Annual Report

July 1, 2018 – June 30, 2019

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, data entry and analysis, and the annual Colorado Grape Grower Survey. Most of the vineyard work was performed by CSU staff at WCRC, one student intern (from the Viticulture & Enology program at Colorado State University), and seasonal temporary staff at WCRC.

Weather conditions in the Grand Valley were warmer than average in July, August and September, but much lower than average in October and November. September 2018 was the second-warmest since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964. A season-ending killing frost occurred on October 14 or 15 for most growing areas in Western Colorado. December temperatures were near average, but with a steady decline at the end of the month. There were no extreme low temperature events in December 2018. Initial bud cold acclimation was slow in October but was better than average with the much lower temperatures in November. The strong decline in temperatures at the end of December 2018 / beginning of January 2019 led to very good cold acclimation so that minimum temperatures at or just below 0 F on 2 and 3 January 2019 caused no damage.

The mild winter of 2017/2018 in Western Colorado resulted in no or minimal bud damage. All of the 48 varieties grown in the research vineyards produced a crop. Data from the 2018 Colorado Grape Grower Survey indicate that the 2018 harvest was by far the largest on record in Colorado. There was a much larger surplus of grapes than in any previous year. With many of the vineyards replanted between 2012 and 2015 now reaching full production potential, the oversupply of grapes during the past four vintages raises serious concerns about the future balance in grape supply and demand.

One more vineyard in the Grand Valley tested positive for phylloxera (*Daktulosphaira vitifoliae*), bringing the total to 15 positive sites in the Grand Valley. In 2018, aerial vineyard surveys were conducted in Mesa county. Surveys were funded through a Specialty Crops Block Grant from the Colorado Department of Agriculture.

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State-wide, phylloxera has now been found in 21 vineyards (15 in Mesa County, 3 in Delta County, 1 in Montrose County, and 2 in Front Range vineyards).

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Growing conditions, July – December 2018

Most of the growing season was hot and dry. In fact, for much of the season, 2018 was on track to become the hottest on record. Temperatures recorded at the Western Colorado Research Center - Orchard Mesa (WCRC-OM) and Western Colorado Research Center - Rogers Mesa (WCRC-RM) were above average during July, August, and September. In contrast, October and especially November temperatures were well below normal. December temperatures were near average. Cumulative precipitation was less than half of normal until the end of September. However, more than 3” of rain was recorded at WCRC-OM in October. November precipitation was again below normal with normal values recorded in December. Annual precipitation at WCRC-OM and WCRC-RM was 7.83” and 6.83”, respectively, near normal for WCRC-OM but well below normal at WCRC-RM.

The very warm July to September led to a very early harvest. Most varieties were harvested before a killing frost in mid October. Due to the dry growing conditions disease pressure was minimal.

Dormant season conditions

A killing frost occurred in most of the western Colorado growing areas on 15 Oct 2018. For WCRC-OM that was 10 days earlier than average but close to average for WCRC-RM. Lower than average temperatures in October and November resulted in good bud cold hardiness acclimation. In the first week of January 2019 low temperatures dropped to single digits and reached 0 F or just below on 2 January. The transition to those cold temperatures was gradual and cold hardiness tests with grapes and peaches showed optimal bud cold acclimation, and no bud damage was observed. Following this cold spell minimum temperatures at WCRC-OM stayed above 10 F.

Mean temperatures for January, February and March were below average. April’s mean temperature was 2.8 F higher than the long-term average. However, due to the cool temperatures prior to April, bud de-acclimation was slow and bud break for most of the varieties grown at WCRC-OM didn’t happen until late April to mid May.

Precipitation over the dormant season was well above average.

Early growing season conditions – May to June 2019

May 2019 was cool! The mean temperature for May at WCRC-OM of 56.7 was 5.5 F below average, equaling 1975 for the lowest since weather observations began at the research center in 1964. The cool temperatures in May resulted in rather slow vine development which, compounded by the late bud break, resulted in a late bloom. The mean temperature for June was 1.8 F below average.

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 2008-2009 as part of the USDA Multistate NE-1020 project (see below). Also in 2008 and as a part of NE-1020, 26 “new” varieties were planted at the WCRC Orchard Mesa site. An additional replicated trial focused on cold-hardy, resistant varieties was established on a grower cooperator site in Fort Collins in 2013 to identify grape varieties that can be grown successfully along the Front Range. And in 2014, a fourth trial focused on cold-hardy, resistant varieties was established with a grower-cooperator in the Grand Valley.

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

  This long-term (2004-2017), USDA multi-state research project (NE-1020) tests the performance of clones of the major global cultivars and new or previously neglected wine grape cultivars in the different wine grape-growing regions within the U.S. and is a collaboration of more than 20 states. USDA approved an extension of this project for a further 5 years (now known as NE-1720). All participating states follow the same experimental protocol. In Colorado, 10 varieties were established in 2008 and 2009 at Rogers Mesa, and 25 varieties at Orchard Mesa between 2008 and 2012. At Orchard Mesa, we have continued to remove poor performing varieties and replant with new entries. For example, in 2016 we added MN 1285, a white variety from the breeding program at the University of Minnesota. MN 1285 was released in 2017 under the variety name 'Itasca'.

  At Rogers Mesa, only two out of ten varieties were harvested on 30 Aug 2018. Yields ranged from 1.4 to 2 ton/acre (Table 1). Data on fruit composition at harvest are presented in Table 2. Despite netting, other varieties were once again lost to due wildlife damage. Micro-vinification was used to produce two varietal wines.

Table 1: Harvest dates and yield information for 2 (out of 10) grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Variety	Harvest date 2018	Yield (ton/acre)
Marquette	30 August	1.96
MN 1200	30 August	1.40

Table 2: Fruit composition at harvest for 2 (out of 10) grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Variety	Soluble solids (Brix)	pH	Titratable acidity ($g\ l^{-1}$)	Tartaric acid ($g\ l^{-1}$)	Malic acid ($g\ l^{-1}$)	Alpha amino nitrogen ($mg\ l^{-1}$)	Ammonia ($mg\ l^{-1}$)
Marquette	27.6	3.14	10.78	3.21	7.57	413	146
MN 1200	27.3	3.37	7.80	6.15	3.45	231	103

At Orchard Mesa, all 25 varieties produced a crop. Harvest started with Marquette on 15 August 2018 and ended with Barbera and Durif on 15 October 2018 (Table 3). A summary of fruit composition is presented in Table 4. Averaged across all varieties, yields were up by 42 % compared to the 2017 season. Despite the higher yield all varieties were harvested earlier than in 2017 (on average by 10 days). Twenty varietal wines plus one blend were produced using micro-vinification techniques.

Very high yields per vine were recorded for four varieties (Refosco, Tinta Carvalha, Tocai Friulano, Verdejo). Vine survival for these varieties is very low and the surviving vines are extremely vigorous, presumably due to a lack of vine-to-vine competition. Hence, cordons are extended far beyond the 5' allocated space. Excluding those four varieties, yield per vine ranged from 5.6 lb for Merlot to 12.4 lb for Verdelho. With 100 % vine survival and a 5' x 8' (vine x row) spacing a yield of 7.35 lb per vine would result in a crop of 4.0 ton/acre.

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 2018	Yield per vine (lb)	Yield (ton/acre)[1]
Albarino	7 September	11.0	4.74
Barbera	15 October	9.3	2.76
Cabernet Dorsa[2]	29 August	8.6	3.11
Cabernet Sauvignon	25 September	8.5	4.43
Carmenere[3]	28 September	10.2	4.40
Chambourcin[2]	25 September	7.5	2.88
Cinsault	28 September	11.8	3.76
Durif[2]	15 October	10.1	4.13
Graciano[3]	12 September	8.8	1.00
Grenache	28 September	11.1	1.77
Malvasia Bianca	5 September	7.5	3.05
Marquette[2]	15 August	6.6	2.39
Marsanne	12 September	9.2	2.09
Merlot	4 September	5.6	1.78
Mourvedre	28 September	10.0	3.87
Petit Verdot[3]	26 September	11.1	2.78
Refosco[3]	12 September	20.0	1.36
Roussanne	5 September	7.6	2.08
Souzao	26 September	10.8	2.93
Tinta Carvalha[3]	28 September	24.5	1.67
Tocai Friulano	27 September	27.8	1.27
Touriga Nacional	26 September	11.6	2.63
Verdejo	27 September	26.8	1.22
Verdelho	4 September	12.4	4.23
Zweigelt[2]	4 September	8.0	4.15

[1] Yield calculation based on number of vines initially planted. Vine survival (out of 24 vines planted originally) ranges from 4 % for Tocai Friulano to 100 % for Marquette.

[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.

Table 4: Fruit composition at harvest for 24 (out of 25) grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Variety	Soluble solids (Brix)	pH	Titratable acidity (g l^{-1})	Tartaric acid (g l^{-1})	Malic acid (g l^{-1})	Alpha amino nitrogen (mg l^{-1})	Ammonia (mg l^{-1})
Albarino	25.0	3.41	5.96	6.46	2.19	171	106
Barbera	28.1	3.08	7.27	7.44	0.92	219	161
Cabernet Dorsa[1]	28.1	3.59	5.25	5.76	1.41	201	123
Cabernet Sauvignon	27.4	3.37	5.85	5.93	0.67	134	128
Carmenere[2]	27.2	3.71	4.28	6.30	0.24	129	130
Chambourcin[1]	26.8	3.04	7.75	6.02	1.75	188	117
Cinsault	27.5	3.49	5.23	5.98	0.48	221	169
Durif[1]	27.8	3.26	6.22	5.38	0.67	167	75
Graciano[2]	30.9	3.04	6.89	6.77	1.29	152	107
Grenache	26.9	3.29	5.06	6.19	0.01	177	136
Malvasia Bianca	23.8	3.32	6.25	7.07	1.76	99	92
Marquette[1]	31.4	3.11	7.58	2.61	2.50	427	131
Marsanne	21.0	3.39	6.58	6.01	2.34	135	91
Merlot	26.0	3.61	5.07	7.23	0.76	95	85
Mourvedre	22.5	3.34	6.72	6.56	1.58	155	112
Petit Verdot[2]	27.1	3.63	4.92	5.56	0.80	180	113
Refosco[2]	25.5	3.23	7.03	6.91	2.13	158	119
Roussanne	23.8	3.31	7.31	7.87	2.62	140	92
Souzao	26.7	3.19	6.97	6.77	1.31	149	95
Tocai Friulano	26.9	3.62	4.43	5.81	0.46	118	96
Touriga Nacional	24.2	3.42	5.34	5.73	0.65	175	125
Verdejo	26.1	3.52	5.18	5.84	0.89	142	99
Verdelho	28.3	3.22	6.03	6.81	0.76	156	139
Zweigelt[1]	25.6	3.28	6.21	7.97	0.51	165	141

[1] Planted in 2011 and 2012.

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

From November 2018 to March 2019, bud wood from six varieties (Albarino, Cabernet Dorsa, Cabernet Sauvignon, Carmenere, Souzao, Zweigelt) was collected approximately once a month and used to determine bud cold hardiness (see below).

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

  A new vineyard was established on a grower cooperator site in Fort Collins in 2013 to identify grape varieties best suited along the Front Range. Repeated cold events have led to a slow vine establishment. Two extreme cold temperature events during dormancy (-9 F on 12 November, and -22 F on 30 December 2014) caused near 100 % bud and trunk damage to Chambourcin, Noiret, and Traminette. In contrast, Aromella, Frontenac, and Marquette had about 90 % live fruitful buds (primary and secondary). However, a severe freeze event on 11 May 2015, when most varieties were near or already past bud break, caused significant cold damage to emerging shoots and near 100 % crop loss. Consequently, many vines needed re-training during 2015. Milder minimum temperatures during the 2015/16 dormant season resulted in no bud or trunk damage, and there were no late spring freezes. However, yields again were low. In 2018, vines were again damaged by late spring frosts as well as hail, leading again to very low yields (Table 5). Additionally, vine vigor at this site is much less than desired, contributing to the low yields.

Table 5: Harvest dates and yield information for 8 grape varieties planted in 2013 at a commercial vineyard in Fort Collins, CO.

Variety	Harvest date 2018	Yield (ton/acre)[1]
Aromella	12 September	0.1
Chambourcin	3 October	0.7
Frontenac	12 September	0.1
La Crescent	12 September	0.1
Marquette	12 September	0.2
Vignoles	12 September	0.1

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

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

  A new replicated variety trial was established in 2014 on a grower cooperator site near Clifton to identify grape varieties that can be grown successfully in cold Grand Valley sites. All varieties produced a crop (Table 6). Data on fruit composition is summarized in Table 7. Of note are the very high values for α-amino nitrogen and ammonia with Marquette, also seen with Marquette grown at WCRC-RM (Table 2) and WCRC-M (Table 4).

  On average, yields were up by 335 % compared to 2017 while harvest was later by 3 days. Yield increases ranged from 170 % for St Vincent to 921 % for Brianna. The large yield increase with Brianna is the result of two factors. First, Brianna was the slowest of the 12 varieties to get fully established. And second, the very low yield in 2017 was due to massive crop loss from bird damage. In this trial, Brianna is the first variety to ripen and its fruit appears to be highly attractive to birds. Learning from the crop losses due to bird damage in 2017 (estimated at >90 %), Brianna was netted very early in 2018 resulting in minimal bird damage. Other varieties that require very early netting are Marquette and La Crescent. Twelve varietal wines were produced using micro-vinification techniques.

Table 6: Harvest dates and yield information for 12 grape varieties planted in 2014 at a commercial vineyard near Clifton, CO.

Variety	Harvest date 2018	Yield (ton/acre)[1]
Arandell	17 September	4.12
Aromella	31 August	6.23
Brianna	8 August	4.47
Cayuga White	17 September	5.99
Chambourcin	1 October	3.28
Corot noir	31 August	4.29
La Crescent	27 August	5.04
Marquette	21 August	3.91
Noiret	14 September	5.59
St Vincent	15 October	2.46
Traminette	14 September	3.50
Vignoles	27 August	2.82

[1] Yield calculation based on number of vines initially planted. Vine survival is >90 % for all varieties except St Vincent (50 %).

Table 7: Fruit composition at harvest for 12 grape varieties planted in 2014 at a commercial vineyard near Clifton, CO.

Variety	Soluble solids (Brix)	pH	Titratable acidity (g l^{-1})	Tartaric acid (g l^{-1})	Malic acid (g l^{-1})	Alpha amino nitrogen (mg l^{-1})	Ammonia (mg l^{-1})
Arandell	27.0	3.92	4.61	7.29	2.07	205	80
Aromella	23.4	3.29	7.44	7.08	2.76	180	93
Brianna	19.9	3.58	6.33	5.82	2.51	224	59
Cayuga White	22.8	3.37	6.48	7.45	0.54	204	113
Chambourcin	28.1	3.16	6.96	8.71	0.75	157	103
Corot noir	21.8	3.53	5.21	6.84	0.55	184	71
La Crescent	25.8	3.42	7.99	5.52	4.82	215	64
Marquette	30.1	3.66	6.54	2.91	3.66	510	188
Noiret	23.0	3.51	5.67	7.46	1.02	169	71
St Vincent	19.6	3.02	8.54	8.70	1.00	113	97
Traminette	26.0	3.24	6.15	8.25	0.73	103	101
Vignoles	29.7	2.83	8.66	8.01	1.82	151	80

From November 2018 to March 2019, bud wood from all 12 varieties was collected approximately once a month and used to determine bud cold hardiness (see below).

One unexpected observation at this site are continuing vine losses with St Vincent. St Vincent was the variety with the best establishment in years 1 and 2. However, we continue to see vines die that grew well in the previous season. At the end of the 2017 season there were 19 live vines of St Vincent. In spring of 2018 seven vines failed to break bud. Even worse, there was no sucker growth coming up from the lower trunks or roots. After five growing seasons only 50 % of the vines are still alive.

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 Wright)

  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, and Chambourcin 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.

  Cold hardiness tests were initiated in early October. Since late October, tests with varieties Chardonnay and Syrah have been conducted on an approximately weekly basis (Caspari and Wright, 2018). Additionally, six entries in the NE-1720 trial at Orchard Mesa were tested on a monthly basis (Albarino, Cabernet Dorsa, Cabernet Sauvignon, Carmenere, Souzao, Zweigelt), as were all 12 varieties from the Grand Valley trial evaluating cold-hardy varieties (Arandell, Aromella, Brianna, Cayuga White, Chambourcin, Corot noir, La Crescent, Marquette, Noiret, St Vincent, Traminette, Vignoles).

  The data for Albarino, Cabernet Dorsa, Cabernet Sauvignon, Souzao, and Zweigelt from the 2018/19 dormant season confirm the trends seen in previous years. Albarino, Cabernet Dorsa, and Zweigelt are generally more cold hardy than Chardonnay (Fig. 1).

