growing grapes in Mesa County. Grand Valley grape growing zones

Caspari, H. and C. Lumpkin. 2015a. Long-term economic analysis of growing grape in Colorado (offline; replaced by Caspari, 2016a).

Caspari, H. and C. Lumpkin. 2015b. 2014 Grower Survey. 2014 Colorado Grape Grower Survey

Caspari, H., D. Iovanni, and J. LaFantasie. 2016. 2015 Colorado Grape Grower Survey. 2015 Colorado Grape Grower Survey

White, R.E. 2003. Soils for fine wines. Oxford University Press.

Zhang, Y. and I.E. Dami. 2012. Foliar application of abscisic acid increases freezing tolerance of field-grown *Vitis vinifera* Cabernet Franc grapevines. Am. J. Vitic. Enol. 63(3):377-384.