Annual Report

July 1, 2020 – June 30, 2021

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, two student interns (one from Colorado State University and one from Western Colorado Community College), and seasonal temporary staff at WCRC.

In addition to small-scale wine lots produced from cultivar trials two larger scale enological trials were conducted in collaboration with two Grand Valley wineries (Centennial Cellars, Peachfork Orchards and Vineyards). One trial evaluated the effect of different timings of tannin additions on the sensory characteristics of Marquette wines. The second collaborative trial explored the potential of several novel yeasts to enhance the varietal characteristics of wine made from two aromatic *Vitis vinifera* cultivars – Gewürztraminer and Viognier.

Weather conditions in the Grand Valley were warmer than average from July to November, but slightly below average in December. August was the warmest since record-keeping began at the Western Colorado Research Center – Orchard Mesa (WCRC-OM) in 1964. A season-ending killing frost occurred on October 26 for most growing areas in Western Colorado.

Vine development and crop ripening was very early in 2020, due to the above-average temperatures from before bud break to late October. A light crop – the result of bud damage from extreme low temperatures event in late October 2019 and in mid-April 2020 – also contributed to the earliest start of the harvest season on record. Only a small fraction of grapes was still hanging at the beginning of October.

Two extreme low temperature events (late October 2019 and mid-April 2020) resulted in significant bud damage on many cultivars. Although there was some fruit on all 48 cultivars grown in the research vineyards less than half produced more than 2 ton per acre, with one quarter producing less than 1 ton per acre. Averaged across all cultivars the

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yield in 2020 was down about 40 % compared to 2019. A similar drop in yield of 35 % is shown in data from the 2020 Colorado Grape Grower Survey. Survey data further indicate a grape surplus of less than 5 % in 2020, much lower than in the previous three years.

An extreme low temperature event occurred on 26 and 27 October 2020 with overnight lows dipping below 10 F. This was only the second time that single digit lows have been recorded in October. This extreme cold event caused much more bud damage than the extreme low temperature event in October 2019. A survey in the Grand Valley showed 100 % or near 100 % kill of fruitful buds on all but a few *Vitis vinifera* cultivars. Cold-hardy interspecific cultivars had minor or no bud damage. Temperatures dipped to near or below 0 F in many locations in Delta and Montrose County, and data from our cultivar trial at the Organic Agriculture Research Station – Roges Mesa show high levels of bud damage even on some cold-hardy interspecific cultivars. As *Vitis vinifera* cultivars account for approximately 80 % of Colorado's grape production the outlook for the 2021 harvest is a state-wide crop loss of at least 80 %, with near 100 % loss in Delta and Montrose County.

There were no further extreme cold temperature events after 27 October 2020, and there was no additional cold damage for the remainder of the dormant season. The dormant season minimum temperature recorded at WCRC-OM was 7.0 F on 2 January 2021. Mean monthly temperatures for January, April and May 2021 were slightly warmer than average while February and March were average. June 2021 was the second warmest on record with a six day heatwave of >100 F in the Grand Valley at the end of the second / beginning of the third week. The daily maximum temperatures during those six days set new records. The average daily high temperature at WCRC-OM from 1 to 22 June was 96 F, which is 9.8 F above the long-term average and 2.4 F higher than the previous record from 2016. However, daily maximum temperatures were 7.8 F below average for the last eight days of June due to a high pressure system set up in the Pacific Northwest that allowed subtropical moisture to move in from the Southwest, resulting in increased cloud cover and the occasional afternoon thunderstorm.

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Growing conditions, 2020 season

Timing of bud break was average towards the end of April. May temperatures were much warmer than average resulting in a fast vine development. Growing degree day (GDD) accumulation was 119 degree days above average by the end of May. June and July were slightly warmer than average. August's mean temperature of 80.9 F set a new record, 5.1 F above average and 1.1 F higher than the previous record set in 2011. September's mean temperature was average followed by very warm conditions in October until a severe temperature drop starting on 25 October. By the time of the killing frost on 26 October 4,081 GDD had accumulated, 441 GDD higher than average.

An extreme cold temperature event resulted in record low temperatures on 26 and 27 October which caused bud damage to many cultivars. November was again much warmer than average with December temperatures slightly below average. All but September had below average precipitation, resulting in a seasonal cumulative precipitation much below normal. Annual precipitation of 4.54" at WCRC-OM was approximately 50 % of normal.

The very warm growing conditions resulted in both the earliest start and completion of harvest. Averaged across all cultivars harvest was 17 days earlier than in 2019. At WCRC-OM all fruit was harvested by 22 September, more than a month before the killing frost on 26 October.

Research Update

I. Cropping reliability

1. Grape cultivars and clones suited to Colorado temperature conditions

Since 2004 we have greatly expanded the number of cultivars under testing. The first-ever replicated cultivar 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" cultivars were planted at the WCRC Orchard Mesa site. An additional replicated trial focused on cold-hardy, resistant cultivars was established on a grower cooperator site in Fort Collins in 2013 to identify grape cultivars that can be grown successfully along the Front Range. And in 2014, a fourth trial focused on cold-hardy, resistant cultivars was established with a grower-cooperator in the Grand Valley.

Yields in all our cultivar trials were down substantially compared to 2019. The reasons for the big yield declines were two record-breaking cold events: one very early into the dormant season (30 and 31 October 2019) and one right before bud break when many cultivars were at bud swell (14 April 2020). Combined those two events caused damage to fruitful buds (primary and secondary buds) which resulted in much reduced cluster number as well as lower cluster weights.

- 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 (2018-2022; now known as NE-1720). All participating states follow the same experimental protocol. In Colorado, 10 cultivars were established in 2008 and 2009 at Rogers Mesa, and 25 cultivars at Orchard Mesa between 2008 and 2012. At Orchard Mesa, we have continued to remove poor performing cultivars and replant with new entries. For example, in 2016 we added MN 1285, a white cultivar from the breeding program at the University of Minnesota. MN 1285 was released in 2017 under the cultivar name 'Itasca'.

At Rogers Mesa, seven out of ten cultivars were harvested. Yields ranged from 0.62 to 3.15 ton/acre (Table 1). Data on fruit composition at harvest are presented in Table 2. Micro-vinification was used to produce three varietal wines.

Table 1: Harvest dates and yield information for 7 (out of 10) grape cultivars planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Cultivar	Harvest date 2020	Yield (ton/acre)
Aromella	24 September	0.71
Chambourcin	16 October	2.25
Grüner Veltliner	29 September	0.62
Marquette	2 September	1.02
MN 1200	2 September	1.54
NY81.315.17	29 September	1.32
Vidal	16 October	3.15

Table 2: Fruit composition at harvest in 2020 for 7 (out of 10) grape cultivars planted in 2008 and 2009 at the Western Colorado Research Center – Rogers Mesa near Hotchkiss, CO.

Cultivar	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	26.3	3.29	8.75	6.69	4.49	151	93
Chambourcin	26.5	3.25	10.34	7.41	5.70	145	92
Grüner Veltliner	24.4	3.31	6.81	8.04	1.55	83	97
Marquette	30.4	3.52	7.99	3.40	4.69	390	159
MN 1200	28.7	3.36	6.77	5.72	1.76	196	125
NY81.315.17	24.9	3.35	6.09	5.46	1.25	154	92
Vidal	25.1	3.36	7.86	6.68	3.33	114	80

At Orchard Mesa, all 25 cultivars produced a crop, albeit many a rather small one. Harvest started with Marquette on 10 August 2020 and ended with seven cultivars on 22 September 2020 (Table 3). This represents both the earliest start and earliest end of the harvest season ever. A summary of fruit composition is presented in Table 4. Averaged across all cultivars, yields were down by 43 % compared to the 2019 season while harvest dates were 18 days earlier. Thirteen varietal wines were produced using micro-vinification techniques.

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

Cultivar	Harvest date 2020	Yield per vine (lb)	Yield (ton/acre)[1]
Albarino	4 September	7.28	3.63
Barbera	22 September	3.49	0.95
Cabernet Dorsa[2]	27 August	5.37	2.07
Cabernet Sauvignon	22 September	5.05	2.63
Carmenere[3]	16 September	4.14	2.26
Chambourcin[2]	14 September	6.48	2.65
Cinsaut	22 September	3.54	1.12
Durif[2]	22 September	5.20	2.24
Graciano[3]	28 August	3.93	0.54
Grenache	22 September	7.81	1.24
Malvasia Bianca	26 August	4.90	2.00
Marquette[2]	10 August	6.79	2.62
Marsanne	15 September	6.25	1.84
Merlot	27 August	4.11	1.58
Mourvedre	22 September	2.77	1.26
Petit Verdot[3]	16 September	5.87	1.47
Refosco[3]	15 September	7.52	0.51
Roussanne	14 September	7.02	2.07
Souzao	16 September	3.22	1.24
Tinta Carvalha[3]	22 September	5.20	0.59
Tocai Friulano	18 September	8.84	0.40
Touriga National	17 September	6.65	1.66
Verdejo	18 September	2.61	0.12
Verdelho	25 August	8.65	2.95
Zweigelt[2]	4 September	4.24	2.21

[1] Yield calculation based on number of vines initially planted. Vine survival (out of 18 or 24 vines per cultivar) ranges from 4 % for Tocai Friulano to 100 % for Cabernet Sauvignon, Carmenere, 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 2020 for 25 grape cultivars planted in 2008 and 2009 at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Cultivar	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	25.2	3.45	6.60	7.88	1.67	173	130
Barbera	30.5	3.47	6.57	8.17	1.89	148	158
Cabernet Dorsa[1]	28.3	3.55	6.50	7.68	2.26	180	129
Cabernet Sauvignon	26.9	3.34	6.59	8.47	1.03	106	130
Carmenere[2]	26.2	3.63	4.71	6.44	0.23	125	130
Chambourcin[1]	25.8	3.16	8.68	8.53	2.05	159	117
Cinsaut	26.9	3.54	5.61	6.78	1.11	157	153
Durif[1]	28.2	3.27	6.74	7.82	1.08	117	111
Graciano[2]	28.4	3.21	8.42	9.00	1.53	139	115
Grenache	27.1	3.47	5.07	6.41	0.20	137	131
Malvasia Bianca	22.8	3.28	7.75	8.18	2.59	90	93
Marquette[1]	29.9	2.95	9.79	4.93	3.81	340	142
Marsanne	25.2	3.65	5.32	7.35	1.25	169	108
Merlot	24.7	3.30	6.88	9.08	1.04	96	108
Mourvedre	24.5	3.39	6.55	6.85	1.71	119	114
Petit Verdot[2]	26.6	3.43	6.27	7.55	1.34	149	121
Refosco[2]	26.5	3.53	6.61	7.22	2.39	100	78
Roussanne	27.6	3.12	9.75	9.56	2.88	140	122
Souzao	25.6	3.17	8.08	8.62	1.82	118	116
Tinta Carvalha	22.4	3.69	5.17	6.12	1.89	142	85
Tocai Friulano	28.7	3.75	4.14	6.78	0.32	131	114
Touriga National	24.8	3.45	6.15	7.28	1.36	124	128
Verdejo	26.8	3.64	4.62	6.32	0.29	167	122
Verdelho	27.8	3.23	7.62	7.59	1.25	185	154
Zweigelt[1]	25.9	3.17	7.47	9.01	0.71	136	132

[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.

- Cultivar 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 cultivars 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 cultivars 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. In 2020, there was no yield and many vines required retraining from the ground. Vine vigor at this site continues to be weak.