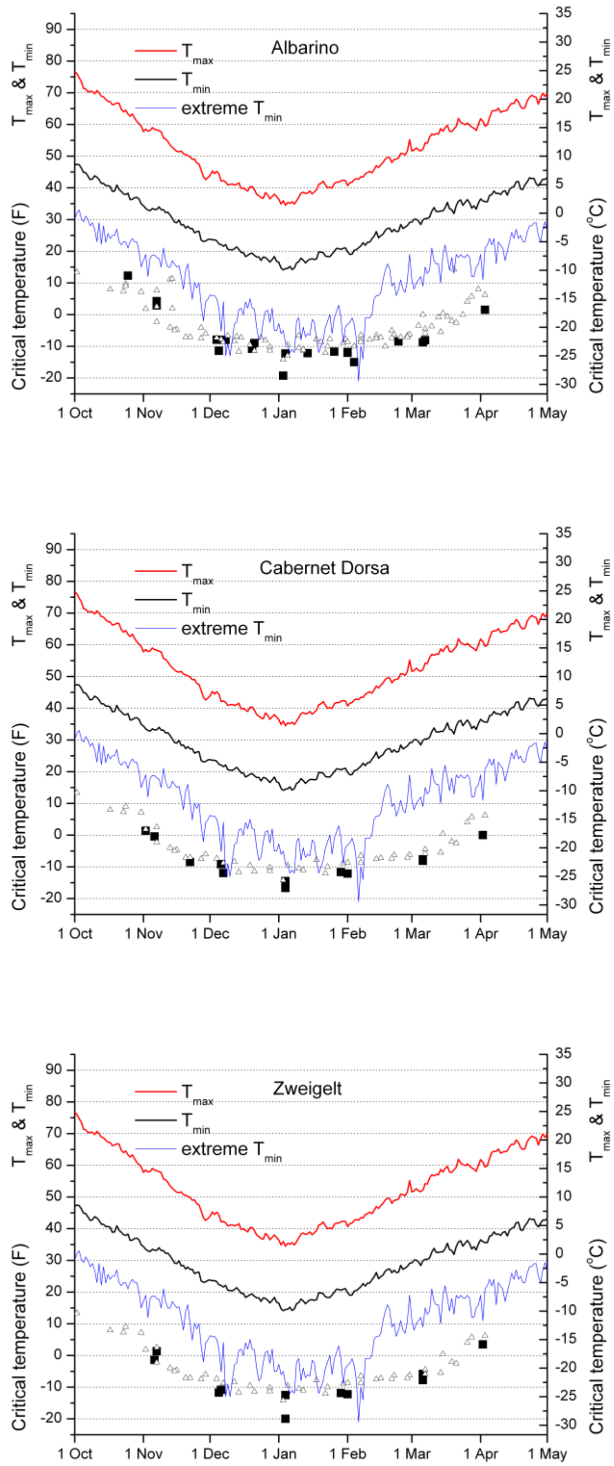

Fig. 1: Long-term average maximum, minimum, and extreme minimum temperatures at WCRC-OM and multi-year data for a 50 % primary bud kill (LT_{50}) for Albarino (top), Cabernet Dorsa (middle), and Zweigelt (bottom) compared to Chardonnay (open triangles).

Multi-year data show that Cabernet Sauvignon and Souzao have similar mid-winter hardiness to Chardonnay but differ in cold acclimation in fall and de-acclimation in spring (Fig. 2). Single-year data indicate that Carmenere has lower bud cold hardiness than Chardonnay in mid-winter but like Cabernet Sauvignon and Souzao is more cold hardy in late spring due to later de-acclimation and bud break (Fig. 2).

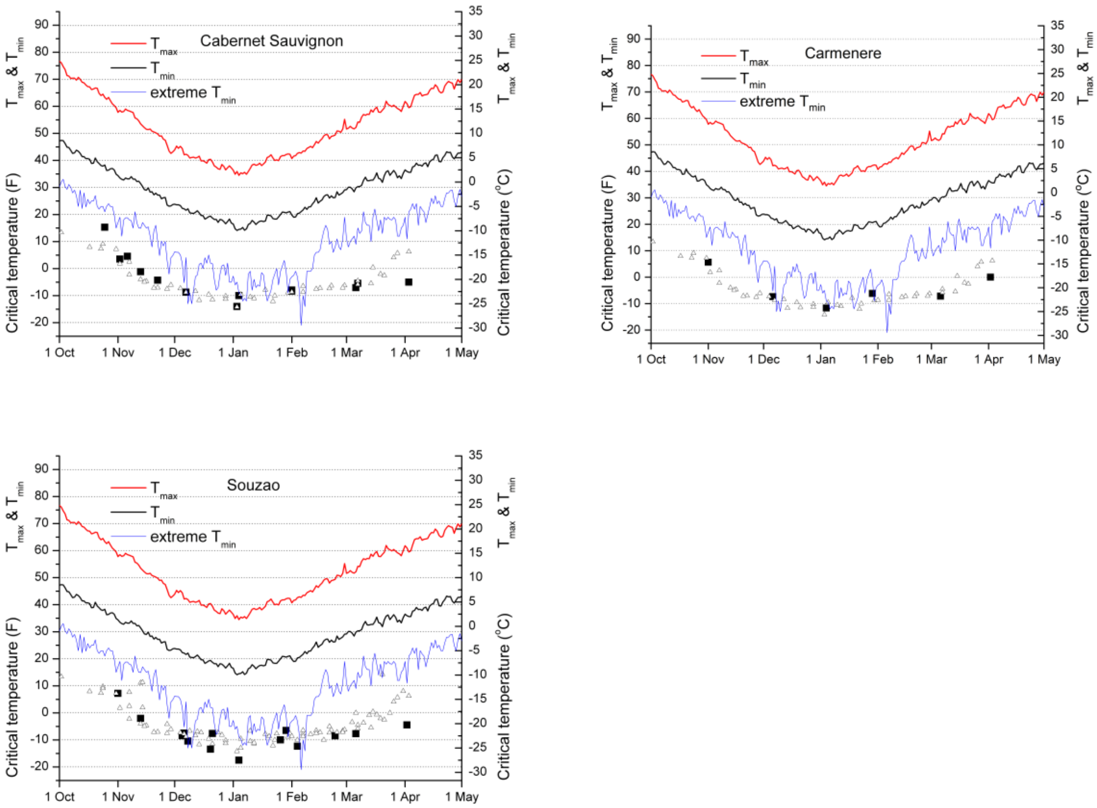

Fig. 2: Long-term average maximum, minimum, and extreme minimum temperatures at WCRC-OM and multi-year data for a 50 % primary bud kill (LT_{50}) for Cabernet Sauvignon (top left) and Souzao (bottom left) and single-year data for Carmenere compared to Chardonnay (open triangles).

Based on single-year data from the 2018/19 dormant season (Fig. 3), the 12 varieties included in the Grand Valley cold-hardy variety trial can be roughly grouped into three groups (from lowest to highest bud cold hardiness in mid-winter: I) Cayuga White, Chambourcin, and Traminette (mid-winter LT_{50} -15 to -18 F); II) Arandell, Aromella, Noiret, St Vincent, and Vignoles (mid-winter LT_{50} near -20 F); III) Brianna, Corot noir, La Crescent, and Marquette (mid-winter LT_{50} below -20 F). These initial values for mid-winter LT_{50} will need to be reassessed in future years.

Most varieties were more cold-hardy than Chardonnay in early November, and all varieties were more cold-hardy than Chardonnay in early December, early January, mid February, and late March (Fig. 3). The exception was Marquette which had similar bud cold hardiness to Chardonnay in late March.

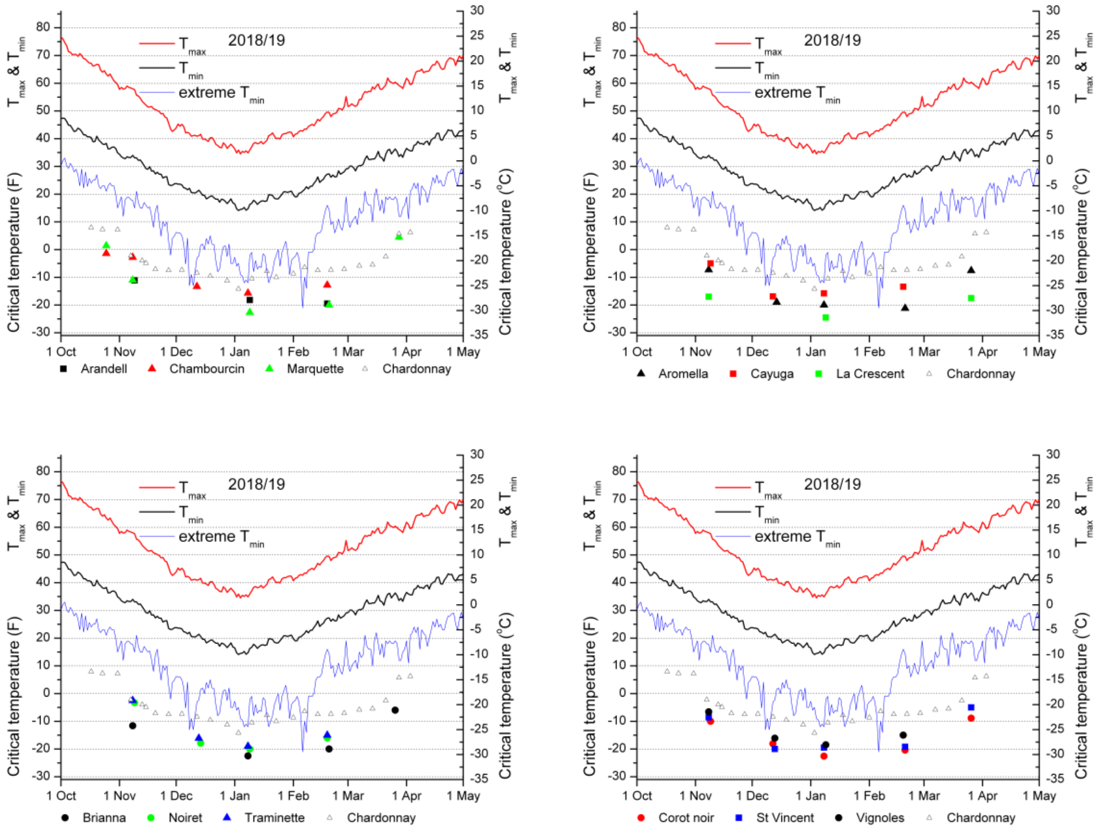

Fig. 3: Long-term average maximum, minimum, and extreme minimum temperatures at WCRC-OM and single-year data for a 50 % primary bud kill (LT_{50}) for 12 varieties included in the Grand Valley cold-hardy variety trial compared to Chardonnay grown at WCRC-OM (open triangles).

Results from our cold hardiness tests are published on the Cold Hardiness page on our web site, and growers are using this information when deciding if freeze/frost protection is needed. In the past we have presented all the results for the entire season in two tables. However, due to the large number of varieties and the high frequency of tests the results are now presented in a single table with the most recent information for each variety. The table includes the lethal temperature thresholds for a 10 %, 50 %, and 90 % bud kill (referred to as LT_{10}, LT_{50}, and LT_{90}).

3. Mitigating damage from grape phylloxera

Grape phylloxera (*Daktulospheira vitifoliae*) is an aphid-like insect that feeds on grape roots. Phylloxera is native to the northeastern United States and many American grape species are tolerant to phylloxera. However, the European grape (*Vitis vinifera*) has no tolerance and phylloxera feeding on roots will eventually kill the vines. The first recording of phylloxera in a commercial vineyard in Colorado occurred in August 2015. During a routine Grape Commodity Survey, personnel working for the Cooperative Agricultural Pest Survey (CAPS) found phylloxera on leaves of hybrid vines in Larimer county. In November 2016, CSU personnel assisting a grower in Mesa County discovered phylloxera on the roots of young *Vitis vinifera* vines. In subsequent surveys by CSU, phylloxera was discovered in six further vineyards in Mesa County, and one vineyard in Delta County. Phylloxera was found in vineyards planted with hybrid as well as *Vitis vinifera* cultivars. More vineyards infested with phylloxera were found in further surveys in 2017 and 2018. Presently there are 15 positive vineyards in Mesa County, 3 in Delta County, 1 in Montrose County, and 2 on the Front Range. It is very likely that in some vineyards phylloxera has been present for more than 10 years.

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

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

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

- 2009 Rootstock trial with Viognier (Caspari and Wright)

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

The mild temperatures during winter 2017/18 resulted in no bud damage. Average yield per vine was 12.8 lb, an increase of 48 % over 2017. However, vine survival is very low for several rootstocks, resulting in low yields per acre (Table 8). Own-rooted vines had the lowest average yield per vine but due to the highest percentage vine survival produced the highest yield per acre. Cumulative yield over the past four seasons (2015-2018) is 13.5 ton/acre for 5C, 12.5 ton/acre for own-rooted vines, 10.3 ton/acre for 5BB and 110R, 8.8 ton/acre for 1103P and 4.2 ton/acre for 140Ru. The very low yield with 140Ru is due to low percentage vine survival. These cumulative yield data confirm the good performance of rootstock 5C previously observed in the 1992/93 Chardonnay rootstock trial. Overall, there were only minor differences in fruit composition at harvest (Table 9).

Table 8: Effect of rootstock on vine survival and yield of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield per vine (lb)	Yield (ton/acre)
110R	57	12.8	3.99
140Ru	18	19.4	1.89
1103P	50	13.8	3.75
5BB	64	11.0	3.85
5C	86	10.6	4.75
Own-rooted	96	9.3	4.86

Table 9: Effect of rootstock on fruit composition at harvest of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Soluble solids (Brix)	pH	Titratable acidity ($g\ l^{-1}$)	Tartaric acid ($g\ l^{-1}$)	Malic acid ($g\ l^{-1}$)	Alpha amino nitrogen ($mg\ l^{-1}$)	Ammonia ($mg\ l^{-1}$)
110R	29.9	3.34	5.62	6.86	1.09	147	113
140Ru	29.5	3.57	5.37	6.81	1.65	189	119
1103P	30.3	3.49	5.45	6.77	1.46	164	103
5BB	30.4	3.35	5.74	6.87	1.30	145	124
5C	31.4	3.45	5.39	6.05	1.20	163	120
Own-rooted	30.4	3.37	6.30	6.76	1.76	162	101

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

Once vineyards planted with own-rooted *Vitis vinifera* cultivars become infested with phylloxera, vine vigor and productivity will start declining. It may take several years from the initial infection for symptoms to appear. Currently it is not known how fast phylloxera spreads throughout a vineyard following initial infestation under Colorado conditions. Based on experiences in other areas of the world it is reasonable to assume that it will take at least 5-10 years from infestation before vine productivity has declined to such a low level that it requires replanting. Generally at this point, vines are pulled in fall shortly after harvest, then the vineyard is prepared for replanting with grafted or phylloxera-tolerant cultivars the next spring. With this approach, similar to a newly-planted vineyard, the first crop is expected in year 3. Another option, however, is to interplant with vines of the new cultivar 2 to 3 years before the anticipated removal. While at that time the vineyard productivity is already declining, vines are still productive enough to not yet warrant removal. With good management, the inter-planted vines can be grown so that at the end of the second or third season, when own-rooted vines need to be removed, canes can be tied to the cordon wire, and a crop can be produced the following season. The advantage of the interplant approach is that there is no 2-year break in crop production. However, it requires good management of the inter-planted vines.

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

Vine establishment in year 1 was very good. All vines established, and many vines had >0.5 m shoot growth. Graft unions were covered with soil in late fall and uncovered again in May 2018. Vines were pruned in late spring 2018, leaving no more than two spurs per vine, and two nodes per spur. No more than two shoots per vine were trained up during the 2018 growing season. After the leaves had dropped in late fall of 2018 an assessment was made of the potential to retain canes for cropping in 2019 (Table 10). Graft unions were protected again with soil in late fall 2018 and uncovered again in May 2019. Vines were pruned in April 2019 and canes tied onto the cordon wire. Actual number of canes tied down was much lower than what was estimated in the fall assessment.

Table 10: Fall 2018 assessment of shoot growth and potential for crop in 2019 compared to actual values from spring 2019 for inter-planted Chardonnay/SO4 vines growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

	Sufficient shoot growth to tie to cordon wire (%)		Insufficient growth (%)	Dead (%)
	2 canes	1 cane		
Fall 2018	6.7	32.5	50.8	10
Spring 2019	4.2	22.5	65.0	8.3

Only about 4 % of the vines had sufficiently strong shoot growth in the second growing season that two canes could be tied to the cordon wire and fill the allocated space (5 feet). Another 22 % had enough growth to tie down one cane. Sixtyfive percent had insufficient growth to tie down a cane, and thus produce a crop in 2019. Vine mortality was rather high at 8 %. It is expected that the 65 % of vines that didn’t have sufficient growth in year 2 will grow strong enough in year 3 to tie down one or two canes in the spring of 2020. With better care of inter-planted vines it should be possible to achieve strong growth so that old, phylloxera-infested vines can be removed after two years.

One interesting observation from this trial is the effect of irrigation (and soil) management on the establishment and growth of inter-planted vines. As mentioned above, we are using the same block as for the cover crop / irrigation study (see below). There was much better establishment and growth when inter-planted vines were irrigated with drip compared to sprinkler – 50 % of drip irrigated vines had sufficient growth to tie down one or two canes compared to only 11 % with sprinkler irrigation. Clearly the higher frequency of irrigation with drip compared to sprinkler resulted in the better establishment of the inter-planted vines.

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

In Colorado, where low temperatures can cause trunk injuries, the graft union needs to be protected during the coldest part of the year to avoid lethal damage to the cultivar. Common methods of graft union protection are hilling up soil around the graft union or covering the graft union with mulch materials. After the risk of cold temperature damage has passed, the graft union needs to be uncovered to avoid self-rooting from the scion. Due to the semi-arid climate of western Colorado, the top part of the soil is very dry and hot during the growing season. Dry and hot soil conditions are generally not conducive for root growth. A field study to test the effect of planting depths, in combination with irrigation method, on the propensity of self-rooting was established at WCRC-OM in early May 2017. Chardonnay (clone 99) grafted to SO4 rootstock was planted with the graft union 2” above ground (Control = standard practice), or with the graft union 2”, 4”, or 6” below the soil surface. Half the vines are irrigated by drip, the other half by micro-sprinkler. There are 10 single-vine replications per treatment. Drip emitters are positioned so that the trunks are not wetted during irrigation events, while micro-sprinklers wet 100 % of the vineyard floor area.

