Annual Report

July 1, 2019 – June 30, 2020

Viticulture and Enology programs for the Colorado Wine Industry

PRINCIPAL INVESTIGATORS

Horst Caspari[1], Peter Goble[2], Stephen Menke[1], Russ Schumacher[2], Adam Wright[1]

COLLABORATING INSTITUTIONS

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

Summary

This report covers the period from 1 July 2019 to 30 June 2020, i.e. the later part of the 2019 growing season, the 2019/20 dormant period, and the beginning of the 2020 growing season. The majority of the work performed during the reporting period included seasonal vineyard and winery tasks such as vine training, canopy management, crop thinning, harvest, small-scale wine making, 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 the Western Colorado Research Center (WCRC), two student interns (one from Colorado State University and one from Western Colorado Community College), 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. October was the second coldest since record-keeping began at the Western Colorado Research Center – Orchard Mesa in 1964. A season-ending killing frost occurred on October 10 or 11 for most growing areas in Western Colorado. November and December temperatures were near average.

Vine development and crop ripening in 2019 was about 2 weeks later than in 2018, due to the very cool temperatures in May. Industry-wide, a large volume of grapes was still hanging on the vines when the relatively early killing frost occurred in the second week of October. Approximately 15-20 % of the grape crop was harvested after the frost. A small percentage of the crop did not get harvested because the fruit did not ripen.

The mild winter of 2018/2019 in Western Colorado resulted in no or minimal bud damage. All of the 48 varieties grown in the research vineyards produced a crop and were harvested. Preliminary data from the 2019 Colorado Grape Grower Survey indicate that the 2019 harvest is down on the 2018 crop, but still a large harvest of over 2,000 ton. The grape surplus appears to be 50 % less than in 2018.

An extreme low temperature event occurred on 30 and 31 October 2019 with overnight lows dipping below 10 F. This was the first time that single digit lows have been recorded in October in Grand Junction by the National Weather Service since record

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

keeping began in 1895. The extreme cold event caused significant bud damage to late acclimating varieties with potential impact on the 2020 crop.

Mean temperatures in January and February 2020 were slightly below the long-term average while March and April mean temperatures were slightly above. The lowest temperature at WCRC-Orchard Mesa (WCRC-OM) during the dormant period was 7.8 F on 30 October 2019. A week-long warm spell in early April was followed by a record low temperature on 14 April which caused additional bud damage on varieties that tend to break bud early (e.g. Chardonnay, Cabernet Franc).

The aerial vineyard surveys initiated in 2018 to detect phylloxera (*Daktulosphaira vitifoliae*) infestations were repeated in 2019 in Mesa County. Surveys were funded through a Specialty Crops Block Grant from the Colorado Department of Agriculture. Three more vineyards in the Grand Valley tested positive for phylloxera, bringing the total to 18 positive sites in the Grand Valley. State-wide, phylloxera has now been found in 24 vineyards (18 in Mesa County, 3 in Delta County, 1 in Montrose County, and 2 in Front Range vineyards).

For further information please contact:

Dr. Horst Caspari, Professor & State Viticulturist
Colorado State University
Western Colorado Research Center
3170 B½ Rd
Grand Junction, CO 81503

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

Growing conditions, July – October 2019

Very cool May and slightly below-average temperatures in June resulted in a slow vine development. Growing degree day (GDD) accumulation was more than 150 degree days below average by the end of June. Temperatures were above average during July, August, and September. Growing degree day accumulation finally reached average values by early September. By the time of the killing frost on 10 October, 3,600 GDD had accumulated, 60 GDD higher than average but more than 400 GDD less than in 2018. An extreme cold temperature event resulted in record low temperatures on 30 and 31 October which caused bud damage to many varieties.

The very cool May and cool June resulted in harvest timing that was near average, but about 14 days later than in 2018. At WCRC-OM all fruit was harvested before a killing frost in early October. However, state-wide a large volume of fruit was harvested after the frost, and some fruit did not get harvested due to insufficient ripeness.

Seasonal cumulative precipitation was less than normal. May and June had near average precipitation but only 0.35” were recorded between 1 July to 31 October. Precipitation in November and December also was below normal. Annual precipitation in 2019 at WCRC-OM was below normal at 7.16”.

Dormant season conditions, October 2019 – April 2020

November and December 2019 temperatures were slightly above average, January and February 2020 slightly below average, and March and April again slightly above average. The dormant season was bookmarked by two record low temperature events – on 30 October 2019 and 14 April 2020. The lowest temperature during the dormant period was 7.8 F on 30 October 2019. A week-long warm spell in early April was followed by a record low temperature on 14 April which caused additional bud damage on varieties that tend to break bud early (e.g. Chardonnay, Cabernet Franc).

Precipitation during the dormant season was well below average with only March having near normal values.

Early growing season conditions, May - June 2020

Very dry conditions continued through May and June with only 0.52” recorded at WCRC-OM compared to the long-term average of 1.48”. Average temperature in May was 3.9 F higher than the long-term average, making it the fifth warmest May since record keeping began at WCRC-OM in 1964. June also was warmer than average by 1.4 F. The warm and dry growing conditions in May and June resulted in rapid vine development and an early bloom. Fruit development is approximately 10 days ahead of 2019 but lagging 2018 by about 4 days.

Research Update

I. Cropping reliability

1. Grape varieties and clones suited to Colorado temperature conditions

Since 2004 we have greatly expanded the number of varieties under testing. The first-ever replicated variety trial in Delta County was planted at the Western Colorado Research Center - Rogers Mesa site in 2004. This trial was expanded with new entries in 2008-2009 as part of the USDA Multistate NE-1020 project (see below). Also in 2008 and as a part of

NE-1020, 26 “new” varieties were planted at the WCRC Orchard Mesa site. An additional replicated trial focused on cold-hardy, resistant varieties was established on a grower cooperator site in Fort Collins in 2013 to identify grape varieties that can be grown successfully along the Front Range. And in 2014, a fourth trial focused on cold-hardy, resistant varieties was established with a grower-cooperator in the Grand Valley.

- 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, nine out of ten varieties were harvested. Yields ranged from 1.34 to 4.16 ton/acre (Table 1). Data on fruit composition at harvest are presented in Table 2. Micro-vinification was used to produce eight varietal wines.

Table 1: Harvest dates and yield information for 9 (out of 10) grape varieties planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Variety	Harvest date 2019	Yield (ton/acre)
Aromella	9 October	2.07
Bianchetta trevigiana	9 October	2.13
Blauer Portugieser	30 September	1.35
Chambourcin	9 October	4.16
Grüner Veltliner	9 October	1.80
Marquette	30 September	3.63
MN 1200	13 September	1.34
NY81.315.17	8 October	3.58
Vidal	8 October	3.74

Table 2: Fruit composition at harvest in 2019 for 9 (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})
Aromella	23.2	3.09	9.98	5.03	5.58	194	98
Bianchetta trevigiana	19.4	3.00	10.61	6.37	5.10	93	67
Blauer Portugieser	19.9	3.44	5.60	3.79	2.43	123	89
Chambourcin	22.4	2.81	13.80	7.16	7.98	143	77
Grüner Veltliner	22.8	3.11	8.04	7.36	2.52	116	105
Marquette	28.9	3.40	8.61	2.30	5.69	406	153
MN 1200	26.8	3.26	8.35	5.87	3.59	271	117
NY81.315.17	22.5	3.08	8.44	6.21	2.50	200	101
Vidal	20.9	3.04	11.11	6.19	5.85	141	74

At Orchard Mesa, all 25 varieties produced a crop. Harvest started with Marquette on 30 August 2019 and ended with ten varieties on 9 October 2019 (Table 3). A summary of fruit composition is presented in Table 4. Averaged across all varieties, yields were up slightly over 5 % compared to the 2018 season. On average, harvest date was 14 days later than 2018. Twentythree varietal wines were produced using micro-vinification techniques.

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

Variety	Harvest date 2019	Yield per vine (lb)	Yield (ton/acre)[1]
Albarino	26 September	9.55	4.55
Barbera	9 October	13.41	3.95
Cabernet Dorsa[2]	9 September	7.59	2.58
Cabernet Sauvignon	4 October	7.12	3.71
Carmenere[3]	9 October	8.54	4.65
Chambourcin[2]	9 October	12.40	4.50
Cinsault	9 October	19.40	5.72
Durif[2]	9 October	10.28	4.43
Graciano[3]	9 October	12.93	1.76
Grenache	9 October	12.11	1.92
Malvasia Bianca	19 September	11.11	4.28
Marquette[2]	30 August	9.28	3.37
Marsanne	25 September	10.36	3.05
Merlot	12 September	7.19	2.45
Mourvedre	9 October	11.39	4.39
Petit Verdot[3]	9 October	9.76	2.44
Refosco[3]	25 September	20.54	1.39
Roussanne	20 September	12.88	3.80
Souzao	9 October	7.62	2.59
Tinta Carvalha[3]	28 September	9.56	1.08
Tocai Friulano	4 October	15.23	0.69
Touriga National	9 October	6.35	1.58
Verdejo	4 October	16.77	0.76
Verdelho	13 September	8.50	2.12
Zweigelt[2]	2 October	8.70	4.54

[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 Chambourcin and 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 in 2019 for 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	24.8	3.29	6.37	5.86	2.16	128	82
Barbera	25.6	3.11	8.08	6.04	3.04	125	102
Cabernet Dorsa[1]	25.0	3.45	6.23	6.15	1.85	161	91
Cabernet Sauvignon	26.2	3.31	5.57	4.72	0.73	101	95
Carmenere[2]	24.9	3.68	4.49	5.00	0.87	83	95
Chambourcin[1]	25.7	3.02	8.00	5.75	2.28	100	74
Cinsault	24.3	3.51	5.20	4.78	1.37	129	108
Durif[1]	23.0	3.33	6.10	4.85	1.55	83	52
Graciano[2]	26.7	3.50	5.15	5.72	1.32	73	73
Grenache	25.2	3.28	5.28	4.95	0.12	121	108
Malvasia Bianca	22.5	3.38	6.24	5.90	2.29	64	61
Marquette[1]	29.9	2.98	8.43	3.82	3.26	343	148
Marsanne	20.2	3.38	6.04	5.66	2.25	94	78
Merlot	26.0	3.40	5.90	6.52	1.06	78	78
Mourvedre	22.9	3.32	6.41	5.19	1.81	79	66
Petit Verdot[2]	26.0	3.37	6.57	5.07	2.62	79	142
Refosco[2]	22.2	3.27	7.53	6.16	3.26	94	82
Roussanne	21.9	3.36	7.07	6.17	2.75	114	77
Souzao	25.1	3.30	6.57	5.66	2.19	86	86
Tinta Carvalha	23.2	3.48	5.58	4.87	1.37	176	98
Tocai Friulano	25.7	3.45	4.74	4.41	0.59	111	90
Touriga National	25.4	3.40	5.46	4.86	1.11	100	87
Verdejo	26.3	3.40	5.22	3.78	1.06	151	94
Verdelho	26.2	3.14	6.59	6.22	1.08	141	122
Zweigelt[1]	25.0	3.17	6.05	7.17	0.05	166	135

[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.

- 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. Low vine vigor in 2018, bud damage from cold temperatures during the dormant season, some damage from a late spring frost, and some hail damage all contributed to very low yields in 2019 (Table 5). Vine vigor at this site continues to be weak.

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 2019	Yield (ton/acre)[1]
Aromella		n/a
Chambourcin	8 Oct 2019	0.04
Frontenac	8 Oct 2019	0.64
La Crescent	8 Oct 2019	0.20
Marquette	8 Oct 2019	0.49
Vignoles		n/a

[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). On average, yields were down by 43 % compared to 2018 while harvest was later by 7 days. Yield decreases ranged from 6 % for Marquette to 84 % for Arandell. A summary of fruit composition is presented in Table 7.

Brianna was harvested on two different dates to evaluate the influence of fruit maturity on wine characteristics. Thirteen varietal wines were produced using micro-vinification techniques.

One unexpected observation at his 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. Another vine died between harvest 2018 and spring 2019, and two more vines between harvest 2019 and spring 2020. After six growing seasons less than 50 % of the vines are still alive.