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

  A new replicated cultivar trial was established in 2014 on a grower cooperator site near Clifton to identify grape cultivars that can be grown successfully in cold Grand Valley sites. All cultivars produced a crop (Table 5). On average, yields were down by 36 % compared to 2019 while harvest was earlier by 13 days. Only Arandell had a higher yield (+95 %) in 2020 compared to 2019. For all other cultivars yield decreases ranged from 9 % for Vignoles to 72 % for Chambourcin. A summary of fruit composition is presented in Table 6.

  Brianna was harvested on 3 August 2020 which was the earliest ever start of grape harvest in the Grand Valley. Due to insufficient yields only six varietal wines were produced using micro-vinification techniques. Fruit from Marquette was used for an enological study on timing of tanning additions on wine quality.

  The extreme cold event in late October 2020 caused moderate to no primary bud damage (from 0 % for Brianna and Marquette to 29 % for Vignoles). However, 25 % of surviving vines did not break bud in spring 2021 and will need to be retrained from suckers arising from the base of trunks. Worst affected are Chambourcin and Traminette while all vines of Brianna and Marquette show no sign of damage and normal development. Further, in early June, a small percentage of vines of several cultivars are showing no sign of life and might have been killed by the October cold event.

  One unexpected observation at this site are continuing vine losses with St Vincent. St Vincent was the cultivar 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 three more between harvest 2019 and spring 2020. After seven growing seasons only 29 % of the vines are still alive.

There are also some unexplained vine losses with Traminette. It appears that sometime between harvest 2019 and the start of dormant pruning in February 2020 four vines were cut down without the knowledge of our grower collaborator. The reason behind this remains a mystery.

Table 5: Harvest dates and yield information for 12 grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO.

Cultivar	Harvest date 2020	Yield (ton/acre)[1]
Arandell	15 September	1.27
Aromella	25 August	2.74
Brianna	3 August	1.19
Cayuga White	1 September	1.54
Chambourcin	23 September	0.35
Corot noir	1 September	1.32
La Crescent	24 August	1.59
Marquette	14 August	2.02
Noiret	1 September	1.74
St Vincent	5 October	0.48
Traminette	1 September	0.79
Vignoles	24 August	0.50

[1] Yield calculation based on number of vines initially planted. Vine survival is >90 % for all cultivars except Traminette (66 %) and St Vincent (33 %).

Table 6: Fruit composition at harvest in 2020 for 12 grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO.

Cultivar	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	22.1	3.80	5.51	6.08	2.82	280	90
Aromella	20.6	3.36	7.93	7.50	3.05	182	93
Brianna	19.5	3.56	6.81	6.08	2.84	238	74
Cayuga White	21.5	3.35	6.17	5.94	0.85	184	85
Chambourcin	24.7	3.32	7.23	5.82	1.85	211	105
Corot noir	21.8	3.79	4.12	6.21	0.28	206	81
La Crescent	25.0	3.57	7.34	7.41	4.09	183	84
Marquette	29.5	3.56	7.43	5.02	3.50	449	185
Noiret	20.6	3.59	5.72	7.16	1.68	145	60
St Vincent	23.2	3.27	7.36	6.97	1.23	234	131
Traminette	22.0	3.37	6.83	7.76	1.89	128	81
Vignoles	27.0	3.24	8.28	7.11	2.38	231	121

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 were originally irrigated by drip but the irrigation system was changed to micro sprinkler in the fall of 2018 as this vineyard block is now used for a new cover crop study (see below). The following rootstocks are included: 110 Richter, 140 Ruggeri, 1103 Paulsen, Kober 5BB, and Teleki 5C.

Bud evaluations following the October 2019 record low temperature event showed the lowest primary bud survival of 44 % on own-rooted vines. At 39 % own-rooted vines also had the highest bud mortality. On grafted vines primary bud survival ranged from 59 % with 110 Richter to 77 % 1103 Paulsen. Bud mortality on grafted vines ranged from 13 % with 1103 Paulsen to 27 % with 110 Richter. Taking into account fruitful secondary buds all entries in this rootstock trial had >50 % fruitful buds, and with long pruning we expected to achieve close to 100 % of a crop in 2020. However, as was the case in all of our trials, the yield was substantially reduced compared to 2019. Again, the most likely reason for the yield decline was the record cold event on 14 April 2020 when buds had started to swell. Average yield per cropping vine in 2020 was 4.1 lb, down 68 % on 2019. Yield per vine was highest on 1103 Paulsen and lowest on own-rooted vines, consistent with the levels of bud damage observed after the October 2019 cold event. However, vine survival is very low for several rootstocks, resulting in very low yields per acre (Table 7). Viognier grafted to Teleki 5C had the third highest yield per vine but due to the highest survival rate of any rootstock included in this trial, it had the highest yield per acre.

Table 7: Effect of rootstock on vine survival after 12 years and yield in 2020 of Viognier growing at the Western Colorado Research Center – Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield (ton/acre)
110R	57	0.82
140Ru	18	0.53
1103P	50	1.79
5BB	64	1.41
5C	86	2.04
Own-rooted	93	0.91

- 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 (110R), 140 Ruggeri (140Ru), 1103 Paulsen (1103P), 1616C, 101-14 Mgt (101-14), 3309 Couderc (3309), Riparia Gloire (RG), Salt Creek (SC), Schwarzmann (Schw), Selektion Oppenheim #4 (SO4), and Teleki 5C (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 10 October 2019.

Graft unions were again hilled over in the fall of 2019 and uncovered in the spring of 2020. Seven more vines were lost during the 2019/20 dormant season. Six out of eleven rootstocks now have 100 % vine survival: 110R, 1103P, 3309, Riparia Gloire, Salt Creek, and SO4 (Table 8). The lowest vine survival of 78 % is with 140Ru.

Yields were very low in 2020 with only three rootstocks exceeding 1 ton/acre (Table 8). Although Cabernet Sauvignon primary bud survival following the October 2019 event ranged from 66 % when grafted to 1103P to 93 % on Schwarzmann the average cluster weight of only 41 g indicates that much of the crop came from secondary buds. Further primary bud damage may have occurred during the record cold temperature event on 14 April 2020.

Table 8: Effect of rootstock on vine survival after four years and yield in 2020 of Cabernet Sauvignon growing in a commercial vineyard in the western part of Orchard Mesa near Grand Junction, CO.

Rootstock	Vine survival (%)	Yield per cropping vine (lb)	Yield (ton/acre)
110R	100	1.88	0.76
140Ru	78	1.51	0.40
1103P	100	2.17	0.83
1616C	96	2.05	0.96
101-14	96	2.35	0.93
3309	100	2.85	1.25
5C	91	2.77	1.08
Riparia Gloire	100	2.03	0.88
Salt Creek	100	1.82	0.61
Schwarzmann	96	2.23	0.94
SO4	100	3.18	1.23

Fruit composition of Cabernet Sauvignon at harvest was very similar irrespective of the rootstock used, except for SO4. Cabernet Sauvignon grafted to SO4 had approximately 1 g/l higher titratable acidity than when grafted to any of the other ten rootstocks. This was the result of both higher tartaric acid (+0.6 g/l) and higher malic acid (+0.7 g/l) and resulting in the lowest pH value. It should be noted, however, that vines grafted to SO4 had the highest yield (Table 8) and the differences in fruit composition might be due to crop load.

Bud evaluation following an extreme low temperature event in late October 2020 showed 100 % bud mortality. At the time of this freeze event graft unions had not been covered up. In spring 2021 there was no bud break from cordons and/or canes, and all vines will require retraining from the ground during the 2021 growing season. At the beginning of June 2021 approximately 30 % of the vines are not yet showing any sucker growth, or rootstock suckers only.

- 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: six on rootstock 110R, two each on 101-14 and 140Ru, and one on SO4. Growth in 2019 was again very vigorous and the extreme low temperature event in late October caused >90 % bud mortality.

  In 2020, vines again needed retraining from buds located below the soil mound. However, a further 91 vines had died bringing the number of missing vines to 102 (out of 243). Another extreme low temperature event in late October caused 100 % bud mortality. At the time of this freeze event graft unions had not been covered up. In spring 2021 there was no bud break from cordons and/or canes, and all vines will require retraining from the ground during the 2021 growing season. At the beginning of June 2021 approximately 45 % of the vines are not yet showing any sucker growth, or rootstock suckers only.

- 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 more 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.

As vine vigor was low in 2019 all vines were pruned back to one or two canes leaving no more than 4 nodes per cane in April 2020. Fifteen out of the 168 vines originally planted failed to grow. Shoot growth in 2020 was severely affected by deer browsing. An extreme low temperature event in late October 2020 resulted in near 100 % bud mortality. At the time of this freeze event graft unions had not been covered up. In spring 2021 there was no bud break from canes, and all vines will require retraining from the ground during the 2021 growing season. In mid-June, 22 vines that were alive in 2020 were not yet showing any growth.

- 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 in 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.

In light of both very high primary bud damage from the October 2020 extreme cold event and declining vine vigor and yield the decision was made to remove the mature own-rooted vines. There was minimal trunk damage to inter-planted vines and bud break in spring 2021 was better than expected, and better than on mature Chardonnay vines growing in the same block. There will be a small crop in 2021.

- Develop planting and maintenance practices for grafted vines that reduce management costs and vine losses due to cold temperature damage to the graft union – 2017 study (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 (vines were donated by Wonderful Nurseries, Wasco, CA) 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.

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 again 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. 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. 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 had previously been observed 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).

In 2020, yields increased about 0.8 ton per acre in both drip and micro-sprinkler irrigation treatments. Drip irrigated vines produced the equivalent of 2.22 ton per acre and micro-sprinkler irrigated vines 1.42 ton per acre. The difference in yield between the irrigation treatments were predominantly due to differences in cluster number per vine (29.8 for drip, 20.7 for micro-sprinkler) with no difference in average cluster weight (69 g). This is a change to 2019 when both cluster number and weight were higher with drip irrigation. A smaller contributing factor was that 3 out of 38 vines with micro-sprinkler irrigation did not produce a crop whereas all 38 drip irrigated vines did produce a crop. The lower yields in both 2019 and 2020 are due to lower vine vigor with micro-sprinkler irrigation in the first 3 years. It has taken longer to establish canes and cordons and reach a full canopy with micro-sprinklers compared to drip. There was a trend for higher yields on Control vines in both irrigation treatments. A similar trend was also found in 2019.

Root development was again assessed in the fall of 2020 on five out of ten reps per treatment. Similar to the process used in 2019 we evaluated vines where the soil had been left undisturbed for two years. The photos below show examples of the progression of root development (size and number) from fall 2018 (top row) to the fall of 2020 (bottom row) for vines with graft unions 2”, 4”, or 6” (left to right) below the soil surface. Aside from the obvious and expected increase in root diameter, a comparison of the images from 2018 and 2020 does suggest minimal or no new root formation above the graft union in two years. If this lack of new root formation can be confirmed in future years then the standard annual management practice of hilling up graft unions in fall and uncovering in spring could be modified to a practice where graft unions are covered and uncovered during the first 2-3 years only, but left covered afterwards.

Photos show root development from the scion part (above the graft union) of the same vines at the end of the second (top row) and fourth (bottom row) growing season of Chardonnay/SO4 vines when the graft union is permanently buried at 2”, 4”, or 6” (left to right) below the soil surface. Left and center photos are examples from drip irrigated vines, right photos from vines irrigated by micro-sprinklers.