Initially, for treatments with the graft union below the soil surface, the planting hole was only partially filled so that the graft union did not get covered by soil. In late fall, more soil was added to those holes right up to the level of the soil surface. Graft unions will remain covered for the remainder of the experiment. Every year in late fall, graft unions of Control vines with graft unions placed 2” above the soil are covered with soil and then uncovered in late spring the following year. Four vines were lost in the first growing season and/or after the first winter: one control vine; one vine with graft union at 2” below ground; and two vines with the graft union at 4” below ground. Two of the lost vines were drip irrigated and two were irrigated by micro-sprinkler. Prior to hilling up soil around the graft unions in fall 2018, root development from the scion and the rootstock was evaluated on 5 vines per treatment. Soil was carefully removed down to the graft union and slightly beyond. All vines had some roots emerging out of the scion (see Photos). Root development varied from just one small root to numerous, strong roots in the scion part. No root development occurred on Control vines where the graft union is 2” above ground.

Although this is a stand-alone trial and there is no interaction with any other ongoing study we again noticed an effect of the irrigation method on vine growth, similar to the inter-plant study. All surviving drip-irrigated vines had sufficient growth in year 2 that at least one cane could be tied onto the cordon wire whereas 16 % of sprinkler-irrigated vines had insufficient growth.

Photos show root development from the scion part (above the graft union) of Chardonnay/SO4 vines when the graft union is permanently buried at 2”, 4”, or 6” below the soil surface. Upper row shows vines irrigated by drip; lower row shows vines irrigated by micro-sprinklers.

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

  A new rootstock trial with Cabernet Sauvignon (clone 33) grafted to 11 different rootstocks was established in early June 2017 on a grower cooperator’s vineyard in the western part of Orchard Mesa using green potted vines. The site is located about 1.5 miles East of WCRC-OM. The following rootstocks are included: 110 Richter, 140 Ruggeri, 1103 Paulsen, 1616 Couderc, 101-14 Millardet et de Grasset, 3309 Couderc, Riparia Gloire, Salt Creek, Schwarzmann, Selektion Oppenheim #4, and Teleki 5C. The trial is set up as a randomized complete block design with 5 replications, and 5 vines per replication. The vineyard is irrigated by micro-sprinklers. Vine establishment in year 1 was very good (255 out of 258 vines planted). In late spring of 2018, vines were pruned back to no more than two spurs per vine, and two buds per spur. On 20 April 2018, two missing entries were replanted using leftover vines from the original planting that had been grown in pots at WCRC-OM.

Shoot growth during 2018 was very vigorous. Five vines were lost during 2018. Graft unions were protected by hilling up soil in late fall 2018. Soil around the graft union was removed in May 2019. Vines were pruned in late April 2019.

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

  A new rootstock trial with Cabernet Sauvignon (clone 33) grafted to 11 different rootstocks was established in May/June 2018 on a grower cooperator's vineyard in the central part of Orchard Mesa. The following rootstocks were planted on 24 May 2018 using dormant potted vines: 110 Richter, 140 Ruggeri, 1103 Paulsen, 1616 Couderc, 101-14 Millardet et de Grasset, 3309 Couderc, Riparia Gloire, Salt Creek, Schwarzmann, and Selektion Oppenheim #4. Green potted vines on rootstock Teleki 5C were planted on 14 June 2018. There was a shortage of vines grafted to 1616C and 1103 Paulsen. Missing vines were planted on 27 June 2019. The site is located about 3.5 miles East of WCRC-OM. The trial is set up as a randomized complete block design with 6 replications, and 4 vines per replication. The vineyard is irrigated by micro-sprinklers.

  Vine establishment in year 1 was very good (240 out of 243 vines planted). Shoot growth during the first year was very vigorous. However, during a field visit in late fall, shortly before a killing frost, we observed minimal hardening of the shoots. Graft unions were protected by hilling up soil in late fall 2018. In spring 2019, most vines resumed growth from buds near the graft union, i.e. under the soil mound. There was minimal survival of buds / canes above the soil mound.

- 2019 Rootstock trial with Souzao in a challenging soil. (Caspari, Wright and grower cooperator)

  A new rootstock trial with Souzao (clone 1) grafted to 7 different rootstocks was established on 28 June 2019 on a grower cooperator's vineyard in the western part of Orchard Mesa using green potted vines. The site is located about 2 miles Northeast of WCRC-OM. The location for this trial is a former hay field that has not been irrigated for >10 years. Although the soil is classified as Gyprockmesa clay loam, the soil in this specific location is more sandy with a high percentage of large gravel and highly alkaline. Soil samples taken in May 2019 indeed show increased salinity in the top 36 inches of the soil profile (1.7 to 2.7 mmho/cm). These salinity values are up to eleven times higher than in soil samples taken at the same time in two adjacent mature vineyard blocks (one drip irrigated, one sprinkler irrigated) as well as soil samples from vineyard blocks at WCRC-OM. Gravelly areas within vineyards with predominantly Gyprockmesa clay loam are common on Orchard Mesa. Also, in the past many vineyards have been established on sites that had not been irrigated for many years, and this trend is likely to continue. Without the leaching effect from irrigation salinity tends to increase in the upper layers of the soil, as is indeed the case at this site. Therefore, this site presents an opportunity to investigate the performance of a smaller set of rootstocks when grown in challenging soil. One or two rootstocks from the main genetic groups used in rootstock breeding [V. berlandieri x V. rupestris (110 Richter, 1103 Paulsen); V. berlandieri x V. riparia (Teleki 5C, Selektion Oppenheim #4); V. riparia x V. rupestris, (101-14 Millardet et de Grasset, 3309 Couderc); V. solonis x V. riparia (1616 Couderc)] will be evaluated.

The trial is set up as a randomized complete block design with 6 replications, and 4 vines per replication. Initially, the grower cooperator will be responsible for all practices related to vine establishment under the guidance of the State Viticulturist. Data collection will be limited during the first 2-3 years. Depending on vine growth, full data collection will begin in year 3 or 4, as described above.

4. Identifying areas suitable for expanded wine grape production

- Colorado microclimates suitable for wine grape production (Schumacher, Goble, and Caspari)

One of the largest limitations on the wine grape industry in Colorado is temperature. Even parts of the state with the mildest winter and shoulder seasons are susceptible to freezes that damage grapes. However, pockets of the state exist in which wine grapes have been grown successfully dating back to the 1800s (Palisade and Cañon City), and other pockets where untapped potential exists.

For the past three years, the Colorado Climate Center has been exploring temperature patterns using observations in Montezuma County. This effort was expanded to Fremont County beginning in December of 2017. In this report, the Climate Center expands on these efforts using several modeled data sources in order to help guide viticultural exploration opportunities in the state. Temperature data are taken from the Parametrized Regression on Independent Slopes Model (PRISM) developed at Oregon State University. Guidance is also based on a gridded version of the Soil Survey Geography (SSURGO) soil texture dataset courtesy of US Geological Survey. This report will be divided into the following five sections:

1. An update on observed temperature data collected in Fremont and Montezuma Counties
2. Estimates of the number of killing freezes/decade across Fremont County, Montezuma County, and Colorado
3. Soil texture information for Fremont County, Montezuma County, and Colorado
4. A comparison of PRISM model temperature data to observations in Montezuma County from 2017
5. An exploration opportunities map for grape growth in Fremont County, Montezuma County, and Colorado

Highlights: Most of Fremont and Montezuma Counties escaped freeze damage in 2018, but drought did limit water supplies for irrigation. Typical water allotments were curtailed in Montezuma County. Winter of 2019 brought the coldest winter temperature on record for the Cortez COOP station since 2013. The Cañon City COOP station only got down to -8 F, a fairly normal wintertime low mark. The subzero temperatures of winter 2018-2019 came in January and February, an optimal time of year for deep freezes as vine tissues generally have reached maximum cold hardiness. Wintertime low temperatures in Fremont and Montezuma

Counties were mostly recorded during a cold air outbreak in the first week of January. Temperatures dropped to zero or lower for all but two stations in Fremont County, and three stations in Montezuma County. It was marked by a stronger temperature inversion (increasing temperatures with elevation) in Montezuma County than other winter cold events since 2017. Stations on the west end of the county were as much as 15 degrees colder than any other time during the past three years. Spring freeze data has yet to be collected from all stations for May 2019, but COOP and CoAgMET reports indicate that freezing conditions occurred in the fourth week of May in both Fremont and Montezuma Counties.

PRISM data from 1981-2017 are used to estimate the frequency of killing freezes years across Colorado. Current criteria for a killing freeze were established in previous fiscal year reports, but the details are also available in section II. These criteria will be revised in the coming year. Areas with the lowest number of killing freeze years/decade are in river valleys on the Western Slope.

Use of PRISM data is justified based on its comparison to observations. This model was compared to observations in Montezuma County for two killing freezes in 2017. Differences between the observations and the overlaying model grid space were mostly under 3 F. More often than not, PRISM temperatures were lower than observations, especially when observations were at higher elevation than immediately surrounding areas. More model and observation comparison is recommended.

Maps of potential locations for grape growth in Fremont County, Montezuma County, and Colorado at large are provided below. On the Western Slope, areas highlighted are mostly in the Colorado and Gunnison River Valleys near the state line. Areas near the Four Corners, and in the Dolores River Basin near the state line are also included. Growing conditions on the east side of Montezuma County are limited by temperature, and on the west side by soils. The valley in the middle of the county, where Cortez is located, is also too cold. There are a few sweet spots: 1. Southwest of Yellow Jacket. 2. Central McElmo Canyon. 3. The Mancos River Valley south of the Ute Mountain Farm and Ranch. In Fremont County, the Cañon City, Penrose, and Wetmore area is all highlighted, but there is a hard cutoff to the north and west based on terrain. Areas to the east of Penrose, but still along the Arkansas River Basin could be worth exploring further, and should be targeted for more temperature observations.

The potential exploration opportunities map is one resource for viticulturists seeking to try Colorado, but not a stand-alone. There are a number of other important considerations. For example, north-facing slopes may break bud later avoiding freezes, soil acidity and soil salinity are important determinants of success, and access to irrigation water is essential for most viable locations in Colorado.

Part I - Cold Winter and Spring Nights of 2018/2019

Thus far, one of the major components to this investigation is observational minimum daily temperature data in Fremont and Montezuma Counties. These data come from three different networks: 1. The National Weather Service's Cooperative Observer Network (COOP) 2. The Colorado Agricultural Meteorological Network (CoAgMET) 3. USB temperature loggers from Measurement Computing that have been sited in fields at vine height specifically for this project. Many of the sensors in the third category are located on current vineyards, but some are also in orchards, nurseries, or other farming and ranching land. In this section, county temperature patterns are explored in Montezuma and Fremont County for cold air outbreaks during the past 12 months.

Temperature Observation Sites in Montezuma County

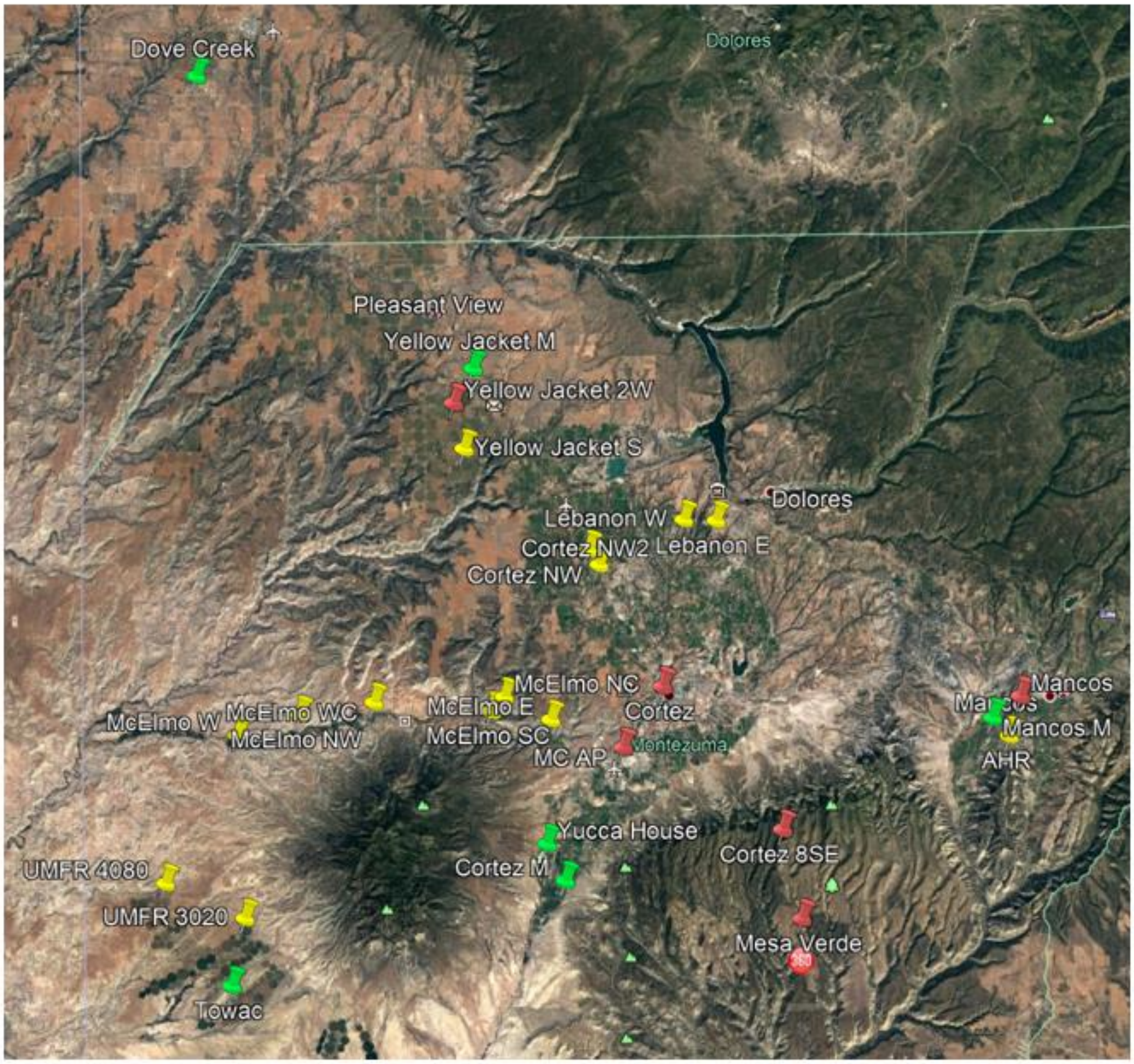

Fig. 4: Montezuma County temperature observation sites used in this study colored by parent network. Red = COOP. Green = CoAgMET. Yellow = Colorado Wine Industry Development Board.

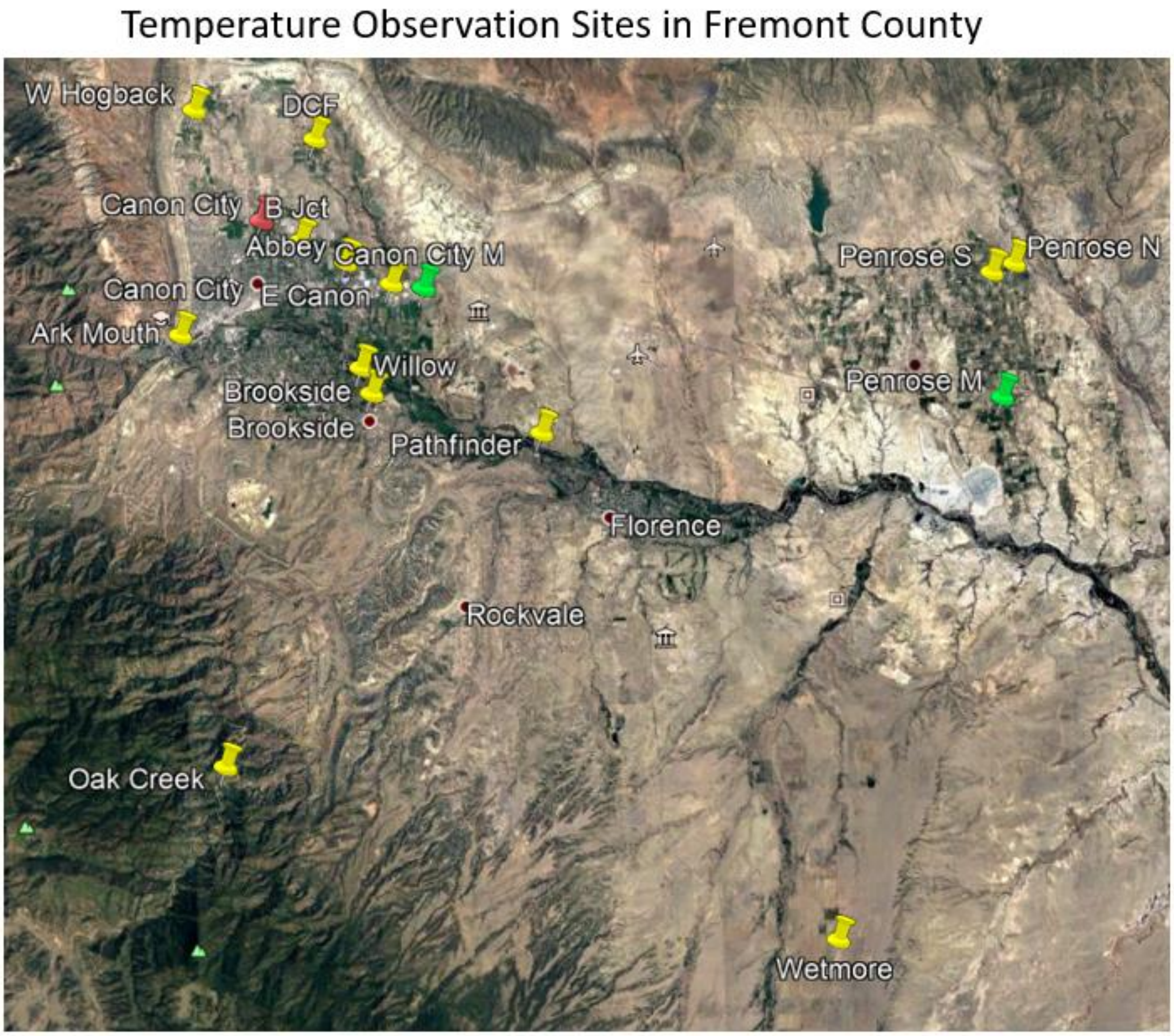

Fig. 5: Fremont County temperature observation sites used in this study colored by parent network. Red = COOP. Green = CoAgMET. Yellow = Colorado Wine Industry Development Board.