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

Variety	Harvest date 2019	Yield (ton/acre)[1]
Arandell	25 September	0.65
Aromella	16 September	4.86
Brianna	16 & 20 August	3.27
Cayuga White	26 September	3.35
Chambourcin	11 October	1.23
Corot noir	13 September	2.20
La Crescent	23 August	4.39
Marquette	23 August	3.69
Noiret	13 September	2.62
St Vincent	11 October	0.96
Traminette	3 October	1.85
Vignoles	13 September	0.55

[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 in 2019 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	22.5	3.85	5.01	6.04	1.95	312	78
Aromella	21.9	3.47	6.08	6.02	1.82	244	90
Brianna 1st harvest	20.8	3.53	6.99	5.84	2.57	335	84
Brianna 2nd harvest	21.2	3.63	5.33	4.95	1.79	308	87
Cayuga White	20.9	3.34	6.45	7.27	0.71	198	106
Chambourcin	23.7	3.05	8.92	8.54	1.86	146	89
Corot noir	22.3	3.56	5.17	6.86	0.49	222	91
La Crescent	25.4	3.10	10.75	6.35	6.86	233	80
Marquette	28.3	3.17	8.79	4.16	3.95	469	174
Noiret	21.1	3.48	6.16	7.36	1.43	185	84
St Vincent	19.3	3.03	8.93	7.88	1.72	118	79
Traminette	24.2	3.31	6.13	5.76	1.11	160	87
Vignoles	26.7	3.19	7.63	5.78	2.21	203	94

2. *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, 2018, and 2019. Presently there are 18 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 80 % 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. Rootstock research is now a high priority area and three further trials, all located on commercial vineyards in the Grand Valley, have been initiated since 2017.

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.

There was no or minimal bud damage during winter 2018/19. Average yield per cropping vine in 2019 was 12.8 lb, identical to the yield in 2018. However, vine survival is very low for several rootstocks, resulting in very low yields per acre (Table 8). Compared to 2018, the yield per acre was up 0.9 ton with 5BB and about 0.3 ton with 5C, 1103P, and own-rooted vines, but down 0.3 and 0.4 ton for 140Ru and 110R, respectively.

Table 8: Effect of rootstock on vine survival after 11 years and yield in 2019 of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield (ton/acre)
110R	57	3.56
140Ru	18	1.57
1103P	50	3.99
5BB	64	4.76
5C	86	5.07
Own-rooted	96	5.15

- 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 1.6 miles East of WCRC-OM. The following rootstocks are included: 110 Richter, 140 Ruggeri, 1103 Paulsen, 1616C, 101-14 Mgt, 3309 Couderc, Riparia Gloire, Salt Creek, Schwarzmann, SO4, and Teleki 5C. The 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. Graft union were uncovered again in spring of 2019. Vine assessment showed 250 out of 258 vines originally planted were still alive. There was 100 % vine survival with eight rootstocks but some vine mortality with rootstocks 5C (2), 1616C (1), and 140Ru (5).

  Although most vines carried a crop in 2019 no harvest data is available as the vines mere mistakenly harvested by a picking crew after the early freeze event on 11 October 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, 1616C, 101-14 Mgt, 3309 Couderc, Riparia Gloire, Salt Creek, Schwarzmann, and SO4. Green potted vines on rootstock Teleki 5C were planted on 14 June 2018. There was a shortage of vines grafted to 5C, 1616C, and 1103 Paulsen. Missing vines were planted in June of 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 of 2018, shortly before a killing frost, we observed minimal hardening of the shoots. That suggested that most of the canes would need to be pruned back to just a few buds near the soil as most of the shoot tissue remained green and thus would not survive the low winter temperatures. Indeed, none of the tissue above the soil mound was alive in spring 2019 and growth resumed from buds that were under the soil mound. Vine inspection in summer 2019 revealed 11 dead vines: 6 on rootstock 110R, 2 each on 101-14 and 140Ru, and 1 on SO4.

Vine vigor was high in 2019 and there was nearly 100 % primary bud kill from the record freeze on 30 October (see Table 11, page 17). Consequently, vines need to be retrained again during the 2020 season from live buds below 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 in late June 2019 on a grower cooperator's vineyard in the western part of Orchard Mesa. The site is located about 1.6 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 very sandy with a high percentage of large gravel, and at present highly alkaline. 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. 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*; *V. berlandieri* x *V. riparia*; *V. riparia* x *V. rupestris*, *V. solonis* x *V. riparia*) will be evaluated.

  The trial is set up as a randomized complete block design with 6 replications, and 4 vines per replication. Vines are irrigated by micro-sprinklers. The following rootstocks were planted on 28 June 2019 using green potted vines: 110 Richter, 1103 Paulsen, Teleki 5C, SO4, 101-14 Mgt, 3309 Couderc, and 1616C.

  Vine establishment in 2019 was very good. However, just as in the 2018 Cabernet Sauvignon trial, there was significant damage from the record freeze on 30 October. Observations in late May 2020 showed no growth on 18 vines (out of a total of 168). The highest mortality of 33 % was with rootstock 1103 Paulsen followed by 1616C at 21 %.

- 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. Graft unions were protected again with soil in late fall 2018.

After the leaves had dropped the fall of 2018 an assessment was made of the potential to retain canes for cropping in 2019. Only about 7 % of the vines had sufficiently strong shoot growth that two canes could be tied to the cordon wire and fill the allocated space (5 feet). Another 32 % had enough growth to tie down one cane. About 51 % had insufficient growth to tie down a cane, and thus produce a crop in 2019. At 10 % vine mortality by the end of the second season was rather high.

Inter-planted vines produced the equivalent of 0.16 ton per acre in 2019 compared to 1.6 ton per acre from the mature vines. Both yields are way too low to meet annual operating costs. It is reasonable to expect a yield of 1 to 2 ton per acre in year 3 so inter-planted vines produced less than 10 % of what is expected. It should be noted, however, that the inter-plant study is located within our long-term cover crop study and this area is managed according to the needs of the cover crop vines, not the interplants. With better care of inter-planted vines it should be possible to achieve strong growth in years one and two so that old, phylloxera-infested vines can be removed after the second growing season and a crop of 1 to 2 ton per acre can be produced in year three. Nevertheless, the results indicate that vine development and yields will be depressed unless special attention is paid to 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. In spring, 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. Hence, a study was initiated in 2017 to evaluate if planting grafted vines with the graft union just below the soil surface would result in no or minimal root development from the scion.

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 holes were only partially filled so that the graft unions did not get covered by soil. In late fall, more soil was added to those holes right up to the level of the soil surface. Graft unions will remain covered for the remainder of the experiment. Graft unions of Control vines with graft unions placed 2” above the soil are covered every fall and uncovered again the following spring.

Five vines were lost in the first growing season and/or after the first winter: one control vine; one vine with graft union at 2” below ground; and three vines with the graft union at 4” below ground. Two of the lost vines were drip irrigated and three were irrigated by micro-sprinkler. Prior to hilling up soil around the graft unions again in fall 2018, root development from the scion and the rootstock was evaluate 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. 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.

Assessment of root development was repeated in the fall of 2019. Root development was evaluated on 3 vines per treatment. The vines selected were vines that had not been evaluated in the fall of 2018, i.e. the soil / root system had not been disturbed for two years (since covering the graft union in fall of 2017). Similar to 2018, all but 2 vines had roots emerging from above or right at the graft union (see Photos). Further, there appeared to be more roots with drip irrigation compared to micro-sprinkler, and the root diameter appeared to be bigger. A similar trend for less and smaller roots with micro-sprinkler irrigation was also noted in the fall of 2018. It should be noted that drip-irrigated vines are more vigorous than vines irrigated by micro-sprinkler, which may explain the differences in root number and diameter. As a result of the higher vine vigor with drip irrigation the yield in 2019 was more than two-fold that with micro-sprinkler irrigation (1.38 ton per acre with drip; 0.66 ton per acre with micro-sprinkler). Another possible explanation for more roots in the drip irrigation treatment is the higher frequency of irrigation events (in mid-summer 2-3 times per week compared to once per week with micro-sprinklers). More frequent wetting may encourage root development near the soil surface in the drip irrigation treatment.

Photos show root development from the scion part (above the graft union) at the end of the third growing season 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.

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

  Cold hardiness tests were initiated in mid-October 2019. Tests with varieties Chardonnay and Syrah have been conducted on an approximately weekly basis. 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).

  Record-breaking cold events on 30 and 31 October 2019 illustrate why it is important to know the cold acclimation pattern of different varieties. In the early morning hours of 30 October 2019, the temperature dropped to 8 F at WCRC-OM, which is 12 F lower than the previous low temperature record for that day. Likewise, the low for 31 October 2019 was 9 F, which is 6 F below the previous record. In fact, the National Weather Service office in Grand Junction reported this to be the first time since record keeping began in 1895 that a single-digit low temperature has been recorded for Grand Junction in the month of October.

  We used this "opportunity" to determine the level of bud damage on all the varieties grown at WCRC-OM, the Viognier rootstock trial at WCRC-OM, a clonal trial with Cabernet Franc located about 2 miles East of WCRC-OM, as well as two rootstock trials with Cabernet Sauvignon in the Grand Valley. In early November, twenty canes were collected from each variety and the basal five nodes on each cane evaluated (i.e. 100 buds per variety). Tables 9 through 13 show the percentage of live primary buds as well as the percentage of buds killed entirely.

Table 9: Bud damage of Viognier grafted to five different rootstocks or own-rooted growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO from extreme low temperature events in late October 2019.

Rootstock	Live primary bud (%)	Dead bud (%)
110R	59	27
140Ru	62	24
1103P	77	13
5BB	73	18
5C	74	18
Own-rooted	44	39

In the Viognier rootstock trial, the lowest survival of the primary bud and the highest bud mortality was found with own-rooted vines (Table 8). Over 70 % primary buds were alive with Viognier grafted to 1103P, 5BB, and 5C. These graft combinations also had the lowest percentage of dead buds (<20 %).

Primary bud survival of 3-year old Cabernet Sauvignon ranged from 66 % when grafted to 101-14 and 1103P to >90 % when grafted to 3309 and Schwarzmann (Table 10). The situation was very different in the second rootstock trial with Cabernet Sauvignon. Vines in the second trial are only two years old. Bud mortality was >90 % in five out of six rootstocks tested; the exception being 3309 with 78 % bud mortality (Table 11).

Table 10: Bud damage of 3-year old Cabernet Sauvignon grafted to 11 different rootstocks growing in the western part of Orchard Mesa near Grand Junction, CO from extreme low temperature events in late October 2019.

Rootstock	Live primary bud (%)	Dead bud (%)
5C	83	13
110R	75	17
140Ru	73	26
1103P	66	25
1616C	81	13
3309	92	4
101-14	66	19
Riparia Gloire	83	14
Salt Creek	70	28
Schwarzmann	93	6
SO4	71	19

Table 11: Bud damage of 2-year old Cabernet Sauvignon grafted to six different rootstocks growing in the western part of Orchard Mesa near Grand Junction, CO from extreme low temperature events in late October 2019.

Rootstock	Live primary bud (%)	Dead bud (%)
5C	1	96
110R	2	94
1103P	6	92
1616C	2	94
3309	20	78
Schwarzmann	4	92

Primary bud survival of varieties growing at WCRC-OM ranged from a low of 24 % for Barbera to a high of 100 % for Cabernet Dorsa and Marquette (Table 12). Late ripening varieties that were harvested immediately prior to the killing frost (e.g. Barbera, Cabernet Sauvignon, Cinsault, Durif, etc.) had much higher bud damage than varieties that were harvested well before the frost. This is indicative of a late onset of cold acclimation of those late ripening varieties and shows that these varieties are at a high risk of bud damage from hard fall freezes.

Table 12: Bud damage for 28 grape varieties growing at the Western Colorado Research Center – Orchard Mesa from extreme low temperature events in late October 2019.

	Live primary bud (%)	Dead bud (%)
Albarino	90	6
Barbera	24	67
Cabernet Dorsa	100	0
Cabernet Sauvignon	43	45
Carmenere	90	6
Chambourcin	98	0
Chardonnay	90	5
Cinsault	48	39
Durif	37	56
Garnacha tinta	73	17
Graciano	44	43
Malvasia bianca	87	6
Marquette	100	0
Marsanne	87	1
Merlot	76	7
Mourvedre	53	41
Petit Verdot	71	16
Noiret	98	2
Refosco	45	25
Roussanne	98	1
Souzao	58	18
Syrah	90	5
Tinta Carvalha	56	31
Tocai Friulano	89	7
Touriga National	61	28
Verdejo	91	5
Verdelho	95	2
Zweigelt	99	0

Primary bud survival of four clones of Cabernet Franc was >80 % with bud mortality of 5 % or less (Table 13).

Table 13: Bud damage of four clones of Cabernet Franc growing in the western part of Orchard Mesa near Grand Junction, CO from extreme low temperature events in late October 2019.