This concept of not uncovering the graft union after year 3 is currently being investigated using 5 out of ten of the Control vines. However, instead of using soil to cover up the graft union we have used wood chip mulch (supplied free of charge by a local tree care service company). Indeed, in late fall 2020 there were no roots found above the graft union on Control vines where the graft union had remained covered since October 2019. Graft unions were again checked for the presence of roots in spring 2021, and again none were found. From a practical perspective it should be noted that the wood chip mound stayed intact around the graft union of drip irrigated vines but there was a need touch up the mound of micro-sprinkler irrigated vines. A few more years of observations are required before a final conclusion about the feasibility of this practice can be made.

Temperatures at the height of the graft union under the wood chip mulch and right above at the fruiting wire were measured on two vines (one drip- and one micro-sprinkler-irrigated) from 9 December 2020 to 23 April 2021. Data confirm that the wood chip mulch provided sufficient thermal insulation to protect the graft union from cold injury. Minimum temperatures measured at the fruiting wire were 6.6 F and 6.9 F compared to 21.5 F and 22.8 F at the graft union.

- Develop planting and maintenance practices for grafted vines that reduce management costs and vine losses due to cold temperature damage to the graft union – 2021 study (Caspari and Wright)

  A new study to evaluate if graft unions can be covered indefinitely without causing scion rooting was initiated in spring of 2021 in three rows of the Chardonnay block at the Orchard Mesa site that was initially planted in 1992. Half the vines in this Chardonnay block were own-rooted with the other half grafted to four different rootstocks. The own-rooted vines were starting to decline due to phylloxera damage. Following the record-breaking cold event in late October 2020 the decision was made to pull out all own-rooted vines rather than to retrain already declining vines during 2021. Instead, 120 dormant Chardonnay vines (clone 37.1) grafted to rootstock SO4 were planted on 21 April 2021. Vines were donated by Wonderful Nurseries, Wasco, CA.

  This experiment is a modification of the 2017 study (see above). Half the vines are planted with the graft union 2" above the soil surface (Control = standard practice) while the other half are planted with the graft union 2" below the soil surface. Unlike the 2017 study, the planting holes for the treatment 2" below soil surface were not filled up entirely at the time of planting, leaving the graft union exposed. In fall of 2021 these holes will be filled up to the soil surface. Half the holes in this treatment will be filled with soil, the other half with wood chip mulch. Graft unions will then remain covered throughout the experiment. Graft unions of Control vines will be covered in fall with either soil or wood chip mulch. In spring, for each covering treatment (soil or wood chip mulch), half the graft unions will be uncovered with the other half remaining covered throughout the duration of the experiment. Over the next five years we will collect data on scion root formation, vine survival, and fruit yield and quality.

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 cultivars that are best suited to Colorado's climate (see cultivar trials above) is a fundamental component for avoiding cold injury.

- Characterizing cold hardiness (Caspari and Wright)

  There are substantial differences in cold hardiness of cultivars. 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 for Aromella. Bud cold hardiness of six entries in the NE-1720 trial at Orchard Mesa (Albarino, Cabernet Dorsa, Cabernet Sauvignon, Carmenere, Souzao, Zweigelt) as well as all 12 cultivars from the Grand Valley trial evaluating cold-hardy cultivars (Arandell, Aromella, Brianna, Cayuga White, Chambourcin, Corot noir, La Crescent, Marquette, Noiret, St Vincent, Traminette, Vignoles) has been evaluated over multiple years. 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.

  Cold hardiness tests were initiated in late September 2020. Tests with cultivars Chardonnay and Syrah were conducted on a weekly basis with other cultivars tested on a monthly basis. Testing of all *Vitis vinifera* cultivars was suspended following a severe cold temperature event on 26-27 October 2020.

  The importance of understanding the cold acclimation pattern was again illustrated by this extreme low temperature event in late October. In the early morning hours of 26 October 2020, the temperature dropped to 14 F at WCRC-OM, which is 9 F lower than the previous low temperature record for that day. Likewise, the low of 9 F for 27 October 2020 was 15 F below the previous record.

  Similar to the late October freeze event in 2019 we determined the level of bud damage on all the cultivars grown at WCRC-OM (Fig. 1), and the Viognier rootstock trial at WCRC-OM (Table 9), and a rootstock trial with Cabernet Sauvignon in the Grand Valley (see above). In early November, twenty canes were collected from each cultivar and the basal five nodes on each cane evaluated (i.e. 100 buds per cultivar). Figure 1 shows that, with the exception of Marquette, bud damage from the October 2020 event was much more severe than from the event one year earlier. Fourteen varieties had >50 % bud mortality and less than 10 % primary bud survival.

  Much higher bud damage in 2020 compared to 2019 was confirmed in the Viognier and Cabernet Sauvignon rootstock trials as well as a Cabernet Franc clonal trial. In the Viognier rootstock trial the highest bud mortality was with own-rooted vines, confirming the results from 2019 (Table 9). Cabernet Franc and Cabernet Sauvignon had 100 % primary bud mortality compared to 11 % and 22 %, respectively, in 2019.

  Contrary to the results with *Vitis vinifera* cultivars the bud damage of inter-specific cultivars in October 2020 was similar to or less than in October 2019. Primary bud damage was less than 10 % for seven cultivars and highest for Cayuga White at 26 % damage (Table 10).

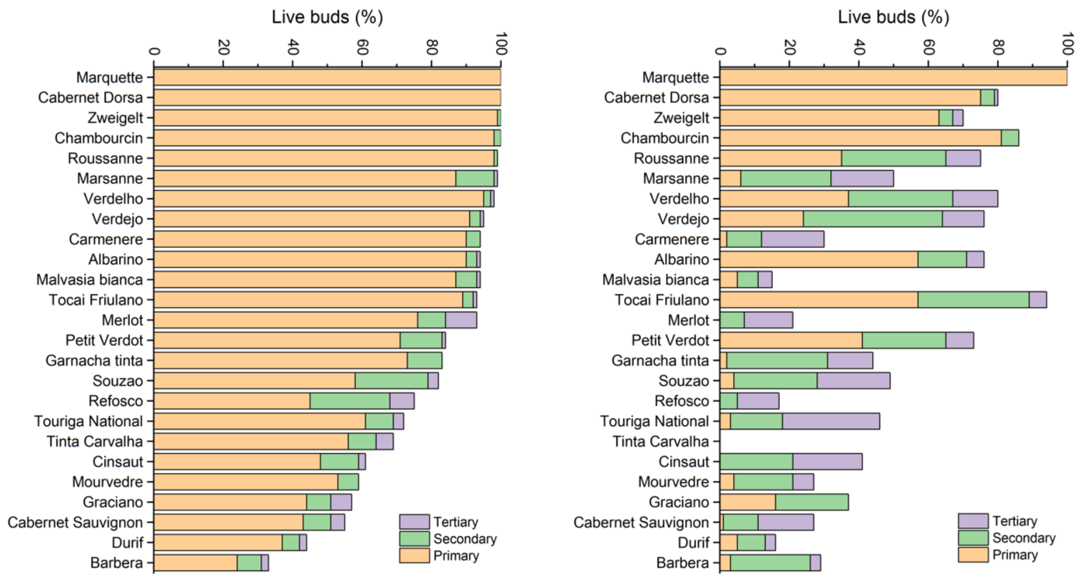

Fig. 1: Grape bud survival of 25 cultivars following extreme low temperature events in late October in 2019 (left) and in 2020 (right).

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 in 2019 and in 2020.

	2019		2020	
Rootstock	Live primary bud (%)	Dead bud (%)	Live primary bud (%)	Dead bud (%)
110R	59	27	3	62
140Ru	62	24	8	50
1103P	77	13	7	40
5BB	73	18	23	19
5C	74	18	11	39
Own-rooted	44	39	0	74

Table 10: Bud damage of 12 inter-specific grape cultivars planted in 2014 at a commercial vineyard near Clifton, CO from extreme low temperature events in late October in 2019 and in 2020.

	2019		2020	
	Live primary bud (%)	Dead bud (%)	Live primary bud (%)	Dead bud (%)
Arandell	95	4	85	8
Aromella	96	3	98	0
Brianna	98	0	100	0
Cayuga White	46	41	74	2
Chambourcin	75	21	89	0
Corot noir	85	14	97	2
La Crescent	96	3	94	2
Marquette	100	0	99	1
Noiret	87	4	88	0
St Vincent	99	0	100	0
Traminette	72	18	90	0
Vignoles	98	2	95	0

Temperatures at the Organic Agriculture Research Station – Rogers Mesa near Hotchkiss, CO dropped to 9.6 F on the morning of 26 October 2020, followed by a low of 0.2 F on the morning of 27 October 2020. Bud damage was evaluated on samples collected on both mornings from six inter-specific cultivars (Fig. 2).

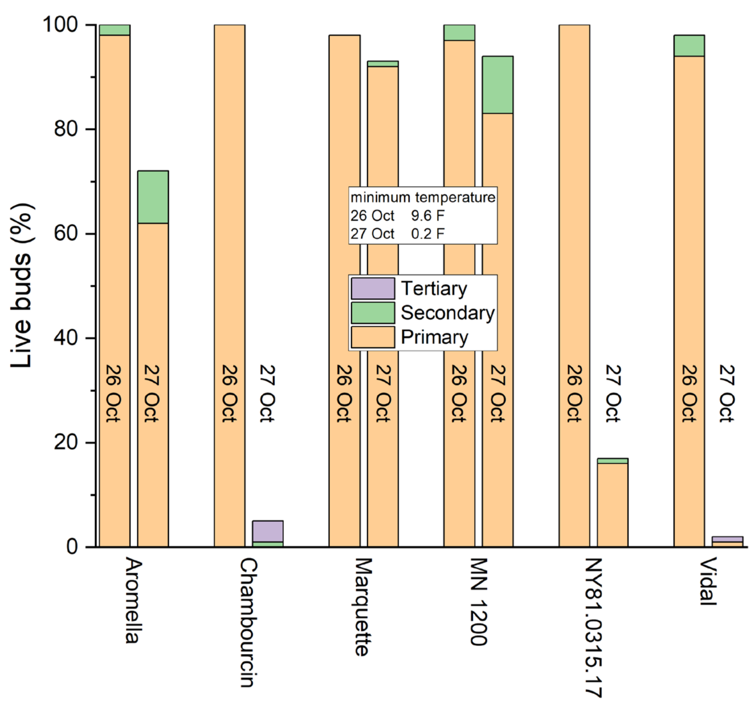

Fig. 2: Grape bud survival of six inter-specific cultivars growing at the Organic Agriculture Research Station – Rogers Mesa near Hotchkiss, Colorado following extreme low temperature events in late October 2020.

There was no or minimal bud damage after 9.6 F on 26 Oct 2020 (Fig. 2). However, all cultivars had bud damage after 0.2 F on 27 Oct 2020. The biggest change in bud damage was found on Chambourcin, NY 81.0315.17 and Vidal. Bud mortality increased from no damage for Chambourcin and NY 81.0315.17 to 95 % and 83 %, respectively, and from 2 % to 98 % for Vidal. Aromella had no dead buds on 26 October but 28 % dead buds on 27 October. Only Marquette and MN 1200 had less than 10 % bud mortality on 27 October 2020.

In addition to the bud evaluations in our replicated cultivar and rootstock trials we conducted a survey in the Grand Valley. Samples were taken in 49 vineyard sites and a total of 32 cultivars were evaluated. Results (Fig. 3, Table 11) showed >90 % bud damage for most *Vitis vinifera* cultivars. Notable exceptions included Chardonnay, Lemberger, Riesling, Teroldego, and Zweigelt. In contrast, only modest or no damage was found on inter-specific cultivars, confirming the results from our replicated trials.