Spring 2018: Spring and summer of 2018 was marked by high temperatures and drought conditions for most of Colorado. This includes Fremont and Montezuma County. One positive impact from this weather is that no notable spring freeze events occurred. Data have not yet been collected from the field for spring 2019, but producers may have experienced freeze damage in spring 2019. Several late cold air outbreaks occurred in May. The Cañon City COOP station recorded a minimum temperature of 33 F on May 19th, 2019, and a low temperature of 29 F on May 24th, 2019 (Fig. 6). Parts of Montezuma County are also likely to have been impacted by freeze damage. The Montezuma County Airport COOP station recorded lows of 29, 31, and 32 F on May 24th, 29th, and 30th respectively in 2019 (Fig. 6).

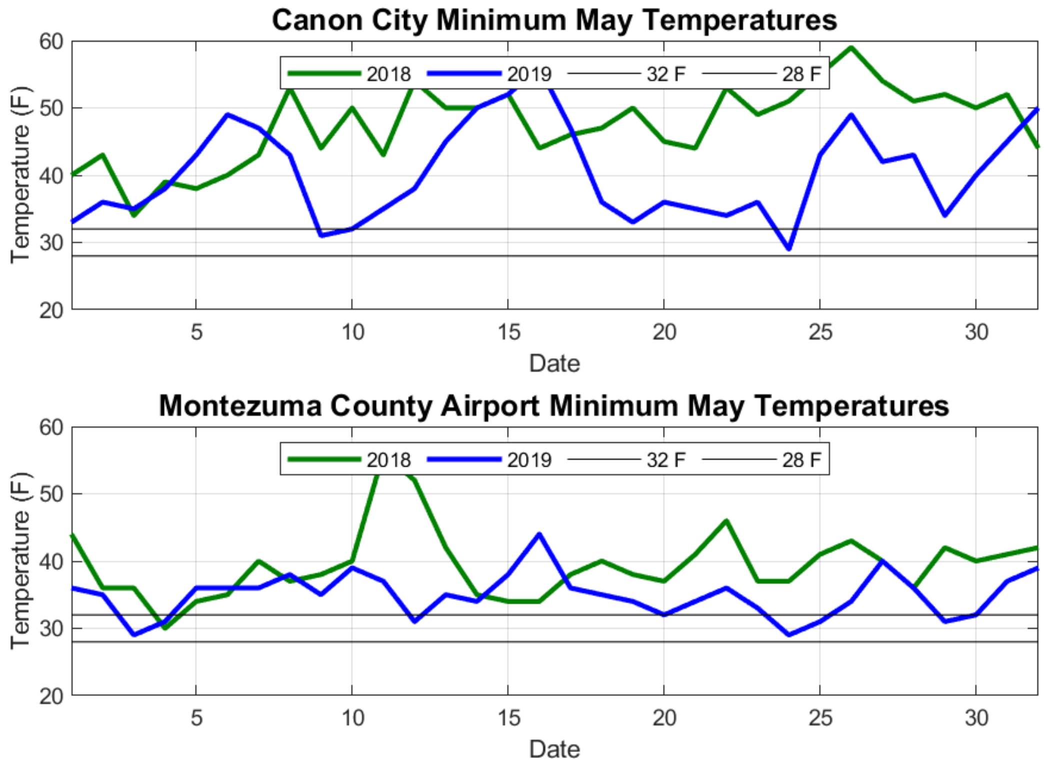

Fig. 6: May minimum daily temperatures from Cañon City (top), and the Montezuma County Airport (bottom) for 2018 (green), and 2019 (blue). Freeze (32 F), and hard freeze (28 F) lines are also plotted.

Montezuma County Winter 2019: Early January of 2019 brought a bitter cold airmass to Montezuma County, colder than anything observed in 2017, 2018, or the rest of 2019. The Cortez COOP station reached -9 F, the coldest temperature recorded since 2013. Observed temperatures were as low as -19 F in Mancos. Most stations in the county experienced the coldest air of the year during this event. Observed low temperatures from this event were quite different than the last two years. In both winters 2017 and 2018, the parts of the county that stayed warmest were located in the far south and west reaches of Montezuma County. Modeled temperature data from section II would likewise suggest that the farthest south and west reaches of the county have the best odds of staying relatively warm during cold nights.

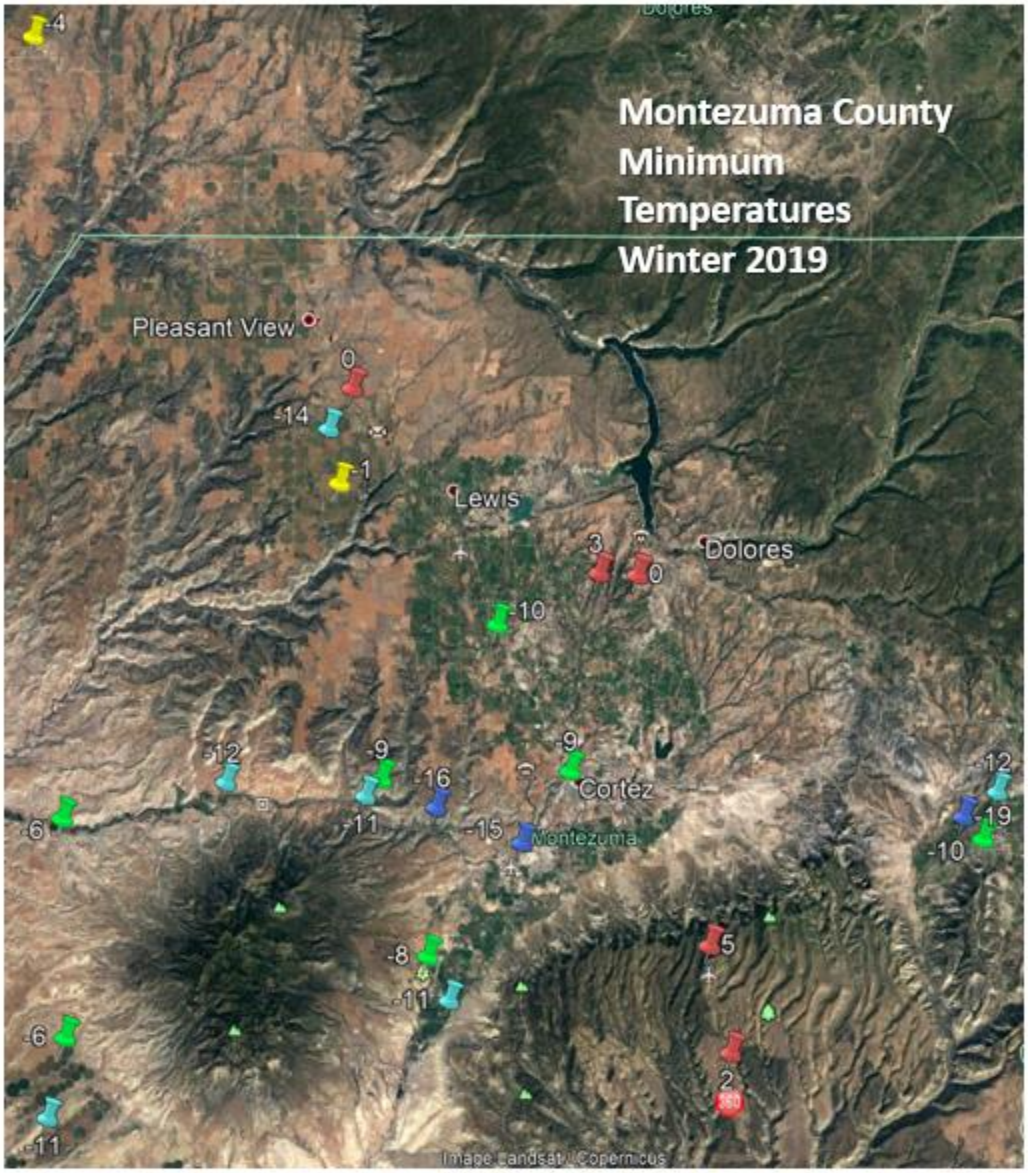

Fig. 7: Minimum observed temperatures at Montezuma County stations from winter 2019. Blue < -15 F. -15 F <= Cyan < -10 F. -10 F <= Green < -5 F. -5F <= Yellow < 0F. Red >= 0 F.

On the night of January 2nd, 2019 temperatures in western McElmo Canyon, and on the Ute Mountain Farm and Ranch were at least six degrees below zero (Fig. 8). For western McElmo Canyon, this was over fifteen degrees colder than any weather event of 2017 or 2018. This event was marked by a particularly strong temperature inversion. The Cortez 8SE COOP station situated atop Mesa Verde experienced a relatively balmy 9 F. Stations staying above 0 F were all above 6200 ft.

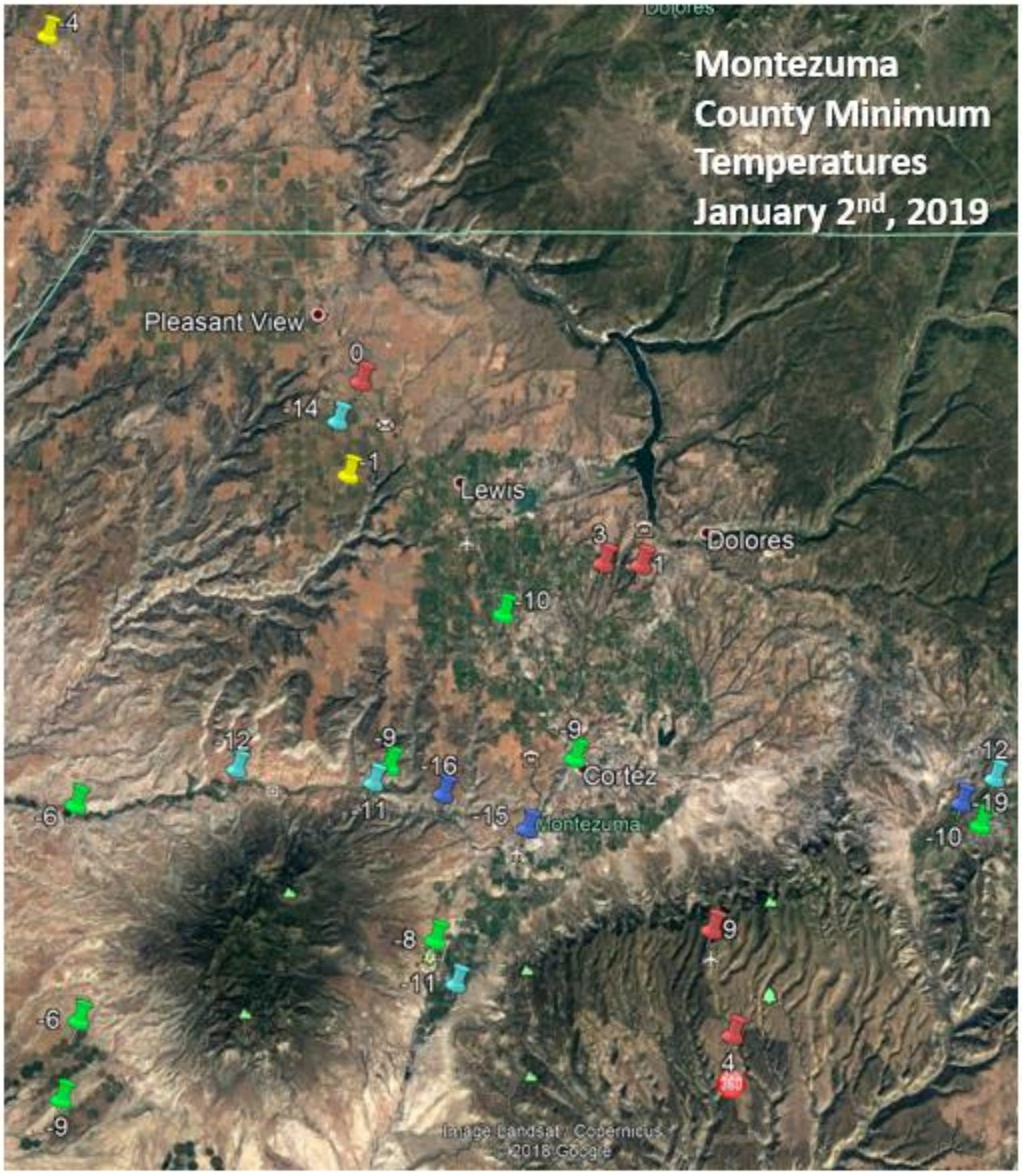

Fig. 8: Minimum daily temperatures for Montezuma County from January 2nd, 2019. Blue < -15 F. -15 F <= Cyan < -10 F. -10 F <= Green < -5 F. -5F <= Yellow < 0F. Red >= 0 F.

Other cold nights for winter 2019 were mostly mild compared to January 2nd and January 3rd. These events were also more similar to previously observed minimum daily temperature spatial patterns in the following ways: 1. Mancos was, in general, colder than areas further west 2. Elevated areas around Cortez were warmer than the valley in which the town sits. 3. The warmest stations were west of the Sleeping Ute Mountain. One example of this pattern is shown in Figure 9. The Yellow Jacket 2W COOP station was an anomaly all winter long. It was consistently much colder than the nearby CoAgMET station (located at the Southwest Agricultural Experiment Station), and other locations north of Cortez.

This merits further investigation. Yellow Jacket, and areas immediately to the west, were identified as prime locations for additional viticultural activities in section V.

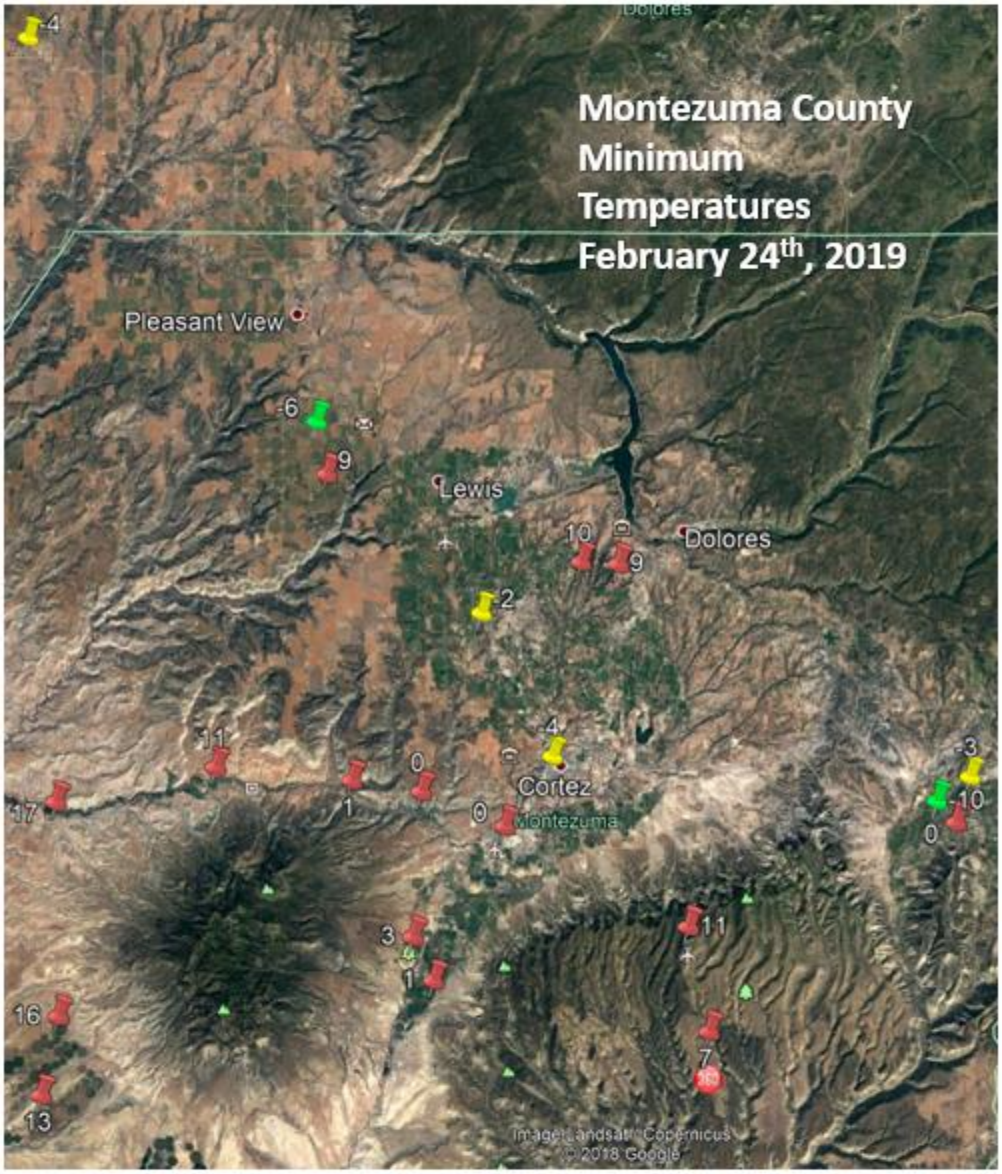

Fig. 9: Minimum daily temperatures from Montezuma County for February 24th, 2019. -10 F <= Green < -5 F. -5F <= Yellow < 0F. Red >= 0 F.