Clone	Live primary bud (%)	Dead bud (%)
FPS 01	83	4
FPS 04	81	5
FPS 09	96	1
FPS 11	97	0

The record low temperature event on 14 April 2020 is another example why it is important to understand the acclimation and de-acclimation pattern of different varieties. The damage from this late spring freeze event was nearly a reversal of the early hard freeze event in October 2019. In the fall event the highest damage was found on late ripening varieties that are slow to acclimate. The spring event damaged varieties that tend to have early bud break, i.e. that de-acclimate early. For example, Cabernet Sauvignon had nearly 50 % primary bud damage from the fall event but did not get damaged in the spring event. In contrast, there was about 15-20 % bud kill on Chardonnay and Syrah from the spring event, but these varieties had minimal damage from the fall event. The lethal temperature thresholds for 50 % bud kill (LT_{50}) determined from controlled freezing tests for Chardonnay and Syrah prior to the spring freeze event was >20 F and 16 F, respectively, while the value for Cabernet Sauvignon was 8.5 F.

Cold hardiness tests during the 2019/20 dormant season confirm the trends seen in previous years. Albarino, Cabernet Dorsa, and Zweigelt are generally more cold hardy than Chardonnay (Fig. 1). However, during the early part of the dormant season Albarino was less cold hardy than Chardonnay until mid-January. This confirms observations from the 2017/18 and 2018/19 dormant seasons that Chardonnay buds are more cold hardy than buds of Albarino early in the dormant season, indicating a faster acclimation of Chardonnay in fall compared to Albarino. In spring, however, Chardonnay de-acclimates earlier and faster and is less cold hardy than Albarino.

Multi-year data show that Cabernet Sauvignon and Souzao have similar mid-winter hardiness to Chardonnay but are slower to acclimate in fall and de-acclimate in spring (Fig. 1). Data from the 2019/20 dormant season confirm the results from the previous season that Carmenere has lower bud cold hardiness than Chardonnay for most of the dormant season but like Cabernet Sauvignon and Souzao is more cold hardy in late spring due to later de-acclimation and bud break (Fig. 1).

Based on two years of data (Fig. 2), 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} near or below -25 F). These initial values for mid-winter LT_{50} will need to be reassessed in future years.

Seven varieties were more cold hardy than Chardonnay throughout the 2019/20 dormant season: Arandell, Aromella, Brianna, Corot noir, La Crescent, St Vincent, and Vignoles. Marquette also was more cold hardy than Chardonnay except for the final observation in early April 2020. Marquette breaks bud before Chardonnay so lower cold hardiness is to be expected. It should be noted that we are including the data for Chardonnay as a benchmark, but that Chardonnay is grown at WCRC-OM whereas the cold hardy variety trial is located on the valley floor to the East of Clifton. Vine development at that site is several days behind the development of the same varieties grown at WCRC-OM. For example, in early April, Marquette grown at WCRC-OM was more than 12 F less cold hardy than Marquette from the variety trial site, and 17 F less hardy than Chardonnay grown at WCRC-OM.

Four varieties had similar or less cold hardiness than Chardonnay in fall but were generally more cold hardy from mid winter onwards: Cayuga White, Chambourcin, Noiret, and Traminette. This apparent slow acclimation in fall also explains the high level of primary bud damage that was found on those four varieties on samples taken after the record freeze event on 30 October 2019 (Table 14).

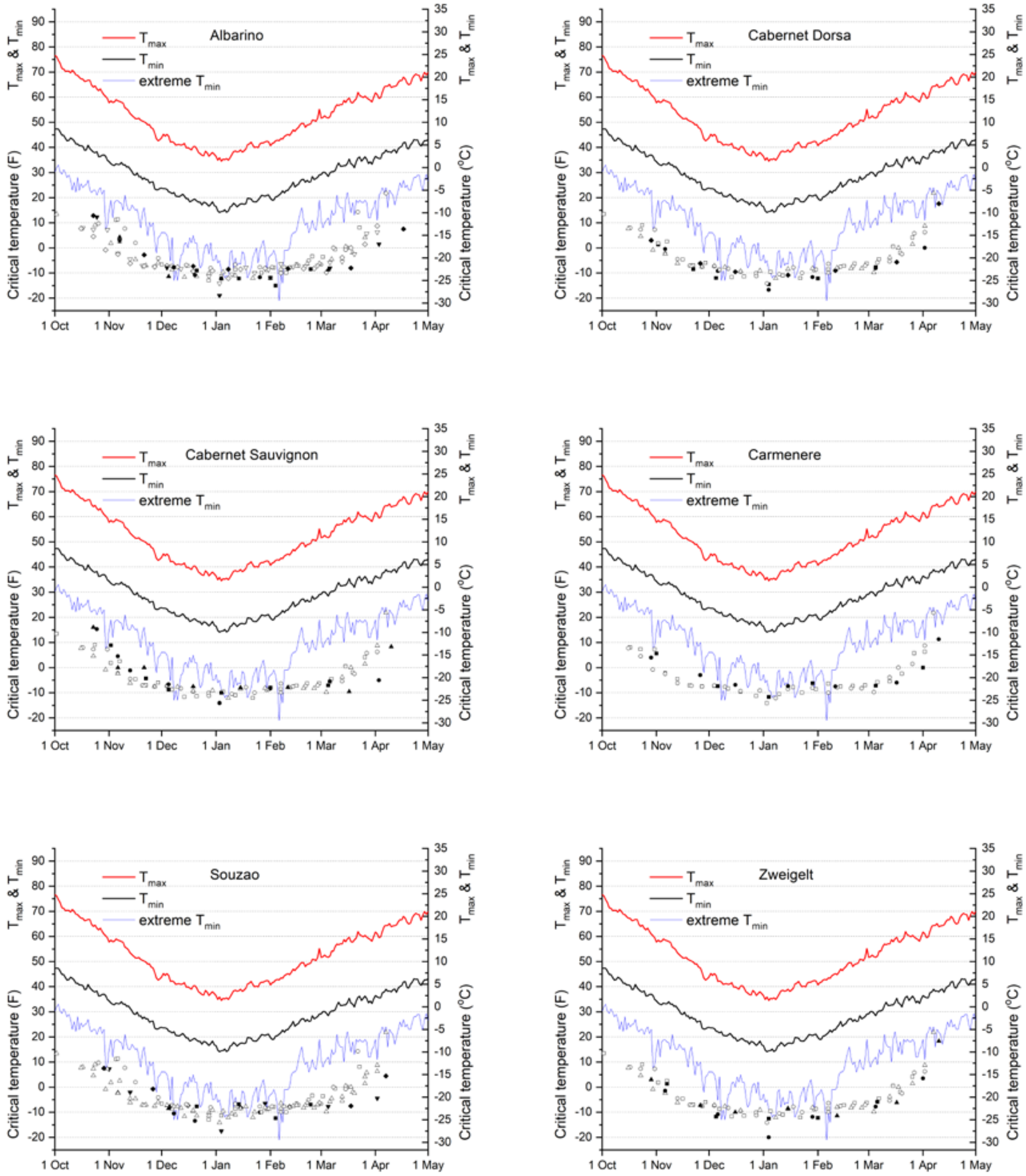

Fig. 1: Long-term average maximum, minimum, and extreme minimum temperatures at WCRC-OM and multi-year data for a 50 % primary bud kill (LT50) for Albarino (top left), Cabernet Dorsa (top right), Cabernet Sauvignon (middle left), Carmenere (middle right), Souzao (bottom left), and Zweigelt (bottom right) compared to Chardonnay (open symbols).

Results from the cold hardiness tests are made available via our Webpage, and growers are using this information when deciding if freeze/frost protection is needed.

Data are 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}).

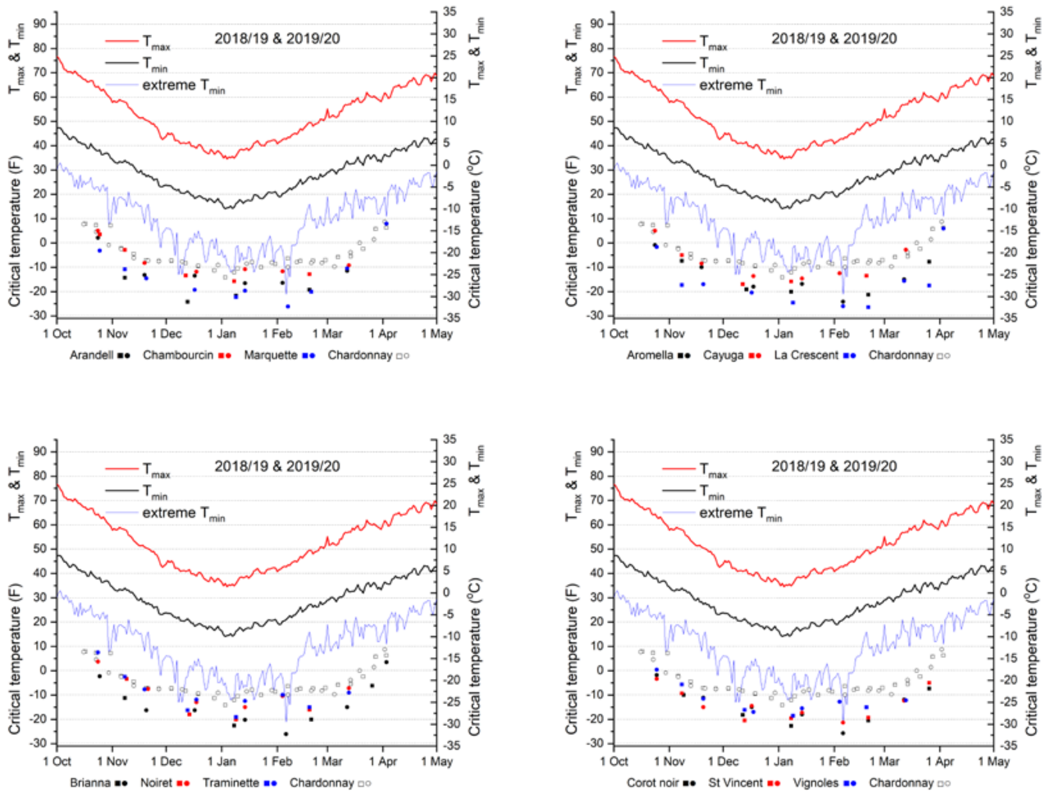

Fig. 2: Long-term average maximum, minimum, and extreme minimum temperatures at WCRC-OM and data from the 2018/19 (squares) and 2019/20 (circles) dormant season for a 50 % primary bud kill (LT_{50}) for 12 varieties included in the Grand Valley cold-hardy variety trial compared to Chardonnay grown at WCRC-OM.

Table 14: Bud damage of 12 varieties growing near Clifton, CO from extreme low temperature events in late October 2019.

	Live primary bud (%)	Dead bud (%)
Arandell	100	0
Aromella	100	0
Brianna	100	0
Cayuga White	50	30
Chambourcin	45	45
Corot noir	95	5
La Crescent	100	0
Marquette	100	0
Noiret	85	10
St Vincent	100	0
Traminette	70	20
Vignoles	95	5

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

- Fremont and Montezuma County temperature investigation (Schumacher, Goble, and Caspari)

    The largest limitation to expansion of wine grape production in the state of Colorado is cold air outbreaks. This report is a continuation of the Colorado Climate Center's investigation into which parts of Colorado stay warm enough on nights during cold outbreaks to be viable for introduction, or expansion, of viticulture. There are two major objectives: 1. Use in-situ data and gridded reanalysis data to explore temperature patterns on anomalously cold nights, and 2. Use long-term climate records and climate change research to understand how probability of damaging freezes are changing with time.

    Sensor Deployment: Thermometer networks were expanded in both Fremont and Montezuma Counties. The project now supports 37 reporting locations. Due to travel restrictions enforced by the COVID-19 pandemic, some of these data have not been collected for winter or spring 2020. While participating landowners were given instructions for downloading and transmitting data remotely, the technology was not compatible with everyone's personal devices. Winter data may be obtained at a later date, though data logger memories are now full; summer 2020 data is not being collected.

    FY 2020 Data: Colorado received its most notable temperature extremes in the shoulder seasons. The final week of October saw temperatures drop into the single digits, below zero in some cases, in both Fremont and Montezuma Counties. This cold was lethal, as the cold air arrived too early in the season for vines to be properly cold acclimated. Following a mild-to-near-normal winter, record cold temperatures were set again in April, but prior to vines coming out of dormancy.