No live primary buds were found with Cabernet Franc (*n* = 13) and Cabernet Sauvignon (*n* = 10). Similar, there were no live primary buds in 10 out of 11 sites with Merlot, 4 out of 6 sites with Gewürtztraminer, 4 out of 5 sites with Malbec, and 5 out of 9 sites with Syrah.

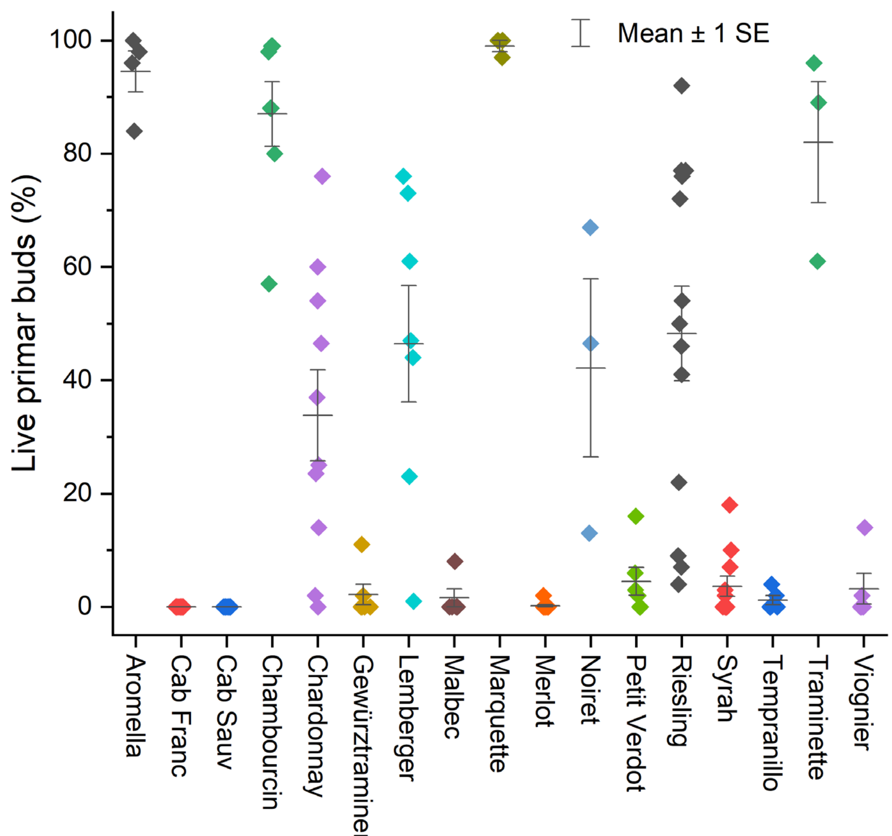

Fig. 3: Grape primary bud survival of 17 cultivars growing in commercial vineyards in the Grand Valley, Colorado after an extreme low temperature event in late October 2020. Each symbol represents the mean primary bud survival at one site.

While Fig. 3 presents data from cultivars grown on at least three different sites Table 11 shows the results from minor cultivars grown on only one or two sites.

Table 11: Primary bud survival of minor grape cultivars growing in commercial vineyards in the Grand Valley, Colorado after an extreme low temperature event in late October 2020. Numbers in parentheses indicate the range.

Cultivar	Number of sites	Live primary bud (%)
Albarino	1	0
Barbera	2	0
Chardonel	1	65
Frontenac	1	99
Grüner Veltliner	1	8
Itasca	1	99
La Crescent	1	94
Petite Pearl	2	86 (80 – 93)
Rkatsiteli	1	76
Sauvignon blanc	1	0
St Vincent	2	93 (88 – 98)
Teroldego	1	66
Verona	1	96
Vidal	1	92
Zweigelt	1	77

The extreme cold event in late October 2020 caused minor or no primary bud damage to cold-hardy interspecific cultivars but 100 % or near 100 % damage on most *Vitis vinifera* cultivars. However, several *Vitis vinifera* cultivars growing in our cultivar trials and/or in commercial vineyards were found to have moderate primary bud damage. Those cultivars included Cabernet Dorsa, Chardonnay, Lemberger, Riesling, Teroldego, and Zweigelt. The comparatively high survival of primary buds of Cabernet Dorsa and Zweigelt supports our results from controlled freezing tests in previous years that those cultivars acclimate early in fall, as does Chardonnay. We do not have data from controlled freezing tests for Lemberger, Riesling, and Teroldego but it should be noted that Lemberger is a parent of both Cabernet Dorsa (Lemberger x Dornfelder) and Zweigelt (St Laurent x Lemberger). The early bud acclimation in fall might thus be a trait inherited from Lemberger, and other cultivars with Lemberger as parent might be of value to Colorado's grape growers.

4. ***Identifying areas suitable for expanded wine grape production*** (Schumacher, Bennett Goble, Caspari)

The Colorado Climate Center has resumed its spatial analysis of damaging freeze events in viticulturally-active portions of Colorado. This study focuses on weather events impacting Fremont, Mesa, and Montezuma Counties. FY 2021's climate study was shorter and less involved than recent years due to COVID-19-related funding and travel limitations. Most notably, project-specific thermometers were not available during freeze events analyzed here. Gridded temperature data and observations from other networks were leveraged. We were able to visit project-specific sites near the end of the fiscal year, putting work back on track for FY 2022. The Colorado Climate Center has begun collaboration with CSU extension in Pueblo County to extend project-specific analysis to southern Pueblo and Huerfano County for future analysis.

Two freeze events from FY 2021 are examined: the first one occurred on October 26th and 27th, 2020, the second occurred April 16-20th, 2021. The October event was the second coldest since 1895 for Grand Junction and since 1950 for Cortez, and the coldest since 1950 for Montrose and Cañon City. This marks the second straight late October deep freeze as the only event cooler for Grand Junction and Cortez is 2019.

All weather stations analyzed in the October event fell well below freezing with most stations ranging 0-20 F, and a few stations in Cañon City and Penrose falling below 0 F. The cold event was weakest in the SW CO. However, PRISM analysis suggests southern La Plata County was warmer than southern Montezuma County, which is atypical for Colorado cold extremes. In Mesa County, Palisade and eastern Grand Junction were some of the warmest areas, but not warm enough to avoid damage. Minimum temperatures here were 10-15 F. Paradox valley was slightly warmer still (17 F). Montezuma County was still severely impacted by the freeze, but stayed slightly warmer than Grand Junction and Palisade. Temperatures varied from 4-21 F. The coolest temperatures in Montezuma County were in Mancos, which is typical. The warmest areas were at higher elevations, underscoring the strength of the temperature inversion. Fremont County was the coldest of the three counties with temperatures falling below 0 F. PRISM data suggests the whole county fell below 10 F.

Temperatures fell well below freezing nearly everywhere in Colorado between April 16th and 20th. This event fell closer in line with previous findings, which suggest Mesa County and the Four Corners area are most likely to be warmest during Colorado cold spells. Temperatures fell into the 20s in Grand Junction and Palisade area only on April 20th, however in the Cortez area from 16th to 19th of April. Fremont County was harder hit. Temperatures fell into the high teens and low 20s in the low elevations, and were cooler at higher elevations.

COVID-19 uncertainty lead to a temporary lapse in the climate study, eliminating site-specific thermometers from analysis. This reduced the granularity of observational data for the FY 2021 report. However, site-specific thermometers have been reset in Fremont County. Montezuma County site-specific thermometers will be transferred to Huerfano County in the coming fiscal year.

October 2020 Freeze Event: Colorado has seen back-to-back Octobers with extreme cold events. Grand Junction, Montrose, Cortez, and Cañon City have all experienced the two most extreme October cold snaps since 1950 in the last two years (Fig. 4). While it is normal for temperatures to freeze shortly after harvest in locations like Grand Junction/Palisade, nocturnal temperatures rarely dip below 20 F. October minimum temperatures at the Grand Junction Walker Field site were 6 and 11 F in 2019 and 2020 respectively. Those represent the lowest and 3rd lowest October temperatures ever recorded in Grand Junction since record keeping began in 1895.

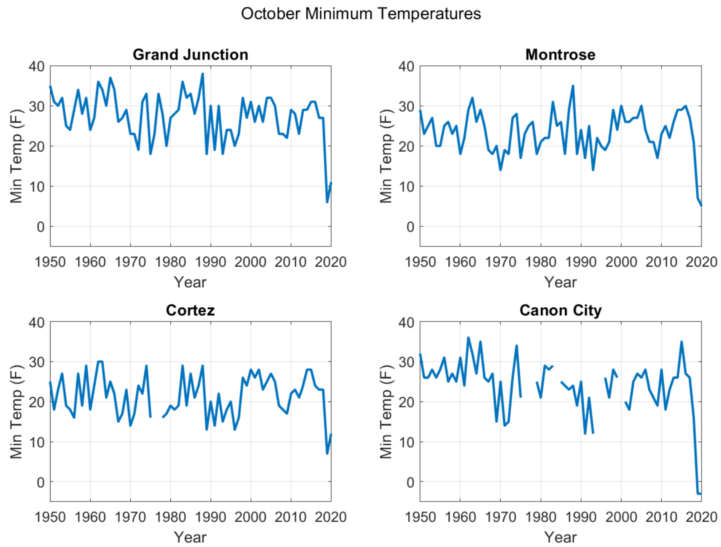

Fig. 4: October monthly minimum temperatures for Grand Junction, Montrose, Cortez, and Cañon City (Fahrenheit). Years 1950-2020.

The impact of the October 2020 freeze was widespread (Fig. 5). On the morning of October 27th the majority of Colorado experienced temperatures below 0 F, including some smaller areas of grape production, such as eastern Fremont County and the northern Front Range. Areas staying warmest were low-lying portions of Animas and Archuletta Counties around Durango and Pagosa Springs. It is unusual for these parts of Colorado to experience warmer minimum daily temperatures than the Grand Valley.

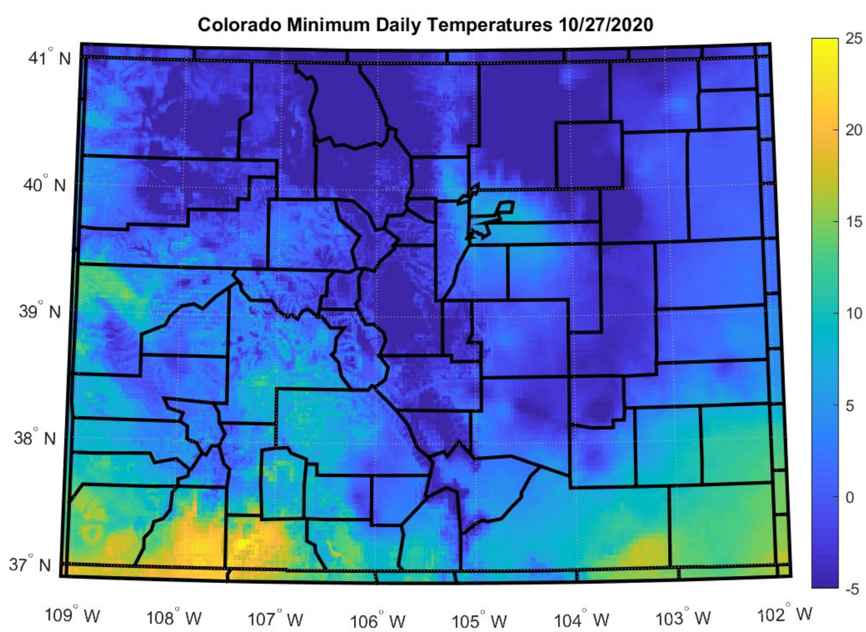

Fig. 5: Colorado minimum daily temperatures for October 27th, 2020 (Fahrenheit).