Fremont County Winter 2019: Minimum seasonal temperatures for stations in Fremont County mostly occurred on either the morning of January 2nd or 3rd. Minimum winter temperatures ranged from -14 F at the Penrose CoAgMET site to 0 in the central portion of Cañon City. The Oak Creek Grade station, which is significantly higher in elevation than any other station in the county, was one of the warmest in this event at -5 F. With the exception of one station in the center of Cañon City, which may have been driven by a bad data point, the warmest locations were north and west of the city. One hypothesis for this is that drainage winds out of the mouths of Royal Gorge and Fourmile Creek Canyon may be aiding in keeping cold, dense, near-surface air mixed in these areas.

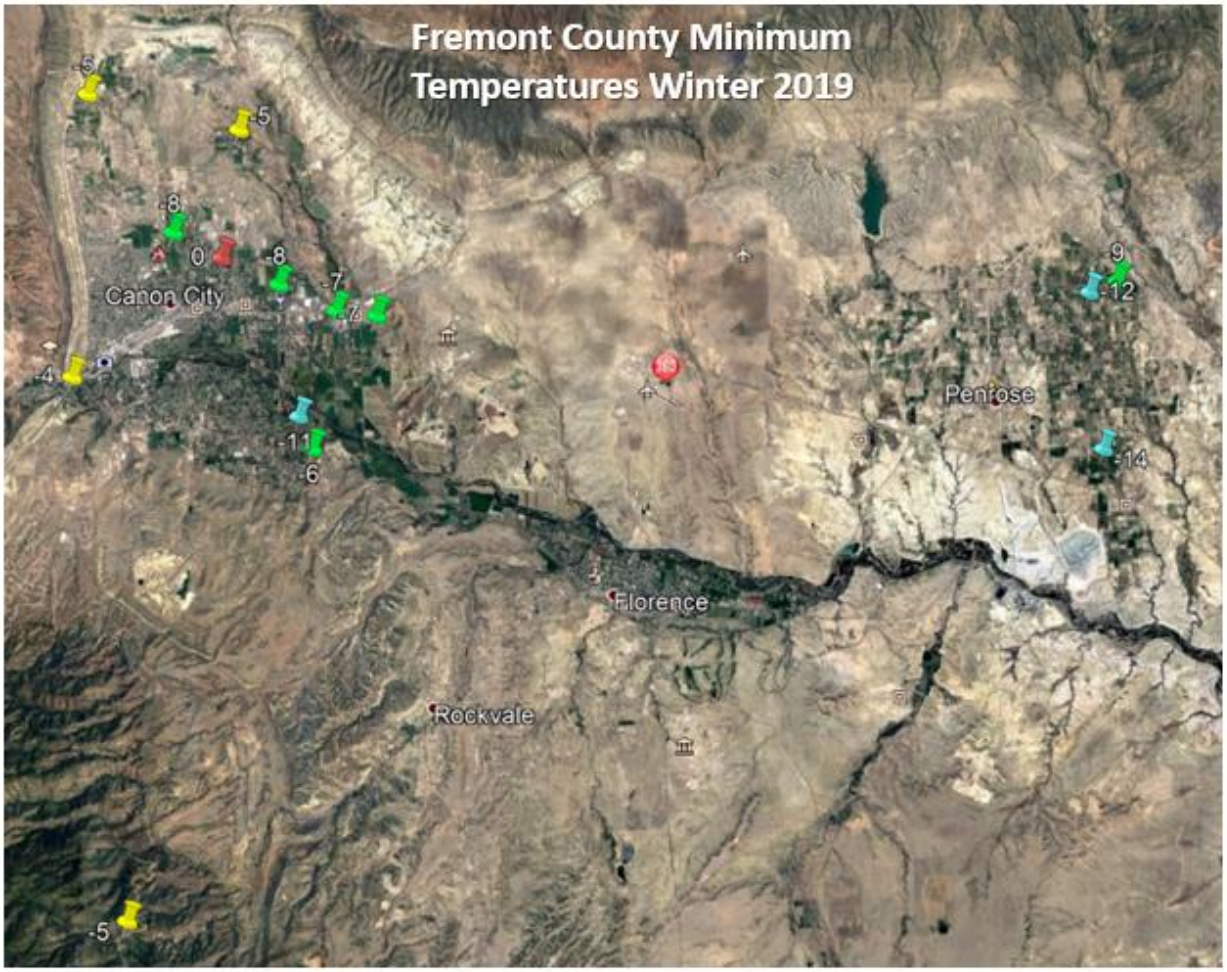

Fig. 10: Minimum temperatures in Fremont County from winter 2019. -15 F <= Cyan < -10 F. -10 F <= Green < -5 F. -5F <= Yellow < 0F. Red >= 0 F.

The January 2nd and 3rd cold event in Fremont County produced a range of low temperatures from -14 F to +12 F (Fig. 11). The 12 F observation in central Cañon City may have been a bad observation; it sticks out like a sore thumb when plotted. One potential cause for this is snowcover. If the thermometer was sufficiently covered, it may have been insulated from the cool, nighttime air. The second warmest site in this event was the official Cañon City COOP site at +1 F, still a good deal warmer than nearby stations. The Oak Creek Grade station bottomed out at just 0 F.

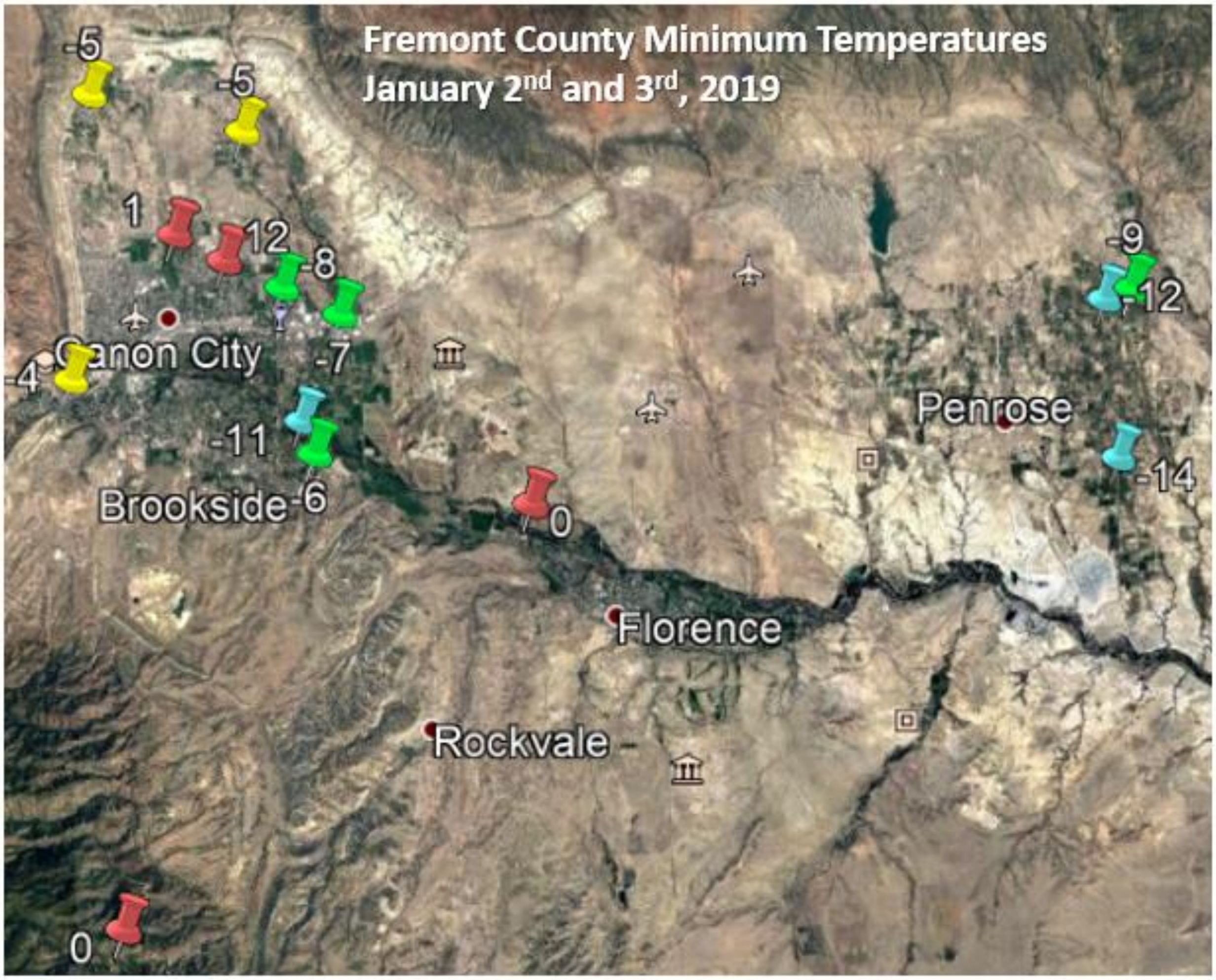

Fig. 11: Minimum observed temperatures in Fremont County from January 2nd and 3rd, 2019. -15 F <= Cyan < -10 F. -10 F <= Green < -5 F. -5F <= Yellow < 0F. Red >= 0 F.

The other winter cold event of note occurred in the fourth week of February. This event was the coldest of the winter for several stations in Cañon City, including the COOP site, and for the Oak Creek Grade station, which sits to the south of and above town. Unlike other notable winter cold events in 2018 and 2019, temperatures were not colder in Penrose than in Cañon City (Fig. 12).

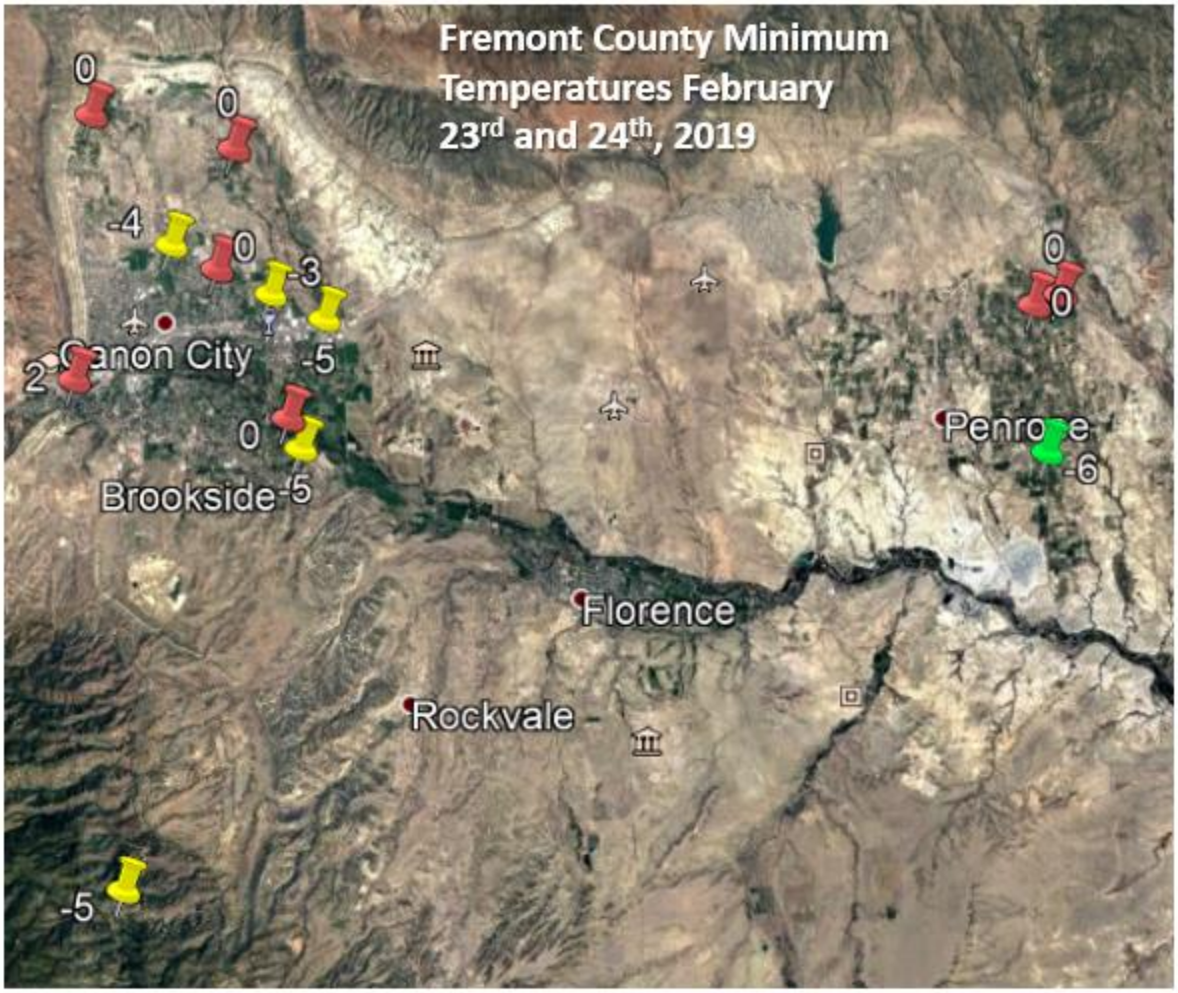

Fig. 12: Minimum observed temperatures in Fremont County from February 23rd and 24th, 2019. -10 F <= Green < -5 F. -5F <= Yellow < 0F. Red >= 0 F.

Part II – PRISM Model Freeze Events

Freezes: In previous years, up to four types of freezes that are known to kill vineyard crops have been examined by the Colorado Climate Center using long-term Cooperative Observer Network (COOP) weather station data. In this section, we estimate the fraction of years in which a killing freeze event will occur using gridded data. This is accomplished using the high-resolution Parameter-elevation Regressions on Independent Slopes (PRISM) Model. 1981-2017 daily PRISM 4 km data are downscaled to 800 m using PRISM 800m monthly mean data.

A weather event is considered a killing freeze if it meets one of several conditions listed below: One set of conditions is designed to show the likelihood of a freeze that impacts cold hardy hybrid grapes. The other set of conditions tests European varieties. Imposed freeze conditions for cold hardy hybrids and European grapes (*Vitis vinifera*) are as follows:

Hybrid grape variety freeze conditions

1. A hard spring freeze (28 F or lower) following bud break (estimated as May 15th)

2. A fall freeze (32 F or lower) prior to harvest (estimated as September 30th)
3. A rapid onset of seasonally-unprecedented cold air in fall (temperatures in October of less than 10 F where the previous seasonal minimum is at least 10 F higher, or temperatures of less than 0 F in November where the previous seasonal minimum is at least 10 F higher)
4. Deep cold early in winter (below -15 F before January 1st)
5. Extreme cold in mid or late winter (below -25 F after January 1st)

European (*Vitis vinifera*) grape variety freeze condition

1. A hard spring freeze (28 F or lower) following bud break (estimated as May 15th)
2. A fall freeze (32 F or lower) prior to harvest (estimated as September 30th)
3. A rapid onset of seasonally-unprecedented cold air in fall (temperatures in October of less than 10 F where the previous seasonal minimum is at least 10 F higher, or temperatures of less than 0 F in November where the previous seasonal minimum is at least 10 F higher)
4. Deep cold early in winter (below -5 F before January 1st)
5. Extreme cold in mid or late winter (below -15 F after January 1st)

These criteria are imperfect indicators of a killing freeze, and will be refined in future scopes of work. Lethal conditions, particularly due to winter cold, vary depending on grape variety. It is also important to consider that not all types of killing freezes have the same impacts. A crop will likely survive one or two freezes after bud break, but yields will suffer. A fall freeze before harvest means grape growth will be stopped, but these grapes can still be harvested. Harsh wintertime conditions that vines are not properly acclimatized for will kill the vines themselves. Thus, impacts are more severe.

Low numbers of killing freeze years were observed in areas like Palisade and Grand Junction. This is unsurprising since these areas are known for grapes. Palisade and Grand Junction were estimated as having had fewer than two killing freeze years/decade over this time frame. Other areas in the Colorado, Gunnison, and Dolores River Valleys were similar. Other than Palisade and Grand Junction, the mostly likely areas not to freeze were right along the Colorado-Utah state line (Fig. 13). One is in the Colorado River Valley, one is in the Dolores River Valley, and one is right at the Four Corners.

No areas in eastern Colorado, including Cañon City, had fewer than two estimated killing freezes/decade (Fig. 13). There was a north-south gradient in the number of freezes with lower latitude areas carrying lower estimates of killing freezes/decade. In northeast Colorado, the urban corridor from Denver to Boulder to Fort Collins was estimated at fewer killing freeze years/decade than surrounding areas in all directions. Even so, this area was estimated to have seen a killing freeze in about half of years. Killing freeze numbers in Cañon City were low for eastern Colorado, but not lower than other low elevation areas in the Arkansas River Basin.

There was a large difference in eastern Colorado between the number of killing freeze years/decade for cold hardy hybrids (Fig. 14) and for European grape varieties (Fig. 13). The level of exposure to extreme winter cold on the eastern plains is elevated compared to the western valleys. These conditions are much more harmful to European grapes than hybrids.