    Observations from this year, and previous years, reveal consistent relative warm spots in Fremont and Montezuma County on cold winter nights. In Fremont County, the north and west ends of Cañon City are most likely to be the warmest spots on cold winter nights. Higher elevation sites may experience higher or lower minimum temperatures depending on strength of cold air drainage. In Montezuma County, McElmo Creek and the Ute Mountain Farm and Ranch stay warmer on cold winter nights than other areas of the county. Land to the north and west of Cortez, such as Lebanon, and Yellow Jacket, also stay warmer on cold winter nights than Cortez or Mancos, but with less consistency. Gridded model data and in-situ observations agree on magnitude of minimum temperatures during cold snaps, increasing confidence in model usage. However, the model commonly underestimates the strength of nocturnal temperature inversions on cold nights, creating a cold bias for high elevation stations.

    Trends: FY 2019's report used gridded weather data to identify the Delta, Olathe, Montrose area as an area suitable for viticulture exploration. Some vineyards are already there. We investigated the long-term climate record of the Montrose National Weather Service Cooperative Observer Network weather station. The Montrose COOP station has been reporting daily maximum temperature, minimum temperature, average temperature, and precipitation since 1900. Increases in average temperatures are statistically significant both annually and seasonally with the most rapid increases in the last 30 years. Climate model studies suggest that minimum temperature extremes should trend upwards in all seasons in southern Colorado by mid-century (e.g. Rangwala et al., 2012). Despite the events of fall 2019, long-term climate data do show declines in dangerous freeze events for Montrose County. Trends in fall cold snaps that kill vines prior to reaching full dormancy are not clear as the sample size of such events is small. Mid-winter cold snaps are growing less intense over time.

Thermometer Deployment Scheme 2020: The project has net five new stations. This project now supports a total of 37 reporting locations, and uses data from an additional 14 (either Colorado State Mesonet or National Weather Service sites).

In Montezuma County, two stations were added (Yellow Jacket 2W, Yellow Jacket 4W), but two stations were retired (McElmo E, and Cortez NW 2). The two added sites are west of Yellow Jacket (Fig. 3), which was one of the largest "exploration opportunity" areas identified in FY 2019. The area west of Yellow Jacket benefits from both warmer nighttime winter temperatures than Cortez, and rich soil profiles according to modeled and observational data. Thanks to enthusiastic study participants, coverage in Fremont County has increased by five stations. This includes expanding coverage to the Florence and Portland areas (Fig. 4).

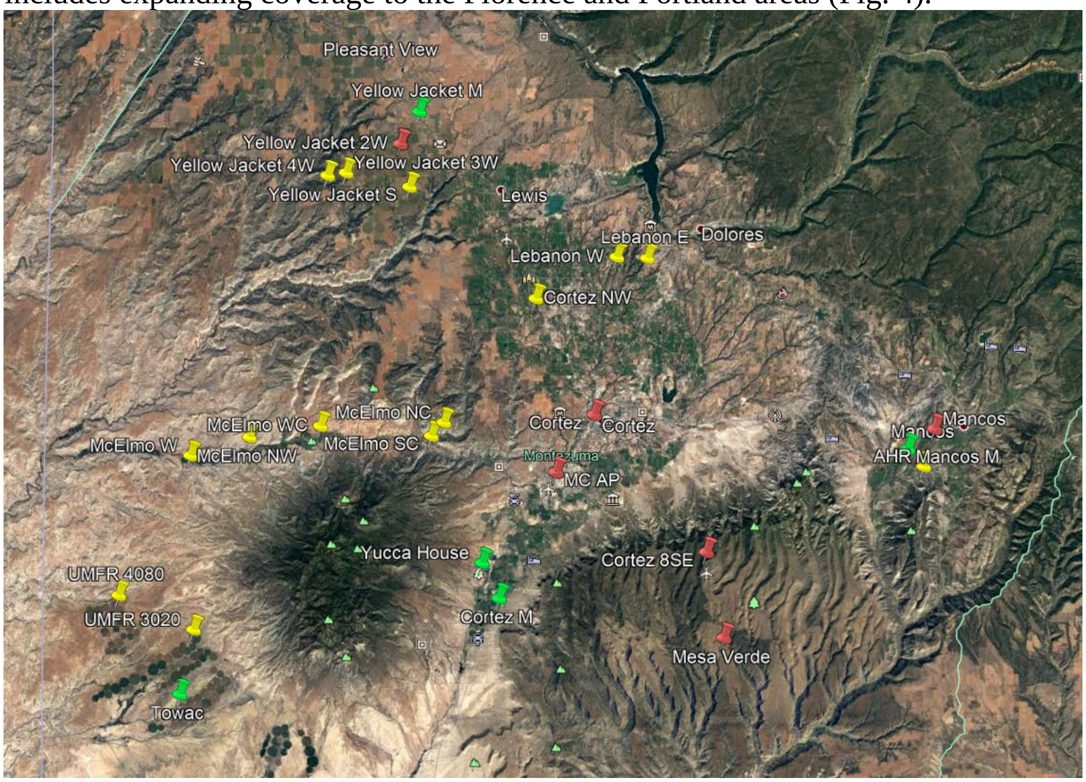

Fig. 3: Thermometer placement in Montezuma County. Red = National Weather Service site. Green = State Mesonet site. Yellow = Study-specific site.

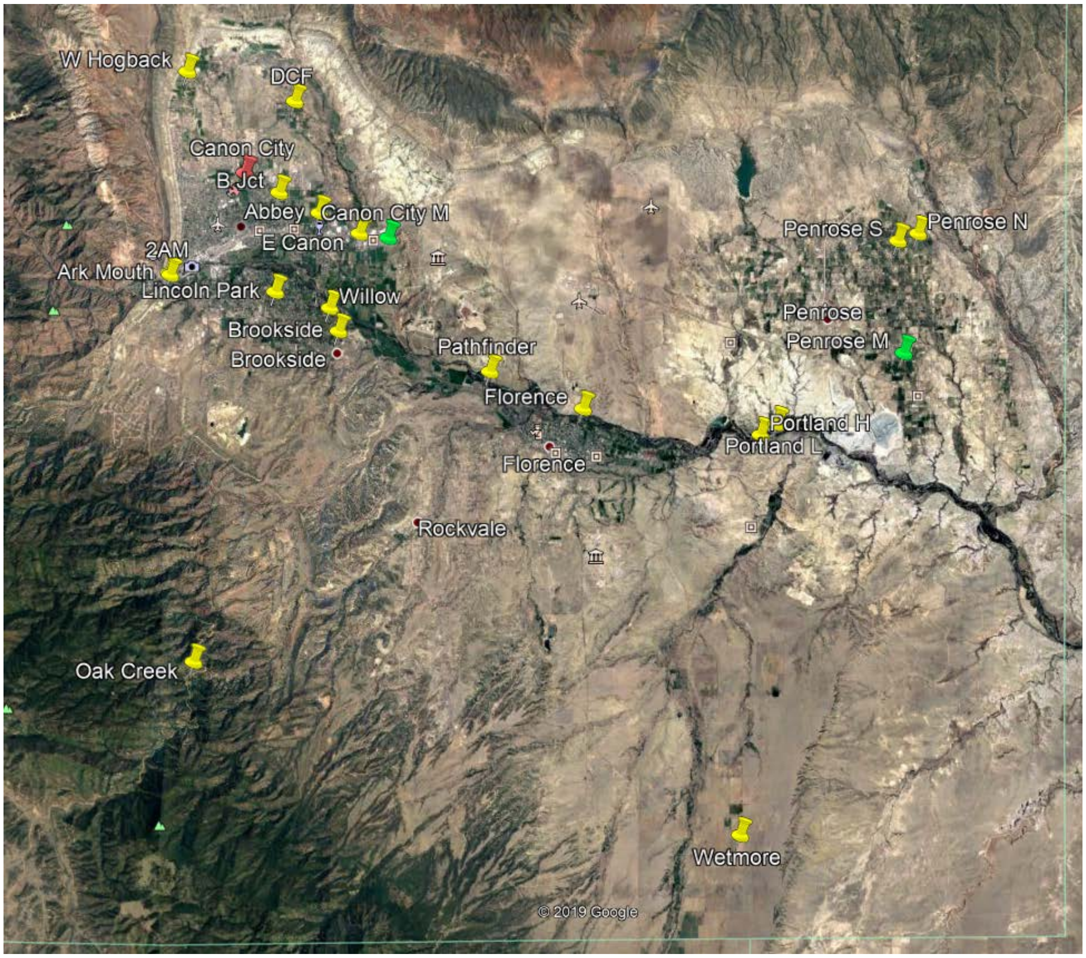

Fig. 4: Thermometer placement in Fremont County. Red = National Weather Service site. Green = State Mesonet site. Yellow = Study-specific site.

Web Presence: The Colorado Climate Center has created a webpage with some general information about Colorado weather's relation to viticultural success (http://climate.colostate.edu/climate_wine.html). This content has been shared via social media.

COVID-19 Impacts: Due to pandemic-related travel restrictions, the Climate Center has not been able to gather data from Montezuma County for winter 2020. Fremont County data were collected from 50 % of project-specific sites thanks to the support of thermometer hosts. Missing data will be available for analysis when collected later; spring and summer data will be lost.

Data collected in fall 2019 were used to examine the anomalous late October cold snap in western Colorado. Winter 2020 cold snaps were still analyzed using daily PRISM 4km data bias corrected to 800-meter resolution, in-situ data from NOAA weather stations, CoAgMET weather stations, and available study-specific sites in Fremont County.

October 2019 Freezes: The state of Colorado experienced its 3rd coldest October on record in 2019 (NCEI 2020). There were two record-setting cold snaps: The first one occurred on October 10 and 11. Temperatures dropped into the teens in both Cañon City and Cortez. These were record lows for both locations. The cold weather was punctuated by a cold snap in the last week of the month. The Walker Field station in Grand Junction reached a temperature of 6 F. This is the lowest temperature ever recorded in October at Walker Field by 10 F, and the lowest in the last 20 years by 14 F (Fig. 5). Cold snaps at this time of year can be catastrophic, as temperatures reaching far below freezing prior to vines becoming fully acclimated can cause substantial bud, cordon, and trunk damage and, in the worst case, can be lethal.

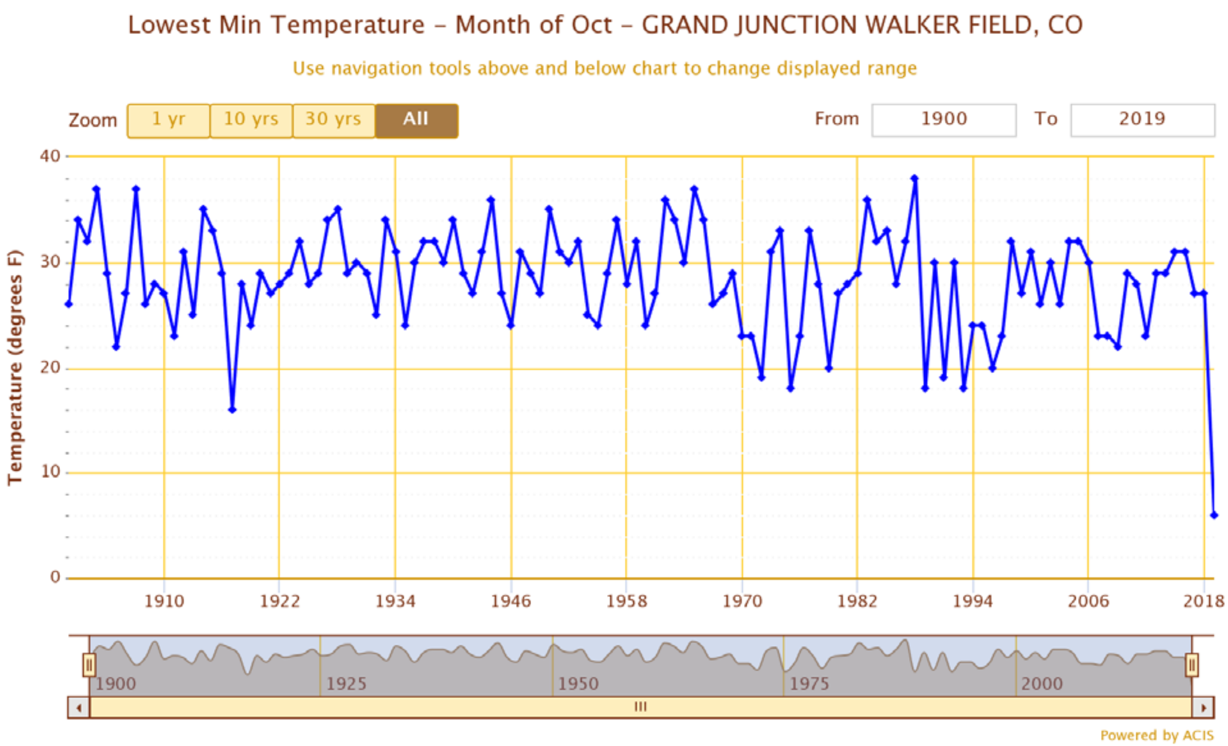

Fig. 5: Timeseries of minimum monthly temperatures during October at the Grand Junction Walker Field Cooperative Observer Network Station.