October 27th, 2020 minimum temperatures were below 20 F across Mesa and Delta Counties (Fig. 6). Palisade and eastern Grand Junction was a relative warm spot, which is normal for the area, but temperatures were still between 10 F and 15 F. Model data suggests portions of the Paradox Valley, and the Colorado River Valley further to the west were slightly warmer. Gateway registered a low temperature of 17 F. Temperature inversions can occur during cold snaps, in which higher elevation stations stay warmer than low elevation stations. Despite the strength of cold air, PRISM model data do not suggest a strong inversion was present with low elevation stations staying warmer than high elevation stations. Indeed, weather data from both the Rogers Mesa and Orchard Mesa site of the Western Colorado Research Center show windy conditions and a lack of temperature inversions from October 25th through to October 29th.

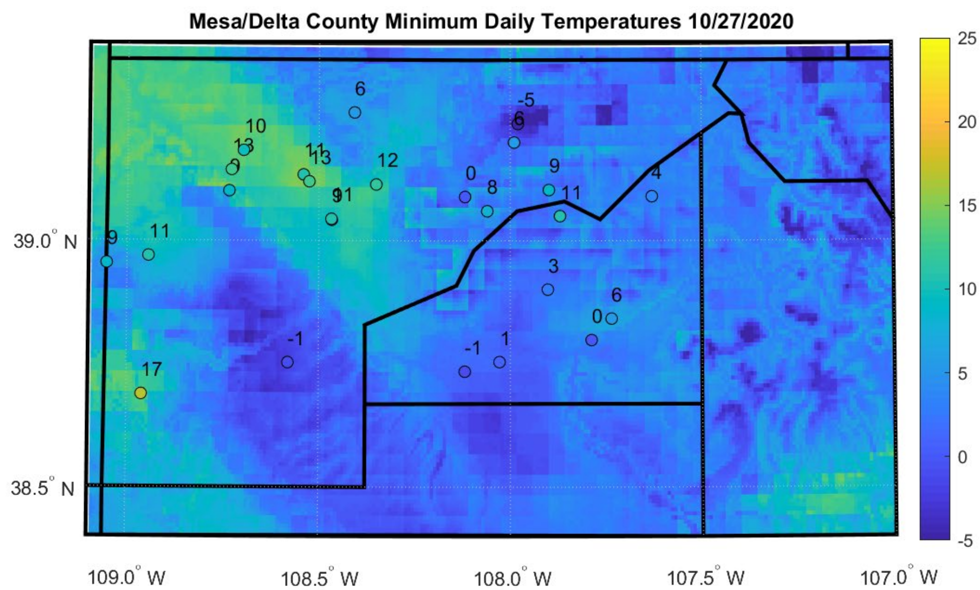

Fig. 6: Mesa and Delta County minimum daily temperatures for October 27th, 2020 (Fahrenheit). Gridded values from downscaled PRISM, point measurements from COOP and CoAgMET.

Montezuma County stayed warmer than other grape producing areas of Colorado, mitigating some of the freeze impacts (Fig. 7). The Cortez Cooperative Observing Network station reached a minimum of 12 F. Unlike Mesa County, model results indicate that this freeze produced an unusually strong temperature inversion in Montezuma County. This is corroborated by the 10 F observation at the Ute Mountain Farm and Ranch site, the lowest and furthest southwest site in the study. Modeled temperatures were highest on the Mesa Verde (low 20s). In previous years, it is common for the Mesa Verde and Cortez 8SE COOP stations (elevations of 7142 and 8034 ft respectively) to be warmer than Cortez (6200 ft) and east McElmo Canyon (5910 ft) on cold nights. However, the west end of McElmo Canyon, and the southwest corner of the county, usually remain the warmest despite their lower elevations (~5500 ft).

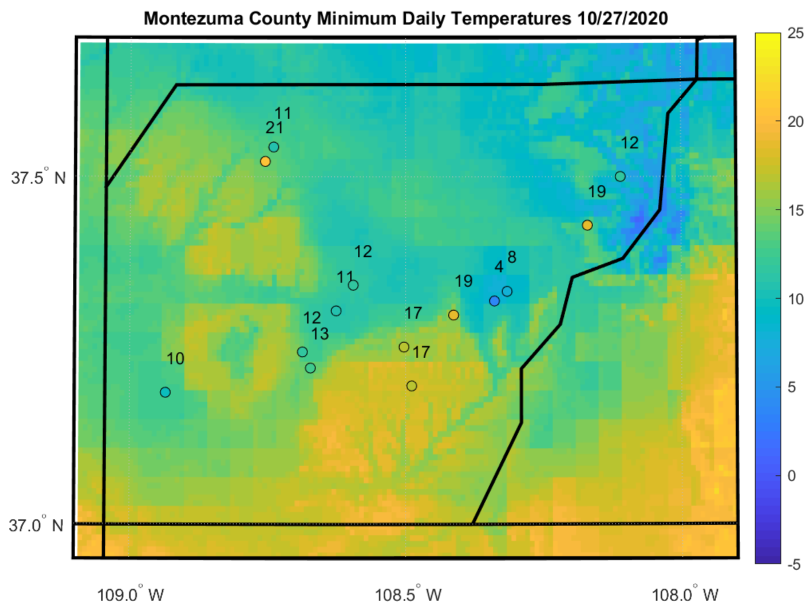

Fig. 7: Montezuma County minimum daily temperatures for October 27th, 2020 (Fahrenheit). Gridded values from downscaled PRISM, point measurements from COOP and CoAgMET.

Eastern Fremont County froze harder than Mesa or Montezuma Counties (Fig. 8). Nearby COOP and CoAgMET observations ranged from -1 F at the highest to -8 F at the lowest. Model results do suggest some of the area south of Cañon City was a little warmer, but the entire area was below 10 F.

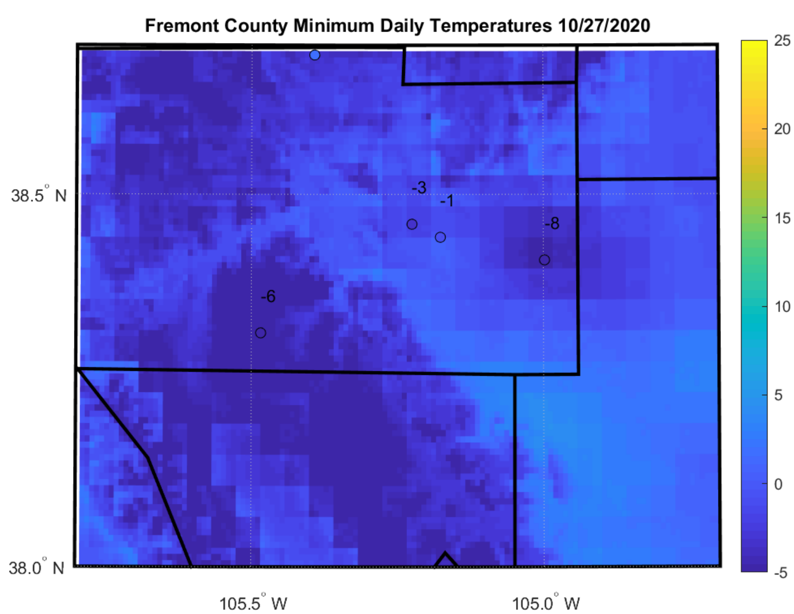

Fig. 8: Fremont minimum daily temperatures for October 27th, 2020 (Fahrenheit). Gridded values from downscaled PRISM, point measurements from COOP and CoAgMET.

April 2021 Freezes: Nearly all of Colorado feel below the freezing mark at some point between April 16th and April 20th (Fig. 9). Damage from this event was minimal for two reasons: 1. Bud break came later than normal in 2021 thanks to a cooler than average spring. 2. October 2020 freezes had already killed all but the most cold-hardy vines.

The highest minimum temperatures in the state during this cold snap occurred in Palisade, Paradox Valley, and the extreme southwest corner of the state.

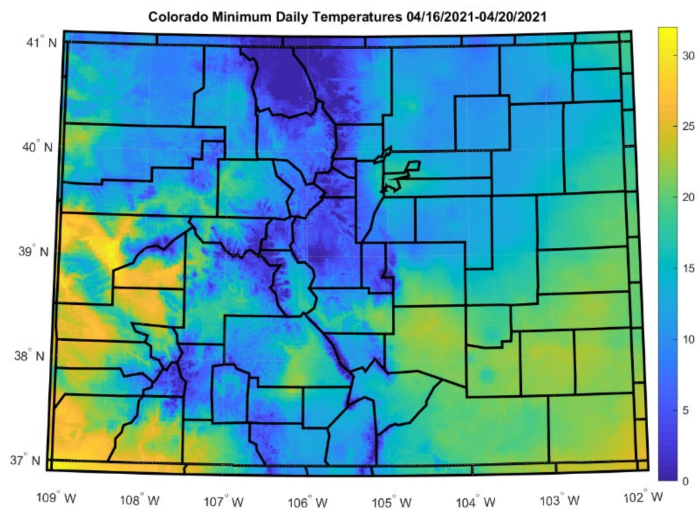

Fig. 9: Colorado minimum temperatures for April 16th, 2021 – April 20th 2021 (Fahrenheit).

Low elevations of Mesa County stayed relatively warm during this cold event (Fig. 10). Minimum temperatures near the valley floor ranged from 28 F in Palisade to 22 F in Fruita. The warmest spot was Gateway, on the other side of the Uncompahgre Plateau.

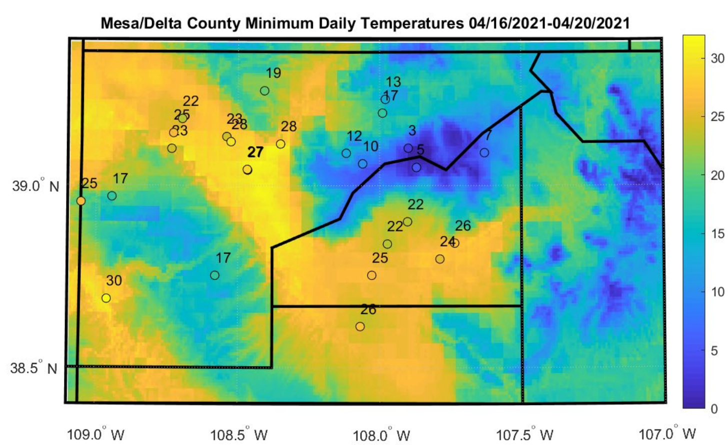

Fig. 10: Mesa and Delta County minimum temperatures for April 16th, 2021 – April 20th, 2021 (Fahrenheit). Gridded values from downscaled PRISM, point measurements from COOP and CoAgMET.

The temperature pattern in Montezuma county during this freeze event followed a northeast-southwest gradient (Fig. 11). Gridded data suggest the temperature stayed above freezing in the Four Corners. The official Cortez weather station reached a low temperature of 20 F. Other low elevation stations in the area showed similar readings. Model data suggest this freeze impacted western McElmo Canyon nearly as much. Often times, observations indicate that the west end of McElmo Canyon stays warmer than the east end on cold nights. We do not have observations in McElmo during this event, but if this temperature gradient was present, the PRISM model did not capture it. Modeled minimum temperatures at both the east and west end of the canyon were between 20 and 25 F. The Warmest station was Mesa Verde (27 F). The elevation of this station is 7142 ft, over 1000 ft above the valley floor. It's not uncommon for high elevation stations to stay warmer than their lower elevation counterparts during a freeze event, but Mesa Verde stands out in this case. Higher elevation stations were colder than low elevation stations in both Mesa and Fremont Counties.