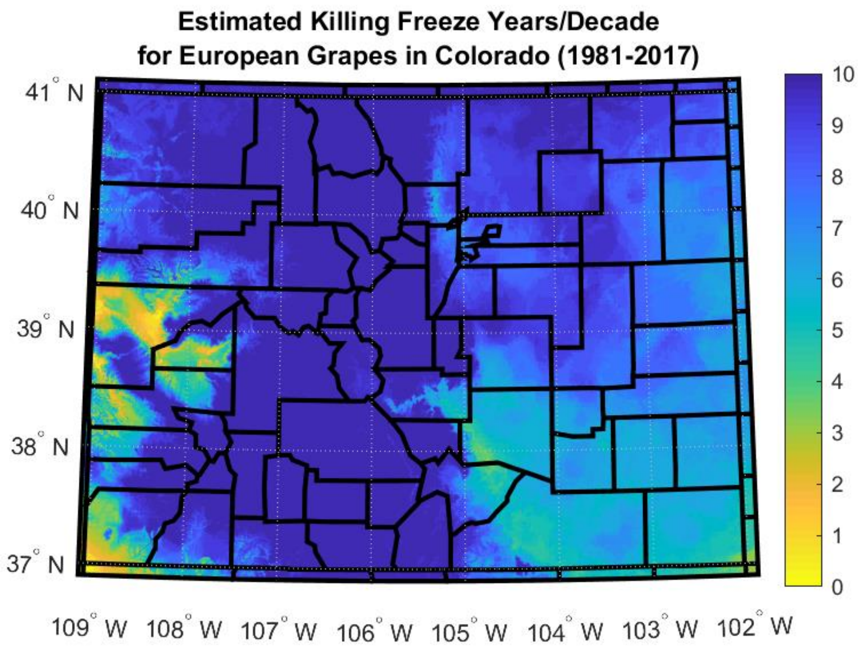

Fig. 13: Estimated killing freeze years/decade for *Vitis vinifera* grape varieties in Colorado (1981-2017).

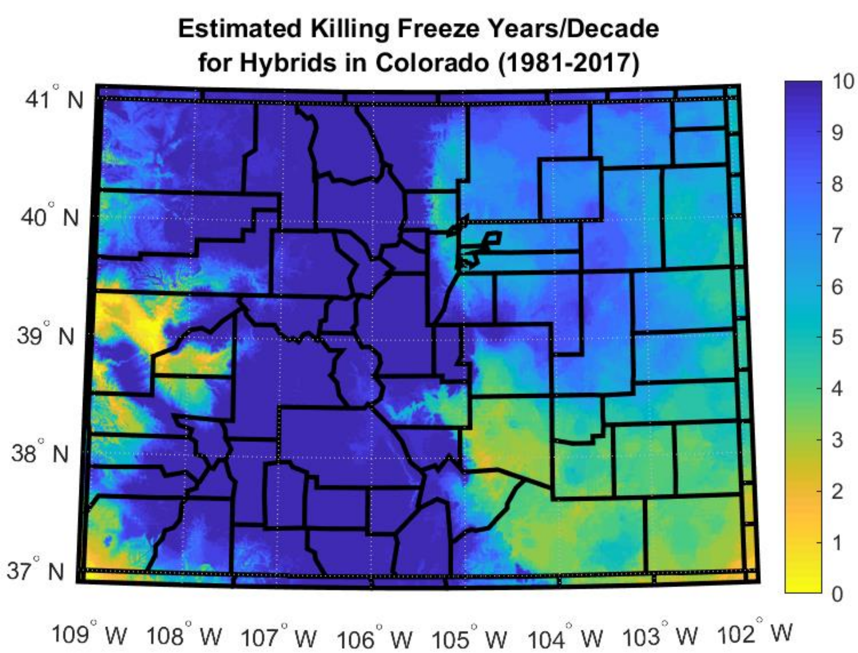

Fig. 14: Estimated killing freeze years/decade for cold-hardy hybrid grape varieties in Colorado (1981-2017).

The number of killing freeze years/decade estimated by PRISM varied widely across Montezuma County. This is to be expected given the topography. The northeast corner of the county (which is in the San Juan Mountain Range) had a killing freeze event every year. The Four Corners was estimated to have less than two killing freeze years/decade. There was also a large amount of variability in the number of estimated killing freeze years/decade among the observation locations used in this study (Fig. 15). For example, the west end of McElmo Canyon was estimated at 3-4 killing freeze years/decade. The east end was estimated at 5-7. Nocturnal temperatures are reliably warmer on the hillsides around Cortez than in the valley where the town is located. This is seen in models, observations, and historic siting of horticultural activities. This includes Mesa Verde, and areas in and west of Yellow Jacket, which can be as much as 2000 ft higher than the town of Cortez. Mancos was estimated to have a high number of killing freeze years/decade (8 or more).

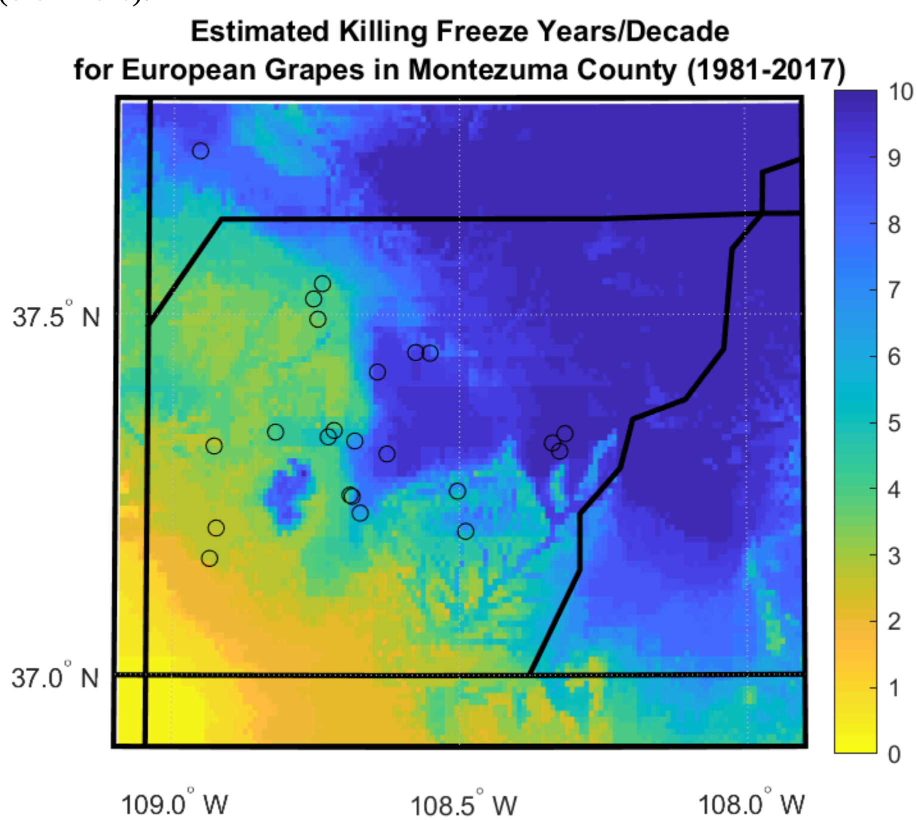

Fig. 15: Estimated killing freeze years/decade in Montezuma County for *Vitis vinifera* varieties (1981-2017). Black circles represent temperature observation sites used in this study.

Killing freezes years are more likely to be attributed to spring and fall weather events than winter weather events in Montezuma County, so there was nearly no difference in estimated killing freeze years for European varieties (Fig 15).and cold-hardy hybrid varieties (Fig. 16)

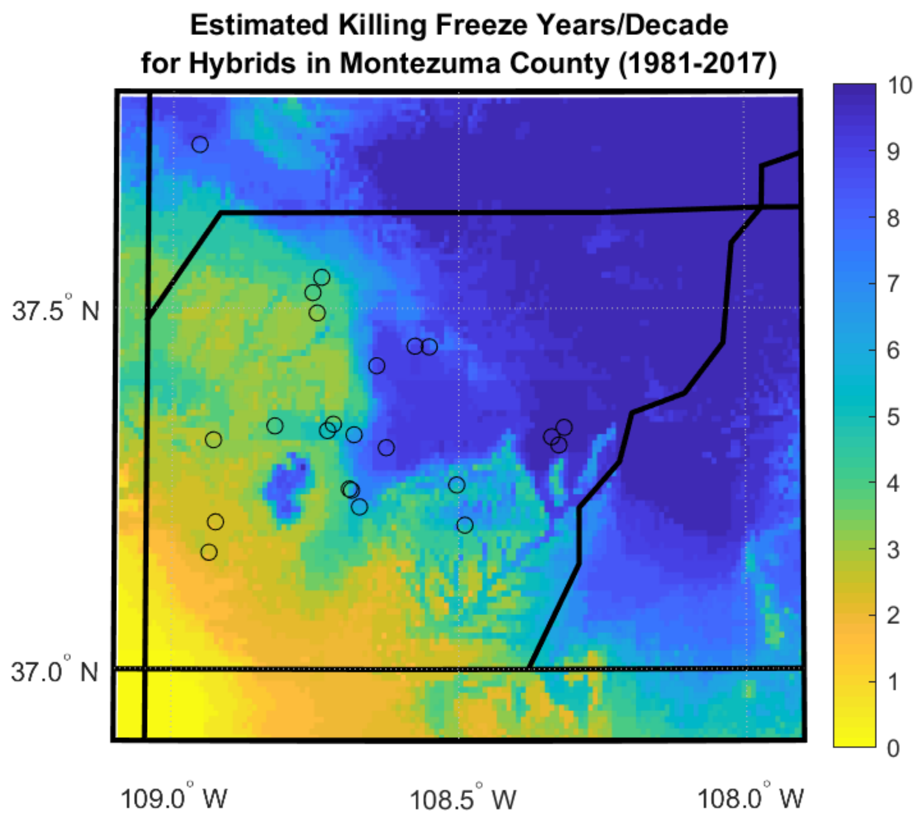

Fig. 16: Estimated killing freeze years/decade in Montezuma County for cold-hardy hybrid grape varieties (1981-2017). Black circles represent temperature observation sites used in this study.

The PRISM model estimated 3-5 killing freeze years/decade between 1981 and 2017 for the Cañon City area (Fig. 17). There were only small variations in the number of killing freeze years/decade across the covered domain in this project. Observations over the two years of this study including Fremont County have shown an east-west gradient in nighttime temperatures with the west side of Cañon City in particular remaining warmer than Penrose, so it was interesting that the model showed these cities as about equally vulnerable. The PRISM model did estimate that the Oak Creek Grade site would have more killing freezes than any other site in the county, but this area is highly topographically complex, and it may be that 800 m is still insufficient resolution for mapping cold air drainage here.

The risk of a killing freeze in a given year is reduced by 30-40% for the Cañon City area for cold-hardy hybrid grape varieties (Fig. 18). Cañon City remains one of the most insulated areas east of the Continental Divide in Colorado during winter. However, temperatures below -15 F in December are more common in Cañon City than Grand Junction or Palisade.

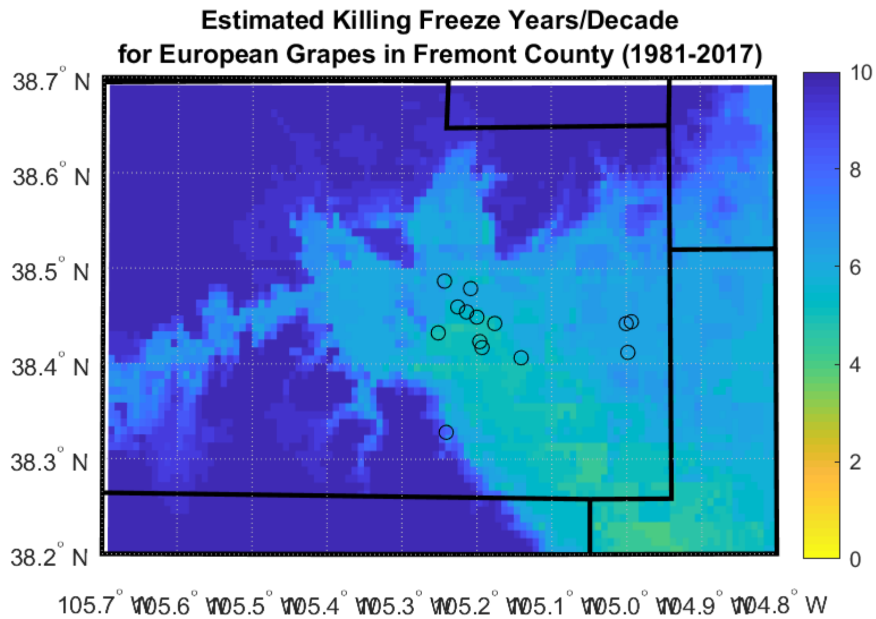

Fig. 17: Estimated killing freeze years/decade in eastern Fremont County for *Vitis vinifera* varieties (1981-2017). Black circles represent temperature observation sites used in this study.

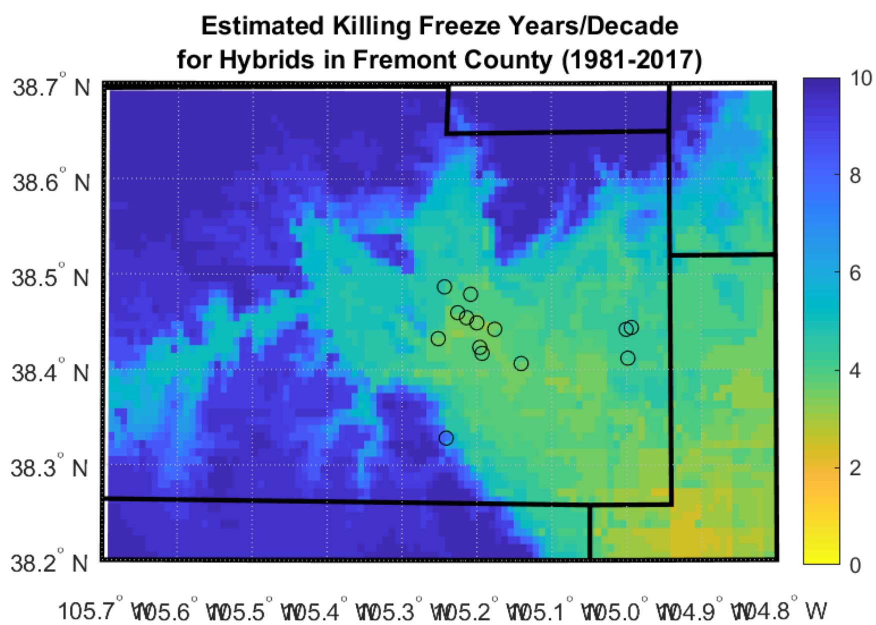

Fig. 18: Estimated killing freeze years/decade in eastern Fremont County for cold-hardy hybrid grape varieties (1981-2017). Black circles represent temperature observation sites used in this study.

Part III - Comparing PRISM Data to 2017 Observations

In May and September of 2017, the Montezuma County network of thermometers captured two killing freeze events impacting much of the county. These were killing freeze events not only in the sense that they met criteria outlined above. Damage to local vines was observed in both events. Observed temperature data from these killing freezes is compared to model data to see where models may be failing to capture dangerous conditions on killing freeze nights. A much greater sample size of events is desirable, but as of right now 2017 is the only year of overlap between data collection in Montezuma County and high resolution PRISM data. PRISM uses observations from COOP and CoAgMET stations. Therefore, modeled and observed temperatures should line up well around these stations. The data from thermometers sited specifically for this project are not ingested by PRISM. Given the complexity of topography in the region, these sites will test PRISM's capabilities to match surface conditions.

The first killing freeze of 2017 occurred on the morning of May 19th (Fig. 19). This event knocked temperatures below freezing at all observation sites in the county other than McElmo West. PRISM model minimum daily temperatures at the nearest grid point to each observation site were within 2.5 F of the observed minimum daily temperature at all sites. This includes sites not used in PRISM's data ingest process. The model's average bias was -0.03 F. This is impressive given the terrain.

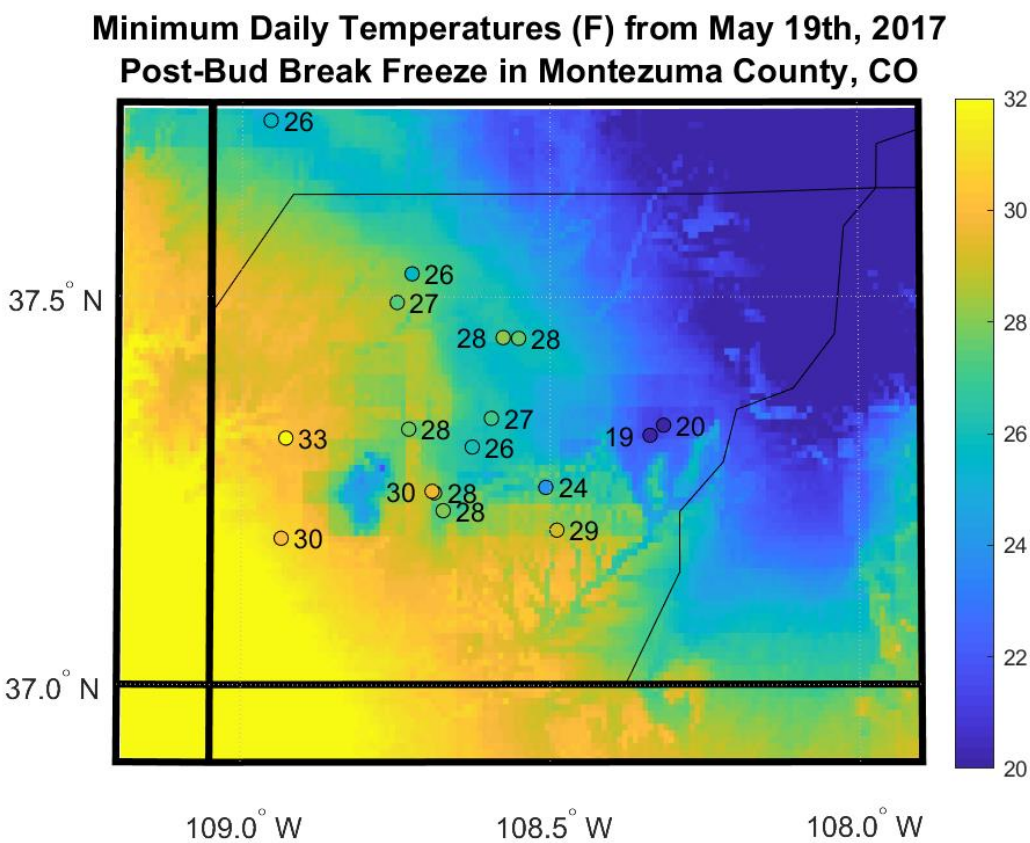

Fig. 19: Comparison between modeled and observed minimum daily temperatures in Montezuma County on May 19th, 2017.