Temperatures were unusually low across all of Colorado during this period. Many of the currently active viticultural centers in Colorado experienced their lowest October temperatures ever recorded. Cooperative observer network stations in Grand Junction, Montrose, Cortez, and Cañon City all set all-time record low October temperatures (Table 15). All four of these stations have been recording daily maximum and minimum temperatures for over 90 years. Palisade reached a low temperature of 12 F, one degree above the record.

Previous reports have indicated that Cortez generally experiences lower overnight minimum than much of its surroundings. Due to favorable drainage winds, areas to the north of town, and in McElmo Canyon, are typically warmer on cold winter nights. Areas to the south are also typically warmer. The late October cold snap proved, at least in part, to be an exception to this rule (Fig. 6). Cortez reached a low temperature of 7 F on the morning of October 31, 2019. This was warmer than low temperatures experienced in Yellow Jacket, Lebanon, Mesa Verde, and the east end of McElmo Canyon. The warmest temperatures recorded in the county were in NW Cortez, western McElmo Canyon, and on the Ute Mountain Farm and Ranch (11-12 F). These areas are warmer on average.

Table 15: Low temperatures at viticultural centers across Colorado for October 2019.

2019 October Low Temperatures in Viticulturally Active Areas of Colorado

	Low Temperature	Departure from Previous Monthly Record Low	Previous Year of Record	Period of Record
Palisade	12	+1	1917	1911-present
Grand Junction	6	-10	1917	1900-present
Montrose	7	-2	1917	1895-present
Cortez	7	-5	1929	1929-present
Cañon City	-3	-5	1917	1893-present
Boulder	3	+5	1917	1893-present

Some cold weather events in Montezuma County produce strong elevation-driven temperature inversions, where the highest elevation stations stay warmest. For example, on January 2, 2019 the Cortez Montezuma County Airport weather station reached a low of -14 F (elevation 5,910 ft). The Cortez 8 SE station recorded a low of +9 F (elevation 8,034 ft). Such elevation-driven temperature stratification cannot be relied upon in all cold events. The October 2019 cold snap is an example. The Montezuma County Airport recorded a minimum temperature of +2 F. Cortez 8SE reached a minimum of 0 F, one of the coldest stations in the county. The PRISM temperature model is less likely to be accurate in cold snaps with strong inversions. Since a strong inversion was not present in Montezuma County on October 31, 2019, PRISM modeled the event well. The largest discrepancy between modeled and observed temperature was 10 F at the Cortez NW station.

October low temperatures in Fremont County were slightly less variable than Montezuma County, and cold air more ubiquitous. Temperatures ranged from -8 F (Pathfinder) to +6 F (Oak Creek Grade, Ark Mouth, and DCF) (Fig. 7). Both the Oak Creek Grade and DCF stations are situated on hillsides, encouraging cold air drainage. The Ark Mouth station, as suggested by the name, is located at the mouth of the Royal Gorge. Cold air drainage is also prevalent in canyons, with temperatures typically warming downwind. Previous investigations have suggested that Penrose and Wetmore are generally cooler than Cañon City and Brookside on cold winter nights. This was true in the Halloween cold snap with Penrose lows at -5 or -6 F, and Cañon City/Brookside temperatures ranging from -3 to 6 F. Modeled and observed temperatures were in the same range, but the model missed areas where temperatures were the warmest. The model had a bias of -8 F for Oak Creek Grade, -7 F for DCF, and -5 F for the Ark Mouth station.

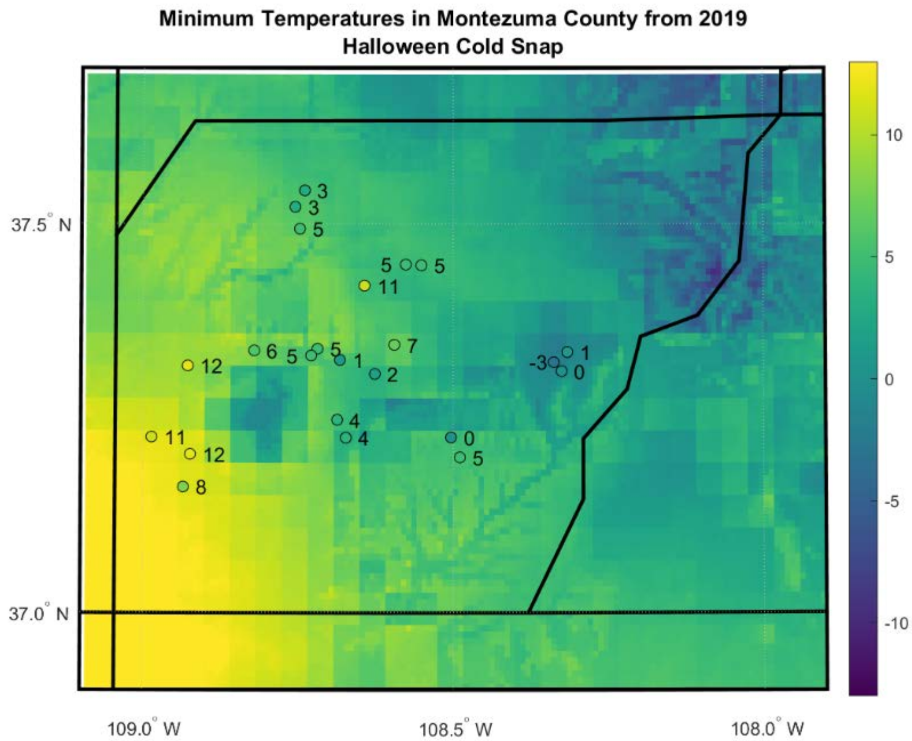

Fig 6: October low temperatures for Montezuma County. Gridded data are bias corrected PRISM data. Dots represent observation sites.

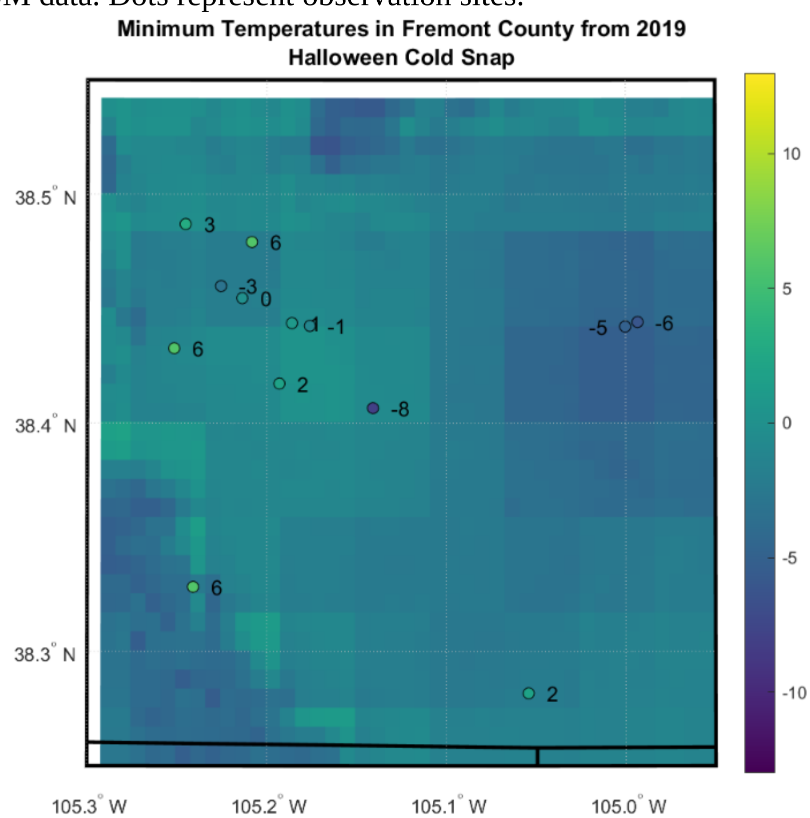

Fig. 7: October low temperatures for Fremont County. Gridded data are bias corrected PRISM data. Dots represent observation sites.

Winter 2020: Colorado experienced a milder winter than normal in 2020. Model results indicated that the average of the lowest 10 winter temperatures in far southwest Montezuma County was on par with Palisade. Cañon City, which has been labeled previously as the warmest location in Colorado in winter, was similar to Boulder in Water Year 2020 (Fig. 8).

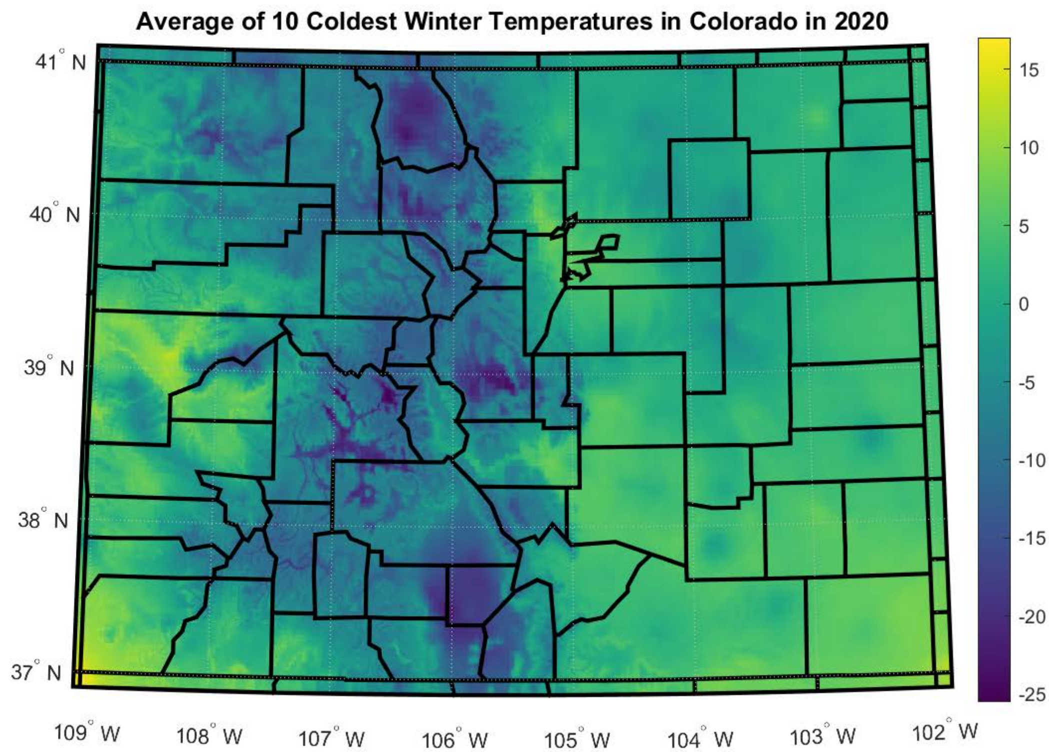

Fig. 8: Modeled average of 10 coldest temperatures from Water Year 2020.

Minimum Water Year 2020 temperatures were +2 F in Cortez, and -3 F in Cañon City. For Cortez, this ranks as a tie for the fourth highest minimum annual temperature since 1930. For Cañon City, -3 F is tied for the 36th highest annual minimum temperature since 1893. The 2020 winter did bring cold snaps to Colorado, but nothing from November-March was near record breaking (Fig. 9, Fig. 10). The year's coldest air in Cañon City was a tie between October 31, 2019 and February 5, 2020. The winter's coldest air in Cortez occurred on February 5, 2020.

Spring 2020 brought cold air as well. Record cold air impacted Cañon City on April 14 and 15 (lows of 8 and 15 F, respectively). The season's final freezes did not occur until early-to-mid May, right around bud break. Cañon City reached a low temperature of 29 F on May 10. Cortez' final freeze was 31 F on May 8.