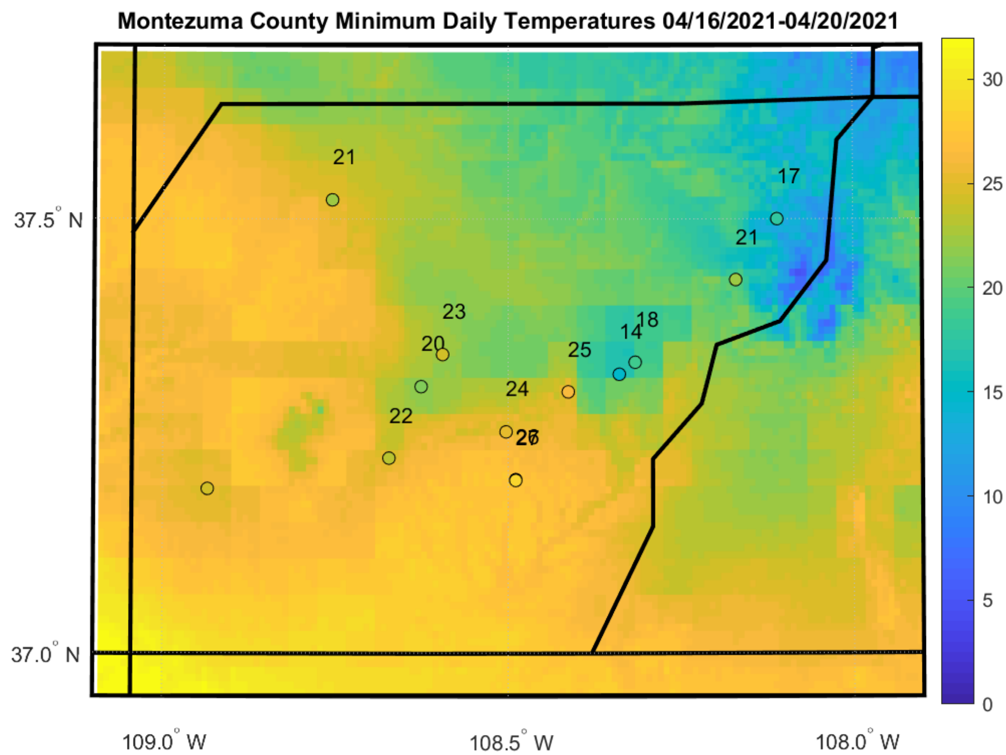

Fig. 11: Montezuma County minimum temperatures for April 16th, 2021 – April 20th, 2021 (Fahrenheit). Gridded values from downscaled PRISM, point measurements from COOP and CoAgMET.

Fremont County was impacted by the April freeze event more severely (Fig. 12). Temperatures in Cañon City and Penrose were 20 and 19 F respectively. These towns reside in the Arkansas River Valley. Higher elevation areas were even cooler according to the PRISM model.

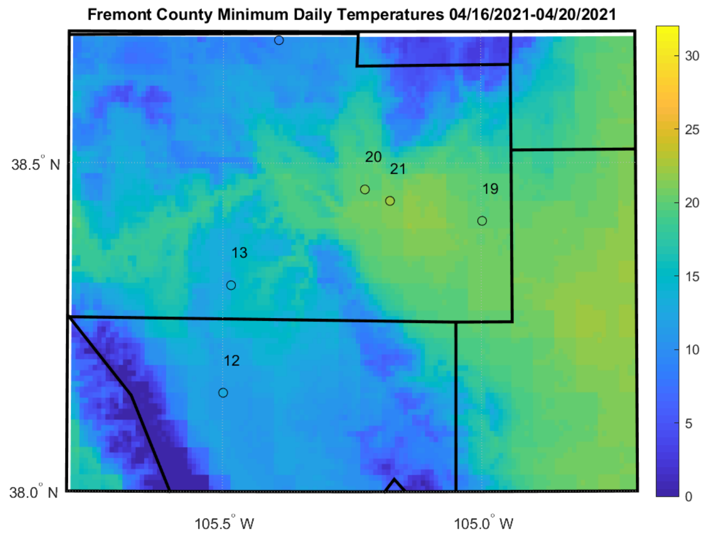

Fig. 12: Fremont minimum temperatures for April 16th, 2021 – April 20th, 2021 (Fahrenheit). Gridded values from downscaled PRISM, point measurements from COOP and CoAgMET.

Preparing for FY22: Thermometers have been removed from Montezuma County. Sensors will be redistributed in southern Pueblo County and eastern Huerfano County next fall. Previous studies indicate the area at the foot of the southern Wet Mountains may be suitable for hybrids and European cultivars (Fig 13). We are working with Colorado State Extension to find landowners for the new proposed area of study. Figure 14 shows a closer picture of our area of interest.

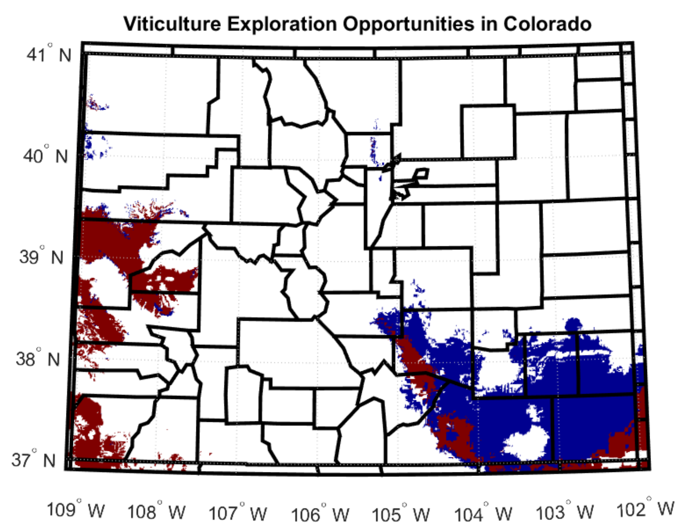

Fig. 13: Map of exploration opportunity (colored) areas for wine grape growth in Colorado based on PRISM estimated freezes/decade and SSURGO soil texture data. Red areas are more likely for successful growth of European grape cultivars than blue areas.

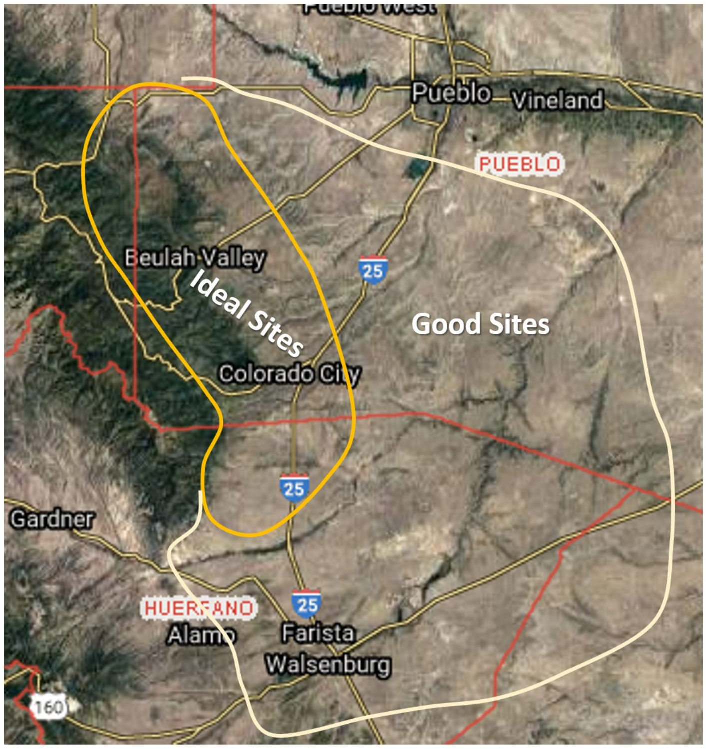

Fig. 14: FY 2022 new area of research. Locations outlined in orange are favored. Locations outlined in light brown are acceptable.

Three new stations will be added in Montezuma County. These stations will interface with the CoAgMET weather station network, and data will be available in real time. The Colorado Climate Center has worked with landowners to identify three prospective sites for these weather stations. Figure 15 shows these locations.

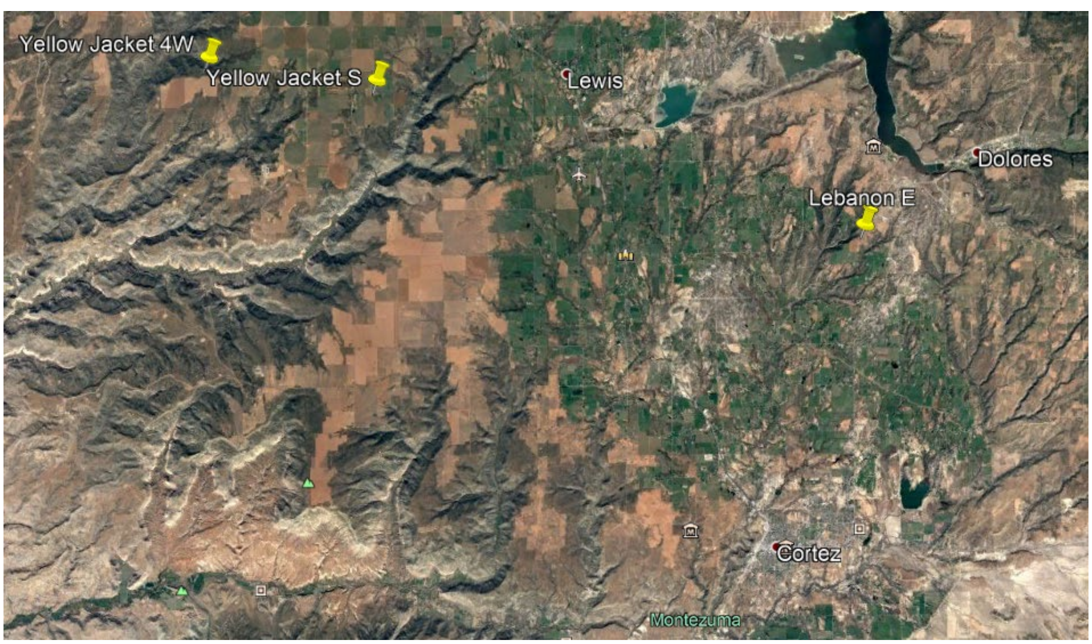

Fig. 15: FY 2022 Montezuma County stations with telemetry.

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 cultivar 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 an initial 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 2020, 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 three times during the remainder of the season, and each time fresh and dry weight of the cover crop biomass was determined. In previous years, seasonal cover crop biomass production in sprinkler-irrigated plots was two to five times higher than in the drip-irrigated crested wheatgrass plots. However, differences in 2020 were much more pronounced than in previous years due to the severe drought conditions that persisted throughout most of 2020. Only 1.67" of precipitation were recorded between 1 May and 2 October 2020 (the day of the final mowing), with 0.99" measured during 9-11

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[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.

September 2020. There was near zero regrowth of the crested wheatgrass after the first mowing in mid-June 2020. Seasonal biomass production of the legume cover crop was 15.4 times that of the crested wheatgrass (Fig. 16).