Vineyards in Montezuma County suffered a second freeze on September 25th, 2017 shortly before harvest. The PRISM model didn't match observations as well in the September freeze event (Fig. 20). Model temperatures were, on average, 1.6 F cooler than the closest observation. The model's cool bias in this event was worse for high elevation stations than low elevation stations. The Cortez 8SE COOP station at over 8000 ft elevation recorded as low temperature of 35 F. PRISM estimated the low here at 27 F. Similarly, stations in and around Yellow Jacket (~6800 ft) stayed above freezing; the PRISM model didn't capture this. The observed daily minimum temperature at McElmo West was seven degrees warmer than estimated by the model. A difference like this is a key miss, as the model would have identified this as a killing freeze, but observations show it wasn't. There were two stations in this event for which PRISM recorded a warm bias: The Mancos CoAgMET station, and the Towaoc CoAgMET station on the Ute Mountain Farm and Ranch. Both of these are stations that are at low elevation with respect to the immediately surrounding areas.

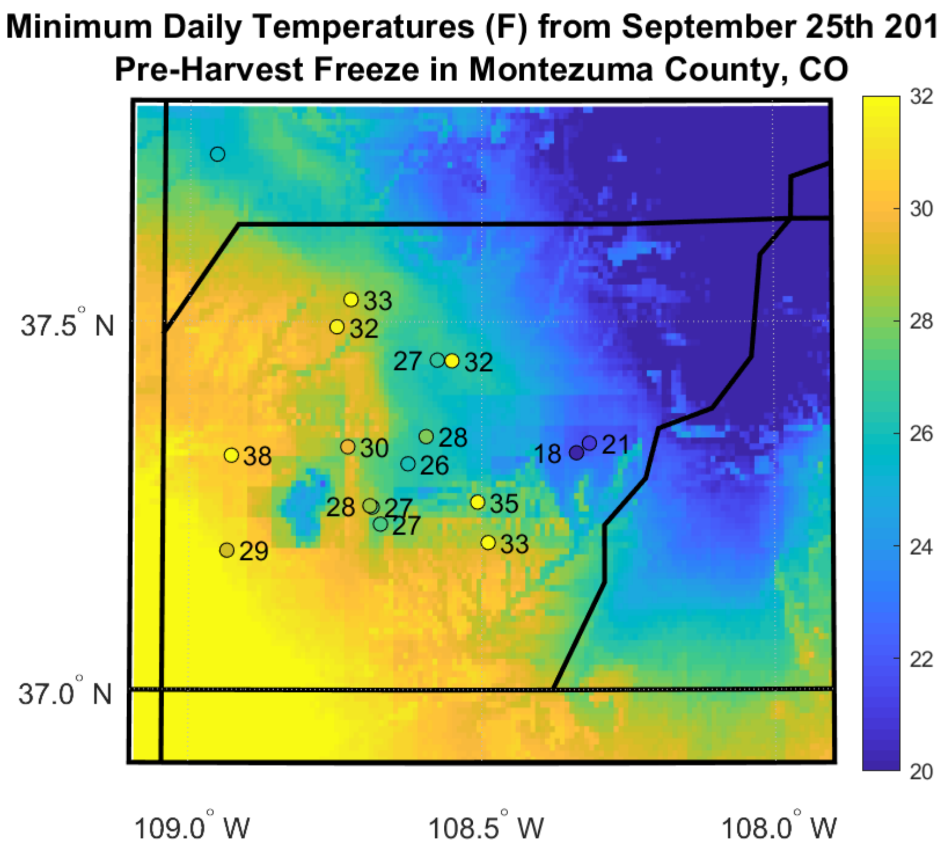

Fig. 20: Comparison between modeled and observed minimum daily temperatures in Montezuma County on September 25th, 2017.

Results here are promising for PRISM. Downscaled PRISM 4 km data may well be useful for identifying warm pockets of the state that are suitable for vineyards in areas where temperature observations are sparse. More comparison of PRISM data to observed temperature data is recommended, especially for stations not incorporated in the PRISM model. This will be included in next year's report for both Montezuma and Fremont County areas.

Part IV – Soils

In this section, soil texture overlays from the US Geological Survey Soil Survey Geographic Database (SSURGO) are used to quantify potential available plant water. Soil texture from SSURGO is based on extensive human surveying, and therefore based on a large volume of ground validated data. Soil textures with the most potential available plant water are classified as "good," soil types with more average levels of potential available plant water are classified as "fair," and sandy or hard, clay soils are classified as "poor" (Fig. 21). Sand and clay are examples of poor soils are poor for opposite reasons. Sandy soils are conducive to drainage, so large amounts of precipitation or irrigation water slip through the root zone without ever being available to vines. Clay soils hold much higher volumes of water, but hold it so tightly as to be inaccessible to vines. Loams and silts allow more soil water from precipitation and irrigation to be available to plants.

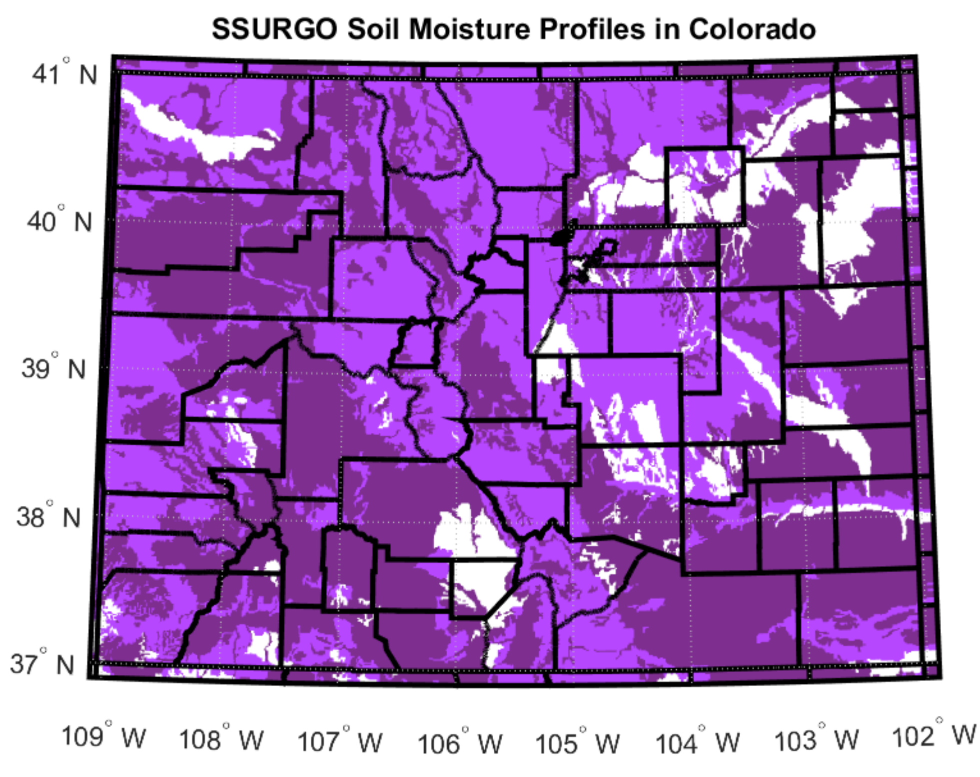

Fig. 21: SSURGO soil textures for Colorado ranked as good (dark purple), fair (light purple), or poor (white).

The usefulness of soil texture masking applied here is debatable. First and foremost, mountain peaks across the state were not characterized as bedrock, and are in many cases being passed off here as "good" soil texture for growth. While this would have been obvious to surveyors, it is oddly not reflected in the gridded dataset. Furthermore, it is impossible to obtain soil samples everywhere, and soil texture changes on fine spatial scales. Producers currently growing grapes in areas masked by this study should not be discouraged if they have a history of productive grape growth. Producers applying this information to prospective land are advised to take soil samples regardless of whether or not their land is masked by the model due to presumed poor soil texture.

It should also be noted that soil texture is not the only soil consideration one must take into account when planning or operating a vineyard. Other factors not considered here, such as soil acidity or soil salinity, may be equally, or more important.

Part V – Exploration Opportunities

PRISM temperature and SURGO soil texture data were combined to construct maps of areas with viticulture potential in Fremont County, Montezuma County, and the state of Colorado. In order to qualify as an "exploration opportunity," a grid space must have an estimated fewer than five killing freeze years/decade, and fair or good soil texture.

Results in western Colorado largely confirm, but perhaps expand upon what is known (Fig. 22). Palisade and Grand Junction are highlighted as exploration opportunities. This can be thought of as a sanity check for the data. Palisade/Grand Junction area is the main hub of viticultural and horticultural activity in the state. It is encouraging that they pass the temperature and soil checks implemented here. Other highlighted areas include parts of the Gunnison Basin in Delta and Montrose Counties. This includes cities such as Delta, Olathe, Montrose, Hotchkiss, and Paonia. It also includes parts of the Dolores and San Miguel River Valleys, such as Paradox. Finally, small parts of La Plata and Archuletta Counties, and a sizable chunk of Montezuma County are highlighted.

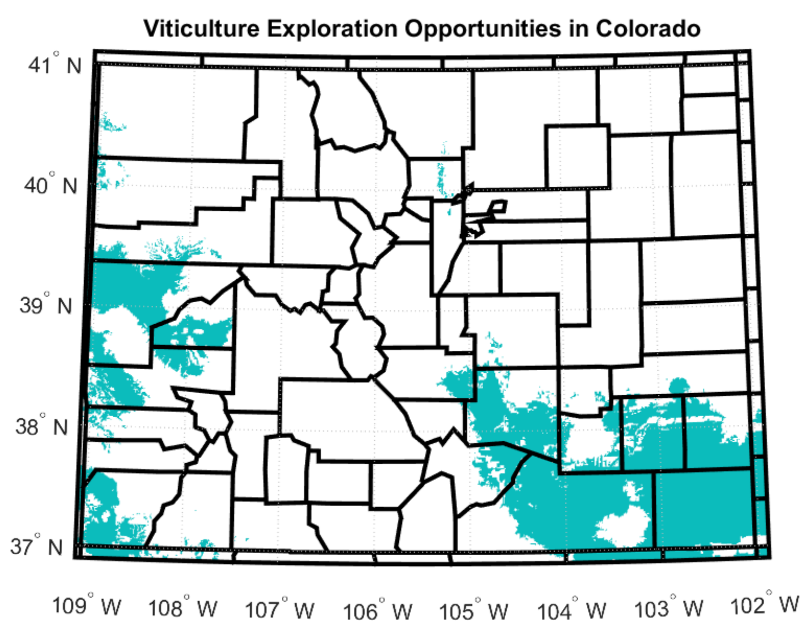

Fig. 22: Map of exploration opportunity (teal) areas for wine grape growth in Colorado based on PRISM estimated freezes/decade and SSURGO soil texture data.

Montezuma County: Hindrances to viticulture potential vary with space. The northeast part of the county is too cold. This includes Mancos and Cortez (Fig. 23). The far southwest portion is warm enough, but was not highlighted based on poor soil quality (hard clay).

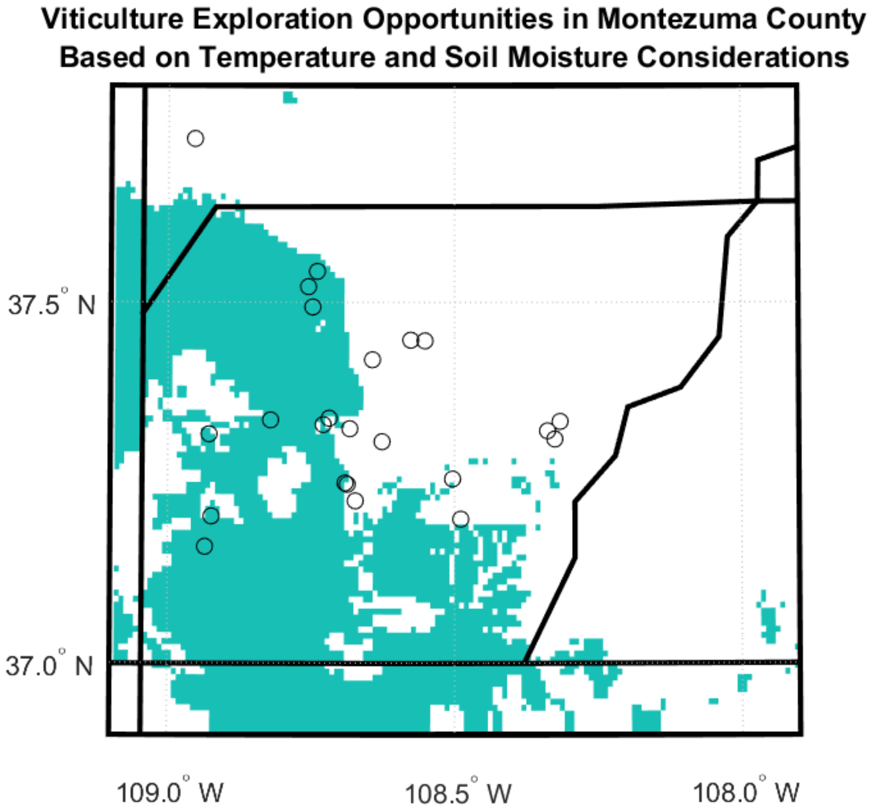

Fig. 23: Map of exploration opportunity (teal) areas for wine grape growth in Montezuma County based on PRISM estimated freezes/decade and SSURGO soil texture data. Black circles represent temperature observation sites used in this study.

Based on these findings, it is recommended that more observations be taken in the central portion of McElmo Canyon, on the Ute Mountain Farm and Ranch, on Ute Mountain Ute land on the Mancos River, and in Yellow Jacket to the south and west of current observation sites (Fig. 23). These are areas with loamy or clay loam soils, access to irrigation water, and projected to experience a killing freeze fewer than three times/decade. If observations confirm what PRISM shows, these spots have potential.

Fremont County: The Cañon City, Penrose, and Wetmore area all passed imposed killing freeze and soil texture criteria for grape growth (Fig. 24). Other areas downstream in the Arkansas River basin also passed. Areas to the north and west of Cañon City are much colder. The only currently monitored site in the area that was not highlighted based on imposed criteria was the Oak Creek Grade station. Elevation changes rapidly in this area. As discussed previously, it is likely that 800 m resolution is still insufficient for capturing microclimates in this area. Areas to the east of Penrose along the Arkansas River also had few enough freezes to qualify, but did have more freezes than Cañon City. It may be worth expanding thermometer coverage to the east, primarily along the Arkansas River, to see how much cooler observed temperatures are in this area on cold nights.

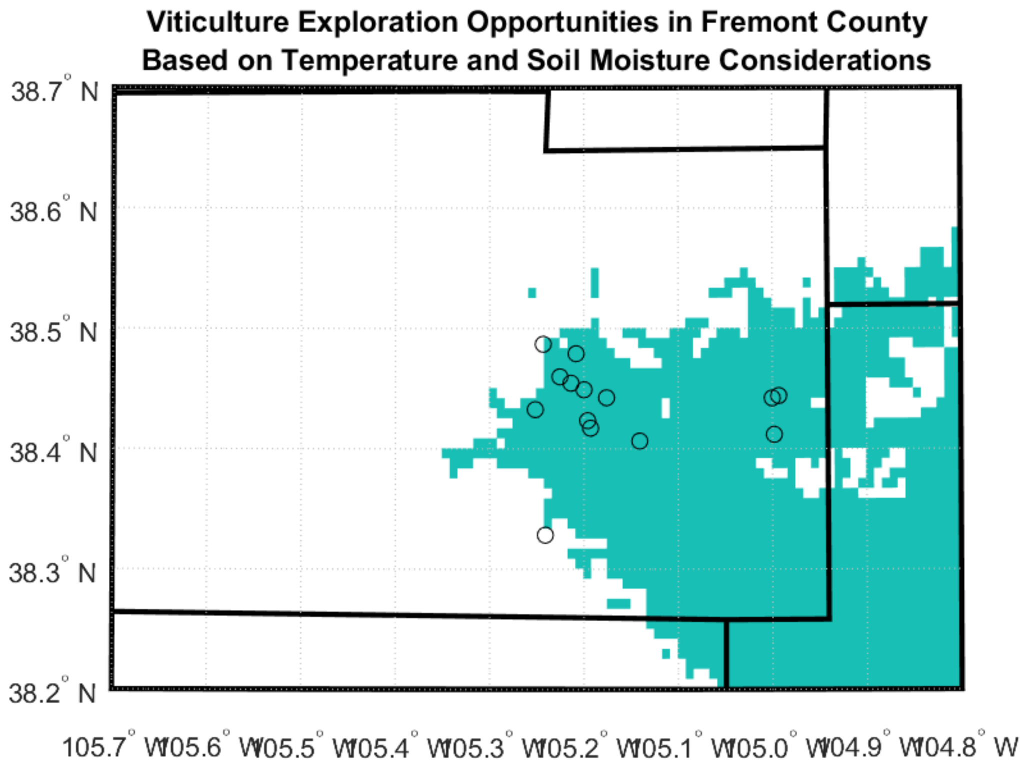

Fig. 24: Map of exploration opportunity (teal) areas for wine grape growth in Fremont County based on PRISM estimated freezes/decade and SSURGO soil texture data. Black circles represent temperature observation sites used in this study.