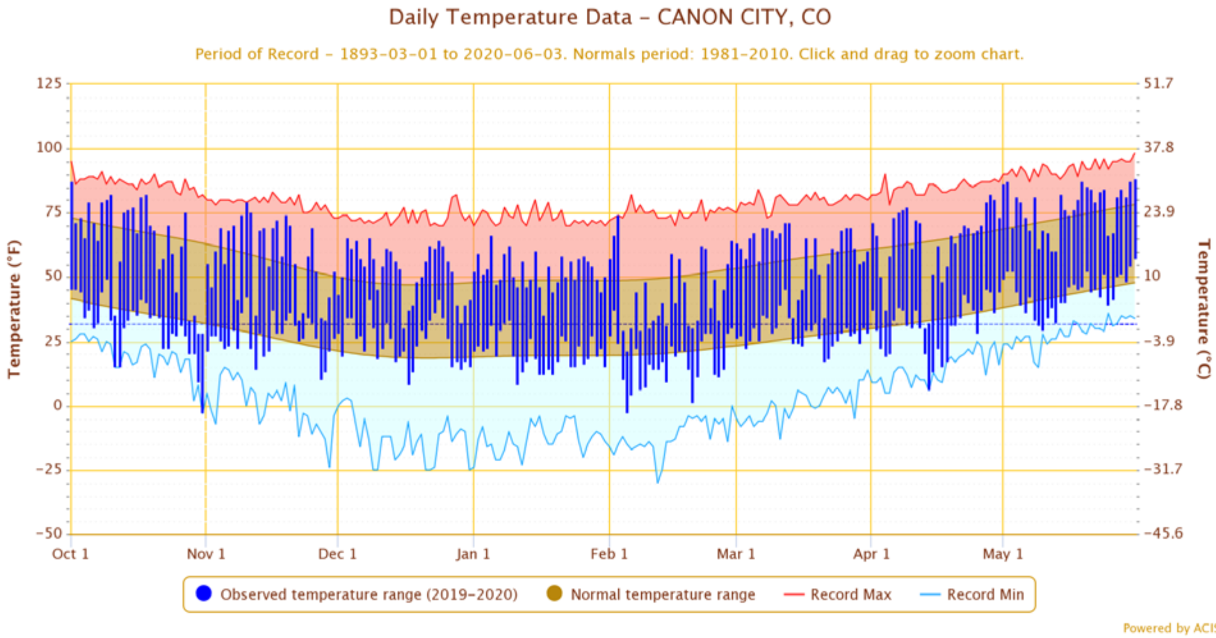

Fig. 9: Water Year 2020 temperature timeseries for Cañon City, CO.

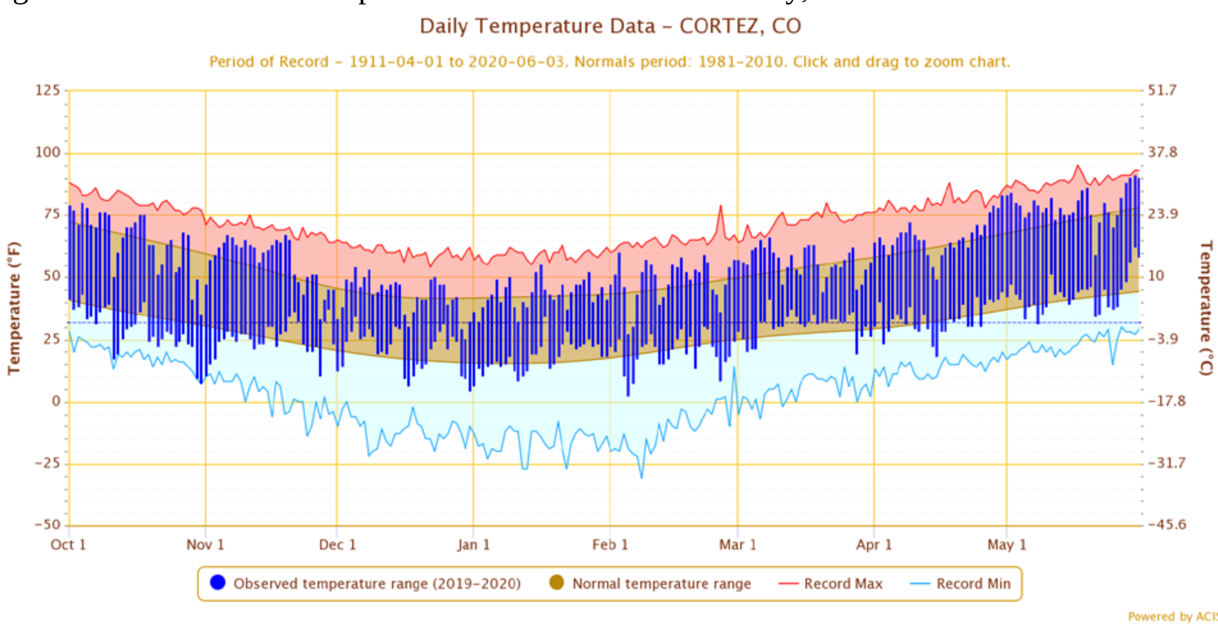

Fig. 10: Water Year 2020 temperature timeseries for Cortez, CO.

The most consequential cold spell to viticulture activity in both Fremont and Montezuma Counties was the late October cold spell. The other cold spells of similar magnitude occurred in February, when such air masses are expected to impact Colorado. These events are unlikely to have damaged vines. Here we examine temperature patterns during the two coldest days in February for Fremont and Montezuma County using the PRISM model, and an observational dataset, which has been limited by COVID-19.

The two coldest winter 2020 mornings in Fremont County were February 5 and 20. The Cañon City COOP station recorded low temperatures of -3 and +1 F on these mornings, respectively. DCF was the warmest station in the county on both occasions with minimum temperatures of +4 and +8 F respectively (Fig. 11). The Ark Mouth station was the second warmest. These two stations were among the warmest during the October cold snap, and have been among the warmest in previous studies. The PRISM model underestimated daily low temperatures for both these stations. Fremont County February 5 minimum daily temperatures were warmest on the north and west sides of Cañon City, decreasing with altitude to the south and west, but also decreasing to the east. The Willow station produced an outlying low temperature of -13 F, 13 F lower than modeled by PRISM. Observations at Pathfinder were likewise cooler in observations than models.

February 20 temperatures ranged from -3 F at Willow to +8 F at DCF (Fig. 11). The PRISM model shows a similar range. The model also indicated warmer minimum temperatures southeast of Cañon City, but these are not evident in observations.

Neither February event produced unusual temperature inversions with height. The Oak Creek Grade Station is located at 6,730 ft, over 1,000 ft above the second highest station (W Hogback). Oak Creek Grade was the fifth coolest station on February 5, and ran middle of the pack on February 20. The PRISM model underestimated the February 5 inversion, showing Oak Creek Grade as the coolest station.

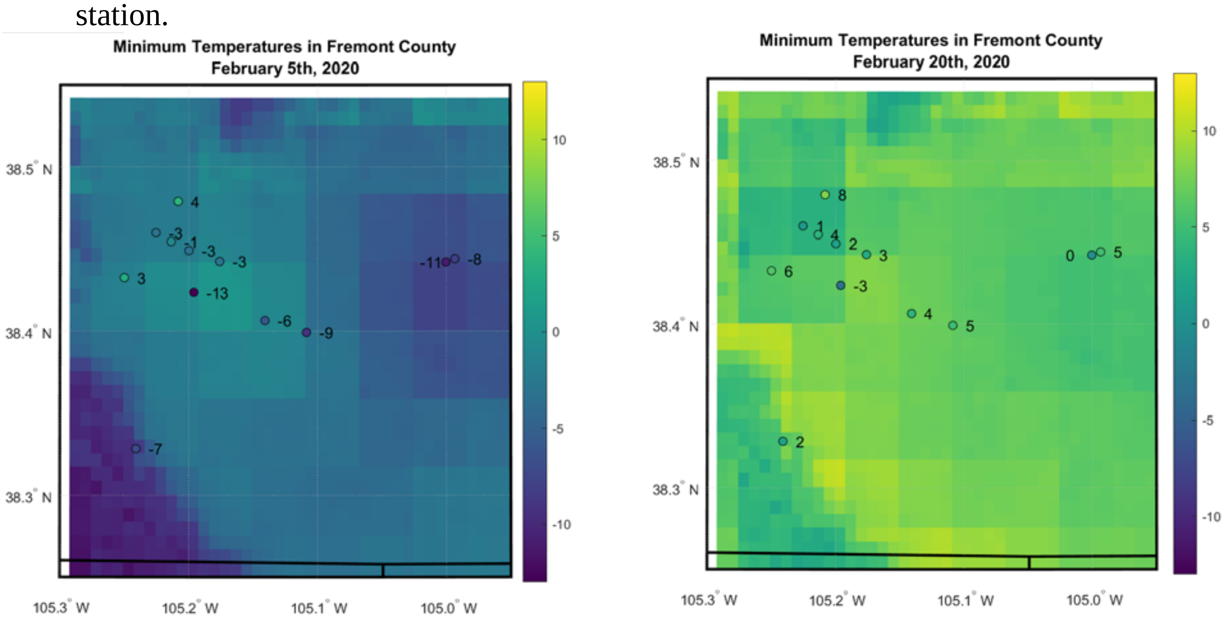

Fig. 11: Low temperatures in Fremont County on February 5 (left), and February 20, 2020 (right). Gridded data are bias corrected PRISM data. Dots represent observation sites.

Montezuma County's two coldest spells outside of October were both in February as well; February 5 and 26. Modeled and observed conditions in both cases agree on an east-west temperature gradient with terrain effects (Fig. 12). Mancos is consistently cooler than Cortez and Yellow Jacket. McElmo Creek and Mancos River near the state line were the warmest areas with potential access to irrigation water.

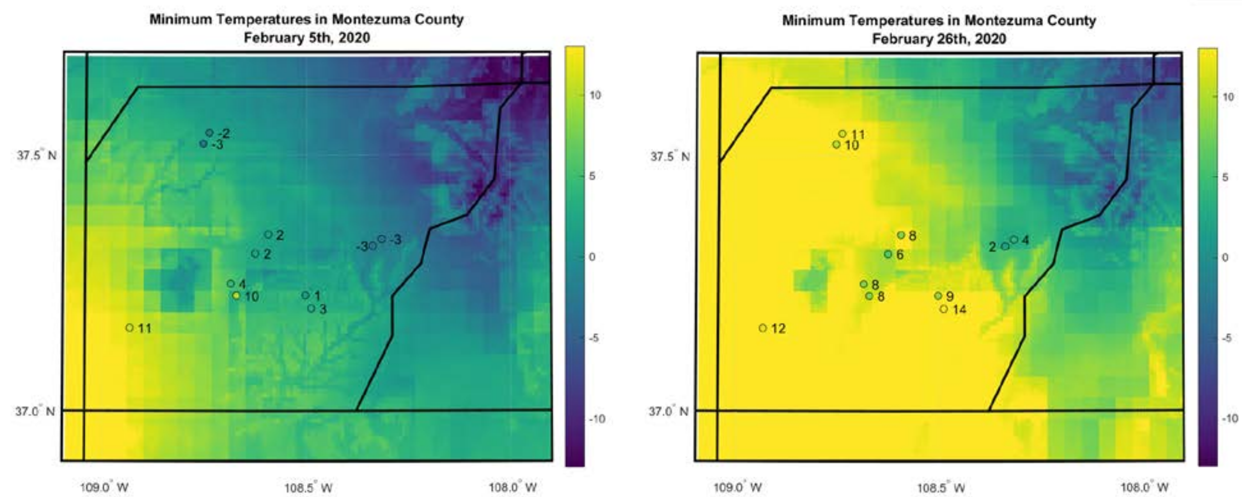

Fig. 12: Low temperatures Montezuma County on February 5 (left) and February 26, 2020 (right). Gridded data are bias corrected PRISM data. Dots represent observation sites.

West Slopes Historical Climate Investigation:

A number of locations across the state of Colorado present opportunities for expansion of the local viticulture industry. The Colorado Climate Center has used long-term stations to investigate the historical probabilities of dangerous freeze events in these locations. Thus far, the Climate Center has analyzed long-term records from Cortez and Mesa Verde in Montezuma County, and from Cañon City in Fremont County. In this experiment, data were analyzed from the Montrose #2 station in Montrose Colorado.

Montrose #2 was chosen due to FY 2019's report, which used PRISM model data and soil moisture model data to identify "exploration opportunities" for the viticultural industry in Colorado. Montrose #2 is a common sense selection due to its excellent reporting history as well. The station has reported maximum and minimum daily temperatures from the beginning of water year 1896 to present date. The station was moved once, in 1906. It has been stationary ever since under the supervision of the Uncompahgre Water Users Association. Data from the station are nearly complete, but imperfect. The station's daily temperature record is 95.1% complete over its 124-year period of record. The largest data quality issue for this station may be the changing land usage around it. Parking lots and storage facilities have encroached on the site.