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 2.7 % over the season. All other cover crops had nitrogen concentrations averaging 2.3 %. Similar trends for lower nutrient concentrations in the crested wheatgrass biomass compared to the legume cover crops were once again found for potassium and sulfur. Other differences were high boron concentrations in the legume biomass and high iron concentrations in the crested wheatgrass biomass. All those cover crop treatment effects are consistent with the results from previous seasons.

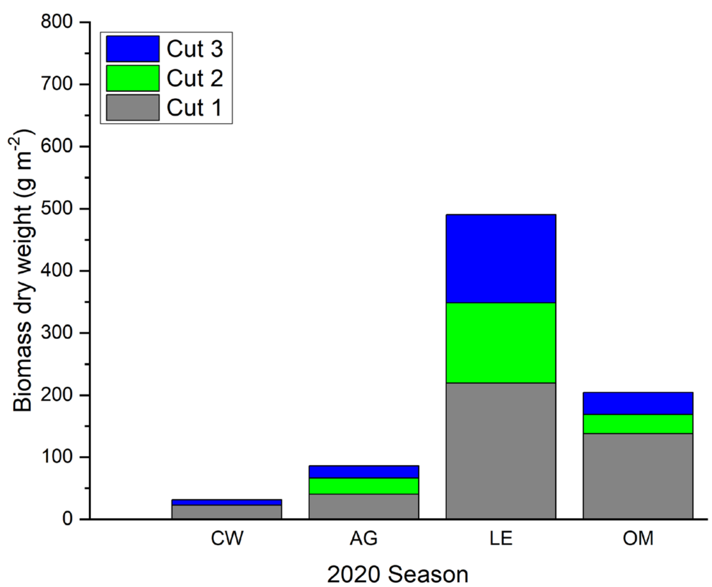
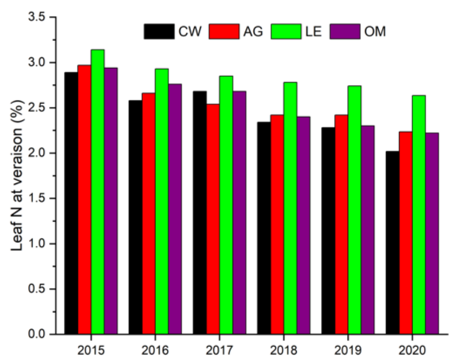


Fig. 16: Seasonal biomass production of cover crops in a Chardonnay vineyard at the Western Colorado Research Center – Orchard Mesa.
CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated. Vines in AG, LE, and OM are irrigated by micro-sprinklers.

Chardonnay leaf samples were taken at veraison and sent 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. 17). 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 every year since 2015 (Fig. 17). 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 2020 for all treatments (Fig. 17). In 2015, leaf nitrogen concentration averaged 2.99 % across all cover crop treatments. By 2020 the leaf nitrogen concentration at veraison averaged only 2.28 %. 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 remained much lower than from 2015 to 2017 suggesting a potential carry-over effect from the high 2018 yields. With a rather light crop in 2020 (1.29 ton per acre), YAN concentrations increased again for all treatments by an average of 43 % over 2019 values.



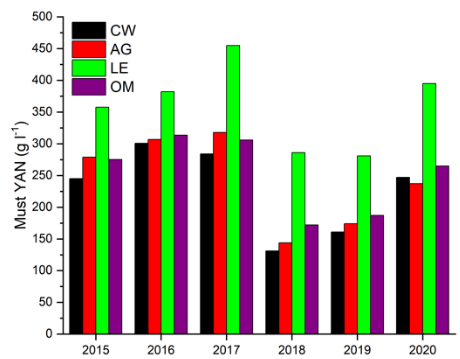


Fig. 17: Effect of cover crops on nitrogen concentration of Chardonnay leaf blades at veraison (left); and on the yeast-assimilable nitrogen (YAN) concentration of Chardonnay musts (right) from 2015 to 2020.
CW, AG, LE, OM: crested wheatgrass, Aurora Gold hard fescue, legume mix, and orchard mix, respectively. Vines in the CW plots are drip irrigated. Vines in AG, LE, and OM are irrigated by micro-sprinklers.

A review of six 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 in five out of six years and the lowest concentration of malic acid in four years. No clear trends are noticeable for the other cover crop treatments.

The average yield per acre in 2020 was 1.69 ton compared to 2.17 ton in 2019 and 4.10 ton in 2018. The average for own-rooted vines (3 reps) was 0.82 ton while vines grafted to rootstock 5C averaged 2.7 ton (1 rep). Vigor and yield of own-rooted vines are declining as phylloxera is spreading through the block. Vines with Aurora Gold or a legume cover crop had the highest yield (1.4 ton/acre) followed by the crested wheatgrass (1.32 ton/acre), and orchard mix (1.04 ton/acre) treatments. The low yields in 2020 are most likely the result of the extreme low temperature event (18 F) on 14 April 2020 causing significant damage to fruitful buds close to bud break as indicated by a 40.5 % lower cluster number per vine.

Drip-irrigated vines received 18.1” of irrigation water during the 2020 season whereas a total of 36.6” was applied in the micro-sprinkler irrigated plots. The irrigation volumes applied in drip were 2.3” higher than in 2019 and about 9” higher for micro-sprinkler. Due to the drought conditions in 2020 more water was applied late in the season compared to previous years to make sure that the soil profile was wet prior to winter. Seasonal rainfall (1 April to killing frost on 26 October) was only 1.8” with more than half (0.99”) occurring from 9-11 September. April through to August were very dry with only 0.62” of precipitation recorded. Reference evapotranspiration (ET_o) for the period 15 April to 25 October was 43.6”.

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. A record low temperature event on 26 and 27 October 2020 caused substantial damage to fruitful buds. With vine vigor declining due to phylloxera and an outlook for a very small or no crop in 2021 the decision was made to remove all own-rooted Chardonnay vines in this block and replant with grafted vines in spring 2021. Cover crop plots will be maintained and the establishment and performance of the new vines will be monitored in future years.

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

Results from the 2004 cultivar 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 same approach was used throughout the 2020 season. Turf density is increasing and slowly suppressing native grasses and other, non-grass species.

III. Enology research

In addition to the small-scale wine lots produced from 22 cultivars planted in three cultivar trials as mentioned above, two larger scale trials were conducted in collaboration with two Grand Valley wineries (Centennial Cellars, Peachfork Orchards and Vineyards).

- Tannin treatments of Marquette (Caspari, Menke, Wright, Centennial Cellars, Peachfork Orchards and Vineyards)

Due to unpredictable timing and severity of cold events in fall, winter, and spring in Colorado vineyards, many growers have planted cold-hardy interspecific cultivars. These cultivars tolerate fall and winter cold events better than traditional *Vitis vinifera* cultivars, though many break bud earlier in spring, making them vulnerable to late spring frosts. Both growers and wineries are still learning how to best use these cultivars, most of which originate from and were tested in breeding programs in areas with a different climate than in Colorado. Thus, the terroir is different than the originally targeted planting regions in mid-western and eastern North America. So, not only are these cultivars genetically different from traditional *Vitis vinifera*, but also are only beginning to be tested rigorously in our Colorado regional terroirs.

Recent research, in midwestern and eastern regions of North America, indicates that wines from these cold-hardy cultivars need to be vinified and marketed (McKee, 2013) differently than wines from *Vitis vinifera* cultivars. Specifically, during winemaking, tannin precipitation causes color and mouth-feel differences (Springer and Sacks, 2014; Springer et al., 2016; Rice et al., 2017; Watrelot and Norton, 2020), while acidity, certain vegetal aromas and unusual fruity flavors also need to be managed. Information on how to improve color and mouthfeel of wines made from cold-hardy cultivars grown in Colorado is missing. A collaborative trial was conducted in 2020 using Marquette grapes to start providing this information.

Marquette grapes used in this study came from commercial vineyards managed by Talbott Farms. Marquette grapes were harvested on 15 August 2020 and processed after two days in cool storage. All grapes were crushed and destemmed at one time. Must composition is shown in Table 12.

The must was divided into 12 lots (4 per cooperator) of approximately equal weight and composition: 3 control lots and 9 treatment lots, with 200 ppm of Gusmer Stellar Tan F grape tannins added at three different treatment time points during fermentation. The treatment time points were: 24 hours after yeast addition; at approximately 2/3 conversion of fermentable sugars; and after first post-press racking from lees. Each of the three cooperators used their own fermentation and post-fermentation protocols, other than the timing of the tannin additions.

Table 12: Fruit composition at harvest in 2020 of Marquette from commercial vineyards in the Grand Valley, CO.

Cultivar	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	29.3	3.54	6.71	6.56	4.18	208	110

All wines were racked two to three times and bottled at WCRC-OM without filtration in early May 2021. Wine analysis results at the time of bottling are shown in Table 13.

Table 13: Wine analysis results at the time of bottling for Marquette with different tannin treatments (None; 200 ppm 24 hours after yeast addition; 200 ppm after 2/3 of fermentation; 200 ppm at first post-press racking).

Tannin addition	Ethanol (%)	pH	Titratable acidity (g l^{-1})	Malic acid (g l^{-1})	Lactic acid (g l^{-1})	Glucose and fructose (g l^{-1})
Ram's Point						
Control (0 ppm)	14.19	3.79	5.51	0.65	1.44	1.19
200 ppm (24 hr)	13.54	3.78	5.20	0.62	1.34	0.96
200 ppm (2/3 fermentation)	14.52	3.78	5.51	0.58	1.38	1.38
200 ppm (1st post-press rack)	14.22	3.80	5.37	0.55	1.44	1.03
Peachfork						
Control (0 ppm)	14.00	3.84	5.35	0.83	1.21	1.40
200 ppm (24 hr)	14.20	3.76	6.25	2.16	0.58	1.06
200 ppm (2/3 fermentation)	13.96	3.90	5.22	0.45	1.43	1.55
200 ppm (1st post-press rack)	14.25	3.72	6.29	2.14	0.56	1.24
Centennial						
Control (0 ppm)	14.66	3.77	6.24	2.23	0.41	0.61
200 ppm (24 hr)	14.46	3.82	5.95	1.61	0.77	0.80
200 ppm (2/3 fermentation)	14.48	3.78	5.96	2.07	0.40	0.55
200 ppm (1st post-press rack)	14.61	3.75	6.18	2.23	0.49	0.60

A panel of seven grape and wine industry volunteers was trained in Quantitative Descriptive Analysis. During training sessions, panelists generated all terms to be evaluated. The panel also determined which terms reached a consensus level of impact for use in the evaluation sessions. Training sessions, each lasting 2 hours, were held on 26 & 27 May and 2 June 2021 and included a 2020 Marquette from the grape breeding and enology project of the University of Minnesota as an example from outside of Colorado. During these training sessions the panel developed a total of 19 Marquette wine descriptive terms for color (1), aroma (5), flavor (7), and mouthfeel (6). Wines, including the 2020 Marquette from the University of Minnesota and one 2019 Colorado Marquette with 400 ppm of Gusmer Stellar Tannin F, were evaluated, using those descriptive terms, by six panel members on 14 June 2021.

Overall, there were only small differences in the average values for the descriptive terms of the 2020 Marquette wines (Table 14). There appear to be some trends, but it should be noted that the data have not yet been subjected to tests for statistical significance. Wines with tannin additions had a slightly higher average scores for fresh fruit (cherry, plum) aroma and flavor, and lower scores for "prune". They also scored higher for "length of finish" and lower for "acidity" and "astringency".

Table 14: Average scores for 19 descriptive terms for 2020 Marquette wines with different tannin treatments (None; 200 ppm 24 hours after yeast addition; 200 ppm after 2/3 of fermentation; 200 ppm at first post-press racking) and a wine from the University of Minnesota as an example from outside of Colorado.