Conclusions: The Colorado Climate Center has collected another year of data in Fremont and Montezuma Counties. This is being done with the aim of more precisely targeting prime grape growing locations in current and future climates. 2018 was a mild year temperature-wise, but winter 2019 had a couple significant cold events. Temperatures in Montezuma County were in some cases the lowest observed since 2013. Stations on the west side of the county recorded temperatures up to 15 F colder than either of the last two years. These events occurred in mid-and-late winter, which is the best time of year for vines to be exposed to frigid temperatures.

Furthermore, the Climate Center leveraged two high-resolution gridded data products to narrow the search for viticultural expansion: 1. PRISM temperature data, which were compared with observations, and 2. USGS soil texture data. Using modeled temperature and soil texture data, maps of exploration opportunities for grapes were created. This map confirms, and hopefully expands upon what is known in Colorado. Areas such as Palisade, Grand Junction, and Cañon City are confirmed by gridded data sources as being reasonable locations for grapes. It also highlights a number of areas that are less known for grapes historically, but may have some potential. Examples include, Paradox, small portions of Boulder County, and much of southeast Colorado. This map can be used as a resource for choosing where to grow, but not the only resource. The map also informs where additional temperature observations in Montezuma and Fremont Counties should be taken as a part of this project.

Future work: In the coming year, the Climate Center will continue to obtain temperature data from Fremont and Montezuma Counties, and expand observations based on this year's findings. Target areas for additional temperature monitoring in Fremont County will be to the south and east of the current network, but with a focus on remaining close to the Arkansas River. In Montezuma County, more data is desired in central McElmo Canyon, the south-central portion of the county, and southwest of Yellow Jacket.

Data Source References:

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Accessed June 2019.

Soil texture maps were remapped into global 30-second regular lat-lon grid. Within CONUS, the soil texture is then replaced by the 30-second STATSGO data obtained from http://www.essc.psu.edu/soil_info/index.cgi?soil_data&index.html. The dominant soil texture from 0-30 cm, and 30 – 100 cm from multi-layer STATSGO soil was selected to match the FAO soil depths and to produce the top and bottom soil texture. Accessed June 2019.

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.

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

Approximately 40% of the vineyards in Colorado are drip irrigated. While drip and sub-surface drip irrigation are the most water efficient methods of irrigation, the question arises how to manage the inter-row area. Precipitation in Colorado's semi-arid climate is generally insufficient to maintain a green cover crop. Many older vineyards were set up with drought tolerant grasses sown in the inter-row area, but over the years those grasses have died out and been replaced by weeds. Some growers opt to clean-cultivate the inter-row, others maintain bare soil through the use of herbicides or mow the resident vegetation. Bare soil or minimal vegetation cover in the inter-row is likely to degrade soil quality that potentially has negative impacts on vine performance. Results from the variety trial at Rogers Mesa (see Viticulture Webpage) show a very strong effect of soil condition and irrigation system on yield and fruit quality[2].

To further investigate the effects of different soil and irrigation management on long-term vineyard productivity and vine and soil fertility, an experiment was

[2] 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.

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 2018, cover crops were kept short by mowing once near the time of bud break 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. Consistent with results from previous years, seasonal cover crop biomass production was up to four times higher in the sprinkler-irrigated plots than in the drip-irrigated crested wheatgrass plots (Fig. 25).

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 3.3 % over the season (Table 11). The Aurora Gold hard fescue and orchard mix biomass had nitrogen concentrations averaging 2.4 %, while crested wheatgrass averaged 2.1 %. Similar trends for lower nutrient concentrations in the crested wheatgrass biomass compared to the other cover crops were once again found for phosphorus, potassium, and sulfur. Other differences were high boron concentrations in the legume biomass and extremely high iron concentrations in the crested wheatgrass biomass (Table 11). All of those cover crop treatment effects are consistent with the results from the 2016 and 2017 seasons.

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 previous three seasons and indicate that the vine nutritional status is being affected by the type of cover crops. Specifically, the nitrogen concentration in leaf blades was again slightly higher with a legume cover crop than with the other treatments (Fig. 26). A higher availability and/or uptake of nitrogen by vines with a legume cover crop is also implied by much higher nitrogen levels in the musts seen in the past 4 seasons (Fig. 26). Treatment effects on all other nutrients in the leaves have been inconsistent between the years.

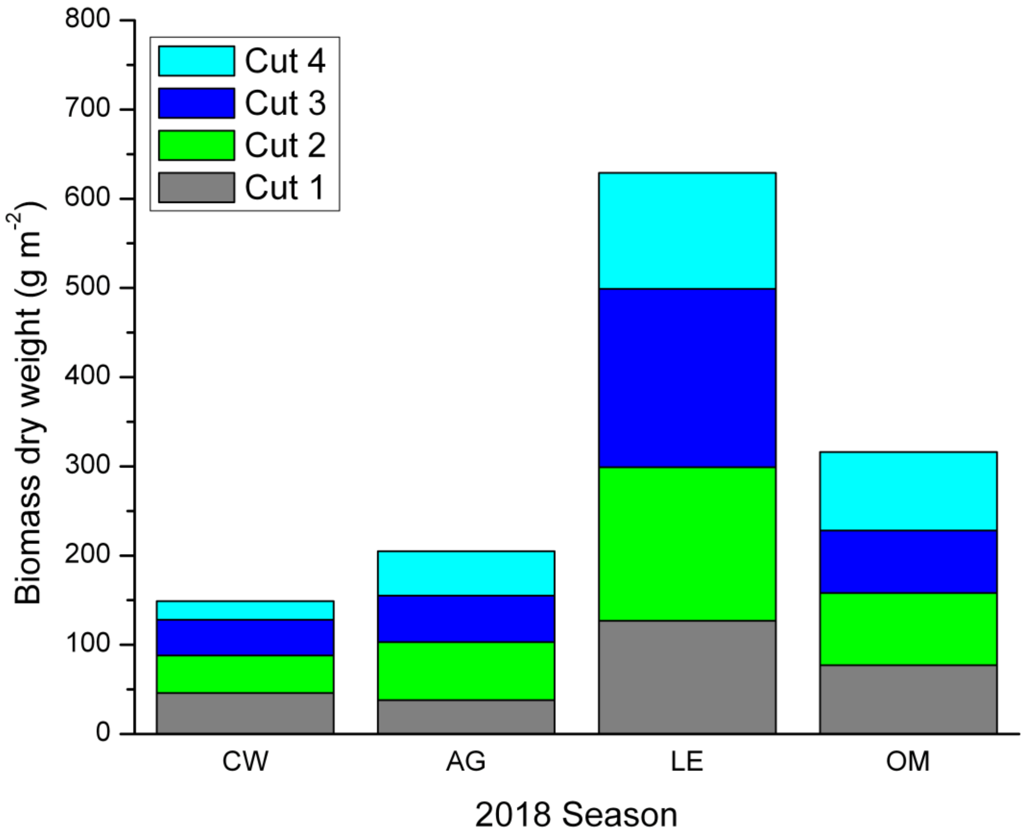

Fig. 25: Seasonal biomass production of cover crops in a Chardonnay vineyard at the Western Colorado Research Center – Orchard Mesa.
CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated, vines in AG, LE, and OM are irrigated by micro-sprinklers.

Table 11: 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	2.15	0.20	1.34	0.23	20	3,712
AG	2.43	0.31	2.13	0.33	22	788
LE	3.35	0.24	2.63	0.40	40	684
OM	2.41	0.34	2.09	0.35	16	805

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.

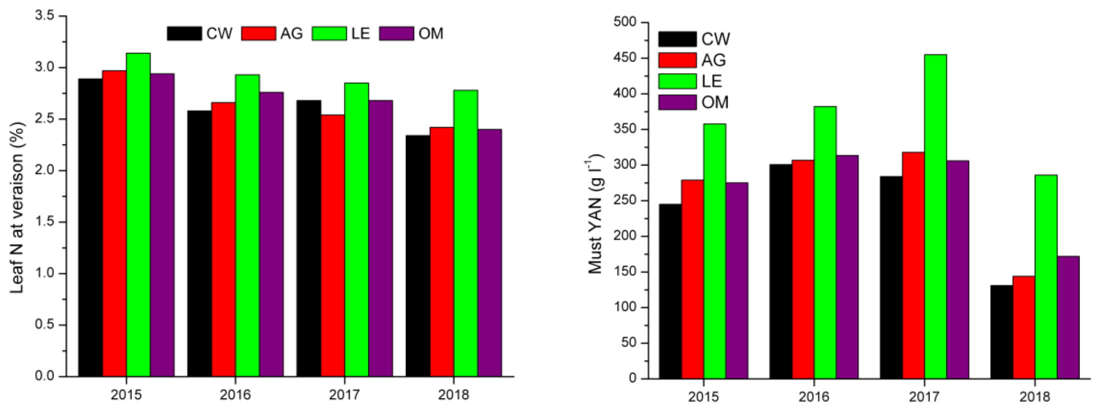

Fig. 26: Effect of cover crops on nitrogen concentration of Chardonnay leaf blades at veraison (left); and on the yeast-assimilable nitrogen (YAN) concentration of Chardonnay musts in 2015, 2016, 2017, and 2018 (right).
CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated, vines in AG, LE, and OM are irrigated by micro-sprinklers.

Yields in 2018 were much higher than in previous years. The average for the entire Chardonnay block was 4.5 ton/acre, the highest yield since 1997. Grafted vines yielded 5.06 ton/acre whereas own-rooted vines produced 3.98 ton/acre. Vines with the Aurora Gold cover crop had the highest yield (5.17 ton/acre) followed by crested wheatgrass (4.91 ton/acre), legume (3.49 ton/acre), and orchard mix (2.84 ton/acre) treatments.

Drip-irrigated vines received 20” of irrigation water during the 2018 season whereas a total of 30.2” was applied in the micro-sprinkler irrigated plots. The irrigation volumes applied in drip were equal to 2017 but much lower for micro-sprinkler. The main reason for the lower annual totals was that there was no large late-season application as more than 3” of rainfall occurred in the first 12 days of October. The rain returned soil water content to field capacity and a killing frost on 15 October limited further water loss through vine transpiration. Prior to the large October rainfall event there were only 1.5” of precipitation between 15 April and 30 September, 2018. Reference evapotranspiration for the period 15 April to 15 October was 52.6”.

In the fall of 2018 soil samples were taken in the alley as well as in the vine row. Where possible, soil samples were taken at three depths: 0-12”, 12-24”, and 24-36”. Samples were dried and sieved and then send to a commercial laboratory for analysis. After five years with different cover crops the most discernible trends were for organic matter concentration, pH, and soluble salts. Soil organic matter in the top 12” tended to be higher with the legume cover crop, both in the alley and under the vine (Fig. 27). Soil pH in the alley was lowest with crested wheatgrass (Fig. 27). All sprinkler-irrigated treatments had lower soluble salts in the top 12” of soil in the alley (Fig 27) There was also a trend for lower salts in the 12-24” layer, but no treatment effect was apparent at lower depths.

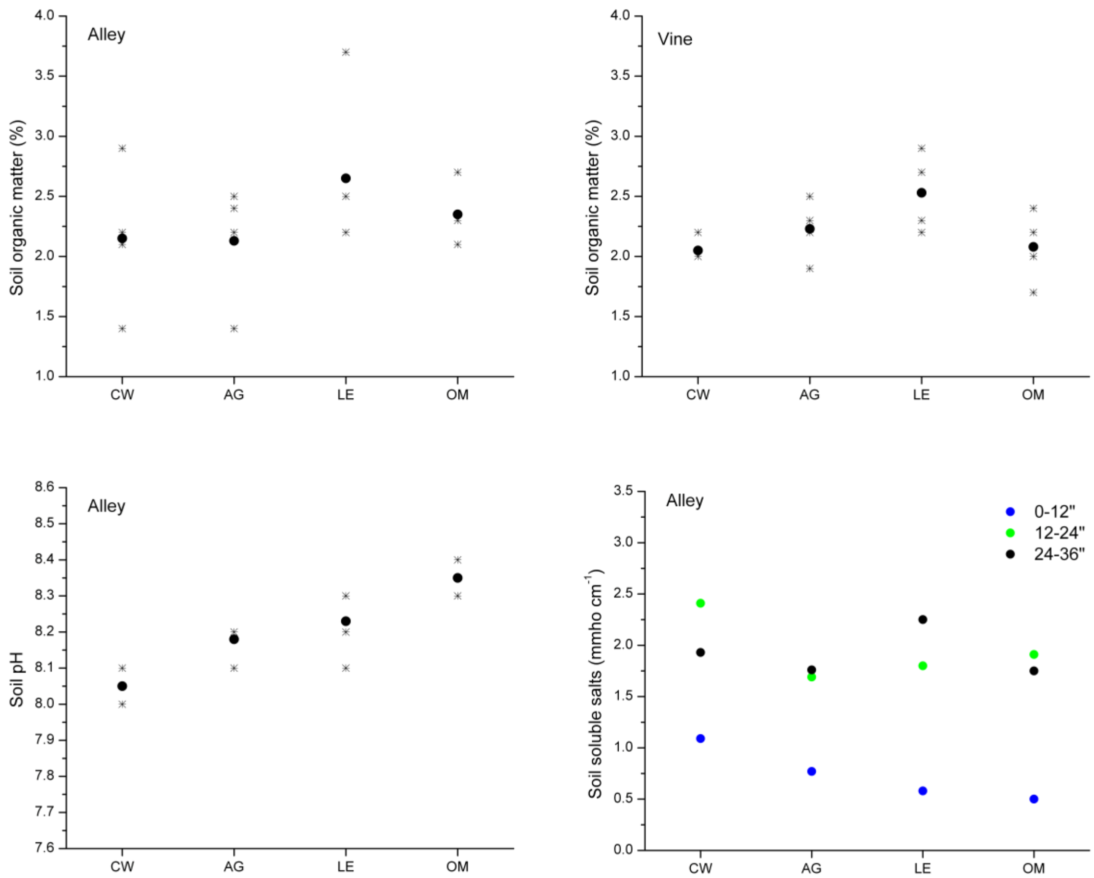

Fig. 27: Effect of cover crops on soil characteristics: organic matter (top row), pH (bottom left), and soluble salts (bottom right). For organic matter and pH, asterisks are values for individual replications while the circle indicates the treatment average.
CW, AG, LE, OM: crested wheatgrass, Aurora 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.

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.

- Vineyard floor management – evaluation of low-growing grass cultivars (Caspari and Wright)

Results from the 2004 variety trial at WCRC-RM show a very strong effect of soil management and irrigation system on yield and fruit quality. Briefly, sprinkler-irrigated vines with a permanent 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. The hard fescue cultivar used in the study at WCRC-RM was

Aurora Gold, a cool-season turf with a natural tolerance to Roundup. It is a low maintenance grass with good drought and shade tolerance. In the study at WCRC-RM, as well as the more recent study at WCRC-OM, Aurora Gold has produced a very dense, low growing turf with minimum weed presence, even in the absence of Roundup applications. Due to its low growing nature and the oppression of weed species it is very easy to manage. Over the years we have received many grower enquiries about this grass cover crop, and where to buy seeds. Unfortunately, seeds of Aurora Gold are no longer available.

In late summer of 2018, a new study to evaluate different grass species / cultivars with similar characteristics to Aurora Gold was established in a mature vineyard block at WCRC-OM. Irrigation in this block was changed from dip to micro-sprinkler. In early September 2018, five different turf cultivars and one blend were sown: 'Shademaster III' and 'Xeric' creeping red fescue (*Festuca rubra ssp arenaria*); 'Ambrose' and 'Enchantment' Chewing's fescue (*Festuca rubra ssp fallax*); 'Eureka' hard fescue (*Festuca brevipila*); and 'Earth Carpet Care Free', a commercial blend of Chewing's fescue (40 %), creeping red fescue (35 %), hard fescue (20 %), and blue fescue (*Festuca glauca*, 5 %). Turf cultivars were selected with assistance from Dr. Tony Koski, Professor and Extension Turfgrass Specialist at Colorado State University. All grass cultivars have growth characteristics similar to Aurora Gold, i.e. low growth habit forming a dense turf, with good drought and shade tolerance. The experimental design is a randomized block with six replications per treatment. Each replication is ~210' long (half a row). The focus of this study is on turf establishment, persistence, weed suppression, and drought and traffic tolerance.

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.

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

2. *Off-station research and demonstration plots*

The uptake of new research results and new production techniques is fastest when growers are directly involved in their development. One way of involving growers in research is to establish research plots on grower properties. Since 2013, we have established two replicated variety trials in grower vineyards. At the Fort Collins site, a CSU student intern enrolled in the Viticulture and Enology concentration managed the vineyard during the 2018 season. Several students helped with netting, harvest, and small-scale wine making. The two replicated rootstock studies with Cabernet Sauvignon (see above) are other examples where the research is sited in commercial vineyards. 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 2018. The majority of forms were send electronically. By June 2019 we had received 79 responses (representing 137 vineyard sites) totaling 601 acres. The main results of the survey are:

- Largest production ever
- 2,261 ton production reported
- Expected total production >2,500 ton, an increase of >300 ton over 2017
- Around 15 % of production did not get sold
- Average yield of 3.87 ton/acre; the highest ever recorded
- Average price of $1,675/ton, a 2.5 % decrease over 2017
- Riesling is ranked #1 in production, but 47 % did not get harvested
- Cabernet Sauvignon is ranked #1 for utilized crop, followed by Merlot, Cabernet Franc and Riesling
- Chambourcin replaces Pinot gris as the 10th most widely planted variety
- The average grower farms 7.6 acres
- Average vineyard size is 4.4 acres
- The median vineyard size is 3.5 acres
- Very few new plantings in 2018
- Vineyard area planted slightly exceeds the area removed
- There is a continued expansion of vineyard area outside of Colorado's main growing areas, especially many small vineyards along the Front Range

LITERATURE CITED

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Cold hardiness 2018/19