In this section, we analyze the time series of daily temperature and precipitation data for Montrose #2, noting significant trends. Trends in maximum, minimum, and average daily temperature, and precipitation accumulation, are analyzed. Statistical significance is determined using a Mann Kendall test for serial correlation. We then quantify the number of potential killing freezes for European wine grape varieties each decade from September 1900 - February 2020 (as used in FY 2019). An event is considered a killing freeze if it meets one of the following five conditions:

i. A rapid onset of seasonally-unprecedented cold air in fall (temperatures in October of less than 10 F, and at least 10 F cooler than the season's previous coldest air, or temperatures of less than 0 F in November, and at least 10 F cooler than the season's previous coldest air

ii. Deep cold in early winter (below -5 F before January 1)

iii. Extreme cold in mid-or-late winter (below -15 F anytime)

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

v. A fall freeze (32 F or lower) prior to harvest (estimated as September 30)

As is the case for most of Colorado, the US, and the world, average temperatures have trended significantly upwards for Montrose, CO. This trend has accelerated since the 1980s.Temperature increases have been highest in summer and fall (Table 16). Warming progression has not been linear, nor consistent from one season to the next (Figs. 13-18).

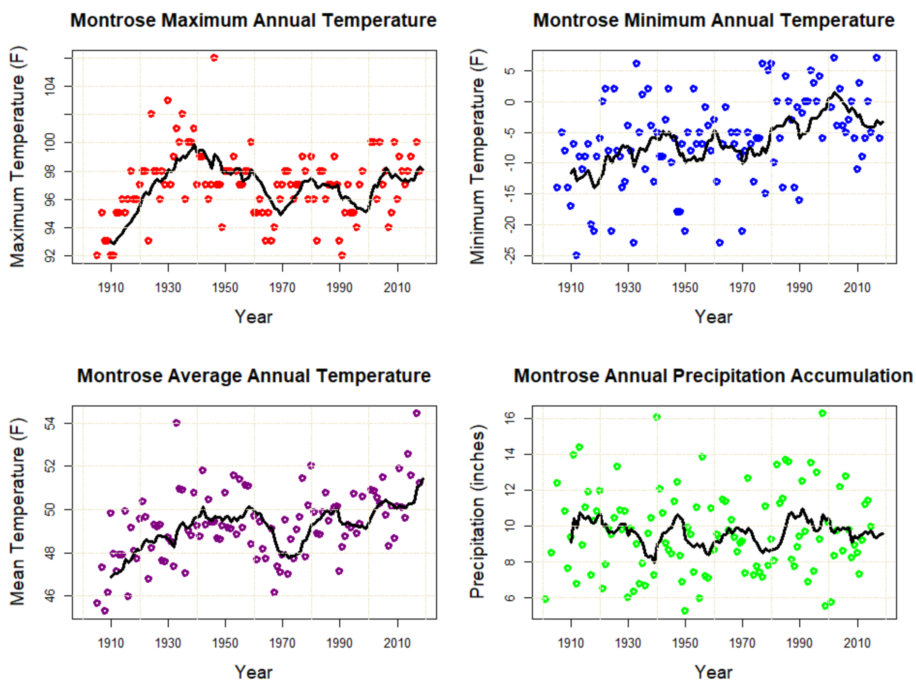

Fig. 13: Time series of annual maximum (upper left, red), minimum (upper right, blue), and average (lower left, purple) temperatures, and annual precipitation accumulation (lower right, green). Colored circles show annual data. Black lines show decadal averages.

While warming has occurred, and is expected to occur based on changes to atmospheric greenhouse gas concentrations, Montrose also experiences seasonal, multi-year, and even multi-decadal climate variability. Montrose warmed more between 1910 and 1950 than from 1950-present. This included a string of anomalously cold years in the 1970s.

Notably for grape growth, Montrose experienced temperatures below -15 F in 13 years between 1910 and 1991. Montrose has not reached a minimum temperature of -15 F since (Figs. 13 and 14). Upward trend in winter minimum temperature is significant at 99% confidence (Table 16). While weather events such as October 29-

31, 2019 are not inspiring, freeze events deemed dangerous for European grape varieties are declining (Table 17). There were an average of six years/decade with at least one dangerous freeze event between 1900 and 1950. That number is down to just three years/decade from 1991 to 2020.

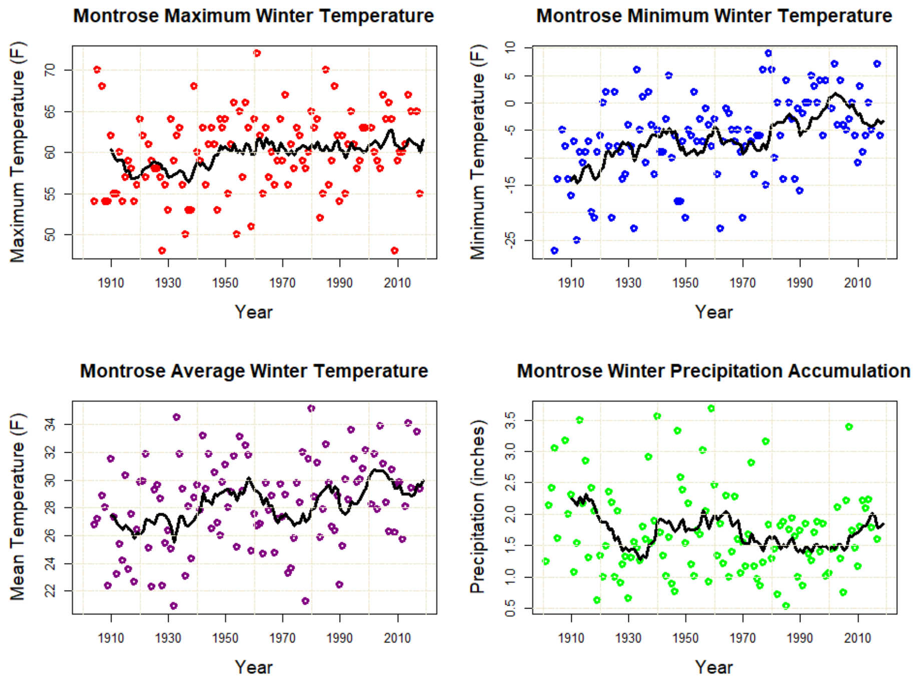

Fig. 14: Time series of winter (DJF) maximum (upper left, red), minimum (upper right, blue), and average (lower left, purple) temperatures, and precipitation accumulation (lower right, green). Colored circles show annual data. Black lines show decadal averages.

Type one freezes are a proxy for the most dangerous/costly freeze damage. Because of their rarity, trends in type one freezes are unclear. These events have occurred at most three times/decade through the historical record. There is a clearer signal number of type two and three freezes/decade, meaning less intense winter cold snaps. Such a trend bodes favorably for the success of progressively more diverse grape varieties. However, more reductions are needed, as even one freeze/decade may destroy long-term profit margins for producers.

Precipitation is trending neither up nor down for Montrose, which is consistent with other parts of western Colorado, and future climate projections. Montrose annual precipitation does vary considerably from one year to the next. Accumulations have varied by over a factor of two annually, ranging from under 6” to over 16”.

Precipitation seasonality has not changed notably over time. The wet season is August and September, which is driven by the North American Monsoon. Even then, only 0.5-0.7” of precipitation is expected every fifteen days. Furthermore, even wet years are indicative of a semi-arid climate. As with Palisade and Grand Junction, irrigation water for grapes would be needed. Irrigation water would come from streamflow fed by seasonal mountain snowpack.

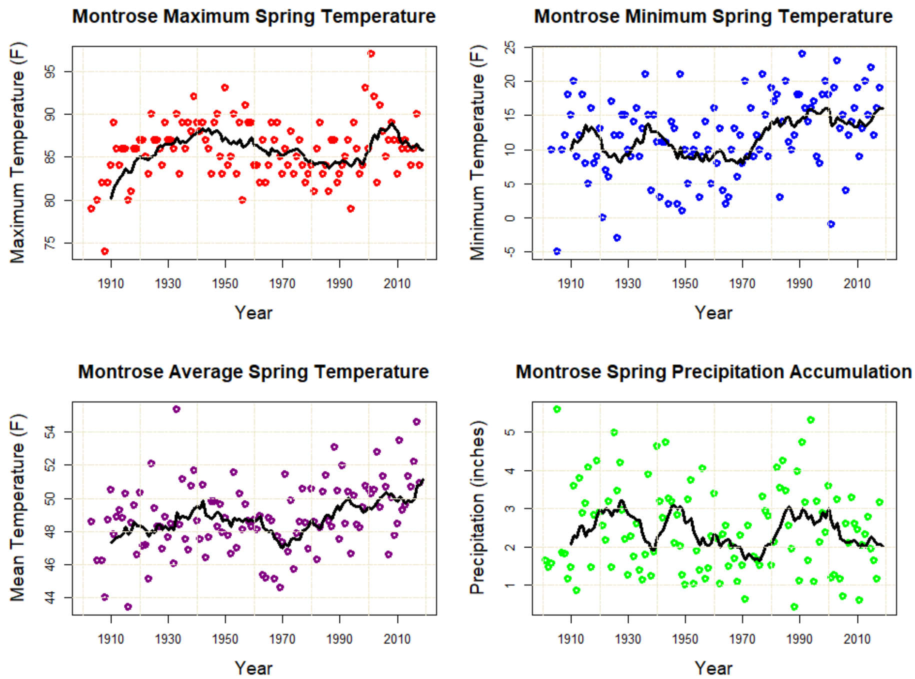

Fig. 15: Time series of spring (MAM) maximum (upper left, red), minimum (upper right, blue), and average (lower left, purple) temperatures, and precipitation accumulation (lower right, green). Colored circles show annual data. Black lines show decadal averages.

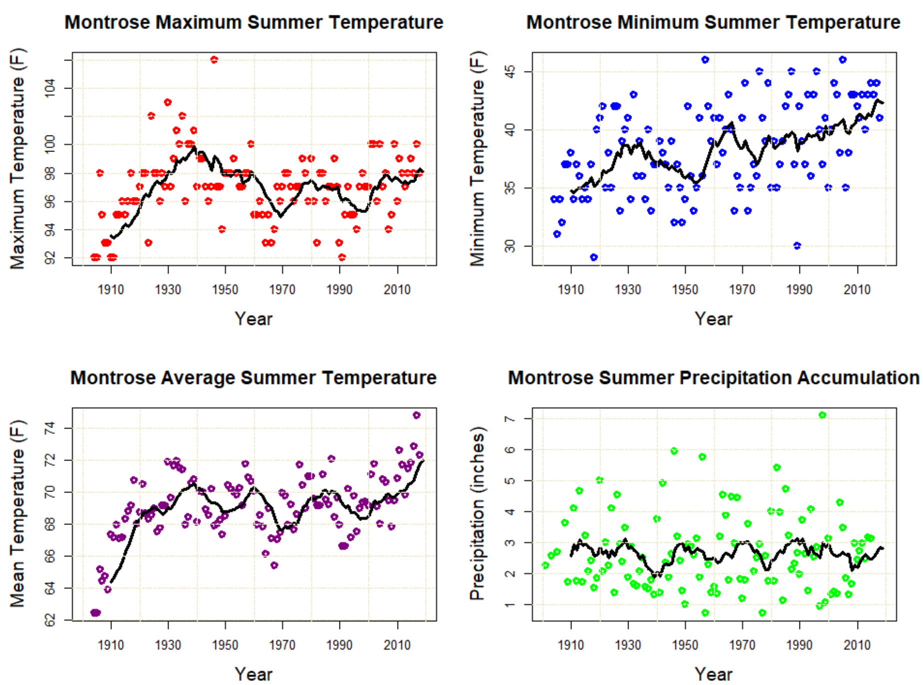

Fig. 16: Time series of summer (JJA) maximum (upper left, red), minimum (upper right, blue), and average (lower left, purple) temperatures, and precipitation accumulation (lower right, green). Colored circles show annual data. Black lines show decadal averages.