	Descriptive term	None	24 hr	2/3 fermentation	First post-press racking	U of MN
Color	Brown to purple	56.7	61.2	56.9	71.4	146.7
Aroma	Molasses	58.4	71.2	79.3	63.8	85.2
	Cherry	57.2	61.9	64.7	68.3	69.8
	Plum	68.6	77.8	77.2	74.3	88.0
	Prune	80.2	77.9	70.1	67.9	54.7
	Acetone	29.3	28.2	35.1	37.4	29.5
Flavor	Cherry	51.8	58.2	59.5	70.4	53.8
	Currant / cassis	86.9	84.2	87.4	74.7	104.8
	Plum	62.2	69.0	78.9	73.8	81.5
	Cocoa	44.2	52.0	48.2	39.7	41.2
	Tobacco	66.2	61.8	59.6	60.2	40.2
	Molasses	57.0	57.2	65.7	60.2	67.2
	Peppercorn	58.4	51.9	47.3	47.7	37.8
Mouthfeel	Dry to sweet	22.5	23.6	22.2	21.0	33.5
	Acidity	71.2	58.8	63.6	54.8	58.8
	Body	67.3	73.2	67.4	66.3	77.2
	Astringency	84.7	73.4	70.3	72.1	59.7
	Tannic	81.6	78.2	81.3	72.7	85.7
	Length of finish	74.2	82.8	85.6	92.4	79.8

- Yeast trials on Gewürztraminer and Viognier (Caspari, Menke, Wright, Centennial Cellars, Peachfork Orchard and Vineyards)

The second collaborative trial explores the potential of several novel yeasts to intensify the varietal characteristics of wine made from two aromatic *Vitis vinifera* cultivars – Gewürztraminer and Viognier.

The yeasts were specifically chosen for their abilities to intensify the tropical aromas and flavors of terpenes or thiols during the fermentation process.

Terpenes are derived from two isoprene 5-carbon units, resulting in monoterpenes with the basic formula $C_{10}H_{16}$, and these may have functional groups or form polymers that can determine their tropical aromatic characteristics.

Thiols are organosulfur compounds in which a thiol group, –SH, is attached to a carbon atom of any aliphatic or aromatic moiety. Some thiol derivatives have attractive tropical aromas and flavors, while some may ultimately release sulfur aromas that are not pleasing. The yeasts chosen are designed to ultimately produce attractive intensities of aromas and flavors, but there is no guarantee that excessive aroma intensity, as well as unpleasant excess SO_2 or reduced sulfur compounds are not also produced.

All Gewürztraminer and Viognier wines were made from the same Talbott Farms harvest lots. For each cultivar, nine lots were crushed, destemmed and immediately pressed, with 3 lots going to each cooperator. Pre-fermentation analysis was done for pressed musts (Table 15) and musts were adjusted, for all lots, to desired level of soluble solids and titratable acidity. Each cooperator fermented lots with either 58W3, Sauvy, or Vin13 yeast. Cooperators used their own protocols.

All wines were racked two to three times. Wines were cold stabilized at 34 F for 6 to 8 weeks prior to final racking and bottling at WCRC-OM without filtration in early May 2021. Wine analysis results at the time of bottling are shown in Table 16.

Table 15: Fruit composition at harvest in 2020 of Gewürztraminer and Viognier from commercial vineyards in the Grand Valley, CO.

Cultivar	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})
Gewürztraminer	22.6	3.61	4.94	5.80	1.39	102.5	131.4
Viognier	24.8	3.92	4.36	5.66	1.92	182.9	126.1

Using the same methodology as described above for the Marquette wines, a panel of seven grape and wine industry volunteers was trained in Quantitative Descriptive Analysis. Training sessions, each lasting 2 hours, were held on 26 & 27 May and 2 June 2021 and included Carlson Vineyards 2020 Gewürztraminer and Bookcliff Vineyards 2020 Viognier as commercial examples of Colorado wines. During these training sessions the panel developed separate sets of descriptive terms for Gewürztraminer and Viognier. For Gewürztraminer a total of 19 descriptive terms for color (1), aroma (8), flavor (4), and mouthfeel (6) were created. A total of 20 descriptive terms for color (1), aroma (8), flavor (8), and mouthfeel (3) were developed for Viognier. Gewürztraminer and Viognier wines, including the commercial samples, were evaluated using those sets of descriptive terms by six panel members on 10 June 2021.

Table 16: Wine analysis results at the time of bottling for Gewürztraminer and Viognier fermented with 3 different yeast.

	Ethanol (%)	pH	Titratable acidity (g l^{-1})	Malic acid (g l^{-1})	Lactic acid (g l^{-1})	Glucose and fructose (g l^{-1})
Gewürztraminer						
Ram's Point						
58W3	13.95	3.24	6.01	1.45	0.37	2.05
Sauvy	13.48	3.27	5.61	0.75	0.59	0
Vin13	14.23	3.16	6.21	1.35	0.45	0
Peachfork						
58W3	13.95	3.25	5.34	0.93	0.47	0
Sauvy	13.89	3.25	5.18	0.90	0.48	0
Vin13	13.96	3.27	5.33	0.93	0.53	0
Centennial						
58W3	13.70	3.22	5.56	1.07	0.48	0
Sauvy	13.61	3.27	5.16	0.53	0.66	0
Vin13	13.50	3.23	5.59	1.04	0.53	0
Viognier						
Ram's Point						
58W3	13.12	3.17	6.36	1.18	0.68	0
Sauvy	13.41	3.25	5.79	0.65	0.79	0
Vin13	13.37	3.19	6.30	1.30	0.66	0
Peachfork						
Vin13	13.64	3.24	5.40	0.86	0.55	0
58W3	13.37	3.33	5.12	0.37	0.79	0
Sauvy	13.66	3.28	5.37	0.79	0.63	0.34
Centennial						
58W3	13.79	3.47	5.04	1.38	0.36	0
Sauvy	13.89	3.60	4.35	0.71	0.40	0
Vin13	13.94	3.51	4.80	1.26	0.38	0

As expected, there was large variation in scores for descriptive terms both between wines and between panelists, leading to very similar average scores for the majority of the descriptive terms (Table 17, 18). However, some clear effects, highlighted in yellow, are noticeable in the data provided in Tables 17 and 18. For example, the commercial Gewürztraminer wine had the highest average scores for the aroma terms "melon" and "floral", with all six panelist giving the highest rating

(Table 17). Likewise, the commercial Viognier wine (Table 18) scored nearly twice as high as the other wines for the aroma term “apricot”, with all six panelists giving it high scores. All six panelist gave low scores for the flavor descriptor “yeasty” for the commercial Viognier wine but predominantly high scores for wines fermented with Sauvy yeast. The higher average scores for SO_2 and reduced sulfur from Sauvy samples are notable, but have not yet been subjected to tests for statistical significance.

Table 17: Average scores for 19 descriptive terms for 2020 Gewürztraminer wines fermented with three novel yeasts reported to enhance varietal characteristics, and a commercial wine (yeast unknown).

	Descriptive term	58W3	Sauvy	Vin13	Unknown
Color	Light straw to golden	40.4	26.8	30.2	27.0
Aroma	Melon	62.7	74.8	50.4	117.2
	Citrus	77.7	77.0	77.5	71.7
	Grapefruit	55.1	63.7	79.7	48.2
	Lemon	70.9	77.3	87.7	64.5
	Apricot	67.7	69.8	37.9	65.3
	Floral	61.7	58.9	52.1	108.3
	SO_2	26.1	42.3	35.4	22.2
	Mushroom / earthy	36.0	51.3	41.2	23.0
Flavor	Pear	74.2	63.4	55.5	81.2
	Grapefruit	60.8	77.1	74.7	55.5
	Lime	79.6	74.1	83.4	58.0
	Pineapple	51.0	43.2	49.4	48.0
Mouthfeel	Acidity	69.2	64.2	70.5	47.3
	Tart / crispy	77.8	73.6	79.8	61.2
	Dry to sweet	25.4	25.0	20.2	52.0
	Body	53.7	51.7	55.8	57.2
	Length of finish	30.3	36.5	33.0	21.7
	Balance	63.3	75.8	70.7	92.0

Table 18: Average scores for 20 descriptive terms for 2020 Viognier wines fermented with three novel yeasts reported to enhance varietal characteristics, and a commercial wine (yeast unknown).

	Descriptive term	58W3	Sauvy	Vin13	Unknown
Color	Light straw to golden	45.8	70.4	63.2	82.5
Aroma	Apple	64.3	48.7	55.8	60.8
	Honey / honeysuckle	77.3	64.8	65.3	78.5
	Lemon grass	58.6	56.4	58.9	77.8
	Floral	75.3	52.7	66.0	93.5
	Earthy / musty	49.3	82.7	51.7	35.5
	Reduced Sulfur	22.4	70.9	32.2	32.2
	SO_2	19.1	38.7	26.6	15.8
	Alcohol	38.8	33.4	23.9	46.3
Flavor	Nutty	55.4	60.6	67.1	70.8
	Lime zest	77.3	60.2	80.1	82.2
	Apricot	52.1	47.7	59.7	103.7
	Grapefruit	80.0	82.1	84.0	80.3
	Yeasty	28.1	53.4	30.2	7.7
	Peach	58.7	46.9	51.4	64.3
	Mineral	49.5	65.1	69.4	33.8
	SO_2	13.3	30.2	12.2	2.7
Mouthfeel	Soft to harsh	47.6	63.6	73.8	52.3
	Acidity	61.9	62.9	64.8	49.3
	Length of finish	67.2	82.3	87.8	105.2

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

Due to the COVID-19 pandemic we were unable to provide tours of the research vineyard and/or the research facilities to growers and other interested parties. There were also no in-person workshops or industry meetings.

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 cultivar 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, as was the case in November 2020 when we conducted a survey of the bud damage in the Grand Valley. Bud wood was collected and evaluated for 32 cultivars across 49 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 sent out in late November / early December 2020. All forms were sent electronically. By late June 2021 we had received 57 responses (representing 110 vineyard sites) totaling 447 acres. The preliminary results of the survey are:

- Approximately 35 % lower production compared to 2020
- 1,082 ton production reported so far
- Expected total production of approximately 1,200-1,300 ton
- Less surplus grapes than in previous three years
- Average yield of 2.4 ton/acre; down 1.4 ton/acre from 2019
- Average price of $1,588/ton, almost identical to 2019
- Very few new plantings in 2020
- Vineyard area planted appears less than the area removed

Literature cited

McKee, L.J. 2013. Northern Grapes Project Sees Results. Wines & Vines, May 2013.

Springer, L. and Sacks, G. 2014. Protein-precipitable tannin in wines from *Vitis Vinifera* and interspecific hybrid grapes (*Vitis* Ssp.): Differences in concentration, extractability, and cell wall binding. J. Agric. Food Chem. 62(30):7515-7523.

Springer, L., Chen, L., Stahlecker, A., Cousins, P., Sacks, G. 2016. Relationship of soluble grape-derived proteins to condensed tannin extractability during red wine fermentation. J. Agric. Food Chem. 64(43):8191–8199.

Rice, S., Koziel, J., Dharmadhikari, M., Fennell, A. 2017. Evaluation of tannins and anthocyanins in Marquette, Frontenac, and St. Croix cold-hardy grape cultivars. Fermentation 3(47):1-11.

Watrelot, A. and Norton, E. 2020. Chemistry and reactivity of tannins in Vitis spp.: A review. Molecules 25(2110):1-24.