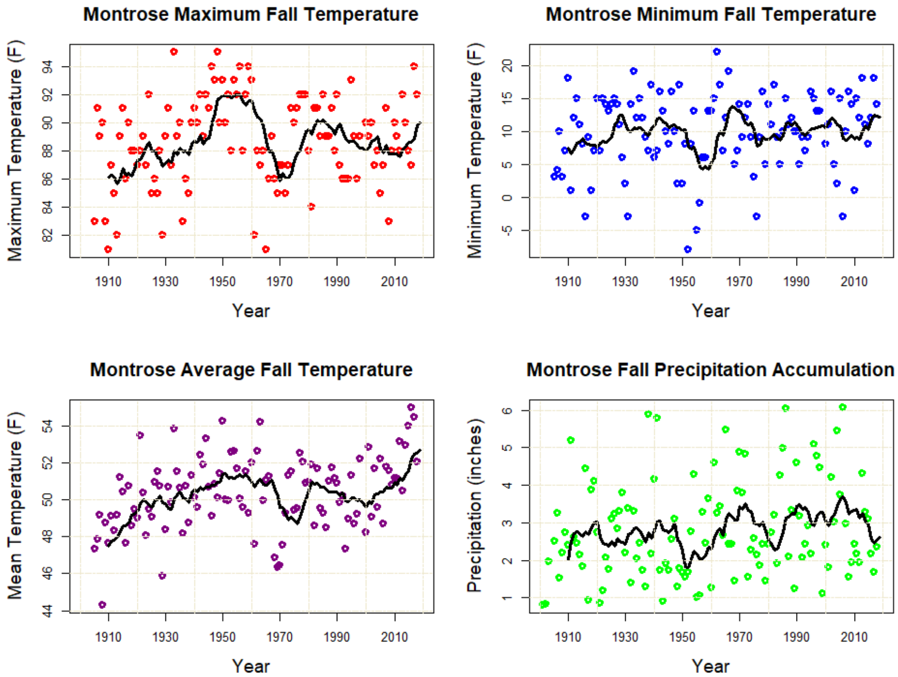

Fig. 17: Time series of fall (SON) maximum (upper left, red), minimum (upper right, blue), and average (lower left, purple) temperatures, and precipitation accumulation (lower right, green). Colored circles show annual data. Black lines show decadal averages.

Table 16: Trends in winter (DJF), spring (MAM), summer (JJA), and fall (SON) maximum, minimum, and mean temperatures (F/decade), and precipitation ("/decade). Statistically significant trends are shaded in yellow (95 % confidence), and orange (99 % confidence).

Trends in Temperature (F/decade) and Precipitation ("/decade) at Montrose Weather Station from 1951-2020

	Maximum Temperature	Minimum Temperature	Mean Temperature	Precipitation
Winter	0.29	0.14	0.11	-0.03
Spring	-0.09	1.15	0.42	-0.06
Summer	0.05	0.55	0.29	0.05
Fall	-0.27	1.15	0.30	0.05
Annual	0.06	0.21	0.25	0.07

Trends in Temperature (F/decade) and Precipitation ("/decade) at Montrose Weather Station from 1981-2020

	Maximum Temperature	Minimum Temperature	Mean Temperature	Precipitation
Winter	0.41	0.90	0.66	0.14
Spring	0.55	0.69	0.65	-0.25
Summer	0.59	1.18	0.85	-0.04
Fall	0.14	0.38	0.79	-0.29
Annual	0.59	0.91	0.69	-0.33

Table 17: Number of damaging freezes/decade for European grape varieties at Montrose #2 weather station

Number of Damaging Freeze Occurrences/Decade by Freeze Type for European Grape Varieties at Montrose #2 Weather Station

	1	2	3	4	5	6
1901-1910	0	2	2	1	5	5
1911-1920	2	5	3	1	5	10
1921-1930	0	3	3	0	4	6
1931-1940	1	2	3	0	2	5
1941-1950	0	1	3	0	3	6
1951-1960	3	1	0	1	1	4
1961-1970	0	2	2	0	3	4
1971-1980	1	2	1	0	2	3
1981-1990	0	1	2	0	4	5
1991-2000	0	1	0	0	2	3
2001-2010	0	1	1	0	2	4
2011-2020	1	1	0	0	1	3

1. A rapid onset of seasonally-unprecedented cold air in fall (temperatures in October of less than 10 F, and at least 10 F cooler than the season's previous coldest air, or temperatures of less than 0 F in November, and at least 10 F cooler than the season's previous coldest air
2. Deep cold in early winter (below -5 F before January 1)
3. Extreme cold in mid-or-late winter (below -15 F anytime)
4. A hard spring freeze (28 F or lower) following bud break (estimated as May 15)
5. A fall freeze (32 F or lower) prior to harvest (estimated as September 30)
6. Any of type 1 to 5

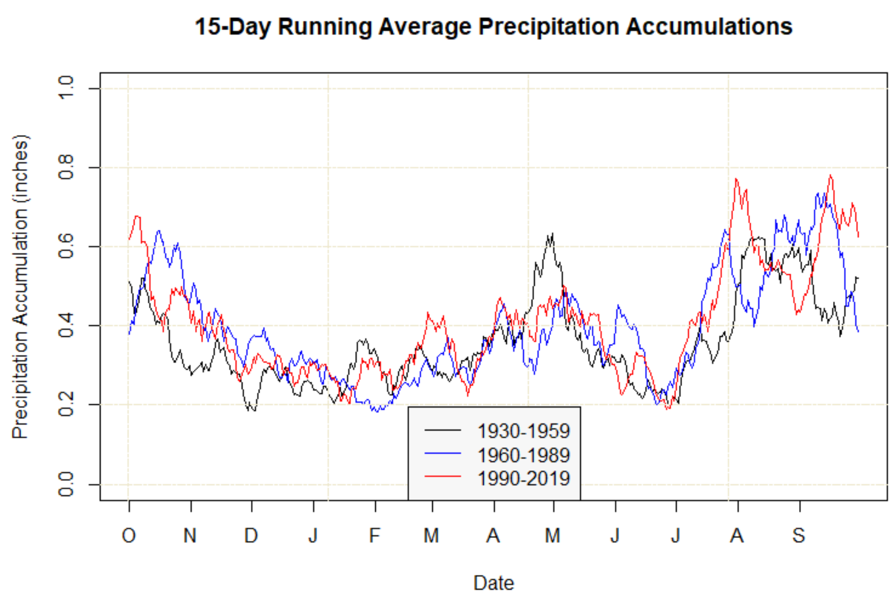

Fig. 18: 15-day moving average precipitation accumulations for each day of water year aggregated over the 1930-1959 (black), 1960-1989 (blue), and 1990-2019 (red) time frames.

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 using 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 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 2019, 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 several times during the remainder of the season.

  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 four 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. 5). A higher availability and/or uptake of

---

[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.

nitrogen by vines with a legume cover crop is also implied by much higher nitrogen levels in the musts seen every year since 2015 (Fig. 19). Treatment effects on all other nutrients in the leaves have been inconsistent between the years.

Leaf nitrogen concentrations at veraison show a continuous decline between 2015 and 2019 for all treatments (Fig. 19). In 2015, leaf nitrogen concentration averaged 2.99 % across all cover crop treatments. By 2019 the leaf nitrogen concentration at veraison averaged only 2.45 %. This continuous decline in vine nitrogen status is not evident from must nitrogen data. The yeast-assimilable nitrogen (YAN) concentrations increased from 2015 to 2017 before a big decline in 2018. The much lower YAN concentrations in 2018 are most likely due to the high 2018 yields. Average yields in 2016 and 2017 were 1.69 ton per acre compared to 4.10 ton per acre in 2018. In fact, the 2018 yield was the highest in over 20 years, despite the fact that part of the vineyard is negatively affected by phylloxera. There was a small increase in YAN concentrations from 2018 to 2019 in all cover crop treatments except the legume. However, YAN concentrations in 2019 remain much lower than from 2015 to 2017 suggesting a potential carry-over effect from the high 2018 yields.

A review of five years of juice chemistry data shows some other consistent, albeit subtle differences between the cover crop treatments. Juice from the legume treatment always has had the lowest concentration of soluble solids yet the highest pH, likely due to the consistently lowest concentration of tartaric acid. Juice from the crested wheatgrass treatment has had the highest concentration of soluble solids and the lowest concentration of malic acid in four out of five years. No clear trends are noticeable for the other cover crop treatments.

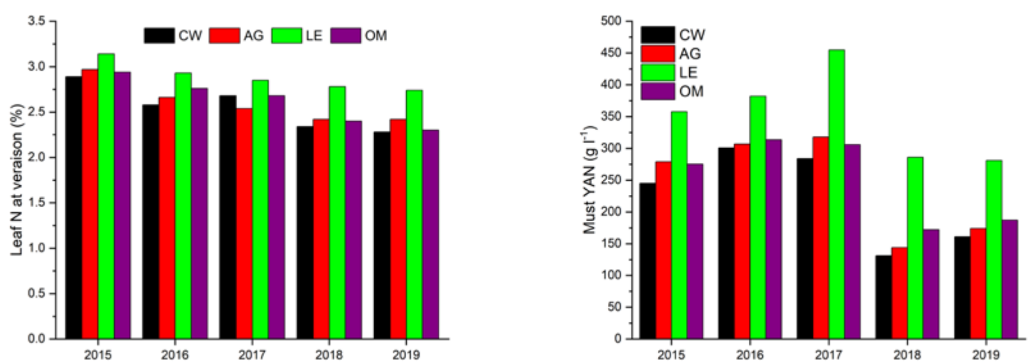

Fig. 19: Effect of cover crops on nitrogen concentration of Chardonnay leaf blades at veraison (left); and on the yeast-assimilable nitrogen (YAN) concentration of Chardonnay musts in 2015, 2016, 2017, 2018, and 2019 (right).
CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated, vines in AG, LE, and OM are irrigated by micro-sprinklers.

The average yield per acre in 2019 was 2.17 ton compared to 4.10 ton in 2018. The average for own-rooted vines (3 reps) was 1.59 ton while vines grafted to rootstock 5C averaged 3.89 ton (1 rep). Vigor and yield of own-rooted vines are declining as phylloxera is spreading through the block. Vines with a legume cover crop had the highest yield (2.60 ton/acre) followed by the Aurora Gold (2.45

ton/acre), crested wheatgrass (2.15 ton/acre), and orchard mix (1.48 ton/acre) treatments.

Drip-irrigated vines received 15.6” of irrigation water during the 2019 season whereas a total of 31.4” was applied in the micro-sprinkler irrigated plots. The irrigation volumes applied in drip were 3.4” lower than in 2018 but about 1” higher for micro-sprinkler. The irrigation system was winterized earlier in October 2019 compared to other years due to earlier-than-normal freezes which limited late season irrigation. A killing frost on 11 October limited further water loss through vine transpiration. Seasonal rainfall (1 April to 31 October) was 3.6” with 3.24” occurring before the end of June. July through to October was very dry with only 0.35” of precipitation recorded. Reference evapotranspiration for the period 15 April to 15 October was 48.5”.

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 is affecting 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 scarce.

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.

All treatments overwintered well. Cover crops were mowed very frequently in 2019 to suppress native grasses and weeds and allow the stand of the selected grasses to thicken. The density of the turf has increased throughout the 2019 season.

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 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, and powdery mildew 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 managed the vineyard during the 2019 season. The three replicated rootstock studies - two with Cabernet Sauvignon and one with Souzao (see above) - are other examples where the research is sited in commercial vineyards. Also, growers often grant us access to vineyards to collect canes for cold hardiness evaluation (e.g. clonal trial with Cabernet Franc) or install sensors for temperature monitoring (e.g. climate mapping in Fremont and Montezuma County). 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 sent out in late November / early December 2019. All forms were sent electronically. Reminder emails were sent in mid-January and mid-June. By late June 2020 we had received 59 responses (representing 117 vineyard sites) totaling 484 acres. In comparison, the completed 2018 survey had 80 responses covering 137 vineyard sites. The preliminary results of the 2019 survey are:

- Again a large production but down from 2018
- 1,725 ton production reported so far

- Total production >2,000 ton (taking into account non-responses)
- Around 7 % of production did not get utilized compared to 15 % in 2018
- Average yield of 3.7 ton/acre; down 0.3 ton/acre from 2018
- Average price of $1,602/ton, a 4.4 % decrease over 2018
- Very few new plantings in 2019
- Vineyard area planted appears to be less than the area removed

LITERATURE CITED

Rangwala, I., J. Barsugli, K. Cozzetto, J. Neff, and J. Prairie. 2012. Mid-21st century projections in temperature extremes in the southern Colorado Rocky Mountains from regional climate models. *Clim. Dyn.* 39: 1823–1840. https://doi.org/10.1007/s00382-011-1282-z